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PROCEEDINGS OF THE SYMPOSIUM ON DRYLAND FARMING RESEARCH IN KENYA

Nairobi, 14–17 November 1983

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PREFACE

Many developing countries in Africa struggling to increase food production face a dilemma in the form of limited essential physical resources, such as land, water, nutrients and energy, and lack of proper technologies. This situation is exacerbated by high population-growth rates, which makes it even more challenging for governments to achieve the elusive goal of alleviating poverty and suffering.

The background to the Kenyan situation is well presented in the opening speech by the Minister for Agriculture and Livestock Development, and in the keynote address by the Permanent Secretary, Ministry of Finance and Planning, and need therefore not be repeated here. It is nevertheless worth while stressing that Kenya is a land-short country in terms of arable land (20 per cent). The other 80 per cent is either semi-arid, receiving scanty and erratic rainfall, or arid desert. Arid and semi-arid lands (ASALs) received prominence during the 1979–83 National Development Plan in response to the plan theme of poverty alleviation. In particular, semi-arid lands have come under increasing pressure as a result of population migration from the crowded high-potential areas. Migrant populations have brought with them farming technologies developed for the well endowed high-potential areas but inappropriate to their new settlements. Inevitably this has led to recurrent crop failures, hunger, and suffering, which can only be alleviated by costly famine-relief operations. Even more serious is the problem of rapid resource degradation in this fragile environment, leading to declining productivity and possible eventual permanent barrenness.

The needs of the higher-potential areas of Kenya have to a significant extent been met through research and the application of new technologies. Semi-arid lands have, however, not received sufficient research attention and therefore traditional production systems have benefited little or nothing from research-tested innovations. This gap became acutely apparent during the early and mid-1970s, when many parts of Kenya experienced a series of poor years for rainfall, coinciding with population migrations from high-potential to marginal rainfall areas. It was during this period that research scientists in the Ministry of Agriculture and the former East African Agricultural and Forestry Research Organization (EAAFRO) began to give serious thought to strengthening research in rainfall-deficit areas. The initial thrust was to be in the Machakos and Kitui Districts of Eastern Province—populous parts of the country where crop failures and famine are virtually endemic.

The first positive action taken was the gradual strengthening of Katumani Research Station by the Ministry of Agriculture, culminating in its elevation in status to the National Dryland Farming Research Station (NDFRS) in 1980, with responsibility for planning and co-ordinating dryland-research activities throughout Kenya. Financial constraints made initial programme development slow. In 1979, however, technical assistance was secured from UNDP/FAO and Project Document No. KEN/74/017 entitled "Dryland Farming Research and Development" was endorsed by the Kenya Government and the donor agencies. At an earlier date UNDP/FAO and the Kenya Government had signed a Project Agreement (KEN/74/016)—"The Kenya Sorghum and Millet Development Project"—a major objective of which was to develop sorghums and millets for the drylands of Eastern Province. Though administratively separate, this project was complementary to KEN/74/017.

In 1974 EAAFRO's twenty years' involvement in the study of the effects of changing land use on the hydrological cycle in East African high-rainfall catchment areas was concluded. Although plans were mooted to initiate similar studies in dryland areas, they were abandoned for lack of funds and manpower. A less ambitious alternative approach capable of being accommodated within the parsimonious budget was therefore sought to tackle the most urgent problems of drylands. This was conveniently done by revision in 1975 of the East African Food Crops Research Project (No. 618-110-10-657), sponsored by USAID in collaboration with the former EAAFRO. Unfortunately, the East African Community collapsed and the USAID Regional Office in Arusha abolished before the revision was completed and a new project formulated. Undaunted, the exercise continued as bilateral negotiations between the USAID and the Kenya Government, the result of which was the formulation in 1979 of Project No. 615-0180 entitled "Dryland Cropping Systems Research Project" and based at KARI, Muguga. Special care was taken at the project-design level to ensure complementarity and collaboration between KEN/74/017 and 615-0180. The approach was typically multidisciplinary, involving both expatriate and Kenyan scientists.

The broad research objectives were as follows:

a. to develop smallholder farm systems that will make efficient use of soil, water, and human resources;
b. to increase agricultural production by developing suitable crop varieties, plant-protection technologies, and cropping systems that will minimize the risk of crop failures;
c. to improve livestock-production systems that can be integrated into the farming system;
d. to make available whenever possible improved seed for bulk production and distribution to farmers;
e. to foster linkages between research and extension by carrying out verification trials of experimental results under real farm situations;
f. to assist in the establishment of an institutional structure for long-term planning and development of the agricultural potential of the dryland areas.

It was obvious at an early stage that an effective co-ordinating machinery was necessary to facilitate team work between project and local scientists. At a higher level a Technical Co-ordinating Committee (TCC), consisting of the Directors of Agriculture, Livestock Development and KARI, and local representatives of the donor agencies (FAO, UNDP and USAID), was established to provide policy guidelines. Another important function of the TCC was to ensure harmonious working relations between participating scientists of diverse nationalities and backgrounds. The technical leadership of the project was the responsibility of a small committee consisting of the Project Leaders of the donor agencies and the Directors of KARI and the National Dryland Farming Research Station, Katumani. More important were the regular joint meetings of the research personnel from the two projects, which were held alternately at KARI, Muguga, and the Katumani Research Station. It was at one such meeting, held on 29 September 1982, that the idea of convening a Symposium on Dryland Farming Research towards the latter part of 1983 was conceived. This crucial decision took into consideration the fact that the two donor projects were due to end early in 1984. Past experience with other projects had shown that only scattered and incoherent records of what had been achieved were left behind for the benefit of future work. The purpose of this symposium was therefore to bring together the results achieved during the rather short lifetime (4–5 years) of the two projects in a form easily available for reference.

These proceedings do not reflect the entire efforts launched during the fourth five-year plan to upgrade the standard of life in the arid and semi-arid areas. Many agencies were involved in this task. They included bilateral and multilateral agencies, the University of Nairobi, and many non-governmental organizations. It would have been impossible to convene a symposium involving all of these agencies, some of which have made notable contributions. Even these proceedings do not fully report the results obtained by all the participating project scientists, due to financial and time limitations. A number of presentations have had to be abstracted, not because they did not meet the required standard but because the editors felt that the subject matter needed more time to polish up. The presentations affected will be accorded priority in the regular issues of this journal.

The most difficult part of this preface is the summing up of achievements. This challenge is made even more difficult because of the short duration of the projects. Nevertheless, the summaries and conclusions at the end of each presentation should give the reader a fair appreciation of the magnitude and complexity of the problems to be surmounted in the dryland farming areas.

By far the most important limiting factor is weather—inadequate and erratic rainfall. These areas have a low biological production ceiling. Therefore, well researched weather-directed cropping systems should form the basis for stable food-crop production. The first technical session of this symposium deals with this exciting and basic environmental problem. Given the dryland environment in which food must be produced, the farmer should have access to scientifically proven rainfall probabilities and expectations. These projects have attempted to define these basic elements and propose alternative farming systems that farmer can adopt according to weather prospects.

Tailor-made crop varieties to suit these dryland areas are crucial to the achievement of the goal of poverty alleviation. These projects have made an initial contribution by developing a short-maturing variety of green gram (KVR 26), and there are indications of many more food-crop species and varieties to suit this environment. The short-maturing pigeonpea developed by the faculty of agriculture of Nairobi University is a good example of what can be achieved. Smallholder farmers in the areas under study depend heavily on livestock as a source of income and as an aid

to crop production. Unfortunately, this aspect of research received less attention than was expected. This is an area that requires intensified research and development work.

It would be presumptuous to claim that the projects have adequately satisfied all their objectives. In a modest way, the projects succeeded in identifying real-life problems through their pre-extension and verification trials. The objective of sensitizing field officers in dryland areas to the farmers' problems was in part achieved through seminars organized by the project research personnel. The success of training Kenyans in dryland-farming methodology is recognized in the Minister's opening speech.

Partial successes achieved by the projects deserve mention. The ambitious objective of helping to establish a strong national nucleus for dryland-farming research has been to a large extent disappointing, especially with the departure and scaling down of foreign technical assistance in support of dryland-farming research. There is a felt need for a strong national institutional structure to address the problems of these difficult areas on a long-term basis.

Fortunately or unfortunately, the proceedings of this Symposium are published at a time when most parts of Kenya are experiencing a drought of a severity not recorded for many decades. These research projects were not designed to find solutions to such exceptional weather conditions. Their main focus was on areas with normally scanty and erratic rainfall capable of sustaining some food-crop production. It must be accepted that severe droughts have occurred in the past and will recur in future as a natural phenomenon. Scientific research alone cannot provide solutions to food security under such conditions. There needs therefore, to be a comprehensive and forward-looking national food policy to cushion the effects of such inclement weather conditions on food security.

Modern published scientific works are rarely the result of a single intellect. Often they involve a mixture of individuals with different attitudes and aptitudes. The proceedings of this Symposium owe their success to dozens of dedicated scientists and policy-makers. most of whom have been mentioned in the keynote speeches. At the risk of pre-empting acknowledgements by guest speakers elsewhere in these proceedings, the USAID project deserves special mention for defraying the cost of sponsoring the symposium and the publication of these proceedings. Much of the co-ordinating responsibility was shouldered by Dr B. W. Ngundo, assisted by Ms P. Penninkhoff, Dr S. Tessema, and Dr B. H. Waite. Miss Lucy M. Ndurya provided valuable secretarial services for the co-ordinator.

Special mention is also due to Mr D. M. Thairu, National Project Co-ordinator, Dryland Farming Research, FAO, Nairobi; to Mr P. K. Kusewa, Director, National Dryland Farming Station, Katumani; and to Dr W. A. Faught, Project Leader, USAID/KARI, Muguga, who almost earned themselves unpopular names for exerting excessive pressure on their scientists to produce manuscripts in time for the Symposium.

The technical sessions were ably and voluntarily chaired by Dr C. L. Coulson, Department of Crop Science, Faculty of Agriculture, Nairobi University; Dr D. B. Thomas, Acting chairman, Department of Agricultural Engineering, Nairobi University; Dr J. D. Wachira, Deputy Director, Animal Production Department, KARI, Muguga; Dr M. P. Collinson, CIMMYT, Nairobi; and Mr G. N. Kibata, Senior Entomologist, National Agricultural laboratories, Nairobi. Messrs D. K. Muthoka, A. M. Marimi, and F. M. Ndambuki, all from NARS, Kitale, were competent rapporteurs for various sessions and their contributions are appreciated.

The cost of this symposium was minimized through the generous offer of the excellent facilities of ILRAD by the Director General, Dr R. Gray, to whom our thanks go.

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B. N. Majisu
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Abbreviations Used in the List of Participants and elsewhere in These Proceedings

AID	Agency for International Development
APRD/KARI	Animal Production Research Department/Kenya Agricultural Research Institute
ARD/KARI	Agricultural Research Department/Kenya Agricultural Research Institute
ASAL Development Project	Arid and Semi-arid Lands Development Project
CIMMYT	International Maize and Wheat Improvement Centre
CSIRO	Commonwealth Scientific and Industrial Research Organization/Division of Tropical Crops and Pasture, Australia
DAO	District Agricultural Officer
DLDO	District Livestock Development Officer
FAO	Food and Agriculture Organization of the United Nations
GLP/NHRS	Grain Legume Project/National Horticulture Research Station
ILCA	International Livestock Centre for Africa
ILRAD	International Laboratory for Research on Animal Diseases
MIDP	Machakos Integrated Development Project
MoALD	Ministry of Agriculture and Livestock Development
NAL	National Agricultural Laboratories
NARS	National Agricultural Research Station
NDFRS	National Dryland Farming Research Station
NHRS	National Horticulture Research Station
PAPO/PDLD	Provincial Animal Production Officer/Provincial Director of Livestock Development
PCO/MoALD	Provincial Crops Officer/Ministry of Agriculture and Livestock Development
PDA	Provincial Director of Agriculture
USAID/KARI	United States Agency for International Development/Kenya Agricultural Research Institute
USDA/USAID	United States Department of Agriculture/United States Agency for International Development

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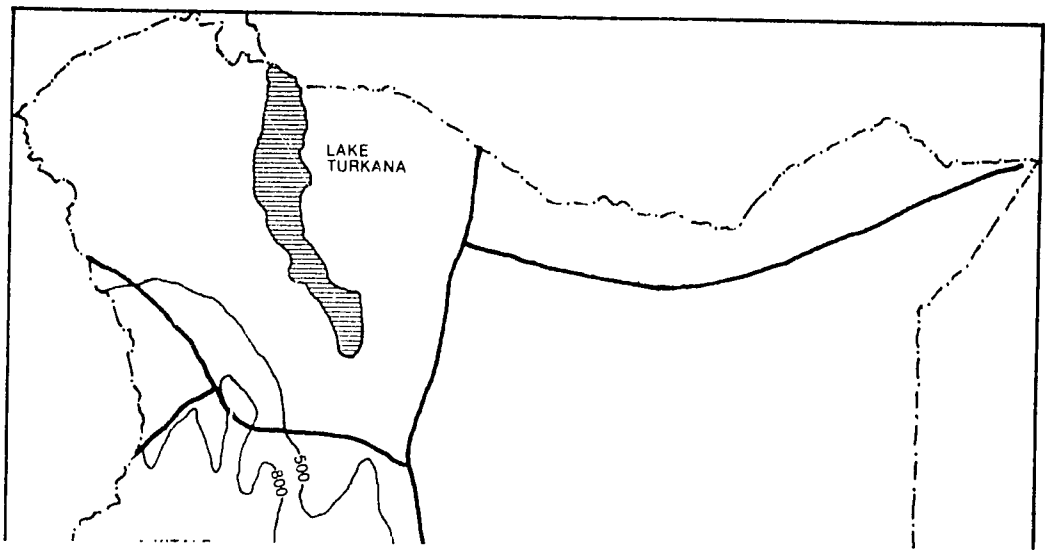

ERRATUM

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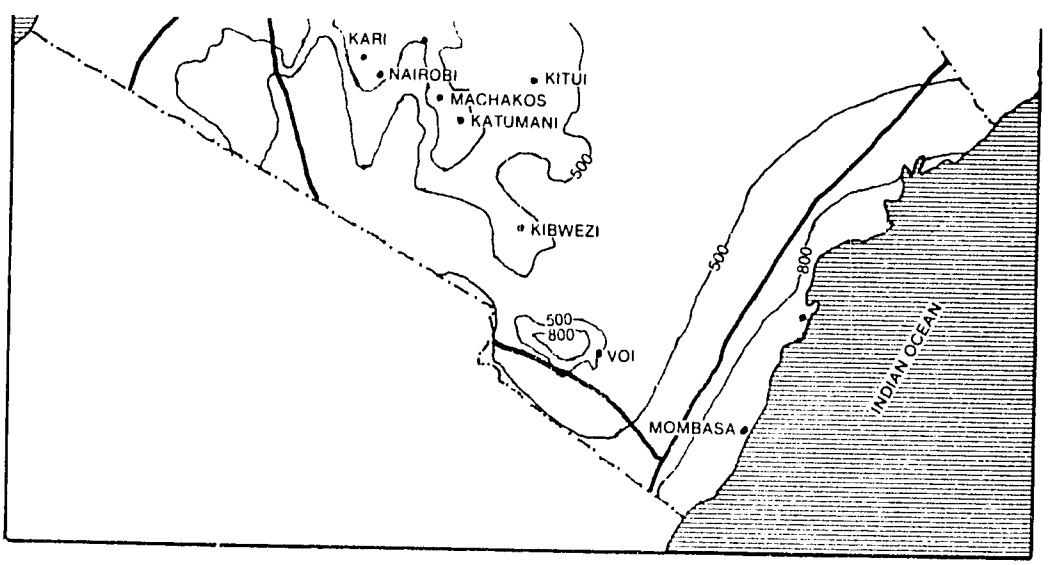
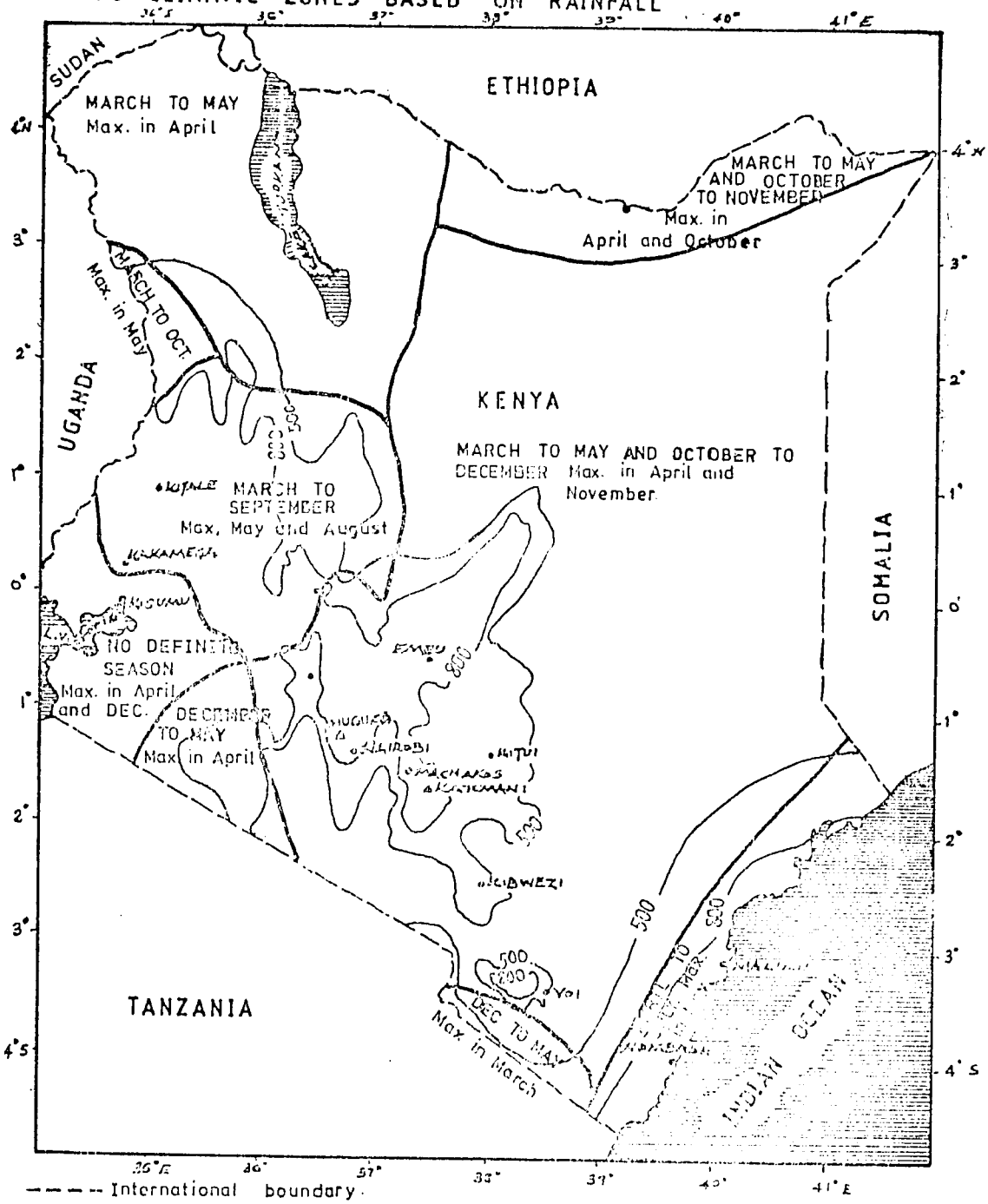


Agroclimatic Zones of Kenya Based on Rainfall

AGRO-CLIMATIC ZONES BASED ON RAINFALL



International boundary.

Towns.

Rainfall season boundary, with duration maximum months indicated

500 800 Isohyets in m.m

20 0 20 40 60 80 100 120 140 160 180 200 Km

Adapted from Kenya Soil Survey

Drawing No 78025

OPENING SESSION

OPENING SPEECH

Hon. W. O. Omamo, M.P.
Minister for Agriculture and Livestock Development

Honourable Guests, Ladies and Gentlemen:

Two weeks ago, I had the opportunity to meet some of you at Kisumu on the occasion of the official opening of a conference on sugar-research priorities. It is my pleasure, once again, to be here to address this assembly of research scientists and to officially open your Symposium on Dryland-Farming Research, with an Emphasis on the Kenyan Experience.

From this analysis of a variety of physical and biological data, coupled with further analyses of rainfall data, soil characteristics, soil-water balance, and of vegetation types and description, it has been established that only 12% of Kenya comprises high potential land. The rest of the country consists of mainly dry land, of which 5.5% is of medium potential and the rest low potential.

It is, therefore, clear that land for arable agriculture is extremely limited, and this makes the theme of this symposium very relevant to us all, and particularly to my Ministry.

The Kenya Government fully recognizes and appreciates the role of scientific research in national development. This position was clearly articulated in the Fourth National Development Plan for the period 1979 to 1983, and I would like to elaborate by quoting the opening sentence of the section on science and technology policy:

> The productivity of the nation and the income-earning opportunities associated with it depend crucially on the application of modern scientific knowledge to the identification and generation of improved technologies, and the use of the technologies in the production process.

Arising from that policy statement, an elaborate research institutional framework has emerged, and it is my wish that this framework should be supportive of our production efforts.

In saying this, Mr. Chairman, I do not intend to imply that priod to 1979 Kenya was lagging behind in scientific research. This is not so. I am aware that our achievements in the scientific research fields compare very favourably with what has been achieved by some developed nations. What has happened is that research efforts have been directed at problems in high-potential areas, with negligible attention directed to marginal-rainfall areas. The results have not yet been altogether cost-effective because migrant farmers have carried inappropriate technologies, developed for high-potential areas, to the low-rainfall areas, with disastrous results in terms of crop failures and degradation of the fragile ecosystem. The position is fast changing, with substantial resources now being directed into the arid and semi-arid areas to meet the special needs of the poor subsistence farmers and pastoralists living in these areas.

At this point, Mr. Chairman, let me pay a particularly glowing tribute to our agricultural research scientists. Over the last 20 year of our Independence we have made major breakthroughs in the development of high-yielding hybrid maize, suited to all ecological zones. Research in coffee and tea has also been a success story. In the area of livestock, major breakthroughs have been recorded in the areas of disease control and up-grading of the indigenous breeds, hence the success of the Kenyan dairy industry. These matters are a source of pride, not only to my Ministry, but also to the Government.

In recognition of the vital role the research scientist is playing in the implementation of our national food policy, more and more resources will continue to be placed at his disposal, particularly as we move to dryland-farming research.

In this respect, let me say that our record has been good, as a nation. In 1970, ninety-nine per cent of the Government expenditure on all research and development was invested in agricultural research. By 1979 the share was seventy-four per cent, seemingly small in relative terms, but increased substantially in absolute terms. This support will be continued and maintained at these levels, and in turn I expect that you will continue with the same vigour as we enter the dryland phase of our research.

Turning to the researcher himself, I would like to inform you that a scheme of service for research scientists is at an advanced stage of pre-

paration. This has been confirmed with the Director of Personnel Management. The idea is to build up a strong national scientific research capability to be supplemented through our usual co-operation and collaboration with friendly governments and international organizations.

At this point, Mr. Chairman, let me say that I am aware that agricultural research takes a long time to yield results. I appeal to the several donor agencies co-operating with us to be with us as we await these results. In particular, I am aware that two donors are patiently assisting us in the dry-land farming research project.

The USAID project to cover the period 1979 to 1984 will cost nearly ninety million Kenya shillings, most of which has already been made available to Kenya. In addition, twenty senior research scientists will have been trained at various levels. We are very grateful for this assistance.

Similarly, UNDP/FAO have contributed over forty million Kenya shillings in the project, in addition to training thirteen scientists. Again we are most grateful.

I also take this opportunity to thank all you foreign scientists working side by side with our local scientists both at Katumani and at Muguga in the project. We very much value this co-operation.

Finally, I wish to commend our research officers, wherever they are, for their dedication, patience, and commitment. This is the only way we can attain and sustain a state of self-sufficiency. My Ministry will continue to support your efforts.

With these few remarks, Ladies and Gentlemen, it is now my pleasure to declare this symposium open, and to wish you very fruitful deliberations.

Thank you.

Kilimo House
Nairobi
14 November, 1983

KEYNOTE ADDRESS

H. M. Mule
Permanent Secretary, Ministry of Finance and Planning

Gentlemen:

It is a great pleasure for me to be here and to have the opportunity to deliver the keynote address for your symposium on Dryland-Farming Research. It is not likely that I can tell you much that you do not already know about the importance that the arid and semi-arid lands have for Kenya, for the welfare of its people, and for its future development potential. That these lands account for 80 per cent of Kenya's land area, 20 per cent of its people, 35 per cent of the cattle, and over two-thirds of the sheep and goats of the country is generally well known. Just as important, but not so frequently mentioned, is the role these lands play as part of the major watershed of Kenya; therefore, the management and use of these lands greatly affects the extent and severity of droughts and floods and the rate of erosion and siltation of streams, rivers, and irrigation dams and reservoirs. The importance of these areas and of dryland-farming research is well stated in the announcement of this symposium. Your invitation to address this symposium suggested that I give special attention to the role of research for dryland farming in the planning of the development of Kenya. This I shall try to do. In making these remarks, however, I am aware that I am addressing a group that is made up largely of plant and animal scientists, whose goals, objectives, and time-frame may be somewhat different from those often held by development planners and policy makers.

I assume that the reason for my being asked to address the symposium is to give you this different point of view. Before commenting on research *per se*, I would like to briefly sketch out some aspects of the economic situation for you to keep in mind when evaluating the worth of your research results and also when planning future research. Relative to the rest of the world, Kenya is a poor country, and, in common with most other African countries, its economy has been experiencing considerable difficulties in the past few years, largely as a result of unfavourable developments in the world economy. The international recession that already characterized 1980—81, deepened further in 1982, and the economic slowdown in the advanced economies inevitably had an adverse effect on world trade and hence upon the economic fortunes of developing countries like Kenya. The depressed state of demand in industrial countries meant continuing weakness on world commodity markets and the terms of trade of non-oil developing countries remained at about 20 per cent below the 1977—79 average.

The improvement in the Kenyan economy recorded in 1981, when the GDP is estimated to have grown by 5.5 per cent, was not sustained in 1982; provisional data indicate 1982 rates of 3.3 per cent, which implies a slight fall in per capita income. The major contribution to the growth of GDP comes from agriculture. Kenya's land resources are, however, limited and there is much unfulfilled demand for land. While there appears to be plenty of land, with 27 persons per square kilometre (according to the 1979 population census; about 33 persons in 1983), there are some districts with very high population densities: 294 persons per square kilometre in Kakamega and 395 in Kisii in 1979. With 80 per cent of the land-base arid or semi-arid, there is little additional good-quality agricultural land available for those wanting it. Therefore, with an annual population growth of around 3.8 per cent, there will be increasing pressure for land and the land most available is in the fragile arid and semi-arid areas.

In addition to satisfying people's desire for land, there is the need for additional land to increase food and export crop production. Again, the major part of any increase in crop-land will have to come from the arid and semi-arid areas now under pasture. Only minor amounts can be added from irrigation and drainage schemes. Therefore, as more and more of the semi-arid lands are used for crop production, it is important that we learn how to manage these fragile lands to safeguard their limited productive capacity and to prevent undue erosion from occurring. At the same time, the output from these areas must be sufficient to provide a decent level of living for those occupying these lands.

I have already referred to the high rate of population growth, which accentuates two other

situations that need to be considered: unemployment and the need for new jobs, and the need for an assured supply of food to meet the needs of a rapidly growing population. The recent crop-production shortfalls in 1979 and 1980 highlighted the importance of food security.

For sustained development of our country we must give priority to our domestic resources. This concerns financial, physical, human, and natural resources. While this symposium is concerned primarily with the use of natural resources, the availability of financial resources affects how they are used. The current heavy dependence on external financial resources for development cannot be continued, and further development must be based to a much greater extent on the utilization of domestic resources. This will have to come about in many ways, but reduction in the use of external resources will be achieved mainly through a reduction in expenditure.

It is also well to recognize that development projects must be carried out in the face of declining external financial assistance, and that a decreasing share of the Government budget will go to these projects. Since it is difficult to curtail the provision of essential Government services in the face of a rapidly growing population, the main impact of cuts in expenditure will fall more heavily on development expenditures. For science and technology research activities we had, in the current plan target, an expenditure equivalent to one percent of GDP. I am afraid that except for the agriculture sector where your activities fall this was not realized.

Another aspect relative to the mobilization of domestic resources is the need to improve the productivity of domestic resources. In the private sector, land is a major under-utilized resource, for reasons such as absent landlords, disputed title deeds, speculative holdings of land, and lack of satisfactory access to markets and input supplies. These problems are to be tackled as a matter of urgent priority, especially since there is a large unsatisfied demand for Kenyan agricultural products both at home and abroad.

The policy of developing arid and semi-arid lands will be intensified during the coming plan period. This brings me to the question of the kind of research needed to develop arid and semi-arid lands and to intensify their use. Before attempting this, I would like to state some broad objectives for the next plan. These are:

i. increased agricultural output, especially food production and commodities for export;
ii. job creation;
iii. adequate income levels for small farmers;
iv. conservation of natural resources; and
v. the achievement of the above in as short a time as possible.

The results of your dryland agricultural research should contribute to achieving these goals; if they do not, then your research is not contributing to development as expected.

Development of arid and semi-arid lands implies increasing the output from these lands, and this can best be done with the use of improved technology. Unfortunately, improved technology does not exist at the present time for much of the arid and semi-arid areas. It must, therefore, be produced, and for this, research is required. But development of improved technology through research is not the final answer or goal. Improved technology, unless adopted, is worthless, and therefore the ease or difficulty of getting research findings (improved technology) adopted is an important aspect to consider when developing a programme of research.

May I digree a little to comment on this important, but all too often ignored, aspect. I would suggest that for all practical purposes, improved technology does not exist until and unless farmers are aware of it. Furthermore, I would suggest that it should not be referred to as improved technology unless farmers are able to adopt it and it results in higher incomes than would be received from the use of conventional practices. Higher yields under experimental conditions are not sufficient evidence for me to consider that research has developed an improved practice.

Until farmers are aware of the practices required to get higher yields and can obtain the required inputs and apply the practice on their farms, with the results that both yields and incomes increase, I would not consider that an improved practice exists. This, of course, means that there must be close co-operation between research and extension personnel, and that in designing research, consideration must be given to such things as the availability of inputs, the ability of farmers to understand how to incorporate the new practice into their farming systems, the money required to purchase needed inputs, the risk of failure, and many more such aspects.

In this regard, I am reminded of the early research that was done at the International Rice

Research Institute (IRRI) in the Philippines. In their search for ways to increase rice yields, researchers ignored the interests of farmers and concentrated on how to modify the rice plant so that it would produce more. After a few years, they were successful and the Green Revolution was born. Technology was developed for greatly increasing rice yields, but many farmers chose not to adopt it. Were these farmers stupid, backward, ignorant, resistant to change, and many of the other terms often applied to traditional farmers? I believe not, and IRRI researchers likewise realized after a time that their initial orientation was wrong. They recognized that instead of expecting farmers to change their practices to meet the requirements of a new high-yielding rice variety, it made more sense to develop new high-yielding varieties that required as few changes as possible from those that traditional farmers were using. So this became the farmework in which much of the research at the International Centres is now being done. The aim is to develop technologies that require as few changes on the part of farmers as possible. You might wish to reflect on your own research approach to see whether it is the farmers who will have to adapt or whether your research is aimed at minimizing the changes farmers will have to make in adopting the improved technology.

Obviously, some things must change or there would be no improved practice, but there is a difference in approach between being indifferent to the number of kinds of changes required and in trying to keep changes to a minimum.

I would also like to suggest that farmers are more interested in increasing their incomes than in increasing output, and I think rightfully so. Fortunately, in most cases, these two things go together—but not always. Mistakes have been made because this difference has not been recognized. I hope none of you has lost sight of this most important aspect and that you take into account the economic implications of your research. Some of the factors to be considered in this regard are:

1. the fact that farmers will not be able to get as high yields as you do under experimental and controlled conditions;
2. the ease or difficulty with which farmers can get the correct kind and amount of inputs on time and the likelihood of their applying them correctly;
3. the amount of money required to adopt the practice and the availability of credit for purchasing the required inputs;
4. the availability of markets in which to sell the increased output, together with price stability; and
5. the fact that farmers have less control than you as researchers have over production and, therefore, farmers are subject to greater risks; furthermore, farmers must bear all the risks and may not be able to afford even partial failure.

If you are still with me, some of you may be thinking that while there may be truth in what I am saying, it is not completely relevant to your research because there is so little known about dryland farming in the arid and semi-arid lands that basic research is first needed in order to develop improved practices that will result in higher yields and incomes. As I look at the titles of the research papers to be discussed in the technical sessions, it appears that much of the research might fall in the category of basic research and may not have produced a set of output-increasing practices that farmers can adopt as a way of increasing their incomes.

I am in sympathy with the interest in and need for basic research. Let me quote from a report on Science and Technology for Development by the National Council for Science and Technology. The report notes that all research is important and should not be subdivided, but that research does serve a number of purposes. In relation to these purposes, research is sometimes classified as basic and applied. The Council defined basic research as that which is concerned with the production of scientific facts and principles. Applied research was defined as that research which is concerned with the application of scientific facts and principles. The Council concluded that the primary distinction between the two types of research is that basic research produces knowledge and applied research produces know-how or technology. They suggest that the resources available for basic research be of the order of 5 per cent of gross national research and development expenditures.

One substitute for doing basic research is to use the results of research carried out in other countries. This is not only appropriate but necessary for countries like Kenya.

Unfortunately, low-income countries like Kenya, with high population growth rates, shortage of foreign exchange, and inadequate agricultural and food production, have neither the time nor the money to afford much basic agricultural research, particularly when much of

it can be borrowed from International Research Centres and other countries. We cannot consider four to five years a short period of time, even though this may be a short time relative to the time required for much basic research. The situation in Kenya at present is such that big increases in (say) ten years are not as desirable (worth as much) as smaller increases in the next two to four years. In other words, what Kenya needs now is research that produces results in the short term, even though these results may be less dramatic than what could be produced from longer-term research. This is not short-sighted planning but a correct decision based on the expected present value of the likely benefits from basic as compared to applied or adaptive research.

My next comment relates to the conflict among some of the goals and objectives I referred to earlier. I am particularly thinking of the difficulty of emphasizing small farms and at the same time having units of sufficient size to be able to apply proper conservation measures and still earn adequate levels of income. There is no conflict among these objectives for the better farming areas; they are complementary and mutually supporting—the attainment of one adds to the achievement of the others. This is probably not the situation in the fragile environment of the arid and semi-arid areas; at least not for the range livestock-management practices currently being used. Therefore, land division and the creation of small farms in the arid and semi-arid areas raise the following kinds of questions: What is the minimum size farm needed to provide adequate income? Is livestock production viable in a small-farm setting? What happens to ranges and wild animals if these areas are subdivided into separate livestock units and/or small farms? Can the watershed be protected and serious erosion prevented? These are important questions.

Decisions are now being made on how land is used in the arid and semi-arid areas, and the impact of some of these decisions is irreversible, at least for a considerable period of time. Does your research provide useful information that decision-makers can use in arriving at correct answers to these questions?

I referred earlier to the apparent suitability of the arid and semi-arid lands range-livestock production. One reason for this statement is the fact that several decades ago these ranges supported huge herds of wild animals. The challenge is how to restore the carrying capacity of the ranges and whether this can be done with domestic livestock and in the context of subdivision into small farms.

Information is needed to determine appropriate types of farming for the arid and semi-arid lands. Kenya needs increased food production and it is natural to look to existing pasture- and rangelands as a place to grow additional food crops. This, however, can only be done at the loss of some livestock production. Do we know what the relative costs and benefits are from using these lands for crop production rather than for the production of livestock?

Such information is essential, and if data are not forthcoming from your research, then decisions will have to be made on the basis of estimates and guesses. A final comment on an area of extreme importance, and that concerns present and future livestock production, watershed protection, erosion, and a host of related conservation concerns. I am now referring to range-management practices. I alluded earlier to the much greater carrying capacity of our ranges in former years. Why the deterioration and in some areas desertification of formerly quite productive land? I have heard much about overgrazing, rest periods, too many cattle, rotation grazing, etc. in relation to this problem. Has any of your research suggested how to manage the range to reverse the deterioration and to increase livestock production?

When one finishes preparing an address such as this, one wonders whether one has addressed the issues that were intended to be covered. I have spoken to you today as a policymaker and tried to point out the kind of information required for policy purposes and the kind of data and information needed by farmers to help them in their decision-making process. I also tried to point out the limiting features of the current environment in which you must carry out your research.

I commend you for your interest in doing research on the arid and semi-arid lands. This is a difficult area and many people will take for granted any success you might have but complain in the absence of positive results. I again commend you for your efforts in trying to understand how to make the dryland areas more productive while at the same time ensuring that they are not destroyed in the process, as has occurred in the past. I recognize the importance of these lands to the future of Kenya—they are both part of the cause and the solution to the number and severity of droughts and floods, to the erosion and silting

of rivers, to the preservation of wildlife, and to the health and welfare of a large part of the Kenya population.

I wish you a most productive and useful symposium and again thank you for inviting me to address you.

FARMING SYSTEMS DEVELOPMENT: THE PLANNED FAO APPROACH

*H. Kunert**

INTRODUCTION

During the last ten years development administrators have recognized the requirement for multidisciplinary co-operation if more efficient and more productive agricultural development is to be achieved. This recognition has rapidly evolved into the concept of a farming-systems approach for research. Simultaneously, a greater awareness has evolved that development programmes and their implementation must be formulated and executed with the full participation of the local people in general and the farmers in particular. This principle was formalized and given highest-priority endorsement by participants in the World Conference on Agrarian Reform and Rural Development (WCARRD) held in July 1979 in Rome. FAO's Advisory Committee on Agriculture (COAG), at its 1974 meeting, recommended that rural development planning should be done "from the bottom up" simultaneously with "top-down" planning. The World Conference, by its recommendation for people's participation, has further strengthened this concept.

An increasing number of requests are being received by FAO to formulate and implement projects using a farming-systems approach to development. These result from the COAG and WCARRD recommendations and the recognition of improvements in agricultural productivity achieved through multidisciplinary co-operation in research for crop and livestock systems.

In response to these demands, and in accordance with advisory-body recommendations, the Director-General of FAO has proposed a separate element entitled "Farming Systems Development" in the 1984/85 Programme of Work and Budget. The purpose of the new element is to strengthen multidisciplinary action within both FAO and member countries, in the search for solutions to the large complex of problems constraining agricultural development. Major emphasis will be directed to the problems of the small farmer and the rural poor. The guiding principles which vere established by WCARRD, designed to benefit this group, specifically, are to be incorporated into the Farming Systems Development Programme. The Council of FAO have commended to the Director-General the establishment of this activity as a separate element and emphasized the paramount importance of multidisciplinary co-operation to improve the impact of development programmes. It is anticipated that the FAO Conference will accept the Council's recommendation and endorse the element during the November 1983 session.

For those of us dedicated to development, a major task now is to define clearly what a farming-systems development approach is and what the roles therein are for farm management and the traditional agricultural sciences. It is apparent, from the WCARRD principles, that farmers must be the *de facto* leaders of the farming-systems development approach. Researchers, including farm management, must function as a team to support and improve their performance.

As the farming-systems development approach evolves, it is to be hoped that both administrators and other scientists involved in development programmes will come to view farm management as a major linkage discipline. The power of the discipline to search for more efficient ways and means to combine inputs, adjust costs by exploring the use of alternative practices, identify policy and institutional changes required to facilitate the adoption of productive technology, etc. can provide a major impetus to development. Yet few of these benefits can be obtained unless all scientists collaborate on a multidisciplinary basis to solve the problems confronting farmers.

In this paper we first define the concept of a farming system and distinguish between Farming Systems Research (FSR) and Farming Systems Development (FSD). We then elaborate the FSR concept and review, with particular attention to KEN/74/017, the types of research usually undertaken in an FSR programme. Consideration is given to the various approaches used for selecting technical problems to be researched by the FSR approach, and the possibi-

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lity of a more formalized approach reviewed. We then outline FAO's approach to FSD and emphasize its foundations in the total development of a community rather than in concern with single activities. In concluding, we summarize the status of the FSR approach in the current project and make some suggestions about how it can be strengthened. It is hoped that this paper will provide a stimulus for discussion which will lead to further review and development of an effective FSR programme at Katumani.

DESCRIPTION OF A TOTAL FARMING SYSTEM

In spite of the impression one might gain from the spate of recent literature, the farming system is not a new concept. By definition farmers have always operated within a system, and it is inconceivable that they did not consider the interactions of various parts of the system, at least informally, when managing their farms. Also, as Gilbert and his colleagues noted in 1980, there are many similarities between FSR and farm-management research as practised during the early part of the century. The current emphasis on farming systems is nothing more than an attempt to formalize the processes that have characterized agricultural research for many years, and to provide a catalyst by which the objectives of many researchers can be harmonized.

General Definition

A system is defined as any set of components (or elements) that are interrelated and interact among themselves Although some authors prefer to reserve the terms for those components having a human element, all components in a system may be classified as either endogenous, that is, both affecting and being affected by the system, or exogenous, that is, only affecting the system. Furthermore, each component within a system may also be regarded as a system in its own right, and conversely any system may be regarded as a component of a much larger system. This has implications for FSR, as will become evident later.

The Farming System

The components of the farming system are shown in the attached diagram. The endogenous components identified as parts of the farming system are the farming household together with its farm, the various inputs and outputs—land, capital, labour, management, production possibilities and "income"—and the processes—off-farm, crop, and livestock—by which the household uses inputs to produce outputs. Exogenous factors are defined as those human factors which affect the farming household and technical factors which affect the production-possibility set. By opting not to complicate the diagram by illustration of the many linkages between the farming system and other systems, the essential interdependencies are highlighted.

The farming household, which, depending on local tradition, may comprise a nuclear family, an extended family, or even a group of families, is at the centre of the farming system. Of all the components, it alone has the capacity to decide actively the ratios in which the various inputs are to be used, and on which of the members of the production-possibility set, to produce that combination of outputs which will maximize attainment of personal goals. When making and implementing these decisions the household decision-makers need to recognize the various interactions if they are to limit the probability of unwanted side effects.

The outputs from these processes may be either direct or indirect. The direct outputs can be considered as "income", either in kind (usually subsistence) or cash. This income feeds back into the farming household as consumption, savings, or investment in subsequent production. The sustainability of the cycle, through its capacity to generate sufficient income to satisfy each of these household needs, is critical to the development process. New technologies which cannot provide this level of income are unlikely to be adopted. The indirect outputs from production may be either positive or negative, and these are modifiers of the production-possibilities set. Indirect outputs, which may take such forms as erosion control/promotion or soil degradation/improvement, will have a longer-term impact on the composition of the production-possibility set, and will thus eventually affect the sustainability of the farming system.

Exogenous factors influencing the farming household can be summarized as community structures, norms and beliefs, the impact of external institutions, and others. While the difference between endogenous and exogenous factors is very clear, it may be difficult to classify the factors in practice. Some decisions may at first sight appear to be made by the farm decision-maker, yet on closer inspection they may be so modified by exogenous factors that they are also exogenous. Such complex relationships need

to be understood by development workers involved with farming systems. Moreover, it must be recognized that the set of exogenous factors will change as development proceeds.

Community structures, norms, and beliefs can take many forms. For example, many farming operations are traditionally undertaken by specific members of the household, or may be allocated to hired labour, whether or not household labour is available. Also in many areas the timing of social occasions has become fixed in slack periods during the traditional farming calendar, so that operations associated with improved farming systems may be constrained by the events. This type of factor must be considered as part of the farming system, and a part for which adjustments are likely to be very difficult.

External factors such as the supply of important inputs—credit, seeds, fertilizer, livestock concentrates, etc.—and markets for output often restrict the farming system. There has been some argument about the extent to which FSR should become involved in these issues. However, they are an important part of the farming system. Related to external factors is the physical environment in which the farming system is located. Factors such as the distance from the nearest town, the local road network, and population density may have an impact both directly on the farming system and indirectly through the impact on external factors.

The technical elements of the farming system are represented by the combination of physical and biological factors that determine the production-possibilities set, that is, the range of potential crop and livestock activities from which the household can select. The physical factors include soil, water, solar radiation, temperature, etc., which together determine the agro-ecological zone. Biological factors are crop and animal physiology, genetics, resistance to pest and disease attacks, etc., which determine the crops and livestock that can be produced in an agro-ecological zone. Traditional research has concentrated on either modification of the agro-ecological zone or the biological factors to extend the production-possibilities set.

The Farming System as a Component of a Larger System

The farming system is just one endogenous component of a much larger system which, depending on circumstances, may be defined as either the local community or the region. This larger system comprises various different production systems, both farming and non-farming, markets for the supply of inputs and sale of outputs, general services to the area, etc. Farming systems are frequently closely linked to the regional system, and development of the farming system will have ramifications in other areas which should be fully understood. Unfortunately, this is rarely the case.

Differentiation between Farming Systems Research and Farming Systems Development

FSR is research, as defined in the next section, into possible development strategies available to a farm household, such research being conducted within the concept of a farming system outlined above. Thus, FSR must take cognizance of the many interrelationships existing in the system. However, it is essentially research. FSD is a much broader concept, which can and should involve FSR as a component. FSD may consider not only the improvement of existing farming systems, but also a complete shift to new and more intensive systems if farms cannot become viable using present enterprise mixes even when they are totally improved. The FSD concept may even go as far as promoting expansion of non-farm employment opportunities to achieve viability for very small holders, thereby making this group part-time farmers. Thus FSD should relate to an entire area, rather than a limited number of farms within the area, and it should include a development/investment plan for implementation of the FSR findings.

Although simple to conceptualize as two distinct stages, FSR and FSD may, in practice, become virtually indistinguishable. Where technologies being researched are clearly superior to traditional technologies, farmers in the surrounding area who can view the benefits are as likely to adopt them as the participating farmers. This may make the problem of monitoring the impact of new technologies very difficult, and will certainly result in the work moving rapidly into the development phase.

THE CONCEPT OF FARMING SYSTEMS RESEARCH

Definition of FSR

Various researchers have attempted to produce a concise definition of FSR and most have been unsuccessful. Stated most broadly, FSR might be defined as research undertaken within the previously defined concept of a farming system.

More concisely, Dillon and Anderson specify that the research:

"i. *views* the whole farm as a system;
ii. is *conducted* with a recognition of and emphasis on the interdependencies and interrelationships that exist among elements of the farm system, and between these elements and the farm system's environment; and
iii. is *aimed* at enhancing the efficacy of farming systems through the better focusing of agricultural research so as to facilitate the generation, testing, and adoption of improved technology."

In common with many others, this definition does not judge the potential relative contributions of "on-farm" or "on-station" research or demonstration and unit farms to FSR objectives. However, there is considerable support, and justification, for the argument that FSR should be conducted predominantly "on-farm".

Stages in FSR

FRS has been conventionally divided into four stages:

i. the *descriptive* or *diagnostic* stage, where existing farming systems are evaluated;
ii. the *design* stage, where a range of potential strategies are identified;
iii. the *testing* stage, where a few promising strategies are evaluated on farmers' fields; and
iv. the *extension* stage, where an attempt is made to disseminate successful technologies over a broader area, and to identify potential problems.

The extension stage is not a part of FSD but rather an essential precursor to it. FSD will be facilitated by success in the extension stage of FSR. All of these stages in FSR should be undertaken in collaboration with farmers to the maximum extent possible.

Attributes of FSR

The inherent nature of FSR provides it with certain important attributes which are frequently missing from conventional research. Most important are recognition of:

Household member roles. FSR should, and usually does, take into account the roles of various household members and the impact research will have on those roles. At Katumani, one of the major items to be considered is the role of women as farm decision-makers. With 50 per cent of farms controlled by women, they must be included in the on-farm programme and, if possible, female researchers should be included in the FSR team.

Consideration of household objectives. By working directly with farm households, FSR recognizes the many objectives (goals), other than profit maximization, of the family. For areas with an uncertain climate food security is likely to be very important.

Community structure and goals. Even if not explicitly recognized, on-farm research soon becomes aware of the impact of community structure and goals on what a household considers feasible and acceptable. This may provide real constraints on the adoption of labour-saving technologies or even incorporation of certain activities into the farming system.

Household and community resources. FSR will operate within the framework of available household and community resources, acknowledging the extent to which sharing is possible, and the role of communal resources. Solutions of problems associated with these resources, e.g. erosion of grazing land, may be very different if the resource is owned by the community rather than by households.

The pool of knowledge of the society. By working closely with farmers, FSR can tap the pool of local knowledge and avoid "reinventing the wheel". This can provide a valuable starting point from which to develop the programme. Particular examples on which the Katumani project can build are the predominance of crop mixes, different types of crop mixes in different areas, and the basic approach to livestock production.

Locality specificity. FSR should be based on homogeneous localities defined by human factors and agro-ecological zones. This will focus attention on relatively few development options, but may also require specification of several, fairly small localities. Failure to be sufficiently specific may result in too indiscriminate testing of possible technologies. For Katumani, the site reports to date suggest that the research area contains at least three distinct agro-ecological zones.

Dynamic and iterative nature. FSR starts from the farmers' current situation and attempts systematically to improve on it. Improvements will almost inevitably be marginal, but in aggregate can be very significant. By working with the

farmer FSR ensures that each stage is compatible with his needs and ability.

Integrative and multidisciplinary process. Unlike conventional research, FSR seeks solutions which are acceptable to farmers and are frequently a compromise between results produced by different disciplines. To be most effectively achieved this implies a multidisciplinary approach to research. A problem well suited to this approach is the use of fertilizer in crop mixes rather than in pure stands.

Non-technical improvements. Although it is often discounted during the initial stages, FSR must ultimately consider the extent to which the farming system is constrained by the availability of inputs, markets for produce, etc. These may be more important than technical problems and will need to be researched.

Complementarity. FSR is not a substitute for conventional research but complementary to it, providing a link between conventional researchers and farmers. Information should be passed both ways to facilitate development.

Components Typically Researched in an FSR Programme

Reference to the structure of the farming system as shown in the diagram on page 19 highlights nine major components. Most farming-systems research to date—including that KEN/74/017—has concentrated on research into one of these components. We therefore review each separately before discussing their integration into the FSR framework.

Off-farm activities. Research in this area is restricted to the studies of economists and other social scientists who are predominantly interested in issues such as labour displacement by new agricultural technologies. Attention to the more positive aspects of off-farm activities, such as the promotion of labour-intensive local industries and development of support industries for improved farming systems, could encourage development.

Crops. The major area for FSR to date has been crops, and annual crops in particular. This is understandable to the extent that annual crops represent a system which can be both researched and changed fairly rapidly. Breeding programmes involve cycles which can be completed at least once, and often two or three times, per year, so that progress is rapid. This type of programme is often oriented towards single crops—for example the KEN/74/017 programmes in pigeonpea, maize, and sorghum/millet—although it may involve scientists from many disciplines in the search for improved varieties. However, of equal importance is the need for these scientists to work with crop mixes where these are the predominant form of production. Crop varieties which perform well when grown separately may not be as impressive under the compromises required by a mixture of crops.

Livestock. Together with forage crops/pasture, livestock have received little attention. Some international and national organizations are now beginning work and this area has vast scope. The potential for work in the livestock sector can be measured to some extent by the differences between developing and developed countries. However, caution is required. FSR workers must base their research on the current resources available to farmers and their objectives in keeping livestock, and then proceed to improve systematically. Livestock are important in semi-arid farming, and could and doubtless will become much more important. But progress needs to be made gradually.

Production-possibilities set. Work in this area is generally undertaken "on-station" and as a part of conventional research. FSR can, and does, contribute to extending the range of production possibilities. Researchers in an FSR programme should take care that this does not become their major role or the programme will suffer.

Land, capital, labour, and management. These major components have all been researched both individually and in combination. Research on land may include such socio-economic aspects as ownership and tenure, through to the technical problems of erosion control and soil degradation. Capital may be broadly defined as farm capital, which will include storage facilities, machinery, and implements. Research in these areas—for example on the improved storage crib, multi-purpose implement, and punch planter—needs to be conducted within an interdisciplinary framework. Labour use and management are also areas considered peripheral to FSR, except for that undertaken by economists.

Farming household. The farming household and the decisions it takes can provide much research for economists, especially where they want to understand the decision-making process. Unfortunately, such work is largely restricted to explaining why new technologies are not

adopted rather than defining technologies that will be adopted.

Integration of Component Research

Although elaborated above in terms of component research, the form in which most FSR is undertaken, improved technologies need to be fully evaluated when tested on farmers' fields. Even then the process does not constitute FSR unless the researchers, whom we assume to represent the various disciplines involved, analyse the results within the context of the *total* farming system, determining how the system works and the levels of inputs and outputs before and after the new introduction. Important questions to be answered are:

—Were there any changes in total farm labour requirements, and seasonal distribution, between the old farming system and the modified one being tested?
—Were there any changes in the labour requirements for different household members?
—Could household members satisfy the labour requirement or was there a need to hire additional labour? If so, is there an adequate labour market?
—Were there any changes in capital requirements?
—Does the technology require an input which is not readily available, and, if so, can it be made available?
—Were there sufficient changes in total farm output and income to make the technology attractive to farmers?
—Were there any beneficial or detrimental effects on the land? If there were detrimental effects, what can be done to alleviate them?

When answering these questions the researcher must take into account the facts that the FSR programme will probably not involve adoption of the new technology in the maximum possible area, and that it will certainly only involve adoption by a very few farmers. Wider adoption may influence the answers to some of the above questions.

FSR as a Part of the Research Process

When considered as a single component, the structure and potential importance of FSR are fairly easy to appreciate. Yet as soon as an FSR programme is implemented it becomes a component of a much broader research system. In this section we briefly discuss some of these issues.

FSR or conventional research? FSR is frequently regarded as a substitute for conventional research. To some extent this will be true where research resources are limiting. Yet really, as we have already stated, FSR is a complement to conventional research, providing a link between the traditional scientist and the farmer. Where resources are limiting, and it may be necessary to reduce those allocated to other areas, the introduction of an FSR programme can only be justified if there is a net gain to the farming community. Such gains we would expect to be always obtainable. In addition, where resources are limiting we would hope that many conventional researchers would be prepared to be involved in FSR at the same time as continuing their traditional work. This should benefit both activities.

"On-farm" or "on-station" research? Some advocates of FSR would suggest that it can only be carried out "on-farm". Yet because of the many complex issues involved in system design, and the likely existence of several potential systems, there is considerable justification for systems design and initial screening to be undertaken "on-station", where the researcher is usually able to impose tighter control. Such activities, however, should not be carried out either at the expense of "on-farm" research or in such a manner that the FSR worker shifts back to the conventional commodity and discipline orientations.

Role of demonstration/unit farm in FSR. Demonstration farms can be either located on station or selected from existing farms, depending on circumstances, and attempt to demonstrate what farmers in an area could achieve given the current state of (researchers') knowledge. The unit farm is by definition "on-station", and is an attempt to simulate what farmers are actually doing. For the Katumani project, Bakhtri and his colleagues have stated the objective of the unit farm as "to simulate as closely as possible the conditions of an average farm".

Demonstration farms can, under certain circumstances, provide a valuable input to a farming-systems programme, although their use is likely to be after the research stage. To be effective, demonstration farms must first have a proven technology, or group of technologies, to demonstrate. This sounds trivial, but all too frequently relatively untried technologies are located on demonstration farms and credibility is lost. Second, the demonstration farm must be located so that it is readily accessible to the farmer audience. No one should expect them to

travel a long distance to view it. Third, the technologies shown should be ones which the farmers in the area can adopt. High-level technologies may fascinate researchers but are irrelevant to farmers operating low-input/low-output systems.

The main contrast of the unit farm (with the demonstration farm) is that it is operated predominantly for the benefit of researchers. Although the unit farm is intended to simulate reality there are many areas in which this is not achieved, and several in which there is no way reality can be achieved. Specific examples of the former situation at Katumani relate to the level of mechanization used and the availability of other resources. These were clearly far superior to the average farm. Also bunding of the fields before the farm started gave the unit farm a substantial advantage. It would have been more interesting to have attempted a solution to this problem after the project had been started. Examples of the latter situation include the entire household component, where is would be difficult, if not impossible, to expect the labourers and their families to rely on farm production, particularly during droughts. Also the nutrition of draft livestock is likely to be better than normal.

Overall, we consider that demonstration and unit farms can have a role in FSR but they should not be promoted at the expense of on-farm research.

Organization of research-station personnel. Gilbert and his colleagues view the organization of an FSR programme in a research station as a matter of establishing a philosophy of research rather than a separate administrative unit. Dillon and Anderson suggest a slightly more formal approach, including establishment of an FSR co-ordinating unit. Where FSR programmes have been established the most common approach has been to establish a department However, since research stations are usually departmentalized on a disciplinary basis, problems are experienced. The FSR unit will inevitably involve researchers from all discipline-based departments as well as its own specific staff. Problems of allegiance may arise. Alternatively, to reorient the entire station to a programme basis may be difficult, since researchers will often feel greater allegiance to their own discipline.

If an FSR programme is to be established within a research station, an acceptable solution to this problem must be found. It will probably involve an FSR co-ordinator with overall control of research and on-farm experiments, but must also operate within a framework which is sympathetic to researchers' needs and has their full support.

Making FSR effective. To be effective, the FSR programme must be capable of relating to its clients and providing them with useful information. Data collection is valuable and should be undertaken, but only to the extent that it helps in execution of the above objectives, and can be rapidly analysed using readily available resources. The FSR programme must therefore have close links to the farmers, which may include suitable field locations to which farmers can relate. Researchers should have the ability to communicate with farmers, which does not imply that they need to hold higher degrees, and should be able to call upon the knowledge of their more specialized colleagues. FSR relies first and foremost on this interdisciplinary co-operation of research scientists with farmers.

Once FSR workers believe they can be effective they must establish and maintain credibility with the local farming community. This will require the rapid solution of relatively simple problems, followed by a steady flow of solutions to more complex problems. This requires special attention to the selection of appropriate problems.

SELECTING THE TECHNICAL PROBLEMS TO BE RESEARCHED WITHIN THE FSR CONCEPT

Selection of an appropriate set of problems to be researched within the FSR concept is critical to the success of the programme. By "appropriate" we mean problems that:

—are relevant to the target farmers;
—can be expected to be solved with a reasonably high degree of certainty; and
—can be expected to yield solutions which are adoptable by a large number of farmers in the target area.

The Current Framework

Although differing in detail between various programmes, the current approach to identifying problems for FSR can be divided into two components. The first is problem identification, where a large number of problems which the farmer faces are identified, and the second is the ranking of these into some order of priority so that the sub-set for research can be selected.

Problem identification. Various approaches,

ranging from discussions with participant farmers, through various types of surveys to meetings confined to groups of scientists, have been used to identify FSR problems.

Local meetings with farmers have considerable appeal, since they relate, or at least appear to relate, to the potential beneficiaries from research. Caution is required, however, as it is quite normal for these meetings to be attended only by the better farmers, average and less-than-average farmers feeling that they will be unable to contribute.

Landless labourers are also unlikely to be represented in these meetings, as, in certain communities, will women, whether as farmers or as household members. FSR which ignores the needs of these groups may produce socially unacceptable solutions to problems or may define problems which do not really exist. Additional problems with meetings may be related to language difficulties, and the need to prime the audience with introductory comments to stimulate discussion. Such comments can easily become the final recommendations at the meeting, even where they are not really considered appropriate. Yet where meetings are carefully co-ordinated they can prove useful.

The simplest types of surveys to use for problem identification are informal reconnaissance or exploratory surveys. Bensten has suggested an approach which requires visits to the villages involved in the study and the elicitation of relevant facts by reference to village records, village heads, key farmers, and any other important person in the village who might be able to provide information. No attempt is made to obtain a random sample. Hildebrand favoured the use of a *sondeo*, consisting of a six- to ten-day reconnaissance survey undertaken by the FSR team. Implicit in the *sondeo* approach is the need for FSR workers to interact not only with the farming systems with which they will be associating but also with each other.

More formal surveys may range from short questionnaires answered by a relatively large number of households through to very complex questionnaires posed to a smaller group. However, if these are to be of value they must be analysed rapidly.

Ranking of problems. Once sufficient problems have been identified, researchers must rank them in order of priority. Some of the critical issues to evaluate are:

—Does investigation of this problem require that another problem should be evaluated?
—What is the likely cost of the research each year of its duration?
—How should success be defined, and what would be the benefits from success?
—If successful, what is the likely adoption pattern?
—What are the likely secondary costs and benefits?

Although formal mechanisms could be suggested for evaluating these questions, they are normally resolved by group discussions. Inefficiencies may appear and some groups may have a greater impact than they should. Agreement has to rely predominantly on the integrity of individual team members.

The Kenya/FAO Experience

Farm surveys undertaken during the first phase of the project should have been completed and analysed *before* the project document was formulated. This means that the design of the project was inherently weak. The survey findings would have provided pertinent information for determining research priorities and for identifying complementary inputs from other projects. Future similar projects should therefore be designed along the following lines:

i. a rapid but carefully planned pre-survey of the target area, which would provide sufficient information for identifying the variety of farming systems existing in the region and at least the important and immediately obvious problems confronting the farmers in each farming system;
ii. development of research programmes tailored to the identified problems;
iii. simultaneously with (ii) above, using the information from the pre-survey as a basis for selecting sample farmers for each farming system for in-depth study and analysis similar to that conducted for this project;
iv. modification/adjustment of research programmes to focus fully on identified priority problems/constraints.

THE FARMING SYSTEMS DEVELOPMENT APPROACH BEING CONSIDERED BY FAO

FSR programmes at international and national agricultural research institutes have developed several crop and livestock systems. Some of these have spread over large areas as a result of outreach programmes operating in collaboration

with local expertise. From the results to date it is evident that the scope of FSR will be limited by resource availability and the economic/political system within which the FSR programme operates.

Within the FSD approach being proposed by FAO, FSR results will be implemented on selected farms. During the implementation period, all difficulties of implementation, risk factors, management weaknesses, etc. will be studied and attempts made to rectify these for subsequent years. Simultaneously, the adequacy of institutional and agricultural policies will be studied to determine adjustments required if large-scale investment follow-up is to be made.

Once the most productive and viable systems are identified, phased investment programmes will be prepared for progressively larger areas. The results and experience will be used to train a development cadre who can design improved systems with farmers and continue development programmes.

The FSD approach will also be concerned with identifying those situations where improvements to existing farming systems are insufficient to ensure viability, even when totally improved. FSD will then consider a shift to new and more intensive systems, if such are available or possibly the expansion of rural employment opportunities which will ensure viability of the farming household, although perhaps as part-time farmers.

Characteristics of the FSD Approach

Based on rural areas. During the past 30 years many countries have emphasized development of the modern, urban-based, non-agricultural sectors. This has attracted the most productive members of rural communities to urban areas, resulting in decreasing land productivity and poor land use in rural areas. Considerable effort has been directed in recent years towards improvements in the agricultural sector, with particular emphasis on labour productivity. In many situations this has been contrary to the perceived needs of farmers.

The FSD approach recognizes that the farm household needs to become more productive if development is to occur, and as the household becomes more productive there will be more income to spend on consumer goods and services. This presents opportunities for infrastructural development, such as communications, schools, health facilities, and retail stores, as well as for local manufacturing industries. The successful FSD approach will ensure that rural life becomes an attractive alternative to urban migration.

Multi-agency. FSD requires farm-development programmes to become an integral part of a much larger multidisciplinary development programme. The systems approach should operate at all levels, up to and including the national level, on the understanding that it can be used to solve many problems. Ministries and individual departments, together with aid agencies, should be encouraged to participate so that the most efficient use can be made of development resources. This approach will have the advantage of generating a single data base for development purposes and a co-ordinated programme of action.

National and local self-reliance. Most developing countries have untapped resources in the form of students attending universities and other institutions, high-school graduates, farmers, and local community leaders. Given encouragement, and training as required, these groups can provide the impetus for the FSD approach. To be successful these local workers need to have development resources available at the local level, to be allowed sufficient flexibility in the implementation of development strategies, and to be judged on the basis of results achieved. Outside experts should be used only when local expertise is unavailable.

Bottom-up. FSD is locality-specific and starts from improving the farmer's situation. FSD will achieve development by reference to the body of FSR results where applicable, but may need to modify these to accommodate specific situations. Where development is tightly controlled by centrally based planners, it is unlikely that the necessary degree of flexibility can be achieved. The ideal situation is one where local personnel are charged with a broad brief for development but allowed to make specific decisions for themselves. There are doubtless many people with this inherent ability in most developing countries.

Household welfare. The central objective of FSD is to improve household welfare, both by short-run improvements in living standards as a result of new farming systems, and long-run improvements through increased quality of resources and shifts to totally new systems.

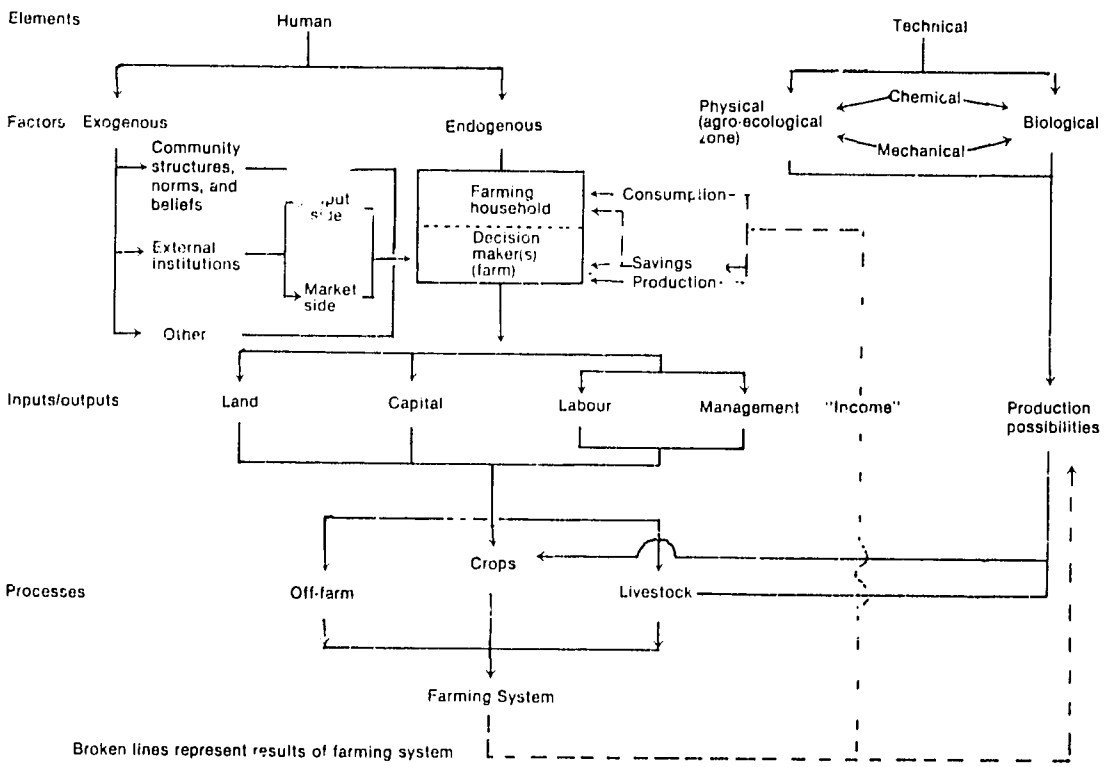
Community welfare. FSD must also be concerned with community welfare. The communities currently existing have long formed the foundations of society. The development ap-

proaches of the past 30 years have had a detrimental effect on these structures, often with disastrous results. FSD can build on what exists ensure that all members of the community benefit.

CONCLUDING REMARKS

FSR is not a new discipline. It is a conceptual approach aimed at making agricultural research more relevant to farmers. To the extent that many researchers have always sought this, and that farmers have always planned in a systems framework, even the concept is not new. The main difference is that we are now attempting to formalize the FSR and FSD concepts and develop them into a workable approach to development.

The success of the approach is going to be highly dependent on the flexibility of research workers and their willingness to work in an interdisciplinary environment. Where researchers are unwilling to look at problems in a whole-farm context, following closely the implications of various potential solutions, FSR programmes are unlikely to be successful.



SOME ASPECTS OF AGRICULTURAL RESEARCH IN KENYA

Francis LeBeau[1]

It is hardly necessary to call attention to the important role that research plays in agricultural development. It suffices to point to some of the major contributions of research in recent years: the development of hybrid maize in many parts of the world, the adaptation of soya beans to a wide range of environmental conditions, the development of high-yielding varieties of rice and wheat. These achievements have had a profound effect on the development of agriculture, on the improvement of the living conditions of farmers, and on overall national economic development in many areas. The impact of these developments has been felt most where ecological conditions are favourable to intensified agricultural production systems or where the conditions could be modified by, for example, irrigation, to create a favourable environment for the application of high-input/high-output systems of production. They have found little application, however, in the extensive areas classified as marginal for crop production in the arid and semi-arid regions, which embrace a high percentage of the arable lands of the world. In certain areas—Australia, North America, the Sudan—considerable progress has been made in developing a commercial semi-arid agriculture. However, that of other semi-arid areas has for the most part remained traditional and extensive in practice though small in scale, low in productivity, and generally providing only a minimal level of subsistence.

Research and development in the semi-arid areas have apparently been unable to find intermediate solutions to the question of scale. Successful commercial production is based on large-scale (extensive) mechanized operations which, while not usually producing high yields, do provide a good return to labour. At the opposite end are the chiefly hand-operated small farms, practising an extensive system of farming on a minuscule scale and providing for a bare subsistence. Neither has research been able to find solutions leading to intensification in the semi-arid areas. Where in certain areas of the world it has been possible through the application of appropriate technology to create intensive systems of production in small-scale farming enterprises leading to high levels of productivity and relatively high standards of living for the farmers, similar developments in the semi-arid areas have so far escaped the researcher.

The challenge to the researcher in semi-arid agriculture is therefore one of developing methods of intensifying the production system on small-scale farms or of developments by which the family farm labour can expand the area which it can cultivate. These two options are not mutually exclusive and in all probability solutions will involve both.

STRUCTURE OF THE SYMPOSIUM

The symposium is at least in part an outgrowth of a recommendation made by a mission (February-March 1982) which made an interim evaluation of two on-going externally assisted projects dealing with research for the semi-arid regions of Eastern Province, Kenya.

The recommendation by the mission stemmed from the recognition of a need to bring into better focus the agricultural problems of the semi-arid areas, and especially issues related to the importance of those areas in the economy of the country and of the relative priority given to them in the planning of development and research and the allocation of resources.

In spite of the high priority given to the semi-arid zones in development plans and in policy statements by governments, the fact of very limited commitment of resources was nevertheless noted. The lack of a well defined plan for addressing the problems of this zone was noted and this was viewed as an important impediment to definition of priority actions to be undertaken within the areas and also to the definition of needed resources (human, material, and financial). The evaluation mission also noted that there were a number of institutional impediments to effective co-ordination of the research being undertaken by the two projects as well as between those and other related projects.

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1. Consultant, USAID

Having participated in this evaluation mission, I view the realization of this symposium with some satisfaction. However, I note the focus is almost exclusively on technical matters. I would have hoped that some of the issues of organization, direction, management, professional development of personnel, and support would have been included as well. The developments which are currently under way in terms of the restructuring and perhaps refocusing of the Ministry of Agriculture and Livestock Development, especially as this relates to research, would seem to make discussion of these points particularly timely. I will permit myself to deal briefly with some of these and perhaps some discussion of them will occur as the technical issues come up for discussion.

While commenting on the structure of the Symposium, I note with a great deal of satisfaction the plan for publication of the proceedings, including numerous technical papers of high professional quality which, because of time limitations, will not be read during the Symposium. These papers record in some detail the many achievements and conclusions from four to six years of research by numerous individuals and teams of individuals, many of whom will shortly be terminating their involvement in this programme. The careful recording of findings and conclusions from research is particularly important in externally supported projects, which are marked by varying degrees of lack of continuity.

The failure to record the results of research adequately, which is so commonly the case, is the cause of frequent duplication of work and inefficient use of resources.

THE INSTITUTIONAL SETTING

The institutional setting for research consists of the structures and organizations for defining the relationship between research, agriculture-development programmes, agricultural policies, resource-allocation processes, and overall national policies. It is from these relationships that research receives direction and obtains support. It is also from these relationships that choices are made in terms of how limited resources (resources are always limiting, even in the most affluent institutions and/or societies) are to be used.

Agricultural research institutions in Africa have evolved primarily as a consequence of economic pressures. Out of this emerged institutional structures which were responsive to the needs of specific sets of interest groups within some broader set of economic and political objectives. In many cases these self-interest groups became the primary if not the only source of support for research, receiving also the primary benefits. The result was an imbalance in the development of research and the benefits therefrom in which certain elements of society remained almost totally unaffected.

As African states emerged as independent nations, the governments have been faced with the need for restructuring their agricultural-research institutions to serve a broader purpose, i.e. the national interest, although national interest is itself a reflection of the composite of interacting self-interests. The first role of the governmental research institutions therefore becomes broadly one of balancing the research programmes with development objectives and prospects and with resource availability. Within this broad area come many detailed planning and operational decisions. The exercise of the decision-making process is frequently dispersed among agencies and departments, making it difficult to relate decisions with central objectives or to ensure that actions reflect the decisions taken.

We have seen in Kenya a series of organizational changes in the research institutions. Among the more recent ones was the creation of KARI as a semi-autonomous institution for agriculture research designed to become the unique entity to direct, manage, and implement all agriculture research (with the exception perhaps of that involving certain semi-private entities). This objective has not been realized. Rather, the impact to date of the creation of KARI has been to add another structure to the complex of agriculture-research entities without improving mechanisms for co-ordination and collaboration among them or for defining priorities among possible research undertakings or for allocation of resources. This lack has been particularly brought to light as the government finds it is necessary to reduce expenditures, applying uniform cuts in the budgets of practically all government departments, which in turn have usually applied uniform reductions in their operational divisions or units without any selectivity to reflect orders of priority.

The recent restructuring of the Ministries of Agriculture and Livestock Development, combining them into a single Ministry of Agriculture and Livestock Development, and the transfer of KARI

to this new Ministry provide a unique opportunity for structuring a research organization which will be capable of planning research programmes in response to development objectives for the agricultural section and capable of directing and implementing that research.

Given the extent of the resources, human and material, which are likely to be available for agricultural research (excluding that of the largely industry-financed specialized institutions) over the next one to two decades, and even assuming substantial external assistance, it would seem that the most efficient use of resources would be obtained by a single entity within or responsible to the Ministry of Agriculture and Livestock Development.

Such an organization would bring the currently dispersed structures operating to a large extent under independent direction—KARI, the Scientific Research Division, the Livestock Production Research Division, the National Commodity Research Stations, other research stations, Muguga as a research station, the National Seed Quality Station, the National Agricultural Laboratory, and perhaps other entities—under the general direction of a central organization.

A central organization under central direction should be able to reach decisions more effectively as to which research programmes should be undertaken, bearing in mind the relevance to national development objectives and the availability of resources, human, material and financial.

Such an organization could be tailored to be responsive to some of the principal requirements of an effective research institution:

1. Strong direction to ensure that programmes and projects undertaken are responsive to important problems affecting significant segments of the agricultural and livestock-producing populations and to overall national development programmes. Strong direction is also necessary to ensure co-ordination and collaboration among programmes.
2. Strong programme/project leadership for direction and implementation of programmes and projects and for ensuring co-ordination and collaboration among projects within programmes.
3. Ensuring a balance between resources, human, material, and financial, and the scope and magnitude of research programmes and projects to be undertaken. A certain critical mass of resources for any given undertaking is essential. Since resources are always limiting, this implies a very careful determination of priorities.
4. A management system of finance, personnel, facilities, procurement and logistics which can ensure that the elements required for the programmes are in place in a timely fashion. Research frequently requires a high degree of precision in the timing of operations. Even very brief interruptions of required services can have serious consequences.
5. Ensuring the maintenance of a balance between budgetary allocation for personnel and operations, and within the personnel component a balance among professional, technical and support personnel cadres.
6. The inclusion in the organization of a plan for professional development and advancement of personnel—training for advanced degrees; opportunity to participate in specialized training; participation in professional meetings, conferences, and symposia within and outside the country; freedom to engage in exchanges among professionals; the opportunity to write and publish professional papers. These are important elements of professional personnel development. Together with the provision of a favourable environment for living and working, these things are important in maintaining a high level of morale and are probably as important as monetary compensation, if not more so, in retaining scientists in research careers.
7. Assuring by means of strong central direction that decisions involving programmes and projects to be undertaken respect a number of general principles:

   i. the problem to be studied must be clearly defined—i.e. defined in researchable terms;
   ii. the problem must be recognized as important in terms of its practical implications for production and productivity. This frequently implies the study of existing production systems for identification of important bottlenecks in the system and the definition of researchable problems;
   iii. research methodology appropriate to the problems should be available. Occasionally the problem is defined in terms of an improved or even a new methodology;
   iv. there must be a reasonable assurance that a positive solution to a problem will lead to application of the results. In other words, the problem must be sufficiently broadly defined and the scope of the research

sufficiently broad to yield applicable solutions;

v. continuity is important; frequent interruptions because of resource limitations result in serious loss in efficiency. This requires a strong commitment to the research programme and long-term resource planning.

A unique central organization would provide a much more efficient mechanism for dealing with external support entities and should ensure as much as possible that the support is committed to priority areas. Interaction with the international agricultural research centres as well as with research institutions of other countries would be facilitated.

Co-operative and collaborative work for the existing specialized research institutions for coffee, tea, sugar, etc., as well as with the University of Nairobi, should also be enhanced.

It would seem that an important reservoir of research capability in the Faculty of Agriculture of the University of Nairobi is not fully utilized because of lack of funds to support research and lack of mechanisms for involving the faculty in the research programmes of the Ministry.

ORIENTATION OF RESEARCH

In Kenya, research has traditionally been organized and oriented along commodity lines. This has served the country well and much of the currently employed agricultural technology was developed or improved through this approach. The approach, however, fails to provide a suitable mechanism for dealing with a number of technical problem areas, not to mention that of broader development issues which need to be studied.

A case in point is that of research in the semi-arid areas of both the east and west. In those areas the principal constraint is water—its availability, use, and management. Although it is possible to bring about improvements in those areas through selection and breeding of better crop varieties and livestock types, the solution of the primary problem (how to conserve and make the best use of water) remains in the development of interactive systems among crops and between crops and livestock, and of production practices which are technically and economically sound and socially viable. This involves not only agronomic and animal research but also socio-economic studies. The single-commodity focus of research programmes does not adequately provide for the planning and implementation of programmes to deal with these problems. This would suggest that an ecological-zone focus based on a systems approach might be more appropriate.

Viewed from the broader developmental point of view, the ecological-geographic-zone approach would also appear to have considerable merit.

One of the objectives of the Government of Kenya in its programme for the development of the crops and livestock sectors in the semi-arid areas is the "integration of the arid and semi-arid lands into the national economy". The achievement of this objective requires that the population move above the mere subsistence level of existence. This means the need for production of surpluses which can be exchanged in the national economy for other commodities. Currently, the principal surplus commodity in the semi-arid areas is livestock or livestock products. Livestock production, however, remains at a low level of productivity.

The areas produce few crops, other than the subsistence food crops which are largely consumed in place. It is not likely that these areas will become surplus producers of the staple food crop (maize), because of the overwhelming comparative advantage in maize production of the high-potential areas. There appears to be an opportunity, however, for expansion of the production of other crops—sorghum, pulses, and oil-seed crops. The opportunity for expansion of sorghum production will depend to a large extent on the development of industrial processing for the grain and appropriate marketing arrangements, which is thus an important area for research in addition to that geared to production of the crop. Secondary crops will be increased to the extent that they fit into a rotation with the basic grain crops. Increasing the productivity (yield per hectare and per unit of labour input) of the staple grain crops, chiefly maize, which is expected to result from research, ill make it possible to devote a larger cultivated area to these secondary crops and result in greater generation of cash income. The outlook for increasing cash income, nevertheless, rests heavily on increasing the production of livestock.

It should be possible to achieve a much closer integration of livestock and crop production for the mutual benefit of both enterprises. In traditional practice, integration is limited to the use of animals for power, some feeding of crop residues, and some use of manure for soil improvement. Livestock production is still largely de-

pendent upon grazing off natural pastures which do not provide an adequate level of nutrition. This would be substantially improved if more adequate and efficient feeds were avaiable, and this means the production of forages as a crop.

Conventional wisdom in Africa generally, and with few exceptions in Kenya also, is that small farmers will not grow a crop for feeding to animals. While it is not likely that grain will be fed to animals in the foreseeable future, the possibility that farmers will accept the growing of forage crops for animal feeding, especially legume forages, which will also improve the soil producing the traditional grain crops, has not been given much serious attention.

There is little information as to which forage species would adapt best to the areas and the existing farming systems. Even less is known about the returns which could be obtained from a hectare of a forage crop fed to animals as compared to the returns obtained from the crops now produced.

A much more concerted effort is needed to evaluate a wide range of forage crops (especially legume species) for possible usefulness as livestock feed and for adaptation in rotation with other crops. The beneficial effects of legumes on subsequent grain and other crops are well known. Having identified suitable forage legumes, the economic advantage or disadvantage, taking into account improved livestock production and the beneficial effects of forage crops on subsequent grain crops, will need to be determined. This entire area of research makes up only a small part of that which is currently under way and should be expanded as rapidly as resources will permit.

FOOD ORIENTATION

Agricultural research and development in developing countries, especially during the past decade, has been heavily focused on food crops and food production. The unsatisfactory state of food production world wide, and especially in Africa, is the cause of grave concern to the peoples and their governments, as well as to those of the developed countries. We are told that no less than 22 countries in Africa alone are currently facing serious food shortages. Viewed in this context, the concentration of development efforts on food production is understandable. Viewed in the broader context of economic development, however, the preoccupation with food is perhaps obscuring more fundamental problems. With agriculture as the prime producer of wealth in most countries in Africa, the economic development of the countries must inevitably be based on greater productivity and production in the agriculture sector. Ignoring for the moment the questions of comparative advantage or the need for foreign exchange, it is possible to show that a food-based strategy for agricultural development does not provide a sound foundation for growth.

A more balanced approach, focusing on overall agriculture/livestock to include both food and non-food commodities, and which more effectively exploits local and national comparative advantages, would appear to provide a better base for agricultural development.

It should be recognized, however, that where the majority of farming enterprises are principally concerned with production of food for subsistence, the introduction of non-food crops, which could advantageously replace food crops, can be made only after subsistence food requirements are met. Consequently, broadening the production base to include non-food elements must usually be preceded by the improvement of the basic food-production enterprises, so that labour or other resources may be applied to other production options. Unfortunately, however, and probably for want of viable options, especially in marginal areas, any excess farm labour tends to seek off-the-farm employment and the farming enterprise remains oriented simply to subsistence.

The objective of research and development in these areas would seem to be that of finding profitable options which could convert the farm into a commercial enterprise.

It is believed by many that competition for resources exists between food and non-food crops. This is frequently given as a reason for placing more emphasis on food crops. That this is probably a false belief was pointed out in a study by the World Bank of the recent performance of 40 African countries in food and non-food commodity production. Among the 40 countries studied there was a high correlation between performance in the food sector and that in the non-food sector. Those countries with the best performance in the non-food sector were generally good performers in the food sector as well. This would suggest that the poor performance of the food sector is not the result of competition for resources but rather of some more fundamental causes, and that those causes impinge on the non-food as well as on the food-producing sectors.

POLICY ISSUES

While much is said on the issue of interregional trade among African countries, the issue of regional specialization within countries and consequent interregional exchanges has received little attention. Although there is an important degree of regional specialization in crop and livestock production in Kenya, this is usually related to historical and demographic factors and the more obvious responses to different ecological conditions. There would seem to be an opportunity for more closely relating the agriculture/livestock production of different regions, one to the other. This involves policy issues, e.g. land, pricing, marketing, etc., which often alter the natural comparative advantage among regions. The latter is not necessarily fixed, but is frequently related to available production technology and to politics.

Research into the impact of policies, of the changes in comparative advantage among regions for various types of crops and livestock production which occur as changes in technology are developed, and of development of transportation, marketing, communication, and other infrastructure would seem to merit more attention.

TECHNICAL SESSION 1

RESPONSE FARMING: WEATHER-DIRECTED CROPPING SYSTEMS

RESPONSE FARMING OF MAIZE AND BEANS AT KATUMANI, MACHAKOS DISTRICT, KENYA: RECOMMENDATIONS, YIELD EXPECTATIONS, AND ECONOMIC BENEFITS

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INTRODUCTION TO RESPONSE FARMING RESEARCH AND PROGRESS TO DATE

In the latter part of 1980 a newly developed crop-specific "effective rainfall analysis" was applied for the first time to the 24-year rainfall record from the Katumani National Dryland Farming Research Station. This included 48 growing seasons due to the bimodality of the rainfall pattern there and throughout the project area. Each season was analysed with regard to how well Katumani Composite B maize, a 120-day maturity type, should have performed. Performance was rated on water use, i.e. expected actual evapotranspiration from germination to maturity, water adequacy with respect to maximum evapotranspiration, and consequent yield (Stewart, 1980b).

The analysis revealed that early rainfall events, starting with the date of onset and continuing on into the season, foretell with increasing accuracy the seasonal rainfall expectation. Early onset is correlated with higher rainfall expectations, justifying higher seeding and initial fertilization rates, and, when considering more than one crop, an increased land allocation to crops with greater water requirements.

The rainfall amount up to thinning time correlates sufficiently to categorize the season as good (A), fair (B) or poor (C), providing a basis for guiding farmers in adjusting plant populations and nitrogen fertilizer amounts. By mid-season the correlation is very strong, permitting a quantitative evaluation of effective rainfall and yield expectations. Stewart and Hash (1982) quantify maize-yield expectations at Katumani, and, using Baysian theory, evaluate the incremental yield and financial benefits from this prediction methodology.

Conclusions formulated by Stewart and Hash are these: "Despite our inability to predict the notoriously variable rains in Kenya's semi-arid areas, a newly developed analysis of 'effective rainfall' for maize production does permit their after-the-fact interpretation in time to give practical advice on farm practices and levels of inputs. The analysis of the available weather records—primarily rainfall and evaporation—when coupled with suitable research findings concerning the crops and soils of interest, accomplishes the following:

1. Permits evaluation of the suitability of a given crop for production at the planning site.
2. Defines the earliest and latest acceptable dates of onset of the rains for growing the study crop.
3. Quantifies the initial rainfall which should be accepted by the farmer as the signal to plant his crop.
4. Reveals that date of onset of the rains is correlated with total season rainfall expectation, and with intensities of early-season rains. Hence, pinpoints ranges of dates properly termed early, late and too late as regards planting, and quantifies early-season rainfall amounts which indicate whether a good, fair or poor season is in store.

Application of the above information occurs at three stages:

1. The date of onset of the rains triggers recommendations to farmers on date of planting, seeding rates and initial fertilizer applications.
2. Rainfall totals 50 days after date of onset in the short rains, and 30—40 days into the long rains permit categorization of season type, and determine farmer recommendations on thinning to desired stands, and on adjustment of nitrogen fertilizer levels through side-dressing.
3. At 75 days into the season, or approximately

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two months before harvest, total season rainfall can be estimated, and predictions of maize yield provided for farmers, economists, and other planners concerned with food supplies."

Kashasha (1982), with supervision from the senior author, extends the analysis to nine additional localities encompassing an area of 13,000 km^2 in Machakos, Kitui and Kajiado Districts. Five of these have longer rainfall records, up to 55 years or 110 seasons. Eight are drier than Katumani, with several considered too risky for maize production. Important findings are that the essential correlations found at Katumani exist at all ten localities, and their underpinning is now firm. Both differences and similarities between localities, some of which are close together and some isolated, have been quantified. This will improve future interpolations in areas between the analysed localities. Also, in the drier localities, the original finding that there may be an onset period "too late" for planting of maize is amplified, and conversely, periods are determined for each locality during which risks in maize production are relatively low.

Stewart and Kashasha (1984) apply the term "onset windows" to the early onset periods when planting of maize is advised, and define the final acceptable dates in each locality for each of the two seasons. Substitution of crops with lower water requirements, including grain sorghum, millet and beans, is suggested for seasons with later onset. Analysis of potential yield benefits from planting the popular maize/bean intercrop, rather than monocropped maize, is developed on the basis of experiments carried out both on experiment stations and on farms in Machakos District. Finally, the term "response farming" is applied to the entire methodology.

Stewart (1982) reports on recent experimental findings of particular significance for the formulation of farm-level recommendations guided by response-farming precepts. A "line source design" (Hanks *et al.*, 1974; Stewart *et al.*, 1977) experiment at Katumani Station shows how essential at least modest soil-nitrogen fertility is for efficient water use, and that, although it applies at all water-supply (rainfall) levels, it is particularly necessary in the lowest rainfall seasons.

The same experiment and four subsequent ones, three conducted jointly with Dr. H. M. Nadar, project agronomist in rainfed conditions, have shown the importance of adapting plant population to rainfall level, and have quantified optimal levels for Katumani maize and the popular Mwezi Moja bean, both monocropped and intercropped.

These and previous findings have culminated in the formulation of response-farming recommendations tested over the past four cropping seasons in "on-farm verification trials" designed to compare crop production using the new methodology with that from normal farm practices. The final season of on-farm testing was the short rains of 1982, which started early, on October 16, and (for maize) ended in the latter part of February, 1983. It was an A or good season, with gross rainfall ranging from 400 to 600 mm over the testing area. Trials of maize, beans and the intercrop were established on 12 farms, consisting of 3-farm clusters at each of four localities in Machakos District. Results of these trials, together with those of experiment-station trials described, will be shown and discussed later.

The present paper up-dates the Katumani rainfall and evaporation records through the 1983 long rainy season, i.e. through July. However, it goes well beyond that to (a) introduce a simplified methodology for rainfall season categorization, both earlier and more accurately than previously, and (b) also introduces wholly new crop-production functions for maize, beans and the intercrop, which predict yields for three field-encountered levels of farm management. The latter are based on whether or not fertilizers are applied, whether maize and beans are rotated (grown sequentially on a given field) or not, the degree of weed control exercised and plant populations utilized, with all of the above matched with the effective rainfall level.

Farming recommendations for the above crops are formulated for each of the three levels of overall farm management, with adjustments of seeding rates and final plant populations, and at the highest management level, fertilizer rates, based initially on the actual date of onset of the rains, and finally on season categorization at 30 days (35 days maximum) from onset.

Economic analyses are applied to crop yields expected at each management level, based on the actual rainfall record and the newly developed crop-production functions incorporating response-farming recommendations. The analyses provide an economic assessment of the value of the new methodology.

OVERVIEW OF KATUMANI RAINFALL AND PAN EVAPORATION

The rainfall record begins in October, 1956, and thus now covers 27 years or 54 growing seasons. The rains are monsoonal in character, with the short rains approaching from the north and the long rains from the south. Onset of the short rains is the latter half of October or November, with peak rainfall in the latter month and tapering off in December. Convective rains follow in January and February, ranging in different years from zero to high levels. These have much to do with the character of the crop growing season. Earliest and latest dates of onset and the median date by which half of the seasons begin are October 16, November 23, and November 2 respectively.

Gross rainfall in the short-rains maize season has been as little as 155 mm (1981), and as much as 925 mm (1961), with a mean of 359 mm. The 1981 season had 27 rainy days spanning a 68-day period, while the next-driest season (1970, 169 mm) had only 13 rainy days over an 82-day period. The season of shortest duration was in 1967, when 212 mm fell over a 45-day period. By way of contrast, 1961 had 52 rainy days over a 133-day period.

The long rains (or southern monsoon) arrive in March or April, peaking in the latter month. However, from a cropping standpoint, an acceptable onset may well occur with the convective rains of February, or on occasion even late January. Since June is reliably dry, and the latter portion of May is often dry also, it behoves maize growers to plant as soon as sufficient rain has come to germinate the seed and sustain the young crop through what is often a 25-day dry spell with little or no rain. Stewart and Hash (1982) place this amount at 40 mm within a period of a few days, starting with 10 February as the earliest acceptable onset date. This still appears workable, except that somewhat earlier dates of onset are now accepted provided that very heavy rains occur in late January or early February, sufficient to restore the soil profile to field capacity. In other words, "onset" for purposes of crop production should be based on actual occurrences in the field, rather than on strict definitions of meteorological phenomena. The crop will be as much benefited by a convective rainstorm as by those of the monsoon proper. Based on the foregoing, the earliest, latest and 50% onset dates for the long rains have been January 23, April 16 and March 6 respectively.

Gross rainfall in the long-rains season has been as little as 133 mm in 1973 and as much as 660 mm in 1979, with a mean of 339 mm. To illustrate the great variation, the standard deviation is 158 mm; thus only 17 of 27 seasons fell within the range of 181 to 497 mm, with five below that and five above. In the driest season (1973), there were 21 rainy days over a 106-day period, while in 1979 there were 52 rainy days over a period of 116 days. The shortest duration was in 1960, when 297 mm fell in 52 days.

Mean annual rainfall over the 27-year period of record keeping has been 701 mm, ranging from a high of 1,121 mm in 1963 to a low of 430 mm in 1976. Table I presents monthly high, low and mean rainfall figures, which help to clarify the pattern and illustrate the magnitude of the short-term variation.

Evaporative conditions during the growing season place a limitation on daily and seasonal maximum evapotranspiration rates, and on maximum yields of maize and beans as well as other types of crops grown in the tropics. There are a number of accepted ways of representing evaporative conditions (Doorenbos and Pruitt, 1977), but the preferred method in the present project is to measure evaporation from a Kenya Standard Class A Pan.

The most common problem with evaporation pan measurements is that the pans and their surrounds are often not standard, and this is true in Kenya. Kaik (1983) has now completed a project-related study in which he has developed "pan factors" which are used to standardize evaporation measurements from non-standard

TABLE I—KATUMANI MONTHLY RAINFALL MEANS AND 27-YEAR RECORDED EXTREMES (mm)

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Mean	38	158	90	50	43	86	144	67	9	5	4	8
Low	0	27	12	0	0	0	20	4	0	0	0	0
High	183	487	267	203	177	229	315	151	35	37	20	43

pans. At Katumani, as at virtually all agro-meteorological sites in Kenya, the grass surrounding the otherwise standard pan dries to brown between rainfall seasons, and sometimes within very dry seasons. Evaporation rates then are higher than they would be in the standard green-grass situation. Kaila's factors include correction for this problem and, through reference to the rainfall record, have been used to standardize the now 9-year record from the Katumani pan. Monthly high, low and mean evaporation rates, adjusted using the factors, are shown in Table II.

TABLE II—KATUMANI MONTHLY EVAPORATION MEANS* AND 9-YEAR EXTREMES (mm/day)

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Mean	5.8	4.9	4.7	5.7	6.3	6.2	4.9	3.5	3.4	3.0	3.6	4.9
Low	4.5	4.2	4.0	4.1	5.1	4.4	3.9	3.3	2.9	2.5	3.0	4.3
High	6.7	5.7	5.6	6.9	7.2	7.6	5.8	4.6	4.3	3.8	4.3	5.3

*Adjusted values to compensate for seasonal grass pan surrounds; after Kaila (1983). Kenya Standard Class A Pan.

UNDERLYING CORRELATIONS AND DEVELOPMENT OF SIMPLIFIED RAINFALL PREDICTION METHODOLOGY

The original effective rainfall analysis for Katumani (Stewart, 1980b) and Kashasha's (1982) analyses of nine additional localities established that correlations exist between seasonal water adequacy for maize, i.e. actual evapotranspiration expressed as a fraction or percentage of maximum evapotranspiration (ET_a/ET_m), and (a) the date of onset, (b) early-season rainfall amount, and (c) mid-season rainfall amount.

A methodology for utilizing these correlations in forecasting seasonal rainfall adequacy, and thereby guiding maize-production practices, was developed and explained. This type of in-depth analysis, based on water-balance calculations covering each season in the record, was essential for placing this new type of rainfall analysis on a firm footing. It was also essential as a basis for making a critical evaluation of both yield and economic benefits from use of the methodology. The latter remains true in this paper for the yield and economic analyses.

However, a major simplification is employed here to show the essential correlations of date of onset, etc., now related to total season rainfall *per se*, rather than to ET_a/ET_m. The importance of this is to illustrate that a very undemanding analysis, with greatly reduced input required from research, can result in rainfall prediction fully as accurate and applicable at the farm level as the more rigorous procedure needed to quantify the benefits.

To explain, the key feature of the new rainfall analysis, whether the rigorous or simplified version, is its link with the farm-level realities of producing a certain specified crop. The growing season from germination to physiological maturity fixes the length of the period of interest, but not the actual dates. These are different for each season analysed, beginning only when the rains begin and the seed is in the ground. Thus, all the seasons are aligned side by side and compared, but with each starting on a different date.

If planting is prior to onset, germination is assumed on the date at which enough rain falls (or has accumulated) to penetrate to the seed depth. If waiting for a defined onset before planting, then the time required to carry out the planting operation must be considered, and a germination date assumed. In this case, accumulated rainfall (less evaporation losses) in the future root zone at germination is included in the season total. Contrariwise, heavy rainfall beyond any possibility of being used by the crop in the latter days of the season is deducted from the season total.

Tables III and IV, for the short rains and long rains respectively, list all the seasons in the Katumani record by date of onset, starting with the earliest. In each table the listing is divided into two groupings, with the first termed "early onset" and the second "late onset". In column I, Table III, the earliest short-rains onset in the record occurred on 16 October 1982. The 57-year

TABLE III—SHORT RAINS: RELATIONS BETWEEN TOTAL SEASON RAINFALL AND (A) DATE OF ONSET AND (B) 30-DAY RAINFALL, KATUMANI, 1956 TO 1982

Year	Onset (days after 15 Oct.)	Total[1] season rainfall (mm)	Season[2] category for maize	30-Day rainfall (mm)	Perceived[3] season category	Categorization errors
Early onset						
1982	1, 16 Oct.	466	A	172	A	
1962	2	369	A	69	C	·,·
1965	3	364	A	230	A	
1972	5	431	A	202	A	
1967	6	212	C	112	C	
1975	7	212	C	102	C	
1974	7	240	B	181	A	+
1961	7	925	A	566	A	
1960	9	265	B	88	C	—
1978	10	595	A	124	A	
1981	10	155	C	89	C	
1968	11	460	A	262	A	
1957	13	560	A	164	A	
1977	18, 2 Nov.	425	A	197	A	
14-Year means		(406)		(1893)		
Late onset						
1966	19, 3 Nov.	236	B	185	B	
1956	19	469	A	153	B	—
1973	19	270	B	152	B	
1979	19	240	B	147	C	—
1980	19	200	C	151	C	
1959	20	225	B	156	B	
1958	21	240	B	122	C	—
1970	21	169	C	51	C	
1969	24	253	B	205	B	
1976	25	250	B	91	C	—
1963	29	700	A	471	A	
1971	39	315	B	163	B	
1964	39, 23 Nov.	290	B	176	B	
13-Year means		(281)		(171)		

1. Rainfall in the final days of the season deleted if in excess of crop requirements.
2. A = 350+ mm; B = 221–349 mm; C = 220– mm.
3. Criteria are shown in Table V. Note that they differ for early and late onset.

record from nearby Potha Estate shows this to be the earliest onset in that entire period. Column 3 shows total rainfall of 466 mm during the 120-day season, and column 4 categorizes this as an A type or good season for maize, defined as 350 mm or more rainfall.

Fourteen seasons in Table III are in the early-onset group, ending with onset on 2 November. Nine of these were type A, while two were fair or B seasons (221–349 mm), and three were poor or C seasons (220 mm or less). Average rainfall in the 14 seasons was 406 mm.

The remaining 13 seasons started late, with onset from 3–23 November. Of these, only two were A type, while nine were B and two were C. Average rainfall for all was just 281 mm. Clearly, early onset in the short rains signifies a higher probability of rainfall in the upper part of the range, and correspondingly, a greater yield of maize.

Nevertheless, the probability of harvesting at least a minimally acceptable crop in the short rains is about the same at Katumani whenever onset occurs. Therefore, the recommendation to

TABLE IV—LONG RAINS: RELATIONS BETWEEN TOTAL SEASON RAINFALL AND (A) DATE OF ONSET AND (B) EARLY-SEASON RAINFALL, KATUMANI, 1957 TO 1983

Year	Onset (days after 22 Jan.)	Total season rainfall (mm)	Season[1] category for maize	Early-season[2] rainfall (mm)	Perceived[3] season category	Categorization errors
Early onset						
1957	1, 23 Jan.	605	A	203	A	
1979	2	660	A	265	A	
1958	19	571	A	254	A	
1983	22	250	B	119	B	
1978	26	447	A	181	A	
1973	26	133	C	52	C	
1969	33	218	C	125	B	
1968	35	522	A	287	A	
1953	35	417	A	150	A	
1980	38	310	B	113	B	
1974	38	451	A	237	A	
1964	39	409	A	89	B	
1966	40	283	B	140	B	
1977	43	513	A	209	A	
1981	54	440	A	348	A	
1962	55, 18 Mar.	308	B	109	B	
16-Year means		(409)		(180)		
Late onset						
1972	19 Mar.	170	C	65	C	
1960	57	297	B	214	B	
1959	60	286	B	136	B	
1965	60	134	C	116	C	
1976	60	183	C	103	C	
1961	60	156	C	108	C	
1970	62	291	B	218	B	
1982	65	269	B	158	B	
1971	68	269	B	200	B	
1967	70	400	A	238	A	
1975	16 Apr.	150	C	132	C	
11-Year means		(237)		(153)		

1. A = 350+ mm; B = 221–349 mm; C = 220– mm.
2. 33-day rainfall for early onset; 30-day rainfall for late onset.
3. Criteria are shown in Table V. Note that they differ for early and late onset.

farmers is to plant maize (if desired) every short-rains season without regard to date of onset. It follows that dry planting, i.e. prior to onset, is also recommended for those who wish to, and who feel they can control the commonly experienced flush of weeds among the newly germinating crop plants. The alternative is to let onset germinate the weeds then plow them down and plant the crop. Both systems have advantages, but the analyses in this paper assume that dry planting will be practised in this season.

Next we wish to know how well the season category can be forecast after just 30 days of rain when action is due either for thinning the plant stand (low rainfall) or for augmenting the nitrogen level by side-dressing (high rainfall). Column 5 of Table III shows the 30-day rainfall season by season. From these amounts, empirical criteria have been selected to permit the maximum number of seasons to be correctly categorized. The perceived season categories may be seen in column 6, while the criteria used to sort them are shown in Table V. Note that the criteria for early seasons differ considerably from those for late seasons. Finally, column 7 of Table III indicates errors which would have occurred had this forecasting method been in use throughout the

recorded period. Of the 27 seasons, seven would have been misjudged, with one A season called B, four B seasons called C, one B season called A, and one totally wrong—an A season called C. On the positive side, 74% would be categorized correctly, 22% off by one category, and 4% totally misjudged.

Table IV for the long rains is set up in the same way as Table III. The extended period of possible onset stretches from 23 January to 16 April. Early onset ends on 18 March, and includes 16 of the 27 seasons. Average rainfall in these seasons was 409 mm, very similar to early onset in the short rains. Of the 16 seasons, ten were A, four B, and two C.

The 11 late-onset seasons averaged only 237 mm total rainfall, markedly less than late seasons in the short rains. Five of these were C seasons, five B, and only one an A season. This might have been anticipated from Table I, which shows little or no rainfall expected from June through September. Thus, duration of the rainy period is always a potential problem with late onset of the long rains, even though the Katumani type maize is relatively well adapted to survival on stored soil moisture alone in the latter half of the season.

Due to the small rainfall expectation when onset of the long rains is late, a recommendation to plant maize at all is questionable. However, the farmers in the area are unaware of these figures, and the majority gamble with maize every season regardless of date of onset. Also, columns 6 and 7 of Table IV show that late seasons are clear as to category in just 30 days from onset, so that practices can be optimized for the rainfall conditions with minimal risk. Therefore, this paper assumes that maize will be planted every season, and that until 18 March farmers will wait to identify onset before plowing and planting, but that on 19 March they will plant dry in anticipation of onset.

Column 5 of Table IV indicates that early seasons in the long rains are to be categorized at 35 days from onset rather than 30 days. Because the crop is planted a few days after onset, this still places categorization at the ideal time for thinning and side-dressing, while utilizing the five extra days to improve the forecast.

An additional note about onset of the long rains: Those seasons shown starting in late January and most of those in February actually began with what are locally known as "grass rains" rather than the true onset of the southern monsoon. Farmers are concerned about planting on these rains because a following dry spell is likely. These considerations have gone into our definition of onset, which before 10 February requires at least 100 mm of rainfall, and from 10 February to 18 March requires 40 mm or more. On the other hand, when the rains start late they tend to be nearly continuous until termination. This makes dry planting both feasible and desirable.

Table IV indicates that forecasting of the long rains should be quite accurate. The 35 or 30-day rainfall criteria for the early and late onsets respectively (see column 6) would have correctly categorized 25 of the 27 seasons. Errors would be one C season predicted as B, and one A season predicted as B.

Table V separates out four maize cropping situations which differ, first by season (short or long rains), and then by onset date (early or late). The number of seasons pertinent to each situation in the past 27 years is shown, and is broken down into A, B and C categories as they actually occurred. Rainfall criteria for predicting season categories are given, together with resultant predictions. For example, 14 short-rains seasons started early and 9 of these fell in category A. Within 30 days of onset 8 of the 9 experienced 122 mm or more rainfall, and hence would have been predicted as A seasons. The ninth season had less than 114 mm and would have been mistakenly judged a C season.

The four situations, totalling 54 seasons, are summarized at the bottom of Table V. Of 22 A seasons, 19 would be judged correctly, two as B and one as C. Of 20 B seasons, 15 are correctly judged, with one as A and four as C. Of 12 C seasons 11 are judged correctly and 1 as B. Altogether, of the 54 seasons, 45 are predicted correctly, equivalent to 83% or five out of six; two seasons are up-graded one category (4%); six seasons are down-graded one category (11%); and one season is down-graded two categories (2%).

Table VI contains the regression equations which relate date of onset and early season rainfall to total seasonal rainfall. The first equation in the table is a good example of the dichotomy which can occur between the practical and the statistical. Speaking first to the latter, the very low r^2 value of 0.026 indicates that total seasonal rainfall bears little relationship to date of onset in the short rains. The lack of statistical significance is emphasized by the low Student's "t" value of 0.82.

TABLE V—EARLY-SEASON RAINFALL CRITERIA: THEIR INDICATED LEVELS OF ACCURACY FOR CATEGORIZING RAINFALL SEASONS TO GUIDE FARM PRACTICES FOR MAIZE PRODUCTION AT KATUMANI

Onset period and dates	Season category	No. of seasons		Predicted season category A	B	C	Prediction criteria
Short rains							
		14		122+	115–121	114–	30-Day R, mm
Early onset (16 Oct.-2 Nov.)	A	9	→	(8)	0	1	
	B	2	→	1	[0]	1	
	C	3	→	0	0	[3]	
		13		210+	152–209	151–	30-Day R, mm
Late onset (3-23 Nov.)	A	2	→	[1]	1	0	
	B	9	→	0	[6]	3	
	C	2	→	0	0	[2]	
Long rains							
		16		148+	89–147	88–	35-Day R, mm
Early onset (23 Jan.-18 Mar.)	A	10	→	[9]	1	0	
	B	4	→	0	[4]	0	
	C	2	→	0	1	[1]	
		11		235+	135–234	134–	30-Day R, mm
Late onset (19 Mar.-16 Apr.)	A	1	→	[1]	0	0	
	B	5	→	0	[5]	0	
	C	5	→	0	0	[5]	
Short and long rains: summary							
		54		A	B	C	As above
All onset dates	A	22	→	[19]	2	1	
	B	20	→	1	[15]	4	
	C	12	→	0	1	[11]	

Yet the same equation shows a slope of −2.93, meaning that the rainfall expectation is reduced by 2.93 mm for each day that onset is delayed beyond 15 October. This is equivalent to a daily loss in maize grain yield of about 60 kg/ha. In a practical sense this must be regarded as important.

Column 3 of Table III shows clearly that the reduction in rainfall expectation with later onset is not smooth, but is more like an abrupt shift from a rather high plateau to a much lower plateau after 2 November. The picture is further confused by extreme lows (1981, 1967 and 1975) and a high (1961) in the early-onset period, and an extreme high (1963) in the late-onset period. Despite these anomalies, the date of onset reveals a great deal about season expectations in most years.

Table VI shows that rainfall during the first 30 days of the short-rains season is a very strong indicator of total season rainfall, speaking from both the statistical and practical viewpoints. Separate regressions are developed for early and late onset because, even though the slopes are nearly the same, the intercepts reflect the advantage of early onset.

For the long rains Table VI shows a closer relationship between date of onset and total

TABLE VI—ESSENTIAL CORRECTIONS BETWEEN TOTAL SEASONAL RAINFALL (TSR, mm) AND (A) DATE OF ONSET AND (B) EARLY-SEASON RAINFALL, WITH SEPARATE REGRESSIONS FOR EARLY AND LATE-ONSET SEASONS

Independent variable	Regression equation	r^2	n	t
Short rains				
Date of onset (days after 15 Oct.)	TSR, mm = 397 – 2.93 days	.026	27	0.82ns
30-Day rainfall (early onset to 2 Nov.)	TSR, mm = 172 + 1.28 R-30	.628	14	3.94**
(late onset, 3 Nov. on)	TSR, mm = 88 + 1.22 R-30	.727	13	5.69**
Long rains				
Date of onset (days after 22 Jan.)	TSR, mm = 544 – 4.60 days	.391	27	4.00**
35-Day rainfall (early onset to 18 Mar.)	TSR, mm = 167 + 1.34 R-35	.611	16	4.69**
(later onset, 19 Mar. on)	TSR, mm = 45 + 1.25 R-30	.713	11	4.73**

1. 120-day maize season

seasonal rainfall, with a coefficient of variation (r) of 0.391 and a Student's "t" value of 4.00, indicating significance at the 1% level. The equations relating early-season rainfall to season total are remarkably like those for the short rains, with respect to both early- and late-onset seasons. For early onset in both seasons, the regressions explain just above 60% of the variation in total rainfall, and for late onset, just above 70%. This correlation is sufficient to achieve the accuracy of season categorization discussed in connection with Table V.

PRESENT MANAGEMENT OF FOOD CROPS AND RECOMMENDED IMPROVEMENTS

The present management level for production of food crops in the project area is, with notable exceptions, rather low. Possibly this reflects shortage of capital and labour more than know-how and desire. Be that as it may, fertilizers and other chemicals are not generally applied, and weed growth often competes strongly for available nutrients and water.

The great majority of farmers mix or intercrop maize and beans in the same field. Our studies, including on-farm trials, indicate distinct yield advantages from this practice, except in the driest seasons, when yields fall below those from monocropping. Contributing factors to the yield advantages of intercropping are not well claritied, but several are likely, relating to increased shading of weeds, increased transpiration rather than evaporation of limited water, improved nutrient sharing and warding off of pests and diseases, etc. This type of crop management, being the most widely practised, is here termed "conventional" and forms the basis of comparison for evaluating new recommendations in this paper.

The recommendations to be presented and evaluated derive primarily from agrometeorological research within the project. However, a notable exception is the rotation of monocropped maize and beans in alternate seasons on the same piece of land, found by the agronomic research programme to boost soil fertility for maize quite markedly (Nadar and Faught, 1984a). Rotation is basic to both of the newly recommended management systems or levels, here termed medium- and high-level management. The latter further incorporates the application of both nitrogen (N) and phosphorus (P_2O_5) in the form of commercial fertilizer. Amounts specified are drawn from agrometeorological-programme experiments both on the Station and at the farm level. They are in close agreement with findings from a 7-season series of replicated experiments carried out by the project agronomist (Nadar and Faught, 1984b).

The other key aspect of the new recommendations, whether applying fertilizers or not, is the adjustment of plant populations (maize in particular) in accordance with the expected rainfall, i.e. with the season category perceived 30 or 35 days after onset. Recommended plant populations were determined in three seasons of replicated experiments in rainfed conditions, carried out jointly with the agronomy programme, in on-farm verification trials, also rainfed (Stewart, 1982), and in a sophisticated "line source" experiment (Hanks *et al.*, 1974; Stewart *et al.*,

1977) at Katumani Station under a wide range of water supply (sprinkler irrigation) conditions (Stewart, 1983).

A more general but equally important aspect of management is weed control. It has not been studied quantitatively in the present project, but has been observed at various levels in the on-farm trials. The newly recommended management levels both call for improved weeds control over the conventional level, described as "good control" for medium management and "rigorous control" for high-level management. For quick comparison, all of the foregoing is summarized in Table VII.

The reader is cautioned that the conventional management level in Table VII does not represent today's average management. That would be somewhat higher, due to the fact that some farmers have already improved their management in the sense of rotating their crops and practising more stringent weed control. A very few even apply fertilizers and other chemicals as required. They are not, however, optimizing plant populations for actual rainfall conditions. This is thought to be new knowledge.

TABLE VII—THREE LEVELS OF FARM MANAGEMENT OBSERVED OR ESTABLISHED IN ON-FARM VERIFICATION TRIALS, WITH THE HIGHEST LEVEL EQUIVALENT TO AND CONFIRMED BY EXPERIMENT-STATION TRIALS

Farm management level	Maize/bean crop rotation	Fertilizer applied	Plant population optimized	Weed control	Yield levels
High	Yes	N-P_2O_5 Adequate for rainfall	Yes	Rigorous	Equivalent to research
Medium	Yes	None	Yes	Good	Above average
Conventional	No; intercropped	None	Yes	Poor	Below average

EXPERIMENT-STATION AND ON-FARM TRIAL RESULTS: DEVELOPMENT OF WATER-PRODUCTION FUNCTION

Linear relations between crop yield and evapotranspiration were developed in preceding research for maize, beans and grain sorghum (Stewart, 1972; Stewart *et al.*, 1976), and have been reaffirmed in Kenyan conditions (Stewart, 1980a, 1982). Stewart and Hash (1982) utilize such a water-production function relationship to evaluate maize yield expectations in the forerunner paper to this one. Stewart and Kashasha (1984) broaden the applications by quantifying different linear functions for fertilized versus unfertilized conditions, for three different climatic zones, and for adjusted plant populations over different ranges of effective rainfall.

This paper combines the findings from the earlier cited line source experiment with those from the on-farm verification trials of the 1982 short rains to develop still more broadly applicable water-production functions for quantitative yield estimation in farm conditions. The new functions are for both maize and beans, either monocropped or intercropped. Rather than being linear *per se*, the maize functions are each composed of several linear segments representing yield expected with optimal plant population for the particular portion of the effective rainfall spectrum. In effect, the resulting function is concave, with slope increasing with increasing effective rainfall. Such a function recognizes the benefits of reducing population in low rainfall conditions and increasing it when rainfall is greater.

In accordance with the three levels of farm management actually encountered in farm trials (Table VII), three different yield-versus-effective-rainfall functions represent each crop in each cropping system. For the sake of brevity, these are shown only for the maize and bean monocrops, respectively in Figs. 1 and 2.

The uppermost function in Fig. 1 shows maize-yield expectations under high-level management. It incorporates optimal plant populations ranging from 10,000 plants/ha (10K on the figure) at low effective rainfall, to 50K at high effective rainfall. The significance of changing population may be better understood by projecting the 50K line downward from the top to the horizontal axis, when it will be seen that about 170 mm of effec-

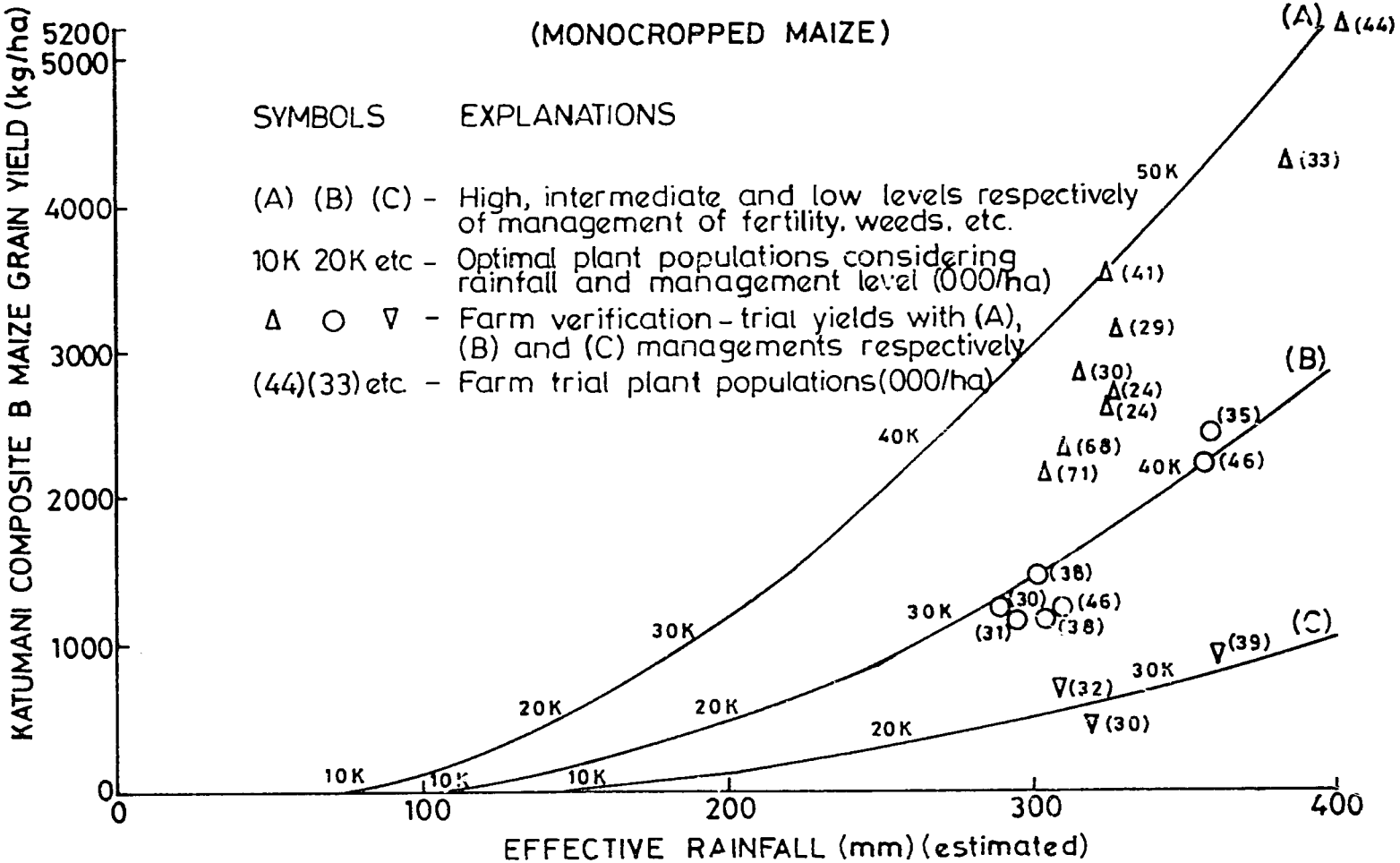

Fig. 1. Research-based water-production functions, showing maize yield expectations under three levels of management of fertility, weeds, etc., but assuming optimal plant populations in all instances. Data points show actual farm yields and plant populations in verification trials in Machakos District, short-rains season 1982—83

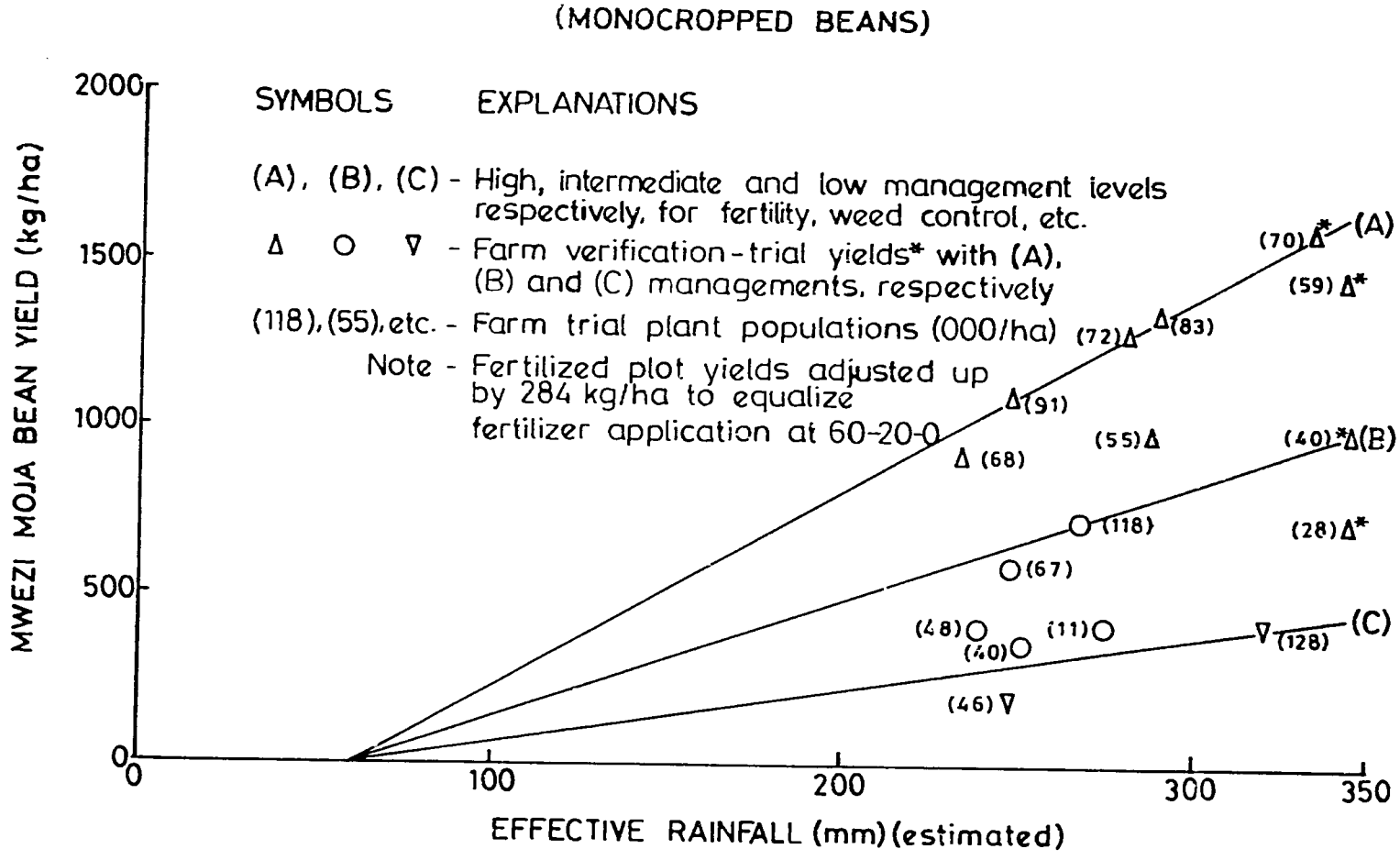

Fig. 2. Research-based water-production functions, showing expected yields of Mwezi Moja Bean under three levels of management. Data points show farm yield* and plant populations found in on-farm verification trials in Machakos District, short-rains season, 1982—83

tive rainfall are required to begin grain production. However, at the optimal population of 20K, this rainfall is sufficient to produce about 700 kg/ha of grain. On the other hand, projecting the 20K line to 400 mm effective rainfall shows maximum production of 3,000 kg/ha versus 5,200 kg/ha with a plant population of 50K.

Figs. 1 and 2 also include actual farm trials with monocropped maize and beans respectively. The latter functions are simply linear, because a single plant population of 100,000 plants/ha is recommended at all rainfall levels. Next to each farm yield result, in parentheses, is the actual plant population, e.g. (44) equals 44,000 plants/ha. Three different symbols are used for the three levels of management, a triangle for high level, a circle for medium, and an inverted triangle for low level (termed conventional when intercropped). Note that the exact placement of the farm results on the figures with respect to effective rainfall is a matter of judgement. While the yields and plant populations represent careful measurements, the effective rainfall for each case does not. This was a high-rainfall season, upwards of 400 mm depending on locality, so that while the range of effective rainfall is known, the precise placement is only approximate.

Despite the above uncertainty, the farm-trial results in Figs. 1 and 2 are still instructive. For example, they show that some farm yields are fully equivalent to those from experiment stations—thus, no "magic" is involved in the latter, but simply an abundance of inputs, labour, and other crop requirements. This demonstrates the real relationship between experiment-station results and farm expectations. They are one and the same in the best farming circumstances. Hence, the yield-versus-effective-rainfall functions pictured for high-level farm management are derived directly from experimental results, with full recognition that only very few farms are operating at this level at present.

Continuing with high-level management, Fig. 1 shows clearly the yield-reducing effect of maize plant population being either too low or too high for the particular rainfall circumstances. Most of the farm-trial plots otherwise managed at the high level had suboptimal plant populations, and therefore yielded well below the possible level indicated by the function. In Fig. 2, the same is seen for beans, for which 100,000 plants/ha are recommended and any level below 70,000/ha is suboptimal.

At medium and low levels of management (same farms, different treatments), Figs. 1 and 2 show similar effects of too low plant numbers, but in general the actual populations attained by the farmers conform more closely to the optimal values indicated by research. Therefore, the results tend to cluster more closely to the yield-versus-effective-rainfall functions projected for these management levels.

RECOMMENDED FARM PRACTICES FOR MAIZE AND BEANS: CORRESPONDING YIELD EXPECTATIONS AT KATUMANI

The immediate purpose of the water-production functions in Figs. 1 and 2 is to evaluate the yields one could expect from following improved (medium- or high-level) management practices at Katumani. Not shown are additional functions for intercropped maize and beans, which look similar but, since the crops share the same land, show lower per-hectare yields. It is the low or conventional level of management of the intercrop from which improvements are to be measured. The authors believe that this fairly represents the current situation for the majority of smallholders in the project area.

However, evaluation of yield expectations from the functions requires first an evaluation of water or effective rainfall. It will have occurred differently in the short and long rains, in the early- and late-onset periods of the latter season, and by definition, in each of the three categories of seasons. Together this adds up to nine separate situations for which past effective rainfall is to be estimated.

Table VIII identifies each of these situations and shows the actual number of pertinent seasons in the record with their mean total rainfall, plus the corresponding estimates of effective rainfall for both crops. Note that effective rainfall for monocropped beans is less than that for maize, due to a shorter growing season, but the figure shown for maize may be used for both crops in the intercrop.

As noted, the recommended plant populations are actually incorporated into the yield-predicting functions. The functions further incorporate the assumption that recommended actions will result in sufficient soil fertility to attain the indicated yields.

Table IX summarizes farm-practice recommendations for maize grown during the long rains under four sets of circumstances. These include two levels of management and both early and late onset. The recommendations define

TABLE VIII—THE KATUMANI 27-YEAR RECORD: MEAN RAINFALL (mm), AND ESTIMATED EFFECTIVE RAINFALL FOR MAIZE, BEANS AND THE INTERCROP IN A, B, AND C CATEGORY SEASONS, BOTH SHORT AND LONG RAINS, WITH THE LATTER DIVIDED INTO EARLY AND LATE ONSET

Season category	No. years occurred	120-day season mean rainfall	Estimated mean effective rainfall	
			Maize	Beans
Short rains, any onset				
A	11	471	370	303
B	11	257	205	185
C	5	190	154	146
Long rains, early onset				
A	10	471	370	303
B	4	288	229	206
C	2	175	142	135
Long rains, late onset				
A	1	382	302	242
B	5	276	220	198
C	5	141	116	110

TABLE IX—LONG RAINS RESPONSE-FARMING RECOMMENDATIONS FOR MAIZE (IN A MAIZE-BEAN ROTATION SYSTEM) AT TWO LEVELS OF FARM MANAGEMENT, KATUMANI AREA

Recommendations at planting time				Season category** and recommended action		
Onset date and corresponding planting instructions	Farm management level	Initial N-P_2O_5 (kg/ha)	Seeding rate (seeds/ha)	Perceived season category	Final maize population (plants/ha)	Side dress nitrogen (kg/ha)
Early onset (23 Jan.-18 Mar.) If onset by 9 Feb.: plant after 100 + mm rain If onset 10 feb.-18 Mar.: plant after 40 + mm rain	High	20—20*	60,000	A	50,000	40
				B	40,000	None
				C	20,000	None
	Medium	None	50,000	A	40,000	None
				B	20,000	None
				C	10,000	None
Late onset (19 Mar. onward) plant 19 Mar. before onset	High	None	50,000	A	40,000	20
				B	40,000	20
				C	20,000	None
	Medium	None	40,000	A	30,000	None
				B	20,000	None
				C	10,000	None

*No initial fertilization of maize in seasons following C-category seasons.
**Early onset seasons categorized at 35 days, late at 30 days. Rainfall criteria shown in Table V.

acceptable ranges of onset dates and corresponding rainfall amounts which should be accepted as the signal to plant. For each management level seeding rates are given, and for high-level management, so is the applied fertilizer rate.

Thirty-five days into early-onset seasons, and 30 days into late ones, a prediction of season category is made, based on total rainfall as of that time. The precise criteria for making these judgements at Katumani are given in Table V.

Returning to Table IX, the perceived category of the season leads to final adjustment of plant population and nitrogen fertilizer as applicable. High rainfall expectations call for higher populations and fertility, and vice versa. Recommendations for maize in the short rains, and for beans in both seasons, are readily explained with reference to tables already seen.

Short-rains maize, like late-onset long-rains maize, is recommended for planting every year on 15 October, prior to onset. And, again similarly, season categorization is done 30 days from onset. However, all other recommendations for short-rains maize are exactly the same as for early onset, long rains. This applies both to planting-time and thinning-time recommendations.

Recommendations for beans are simple by comparison, because, unlike maize, no adjustments are to be made to plant population or fertilizer rates to accord with the type of season. A summary of recommendations for beans follows:

a. Onset criteria and planting dates are the same as for maize.
b. The single recommended seeding rate, for both medium- and high-level management, is 120,000 seeds/ha, to result in 100,000 plants/ha.
c. Nitrogen fertilizer is only applied for high-level management, always at planting time at the rate of 20 kg/ha. For late onset, long rains, phosphorus is added to the nitrogen at 20 kg/ha P_2O_5, thus 20–20–0.

Tables X, XI and XII show maize- and bean-yield expectations respectively for the short rains, long rains, early onset, and long rains, late onset.

TABLE X—SHORT RAINS, ALL DATES OF ONSET: AVERAGE YIELDS* EXPECTED OF MAIZE AND BEANS IN DIFFERENT TYPES OF RAINFALL SEASONS, ASSUMING RECOMMENDATIONS BASED ON PERCEIVED SEASON CATEGORY ARE FOLLOWED AT THREE LEVELS OF FARM MANAGEMENT

Actual category of season	Maize			Beans		
	Action taken			Action taken		
	A	B	C	A	B	C
High-level management						
Good: A	[2,270]	1,815	1,340	[705]	705	705
Fair: B	480	[580]	525	360	[360]	360
Poor: C	NA	NA	[275]	NA	NA	[245]
Medium-level management						
Good: A	[1,210]	900	560	[425]	425	425
Fair: B	40	[270]	220	220	[220]	220
Poor: C	NA	NA	[100]	NA	NA	[150]
Conventional management						
Good: A	[440]	380	380	[320]	320	320
Fair: B	0	[65]	65	165	[165]	165
Poor: C	NA	NA	[15]	NA	NA	[120]

*Table is based on yields from one hectare, divided equally between maize and beans, i.e. each figure shown represents kg/0.5 ha.

TABLE XI—LONG RAINS, EARLY ONSET: AVERAGE YIELD* EXPECTATIONS FOR MAIZE AND BEANS IN DIFFERENT TYPES OF RAINFALL SEASONS, ASSUMING RECOMMENDATIONS BASED ON PERCEIVED SEASON CATEGORY ARE FOLLOWED AT THREE LEVELS OF FARM MANAGEMENT

Actual category of season	Maize			Beans		
	Action taken			Action taken		
	A	B	C	A	B	C
High-level management						
Good: A	[2,270]	1,815	NA	[705]	705	NA
Fair: B	NA	[810]	NA	[425]	NA	
Poor: C	NA	0	[220]	NA	215	[215]
Medium-level management						
Good: A	[1,210]	900	NA	[424]	[425]	NA
Fair: B	NA	[390]	NA	NA	[255]	NA
Poor: C	NA	0	[75]	NA	135	[135]
Conventional management						
Good: A	[440]	380	NA	[320]	320	NA
Fair: B	NA	[100]	NA	NA	[190]	NA
Poor: C	NA	0	[0]	NA	105	[105]

*Table is based on yields from one hectare, divided equally between maize and beans, i.e. each figure shown represents kg/0.5 ha.

Yields are given at all three management levels, i.e. the high and medium levels for which recommendations have been presented, and the conventional level used as a basis for evaluating incremental yields and benefits. As noted earlier, conventional management assumes only intercropping, no fertilizers applied, and weed control at a low level. However, yields shown embody the assumption that maize plant populations are adjusted in accordance with season categorization. Recommended populations for actions A, B and C respectively are 30,000, 20,000 and 10,000 plants/ha (short rains and early onset, long rains), while for late onset, long rains, A and B actions both call for 20,000 plants/ha, with C action still at 10,000 plants/ha.

For a brief illustration of how these tables are set up, let us look at Table X. The actual season categories are repeated down the left-hand column for each management level. "Action taken" across the top implies that the season, rightly or wrongly, has been categorized that way. If correct, the yield is bracketed, while incorrect categorization results in the generally lower yields shown without brackets. NA means not applicable, deriving from Table V, which shows that no such categorization would have occurred in the rainfall record studied.

Yield figures for maize and beans are shown separately in Table X, with each figure representing the produce of 0.5 ha. Thus, in each management level it is assumed that one hectare of land is devoted to maize and beans, divided equally between the two crops. For example, a good season correctly categorized should produce maize and bean yields respectively of 2,270 and 705 kg from the hectare of land under high-level management, as against 440 plus 320 kg under conventional management. Incremental yields are 1,830 kg of maize and 385 kg of beans. But if incorrectly categorized as a fair (B) season, high-level management yields would fall to 1,815 kg maize plus 705 kg beans, while conventional yields would be 380 plus 320 kg. Incremental yields would then be 1,435 kg maize plus the same 385 kg beans, since bean yields are not affected by incorrect categorization. The reduction in maize yield would result primarily from

TABLE XII—LONG RAINS, LATE ONSET: AVERAGE YIELD* EXPECTATIONS FOR MAIZE AND BEANS IN DIFFERENT TYPES OF RAINFALL SEASONS, ASSUMING RECOMMENDATIONS BASED ON PERCEIVED SEASON CATEGORY ARE FOLLOWED AT THREE LEVELS OF FARM MANAGEMENT

Actual category of season	Maize			Beans		
	Action taken			Action taken		
	A	B	C	A	B	C
High-level management						
Good: A	[1,500]	NA	NA	[480]	NA	NA
Fair: B	NA	[720]	NA	NA	[400]	NA
Poor: C	NA	NA	[90]	NA	NA	[145]
Medium-level management						
Good: A	[720]	NA	NA	[320]	NA	NA
Fair: B	NA	[310]	NA	NA	[240]	NA
Poor: C	NA	NA	[40]	NA	NA	[85]
Conventional management						
Good: A	[290]	NA	NA	[260]	NA	NA
Fair: B	NA	[80]	NA	NA	[160]	NA
Poor: C	NA	NA	[0]	NA	NA	[80]

*Table is based on yields from one hectare, divided equally between maize and beans, i.e. each figure shown represents kg/0.5 ha.

omission of the 40 kg/ha side-dressed N called for by action A. Had this good season been still more incorrectly categorized as poor (C), the further loss of maize yield would be due mostly to too low a plant population, brought about by thinning to 20,000 plants/ha. Tables XI and XII are similar for the early- and late-onset long rains respectively.

Table XIII summarizes average yields of maize and beans expected at Katumani at each of the three levels of management. All 54 seasons have contributed to the averages, including those which would have been incorrectly categorized. The upper half of the table compares the short rains to the long rains, with the latter season divided into early- and late-onset periods. Expected yields with late onset are much less than those for early onset. In fact, late-onset maize yields under conventional management are unacceptably low. However, they increase to acceptable levels with improved management. Average yields for all long-rains seasons are not shown, but are remarkably close to the short-rains averages, resulting in nearly the same figures for the overall averages at the bottom of the table.

The lower half of Table XIII contains yield figures for the three season categories based on rainfall amount, without regard to season name or onset period. Poor seasons are expected to produce virtually no maize under conventional management, more but still unacceptably low yields with medium management, and only very modest yields with high-level management. Even in fair seasons, maize-yield expectations are very low with conventional management, but they increase dramatically with improved management based on response-farming methodology.

YIELD STABILIZATION AND ENHANCEMENT: PRIORITIES OF THE AGROMETEOROLOGICAL RESEARCH PROGRAMME

From the inception of the project the main priorities have been stabilization and enhancement of yields of basic food crops. Table XIII shows that the latter priority is potentially well met through response farming. Maize and bean yields should increase to 2.9 and 1.3 times present (conventional) levels respectively with improvement to medium-level management, and

TABLE XIII—MAIZE AND BEAN YIELD EXPECTATIONS AVERAGED FOR DIFFERENT SEASONS AND CATEGORIES OF SEASONS AT KATUMANI. YIELDS IN KILOGRAMS FROM ONE HECTARE OF LAND EITHER INTERCROPPED WITH CONVENTIONAL MANAGEMENT, OR MONOCROPPED AND ROTATED WITH MEDIUM- OR HIGH-LEVEL MANAGEMENT

Season or category	No. seasons averaged	Farm management level		
		Conventional maize + beans	Medium maize + beans	High maize + beans
Seasons by name and onset period				
Short rains	27	202 + 220	570 + 291	1,149 + 479
Long rains, early	16	296 + 261	839 + 346	1,607 + 574
Long rains, late	11	63 + 133	225 + 177	504 + 291
Seasons categorized by rainfall amount				
Good (350 + mm)	22	425 + 317	1,130 + 420	2,151 + 695
Fair (221 – 349 mm)	20	72 + 169	282 + 232	645 + 383
Poor (220 – mm)	12	6 + 101	65 + 120	170 + 198
All seasons	54	201 + 214	579 + 284	1,153 + 469

to 5.7 and 2.2 times present levels with high-level management.

Impacts on yield stabilization, i.e. attainment of a minimum subsistence-level food supply for the farm family in the poorest seasons, are less obvious. Tables V, X, XI and XII show that conventional management would have resulted in maize yields of 80 kg/ha or less in fully 28 of the past 54 seasons, with zero yield in eight of these. Medium management should boost 20 of these seasons into the 100—320 kg/ha range, averaging 225 kg/ha. Seven others should yield at or under 80 kg/ha, while only one zero season would remain. With high-level management one season is still zero, five average 90 kg/ha, and 22 are increased into the 220—720 kg/ha range, averaging just over 500 kg/ha. The reader is reminded that these are really half-hectare yields, with bean yields in addition.

Summarizing with regard to stabilization of yields, the failure or virtual failure of the maize component, now occurring approximately one season out of two with conventional management, can be reduced to one in seven seasons using response-farming techniques at the medium-management level, and still further, to one season in nine, with high-level management. From the standpoint of providing a basic food supply, the recommended approach in large measure stabilizes as well as enhances yields.

ECONOMIC EVALUATION

Estimates of costs and returns associated with each of the actions recommended on the basis of early-season rainfall amounts were calculated for each type of season and level of management. Gross returns were calculated from the yields indicated for each set of conditions, and from minimum prices for maize and beans established at Kenya Farmers' Association stores for the 1982—83 short rains, adjusted for transport cost from farms to points of delivery.

Labour requirements for each activity were estimated from reports of farmers participating in the verification trials, FAO surveys, or pre-extension trials and secondary sources. Opportunity costs for labour were assumed to be KSh. 2.0 per hour, which approximates the minimum wage for the area and is the wage at which a number of casual labourers were employed.

Opportunity costs for the use of oxen for land preparation and one weeding were calculated at KSh. 540 per hectare based on the charges for such services reported paid by some farmers participating in the verification trials. Input costs for fertilizers and seeds were estimated on the basis of amounts specified in the recommendations (Table IX and text) and prices at KFA stores, adjusted for transportation costs. Interest was calculated at an annual rate of 16 per cent for

a period of six months for pre-harvest costs and two months for harvest costs.

Since the major objective was to evaluate the relative benefits of applying the recommendations based on the response-farming methodoloy, results expected from applying these recommendations have been expressed as increments from the results given by conventional practices. These practices are those of a farmer producing a maize/bean intercrop, with relatively low managerial skills, applying no fertilizer, and providing only about half the labour required for fully effective weed control. His average yields for the 54 seasons would have been 201 kg of maize and 214 kg of beans per hectare (Table XIII). His gross returns would have averaged KSh. 1,001 ha and he would have recovered only 54 per cent of his total opportunity cost. After deducting the usual charge for the use of oxen, he would have received only KSh. 0.47 per hour for the 439 hours of labour input, compared with the minimum wage of about KSh. 2.0 per hour.

The incremental costs and returns for improved management may be seen in Table XIV. Figures are in KSh. ha, and derive from production of both maize and beans, divided equally as to area. Figures are given separately for each situation for which an expected yield is given in Tables X, XI and XII, but are omitted for season categorizations which never occurred in the Katumani analysis.

In Table XV, the summarized results of this research indicate that a producer applying a high level of managerial skills and following response-farming recommendations could have increased his seasonal per-hectare average yields of maize by 952 kg and beans by 255 kg over those attained by a producer following conventional practices. It might also be noted that he would have achieved a marked increase in yields over the conventional producer in each of the 54 seasons, except the single poor early-onset long-rains season wrongly categorized as a fair season, thus leaving too great a plant population in the field. Attainment of the high-yield increments would have required him to rotate his crop land between monocropped maize and beans each season rather than continuously intercropping them.

It would also have required him to incur substantially higher costs for fertilizer, and to make substantially greater inputs of labour for weeding and for thinning maize to an appropriate number of plants to conform with the early-season rainfall prediction (Table IX). These added costs would have averaged KSh. 669 for the 54 seasons, a greater amount than many farmers would be able or willing to risk. However, for this added risk he would have received an incremental net return of KSh. 1,480, or a rate of return of 221 per cent. This rate of return would be likely to attract any producer with access to the added operating capital required, and the managerial skills to utilize it effectively.

A producer following medium-level management practices would have achieved lower yields than the higher-level manager, but would still have had yields substantially above those of the conventional producer. Inputs of labour would be midway between the high-level management and conventional inputs. Seeding rates and final plant numbers would be less than for a high level of management, since without additional nitrogen the lower plant numbers would easily produce the possible yield, and with more efficient use of available moisture.

His incremental yields would have averaged 378 kg for maize and 70 kg for beans for the 54-season period. Although these yields were equal to only 40 per cent and 27 per cent respectively of maize and bean yields achieved by the high-level manager, his incremental costs would have been only 22 per cent as much, and his operating capital requirement and risks would have been much lower. Incremental costs would have averaged only KSh. 144, which would have produced an incremental net return of KSh. 602. The rate of return would have been 418 per cent. The small increase in total costs, due to extra labour for weeding and harvesting, would certainly be justified by this rate of return.

For the long run, it appears desirable from the standpoint of national food supplies, as well as the welfare of the farmers themselves, to encourage as many as possible to move toward adoption of the practices recommended for high-level managers. The increase in average yields of 474 per cent in maize and 119 per cent in beans over those achieved from application of conventional methods would make a major contribution to alleviating the critical food-supply problem, as well as dramatically improving the economic welfare of participating farmers.

However, for the near future, first priority might be given to encouraging farmers to adopt the methods recommended for the medium-level managers. These methods are relatively simple and inexpensive, involving the use of the rotation system that at least some farmers are now

TABLE XIV—INCREMENTAL COSTS AND RETURNS FROM MAIZE/BEAN ROTATION SYSTEM FOR SHORT AND LONG RAINS BY TYPE OF SEASON, RECOMMENDED ACTION AND LEVEL OF MANAGEMENT, KATUMANI 1956–1982 (KSh./ha)

Type of rains and level of management	Actions taken							
	Good seasons			Fair seasons			Poor seasons	
	A	B	C	A	B	C	B	C
Short rains								
a. High-level management								
Gross returns	3,774	3,242	2,604	1,311	1,358	1,284	—	776
Total costs	887	669	615	794	607	598	—	542
Net returns	2,887	2,573	1,989	517	751	686	—	234
b. Medium-level management								
Gross returns	1,393	1,057	600	242	464	396	—	216
Total costs	199	141	67	112	130	90	—	58
Net returns	1,194	916	533	130	334	306	—	158
Long rains-early onset								
a. High-level management								
Gross returns	3,774	3,242	—	—	1,756	—	376	672
Total costs	861	623	—	—	579	—	456	504
Net returns	2,913	2,619	—	—	1,177	—	−80	168
b. Medium-level management								
Gross returns	1,393	1,057	—	—	611	—	94	195
Total costs	253	195	—	—	191	—	123	141
Net returns	1,140	862	—	—	420	—	−29	54
Long rains-late onset								
a. High-level management								
Gross returns	2,377	—	—	—	1,678	—	—	339
Total costs	711	—	—	—	618	—	—	375
Net returns	1,666	—	—	—	1,060	—	—	−36
b. Medium-level management								
Gross returns	783	—	—	—	582	—	—	71
Total costs	123	—	—	—	103	—	—	20
Net returns	660	—	—	—	479	—	—	51

following, increasing the rate of planting moderately, improving weeding substantially, and adjusting plant numbers in accordance with the amount of rainfall received during the early part of the season. The increase in yields over conventional methods of 188 per cent in maize and 33 per cent in beans would make a significant contribution to a solution to recurrent food problems and at the same time substantially alleviate the problem of rural poverty.

CONCLUSIONS

A simplified crop-specific rainfall analysis based solely on gross rainfall has been developed, with the capability of correctly predicting five of

TABLE XV—INCREMENTAL YIELDS, COSTS AND RETURNS FROM ONE HECTARE OF LAND IN A MAIZE/BEAN ROTATION SYSTEM, BY SEASON,[1] SEASON CATEGORY[2] AND LEVEL OF MANAGEMENT, KATUMANI, 1956–1982

Season or category	Maize + beans (kg/ha)	Gross returns (KSh./ha)	Total costs (KSh./ha)	Net returns (KSh./ha)
High-level management				
Short rains	947 + 259	2,159	696	1,463
Long rains, early	1,310 + 313	2,830	728	2,102
Long rains, late	441 + 159	1,133	516	617
Good (350+ mm)	1,726 + 378	3,609	834	2,775
Fair (221–349 mm)	573 + 214	1,500	612	88
Poor (220– mm)	164 + 97	552	462	90
All seasons	952 + 255	2,149	669	90
Medium-level management				
Short rains	368 + 71	736	131	605
Long rains, early	543 + 85	1,020	219	801
Long rains, late	162 + 44	368	67	301
Good	705 + 103	1,299	209	1,090
Fair	210 + 63	498	126	372
Poor	59 + 19	144	55	89
All seasons	378 + 70	746	144	602

1. Figures are averages for 27 short-rains seasons, 16 long rains early, and 11 long rains late, totalling 54 seasons in all.
2. Averages for 22 good, 20 fair, and 12 poor seasons, 54 in all.

six rainfall seasons as good, fair or poor, in time to respond with field adjustments of plant populations and nitrogen-fertilizer rates found in research to be optimal for the expected range of rainfall. The new analysis, unlike its predecessor "effective rainfall analysis" (Stewart and Hash, 1982), does not require extensive additional research on crop water utilization and consequent yield responses, yet provides equally valid farm-practice recommendations.

Wholly new crop water production functions, introduced here for a maize/bean cropping system under three levels of farm management, incorporate research-based recommendations matching plant populations and fertilizer rates to, in this instance, effective rainfall expectations. The latter are still required for absolute value predictions of yield, and for economic analyses of expected costs and returns. The new productions are based on rigorous field research at both the experiment-station and farm levels.

In connection with the above, it is demonstrated that the highest level of farm management is fully as productive as plots on experiment stations, although few farmers in the project area command the resources needed to farm at this level.

The present study for Katumani indicates that response farming is capable of satisfying the research-programme priority of yield stabilization, with particular regard to maize, since beans require less water and seldom fail utterly. Whereas 28 of the past 54 seasons should have produced maize yields from zero (8 seasons) up to 80 kg/ha (20 seasons), i.e. essential failure in half of all seasons under conventional management, response farming with medium-level management could reduce this to one failure in seven seasons, and with high-level management, to one failure in nine seasons.

As to yield enhancement, the other principal programme priority, response farming with

medium management could boost maize and bean yields respectively to 2.9 and 1.3 times the conventional level, while high-level management should produce 5.7 and 2.2 times as much as conventional practice.

Economic analysis indicates that the incremental costs of the above medium- and high-level management procedures would average 144 and 669 KSh./ha respectively, with corresponding incremental net returns of 602 and 1,480 KSh./ha, or rates of return of 418 per cent for medium-level management and 221 per cent for the high level.

The much-increased yields and high rates of return suggested from response farming make it appear desirable, from the standpoints of both national food supplies and farmers' welfare, to move toward adoption of the recommended practices as rapidly as possible. Considering the low costs involved in moving to the medium management level, this is proposed as the first step for the near future, to be followed in the long run by adoption of the high-level management recommendations.

SUMMARY

A simplified crop-specific rainfall analysis based solely on gross rainfall has been developed, with the capability of correctly predicting five of six rainfall seasons as good, fair or poor, in time to respond with field adjustments of plant populations and nitrogen fertilizer rates, found in research to be optimal for the expected range of rainfall. The new analysis, unlike its predecessor "effective rainfall analysis" (Stewart and Hash, 1982), does not require extensive additional research on crop water utilization and consequent yield response, yet provides equally valid farm level guidance.

Wholly new crop water production functions, introduced here for a maize/bean cropping system under three levels of farm management, incorporate research-based recommendations matching plant populations and fertilizer rates to, in this instance, effective rainfall expectations. The latter are still required for absolute value predictions of yield, and for economic analyses of expected costs and returns. The new production functions are based on rigorous field research at both the experiment station and farm levels.

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MATCHING RAINFALL PATTERNS AND MAIZE GROWTH STAGES UNDER MACHAKOS AREA CONDITIONS

H. M. Nadar[1]

INTRODUCTION

From the crop-production point of view, the Machakos area is classified as one of the low-potential areas of Kenya. From 1954 to 1973, rainfall per season ranged between 250 and 400 mm, which is considered marginal (Dowker, 1961). The rainfall duration each season was less than 60 days (Harrison, 1970). Under these rainfall conditions, a 120-day maize composite (Katumani Composite B) is grown each season in most of the areas allocated to crop production. Maize yields in the area ranged between 240 and 750 kg/ha under the conditions of the long rains of 1977, when the precipitation was exceptionally high (IADP, 1977). It has been suggested that these low yields were caused by the difference between the length of the growing season and the length of the rainy season, and the development of a quicker maturing maize was proposed (Marimi, 1978). Dagg (1965) followed the approach of matching water availability to crop water demand to determine the probability of success of growing maize at Muguga, near Nairobi. He concluded that rains which fell during June, July, and August were critical for the survival and yield of maize grown in that area during the long rains. To determine the feasibility of improving maize production in the Machakos area, it should be determined first whether or not the water requirements of the maize growing in the area can be fulfilled by the rainwater expected to be available during the growing season. The objective of this study was to compare the long-term average weekly rainfall in the Machakos area and the major growth stages of Katumani Composite B, in order to determine the possibility of improving maize production in the area under the prevailing rainfall conditions.

MATERIALS AND METHODS

Maize (*Zea mays* L., Katumani Composite B) was planted for the phenology study at both the Dryland Farming Research Station at Katumani and the substation at Kampi ya Mawe. The Katumani station is located 10 km south of Machakos town, Machakos District, in eastern Kenya, with centre co-ordinates 01° 35′ S and 37° 14′ E and lying at an altitude of 1,575 m. The Kampi ya Mawe substation is located 5 km south-east of Makueni town in the same district, with centre co-ordinates 01° 50′ S and 37° 40′ E, at an altitude of 1,125 m. Because of its lower altitude, the Kampi ya Mawe substation has a mean temperature 5°C higher than that at Katumani. The soil in both localities is well drained, dark reddish-brown sandy clay. It is classified as Oxic Paleustalf (Chromic Luvisol). It has a relatively low water-storage capacity and is of medium depth; the average depth is 120 cm, with total water-storage capacity of 100 mm. Maize was planted in rows 0.75 m apart with 30 cm spacing within the row at 1 plant per hill.

For the phenology analysis, a sample of 10 plants was picked randomly from each location. The samples were drawn from both localities on the same day. They were brought to the laboratory for dissection and identification of the development stage. Samples were drawn every two days during the first month; after that weekly sampling was considered satisfactory. Sampling continued until maturity.

Daily rainfall data for the period 1954 to 1973 were obtained from the Machakos Meteorological Station and 20-year weekly averages determined. The number of years when measurable rains fell during the week were counted and used as a measure of rainfall probability during that week. Five mm or more of rain during the week was considered measurable rainfall. No statistical analysis was used. Total weekly rainfall was also determined for the season when the study was taking place.

RESULTS AND DISCUSSION

The different growth stages of the crop and accompanying rainfall are presented in Fig. 1. These stages can be grouped into three major stages. The first growth stage, GS1, is the vegetative stage. During this the plant mirestem (the growing point) is totally devoted to producing the leaves. GS1 of Katumani maize was found to last 28 to 32 days at Katumani but only 21 to 25 days

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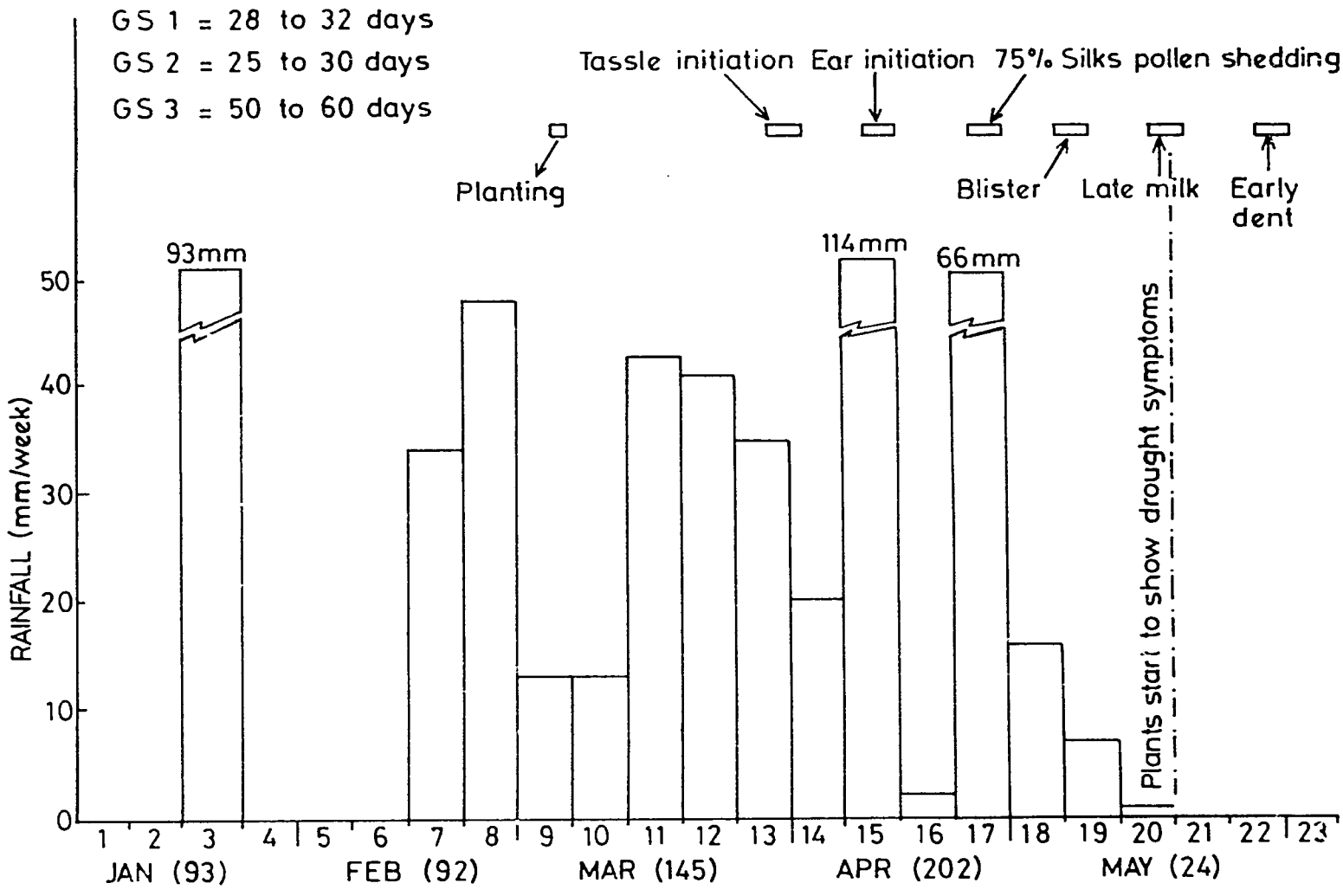

Fig. 1. Weekly Rainfall at Katumani Station from January to May 1978 with Katumani Maize Phenology Analysis Superimposed

at Kampi ya Mawe. The plants' evapotranspiration demand during this stage is very low compared to the other growth stages and usually ranges between 0.1 and 0.4 of pan evaporation. Maize is least affected by water stress during this period. As a matter of fact, mild to moderate drought conditions during GS1 can help condition the plant to better tolerate or avoid future water-stress situations occurring during more drought-sensitive growth stages. This conditioning can develop through many physical and/or biochemical changes within the plant itself. It can develop greater ability to extract water from the soil, either by deepening its roots to reach further down or by increasing the roots' ability to extract more tightly bound water. Other changes include increasing the ability of the plant cells to maintain their turgor, or increasing their ability to tolerate desiccation while maintaining the plant's photosynthetic activity. By the end of this stage the initiation of leaves and internodes is completed.

The second growth stage, starting by the end of GS1, is the floral-initiation stage, or GS2. During this stage the plant meristem stops leaf initiation and directs all its activities to the initiation of the flowers. Rapid expansion of leaves and extension of internodes takes place. When tassel initiation is almost complete, ear initiation is started. It begins during the last 10 days of GS2. GS2 lasts 25 to 30 days under Katumani conditions, and 20 to 24 days at Kampi ya Mawe. During this period the plant's demand for water is very high, and reaches its maximum by the end of this stage. Drought stress during this period has a very harmful effect. It affects the plant's overall growth by reducing the rate of leaf and internode expansion. A severe drought during ear initiation can result in barren plants or the formation of very small ears. Ear size, seed number, and yield potential are determined during ear initiation. This period ends with silking and pollen shedding, when pollination starts.

The third growth stage (GS3) starts with pollination and ends with physiological maturity. It lasted for 50 to 60 days under Katumani conditions and for 40 to 50 days at Kampi ya Mawe. This period is mainly devoted to grain filling, and the first 25 to 30 days of the period have the highest water requirements. Water stress during this period will cause reduction in the number of mature seeds and yield is consequently reduced.

From this analysis it can be seen that there are about 40 days during the Katumani maize-growing season when the plant is most sensitive to drought stress. To grow maize successfully, this 40-day period needs to coincide with the rainy season, when water stress is least probable.

To have a complete picture of moisture availability and adequacy during a given rainy season, laborious meteorological and soil analyses are required, but it was found that relatively long-term weekly averages provided reasonably adequate information for the purpose of this study. Study of these averages (Fig. 2) showed that rainfall in the Machakos area is bimodal. The two rainy seasons have roughly equal amounts of rainfall of almost equal duration. The two rainy seasons are referred to as the long rains, which usually start by the middle of March and end by the middle of May, and the short rains, which usually start by the end of October and end by the middle of December. The long rains are followed by five months of almost complete drought, but the period following the short rains (January and February) is frequently marked by substantial rains. If we deal with each rainy season separately, neither can provide adequate moisture to fulfil the water requirements of a 120-day maize crop. On the other hand, if we combine the two seasons, starting with the short rains, we can have a 7-month potential growing season (October to May) interspersed with a number of potential drought periods differing in their duration and severity. These potential drought periods are: 1 to 2 weeks during December; 2 to 3 weeks during January; 3 to 4 weeks during February; 1 to 3 weeks during March; and 1 to 3 weeks during May. The drought spells during the months of December, January, February, and March were never continuous during the period studied. In most years, good rains fell during January and/or February, breaking the long drought period into short, less severe spells.

From this rainfall analysis it can be seen that no significant rain is to be expected after 1 June or before 21 October. Between these two dates rain may fall at any time, with the highest probability during November and April. The whole month of November expires before the short-rains maize crop reaches the ear-initiation stage. Ear initiation is the start of the 40-day growth stage of greatest drought sensitivity. Under the preceding rainfall pattern, it is impossible to have this 40-day stage coincide with the month of November, which is the month with the highest rainfall probability. In order to assure maximum water availability during the critical ear-initiation stage, it is essential to conserve as much moisture in the soil as possible to supple-

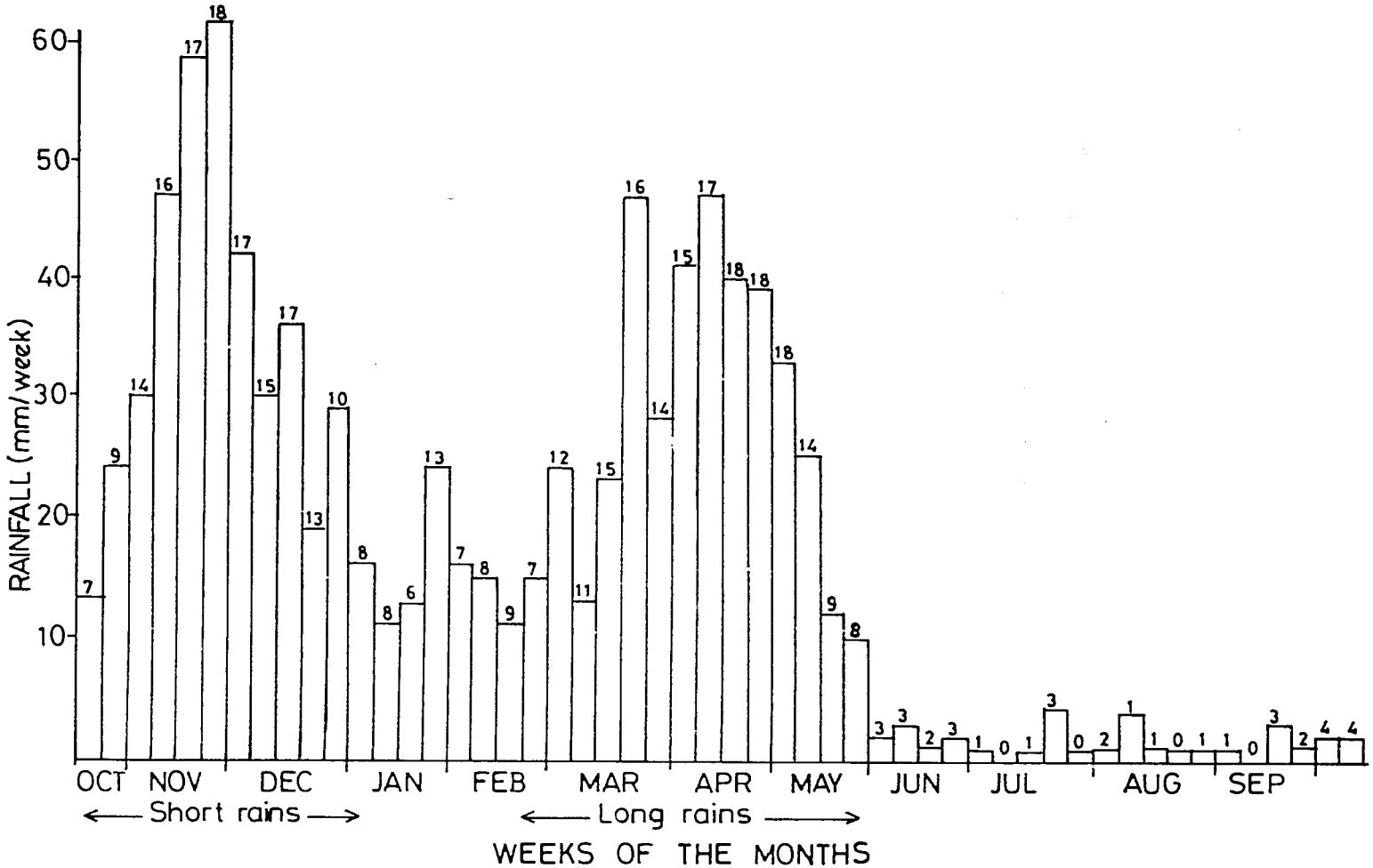

Fig. 2. Average Weekly Rainfall at Machakos Weather Station, 1954 to 1973. Number above Bar = Number of Years with More than 5 mm of Rain during the Week

ment the more limited December rainfall.

One important method of water conservation, early in the season, is effective weed control. As mechanical weed control is the main method practised in the area, ploughing after the beginning of the rains and germination of the first flush of weeds appears to be the most effective method for early weed control. Planting after ploughing to control the first flush of weeds allows the crop a chance to develop in a relatively weed-free environment until it is strong enough to compete with later emerging weeds and able to withstand mechanical weeding. Moisture loss due to inefficient weeding is much higher than that caused by delaying planting until after the first flush of weeds has been controlled, and can make the difference between success and failure, especially under limited water-supply conditions. If the crop requires more water after the end of the short-rains season (end of December), there is a reasonably high probability that at least a significant part of its water requirements will be satisfied by the rains which usually fall during January and/or February.

During the long rains, more flexibility in the manipulating of planting dates is possible. To make the highly drought-sensitive 40-day period coincide with the time of the season of high rainfall probability (the month of April), maize needs to be planted before 1 March. Fig. 1 shows the timing of the maize growth stages, planted on 2 March 1978, superimposed on the weekly rainfall at Katumani station from 1 January 1978 until the end of the rainy season. Drought symptoms appeared in the plants at the late milk stage of growth. If maize had been planted 2 weeks earlier, the drought effect would have showed up at the early dent stage, which is less sensitive to drought. On the other hand, if planting was delayed for three weeks, the drought would have coincided with the pollination stage. A severe drought during pollination may cause a total yield loss. As can be seen from Fig. 1, in 1978 about 80 mm of rain fell during the last two weeks of February, which shows that planting by 15 February was possible. The only problem connected with the early planting of maize for the long rains would be that the land is usually still occupied by the short-rains maize crop. Relay cropping would solve such a problem.

The results of this study indicate that it is possible to grow two successive and successful maize crops in one year by effective weed control before short-rains planting and by relay planting of the long-rain crop.

SUMMARY

To determine the feasibility of improving yields, maize was grown during the long rains of 1978 at two localities with a difference in mean temperature of about 5°C, for the purpose of phenology analysis. Growth stages were timed and matched to a 20-year weekly rainfall average. The crop was found to require 120 days from planting to physiological maturity at Katumani and less than 100 days in a locality with a higher mean temperature (Kampi ya Mawe). The crop's most drought-sensitive 40-day period starts with the beginning of ear initiation, 35 to 50 days after planting. To satisfy most of the water requirements of this period it is important to control the first flush of weeds effectively before planting for the short rains, and to relay plant the long-rains crop before March. By applying these agronomic practices to maize planting in the Machakos area it would be possible on the average to satisfy most of the crop's water needs, and consequently to increase production.

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THE IMPORTANCE OF RESIDUAL MOISTURE RESERVES FOR INCREASING THE RELIABILITY OF CEREAL YIELDS IN EAST AFRICA (ABSTRACT)

P. Whiteman[1]

The use of crop sequence and particularly the use of a bare fallow in increasing the supplies of residual moisture to succeeding crops are discussed. Trials conducted at Katumani over three consecutive seasons showed that it was possible to obtain a five-fold increase in sorghum grain yield after fallow (1,720 kg/ha), compared with a virtually failed crop (320 kg/ha) after cereals, and intermediate yields after beans (881 kg/ha) in a season that only provided 201 mm of rainfall. Grain yields were highly correlated with the amount of residual moisture in the profile at planting time. From historical rainfall records, the frequency of expected response to both full and partial fallow in pairs of successive seasons is assessed, and it is shown that on 90% of the occasions when there would have been a crop failure (which occurs in one-third of all seasons), a fallow would have allowed adequate subsistence yields to have been achieved. The practical implications of this are discussed in relation to existing ecological-zone classification.

1. FAO, Pakistan

RAINFALL CRITERIA TO ENABLE RESPONSE FARMING THROUGH CROP-BASED CLIMATE ANALYSIS

J. Ian Stewart[1] *and D. A. R. Kashasha*[2]

INTRODUCTION

The hallmark of crop production in the semi-arid tropics is extreme variability in rainfall, coupled with near total unpredictability. Rainfall in a season may be very low, moderate or high, even excessive.

In more stable rainfall areas reasonably fixed cropping systems are developed by researchers, extension advisors and farmers, which are in accord with the level of rainfall, whatever it may be. Components of cropping systems, including crop types and varieties, planting dates, practices, and levels of inputs differ in different rainfall regimes.

Agriculturists in the semi-arid tropics, certainly those in East Africa, exist at once in a wide range of rainfall regimes, for which any fixed cropping system will be less than optimal most of the time. But with no clue to rainfall expectation in the coming season, what is the farmer to do—and what should we advise him to do? This has been the challenge faced since October 1977 by the USAID-funded Dryland Cropping Systems Research Project, headquartered at the Kenya Agricultural Research Institute, Muguga, Kenya, and staffed by seven USDA scientists.

Project operations are in Eastern Province of Kenya, where mean annual rainfall is between 500 and 800 mm, occurring in two distinct seasons. These are commonly termed the "short rains" and the "long rains", with peaks in November and April respectively.

Smallholders, for whom cropping is primarily a means of feeding the family and only secondarily a source of cash, are dominant in the project area. Many lack experience in semi-arid conditions, having migrated from higher-rainfall zones which are overcrowded. Food preferences and farming practices have tended to migrate with them. Two preferred foods are maize and beans, generally intercropped; virtually all farmers grow these crops if rainfall allows.

In drier areas other crops grown in addition to, or substituted for, maize and beans include grain sorghums and millets as cereals, and cowpeas and pigeonpeas as legumes.

The first priority of the project, as established by the Government of Kenya, is development of cropping systems which will stabilize family food production, albeit at a low level, in low-rainfall seasons—thereby averting or at least minimizing the need for famine-relief programmes.

The other principal goal is to develop systems which utilize all available water in better rainfall seasons to produce food and other crops profitably for the market so as to improve the quality of life in the rural areas. Details of project objectives and operations are described by Stewart and Wangati (1980a).

Stewart and Wangati (1980b) review pertinent agrometeorological research in East Africa and outline the approach being taken in the project. Briefly, it is to determine, for each major crop of interest, how it relates to or responds to its environment. Four functional relations between crop and environment are formulated: (1) crop water requirements as related to evaporative conditions of the atmosphere; (2) root-system ability to extract soil water when the crop is stressed, as related to soil depth and water-holding capacity, and to the approximate crop water adequacy; (3) maximum yield of the crop under optimal conditions, including water supply, as limited by energy—primarily sunshine and temperature—for growth processes; and (4) water-production functions, which quantify the rate of decline in yield with declining actual evapotranspiration due to limited water.

Techniques utilized in determining these and associated equations and relationships are the outgrowth of a long-term research effort by the senior author and colleagues at the University of California, Davis. Crops studied there include maize, beans, grain sorghum, alfalfa, cotton and

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tomato. Pertinent examples of crop-versus-environment relationships may be seen in Stewart and Hagan (1969: alfalfa) Stewart (1972), Stewart and Hagan (1973), Stewart *et al.* (1874: maize), Stewart *et al.* (1975: maize and grain sorghum), Stewart *et al.* (1976: grain sorghum, alfalfa, beans), and Stewart *et al.* (1977: maize). Methodologies developed are utilized by Doorenbos and Pruitt (1977) for estimation of crop water requirements, and by Doorenbos and Kassam (1979) to estimate water-production functions of crops.

The four critical crop-versus-environment relations, when coupled with field records or measurements of rainfall, evaporation, soil depth and water-holding capacity, permit water-balance calculations to be carried out which simulate water use (actual evapotranspiration) throughout the growing season of the study crop. Water-production functions translate the results into estimates of crop yield.

Frere and Popov (1979) describe such calculations and have used them to analyse rainfall records in Tanzania and other countries for the purpose of establishing drought-warning criteria. Stewart (1980a) and Stewart and Hash (1982) introduce an "effective rainfall analysis" based on the crop/environment relations determined in the present project for Katumani Composite B maize, a highly versatile cultivar bred in Kenya for the semi-arid project area (Stewart, 1980b). The initial analysis was performed for each of the 48 seasons in the 24-year rainfall record (1956–1980) from the Katumani National Dryland Farming Research Station, Machakos District, leading to the following conclusions.

Despite our inability to predict the notoriously variable rains in Kenya's semi-arid areas, a newly developed analysis of "effective rainfall" for maize production does permit their after-the-fact interpretation in time to give practical advice on farm practices and levels of inputs. The analysis of the available weather records—primarily rainfall and evaporation—when coupled with suitable research findings concerning the crops and soils of interest, accomplishes the following:

1. Permits evaluation of the suitability of a given crop for production at the planning site.

2. Defines the earliest and latest acceptable dates of onset of the rains for growing the study crop.

3. Quantifies the initial rainfall which should be accepted by the farmer as the signal to plant his crop.

4. Reveals that date of onset of the rains is correlated with total season rainfall expectation, and with intensities of early-season rains. Hence, it pinpoints ranges of dates properly termed early, late and too late as regards planting, and quantifies early-season rainfall amounts which indicate that either a good, fair or poor season is in store.

Application of the above information occurs at three stages:

1. The date of onset of the rains triggers recommendations to farmers on date of planting, seeding rates and initial fertilizer applications.

2. Rainfall totals 50 days after date of onset in the short rains, and 30–40 days into the long rains permit categorization of season type, and determine recommendations to farmers on thinning to desired stands, and on the adjustment of nitrogen fertilizer levels through side dressing.

3. At 75 days into the season, or approximately two months before harvest, total season effective rainfall can be estimated, and predictions of maize yield given to farmers, economists, and other planners concerned with food supplies.

The above findings confirmed the practicality of the concept here termed "response farming", which means manipulation of the cropping system in accordance with rainfall predictions based on the date of onset of the rains and actual amounts received in the early part of the season. Farm-level recommendations for maize production at Katumani were issued covering (a) defining and recognizing onset, (b) planting time in relation to onset, (c) seeding rate and geometry, (d) initial fertilizer rate, and (e) final plant population and fertilizer rate according to early rainfall amount.

Further research was then initiated to confirm and/or modify the above findings. Stewart (1982a) includes beans and the intercrop of maize and beans in the analysis and concludes that while intercropping of these crops yields advantageously in better rainfall seasons, it is decidedly damaging to overall production when total season rainfall is less than about 325 mm, since modified to about 290 mm (Stewart, 1982c).

Stewart (1982a) also quantifies the contribution of nitrogen to water-use efficiency, noting its particular importance in low-rainfall conditions.

He concludes that each plant must attain a certain mass before grain production can begin, that the critical mass is somewhat greater for plants grown in infertile soil, and that production of dry matter per unit of water is less for crops on infertile soil, resulting in a much greater rainfall requirement to begin grain production in infertile conditions. The addition of 40 kg/ha N resulted in grain production beginning with 218 mm of actual evapotranspiration, as against 298 mm without nitrogen. The experiment cited was with a high plant population, approximately 58,000 plants/ha. Stewart suggests that a reduced population will partition more water (and nutrients) to each plant, enabling grain production to begin at still lower rainfall levels.

Stewart (1982b) tests the validity of the criteria of onset date and early rainfall amount embodied in the 1980 recommendations during the succeeding four seasons, i.e. the 1980 and 1981 short rains, and the 1981 and 1982 long rains. Necessary modifications in the recommendations, including the incorporation of beans and the maize/bean intercrop, are given.

Now the 1982 short rains and the 1983 long rains are essentially finished, giving two more opportunities for refinement of prediction criteria, and for further on-farm trials in which decisions on crop types, input levels and practices have been made in response to the date of onset and the amounts of early-season rainfall. Stewart (1982c) reports the findings from these trials, which resulted in considerable improvement over the farmers' production using their normal cropping systems.

Kashasha (1982) utilizes data from the Kenya Meteorological Department and from the Kenya National Master Water Plan (Tippetts-Abbett-McCarthy-Stratton, 1980) to extend the analysis to nine additional localities, encompassing an area of approximately 13,000 km² in Machakos, Kitui and Kajiado Districts. All of the now ten localities have a bimodal rainfall pattern, but mean annual precipitation ranges from a high of 1,048 mm in Kitui town to a low of 504 mm at Kajiado. Five of these localities, including the two mentioned, have rainfall records which begin in the 1926 to 1931 period, much longer than the initially analysed record from Katumani, which begins in 1956.

Kashasha confirms that seasonal effective rainfall is correlated with date of onset, and more closely with early-season gross rainfall, and greatly strengthens the statistical underpinning of these key findings. Kashasha also shows both the similarities and the differences in rainfall behaviour in the different localities, giving increased understanding of distances over which a given set of rainfall criteria are valid for guidance in planning cropping systems.

In this paper a water-production function for maize is introduced which relates grain-yield expectations to effective rainfall (synonymous here with actual evapotranspiration). Actually, two families of three curves each show yield expectations at the smallholder farm level in three different weather zones. The difference between families is largely whether or not commercial fertilizer is used.

To tie together with these production functions, analyses from all ten locations have been reworked to express effective rainfall expectations directly in mm of water rather than in "water adequacy indices" for maize. A minimum acceptable yield of maize is defined, and probabilities are determined of effective rainfall being equal to or greater than the amount required to achieve the yield at the different localities.

It is shown that the probabilities (expected success rates) decline markedly with later onset of the rains at all localities in the long rains and at five of the 10 localities in the short rains. Thus, at some particular date it may be decided that the risk of failure is unacceptably high and maize should not be planted if the rain starts that late. The paper also defines the higher water requirement and thus lower probabilities of success for the intercrop of maize and beans. This is a popular cropping system which produces yield benefits when water is adequate. Lower-water-requirement crops, including beans, grain sorghum and millet, are also discussed.

The focus of the paper then is on date-of-onset criteria which farmers can respond to in terms of selecting the crops to be grown that season, the relative areas of each, the seeding rates to be employed, and the initial rate of application if fertilizers are used. Specific criteria are developed for each of the ten study locations and comparisons are discussed.

Early-season rainfall criteria to which farmers may respond by adjusting plant populations (thinning) and/or nitrogen rates (side dressing) are not as yet fully developed except for the Katumani area. These will be left for a later paper.

THE STUDY AREA

TABLE I—DESCRIPTION OF LOCALITIES FOR WHICH EFFECTIVE RAINFALL ANALYSES ARE COMPLETED

Station number	Name of locality	Latitude	Longitude	(m)	Rainfall record	Mean annual rainfall (mm)
9138000	Kitui Agriculture Office	1°22′ S	38°01′ E	1,177	1926–80	1,048
9038003	Mwingi Mission	0°55′ S	38°05′ E	1,066	1957–80	783
9137089	Katumani NDFRS*	1°35′ S	37°14′ E	1,575	1956–83	701
9238006	Ikutha Agriculture Station	2°04′ S	38°11′ E	732	1957–80	699
9138006	Kanziko Health Clinic	1°58′ S	38°20′ E	914	1957–80	689
9137014	Potha Estate	1°34′ S	37°18′ E	1,676	1931–80	632
9237003	Simba Railway Station	2°09′ S	37°36′ E	1,036	1930–80	632
9237018	Kiboko Camp	2°12′ S	37°43′ E	975	1957–80	589
9237000	Makindu Meteorological Sta.	2°17′ S	37°50′ E	1,000	1926–80	560
9136039	Kajiado District Office	1°50′ S	36°48′ E	1,737	1931–80	504

*Location of orginal analysis: Stewart (1980a); Stewart and Has (1981). For other analyses see Kashasha (1982).

Table I lists the ten localities for which effective rainfall analyses have been completed, showing their geographical positions, elevations, mean annual rainfall and the length of the record. The ranges in latitude and longitude are from 0°55′ to 2°17′ south and from 36°48′ to 38°20′ east respectively. The elevations range mostly around 1,000 m, but may be as low as 732 m or as high as 1,737 m. Mean annual rainfall (two seasons) is well distributed, being in the 500–599 mm range at three localities, the 600s in four localities, the 700s in two localities, and above 1,000 mm in one locality. There are five long records which, considering missing data, range from 41 to 54 years for the short-rains season and from 45 to 55 years for the long rains. The five shorter records analysed are 20 to 27 years for the short rains and 23 to 27 for the long rains.

Figure 1 is a map of the study area showing the localities of analyses. Katumani National Dryland Farming Research Station is close to the centre of the map. Potha Estate, with a 54-year rainfall record, is only a few kilometres away, and though somewhat drier, has rainfall behaviour very similar to that determined from the 24-year record at Katumani in the original analysis (Stewart, 1980a). The latter is extended to 27 years in this paper.

This raises the question of length of record required for a meaningful analysis. Initially Stewart performed the analysis on 15 years of data from Katumani, after which nine more years

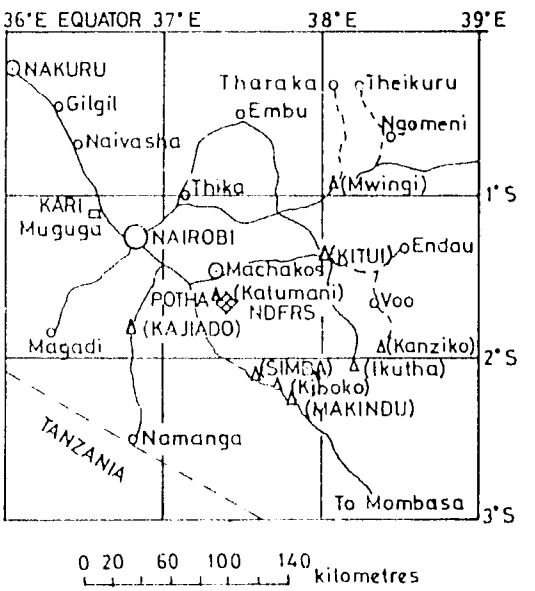

Fig. 1. Ten locations in Machakos, Kitui, and Kajiado Districts, Eastern Province, Kenya, for which "effective rainfall" analyses are completed. Location names are in brackets and the five localities with longer-term rainfall records (41–55 years) are in capital letters. Symbols are triangles except for the Katumani National Dryland Farming Research Station, where the initial analysis was made.

were retrieved from the files and added in. This made very little change in the results, none of any practical import. This paper will show the same for Kashasha's analyses—very little apparent difference between findings from 20-year and 55-year records. This is not to suggest that a short record is equal in value to a long one, nor does it completely answer the question of what the minimum useful record is. However, it does suggest the possibility of useful analyses being performed in areas of the third world for which data are scanty.

A FARM-LEVEL WATER-PRODUCTION FUNCTION FOR MAIZE

Figure 2 shows maize yield expectations at different levels of effective rainfall by smallholders in the study area. The crop is Katumani Composite B Maize, a highly versatile cultivar bred specifically for the semi-arid study area. In experiments conducted by the senior author, a yield of 1,000 kg/ha has been obtained with a gross rainfall of only 155 mm, while yields up to 3,000 kg/ha have been obtained under full irrigation. The zone of adaptability ranges from the cool climate of Muguga (2,170 m elevation), where maturity is 137 days from germination, to elevations less than 1,000 m where higher temperatures and sunnier skies shorten maturity to 100 days or less. In late-season drought conditions, a frequent occurrence, maturity can be attained even sooner.

The water-production functions in Figure 2 assume two levels of technology and three weather zones. The lower level of technology, specifically excluding commercial fertilizers, is represented by the lower family of three curves in the figure. This shows grain production starting with 150 mm of effective rainfall, depending on which of the three weather zones is being considered. The locations analysed in each zone are shown on the upper family of curves. For example, Kitui Agriculture Office is shown on the uppermost curve indicating relatively mild evaporative conditions, and hence higher water-use efficiency. Makindu, on the lower curve, indicates the opposite.

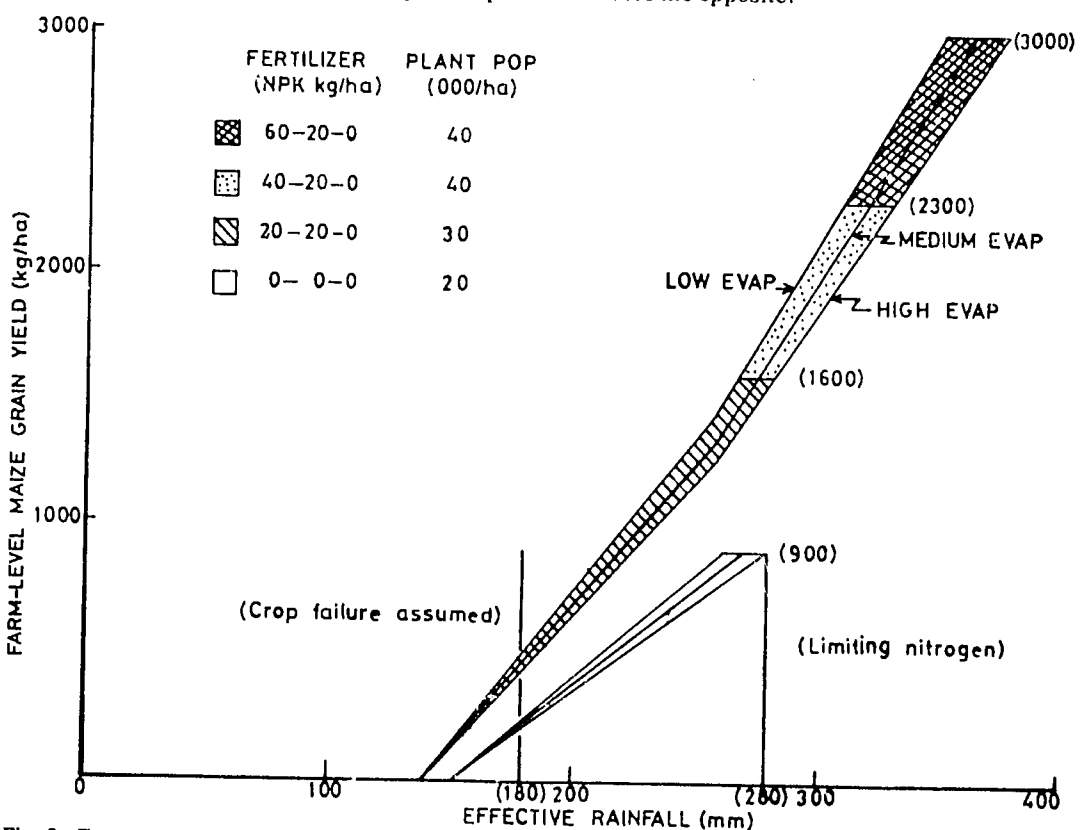

Fig. 2. Expected farm maize grain yields with practices adapted to rainfall: Machakos, Kitui, Kajiado Districts

In the legend it may be seen that the lower family of curves assumes, as noted, no fertilizer and a density of 20,000 plants/ha. This fairly well fits normal practice in the area as revealed by surveys (Collinson, 1978; Rodewald, 1978; Rukandema *et al.*, 1981).

Both families of curves in Figure 2 assume that farm yields are going to be lower than research-plot yields, regardless of level of technology. Yield expectations depicted are reduced by 25% in the milder weather zone, e.g. Katumani, 30% in the intermediate zone, and 35% in the highest evaporative-rate zone, e.g. Kiboko.

The upper family of curves, representing a higher level of technology, assumes an uppermost yield of 3,000 kg/ha, limited not by water but by nitrogen. This is attained (when water is available) with the addition of 60 kg/ha N, plus a basic addition of 20 kg/ha P_2O_5. The assumption is that added grain yield per kg fertilizer N will be 35 kg maize at 15.5% moisture content. This represents approximately 80% efficiency of N usage, which may be optimistic. The 1982 short rains offered an excellent opportunity to test these production functions.

Farmer-operated plots were established on twelve farms, seven of which included monocropped maize with the farmers' normal practices being compared directly with practices responding to actual rainfall conditions. The date of onset was 16 October, the earliest in the 50+ year rainfall history of the area. This signalled a high probability of a good season for maize, and probable additional benefits from intercropping maize and beans. Therefore both were planted. Maize (monocrop) was seeded at 60,000/ha and fertilized at that time with 20–20 kg/ha of N and P_2O_5.

Forty days later, on 24 November, rainfall exceeded 238 mm, the criterion for a good season if reached within 50 days. Decisions were then made to leave the high plant population unthinned and to side dress with 40 kg/ha N, making the total 60 kg/ha. The farmers, following normal practice, neither fertilized nor thinned. Results are shown in Table II.

Table II shows that plant population in the farmers' own plots were higher than surveys indicate, ranging from 30 to 38 thousand plants/ha, averaging 34,700/ha. Maize yields ranged from 443 to 2,434 kg/ha, with no apparent relationship to either plant population or rainfall, the latter being high in all cases. The response-farmed plots, also husbanded by the farmers, had populations averaging 40,900 plants/ha, and ranging from 24 to 71 thousand plants/ha.

Every one of the seven farmers benefited perceptibly from nitrogen fertilization, which was at the rate of 60 kg/ha N in all cases. The improvement in yield from applied N ranged from

TABLE II—FARM YIELDS OF MAIZE IN A GOOD RAINFALL SEASON, COMPARING RESULTS OF FOLLOWING NORMAL PRACTICES AND PRACTICES ADJUSTED IN RESPONSE TO ACTUAL RAINFALL (MACHAKOS DISTRICT, SHORT RAINS, 1982)

Farmer designation	Farmers' normal practice[1]		Farm plots responding to rainfall events[2]		Increased yield due to nitrogen fertilization		Nitrogen efficiency[3] (%)
	Population ('000/ha)	Yield (kg/ha)	('000/ha)	(kg/ha)	(kg/ha)	(kg grain/kg N)	
A	30.0	443	30.0	2,843	2,400	40.0	91
B	31.7	674	46.0	1,216	540	9.0	21
C	39.3	887	46.0	2,208	1,321	22.0	50
D	31.0	1,155	41.0	3,512	2,357	39.3	90
E	38.3	1,165	70.7	2,139	974	16.2	37
F	37.7	1,429	24.0	2,703	1,274	21.2	48
G	34.7	2,434	28.7	3,122	688	11.5	26
Mean	34.7	1,170	40.9	2,535	1,365	22.75	52

1. Normal practice is neither to use commercial fertilizer nor to thin the stand if rains are weak.
2. When early rains are strong, the recommended response is to leave plant population high and boost N to 60 kg/ha.
3. 100% efficiency is assumed to result in an increase of 43.75 kg/ha grain at 15.5% H_2O content per kg N.

9 to 40 kg grain per kg N, averaging 22.75. Considering the normal N content of grain and stover, and the harvest index of Katumani maize, this represents approximately 52% efficiency of nitrogen utilization by the crop. At today's prices, about 17% efficiency (about 8 kg increased grain yield per kg N) is the break-even point for nitrogen use. In this instance it also includes the cost of the P_2O_5, which was applied at 20 kg/ha.

Returning to Figure 2, the lower family of curves suggest that farmers should have averaged a little less, 900 kg/ha grain versus the 1,170 obtained, and our treatment a little more, 3,000 kg/ha versus the 2,535 obtained. The plant populations recommended in Figure 2 (a departure from earlier higher recommendations) were fitted well in the response plots, but were considerably higher in the farmers' own plots, where 20,000/ha were recommended and 34,700 found. However, there is little reason to believe that this greatly affected the farmers' yields in this high-rainfall season.

However, there is reason to believe that yields in our plots with farmers A, F and G might have been higher with plant populations of 40,000/ha. If so, the average yield would have been closer to the 3,000 kg/ha predicted by Figure 2. This is something for future research to resolve. The conclusion for the moment is that the water-production functions in the figure, and the recommendations implied therein, are satisfactory and will be retained for the present.

HOW DATE OF ONSET AFFECTS EFFECTIVE RAINFALL EXPECTATIONS

Stewart (1980a) and Stewart and Hash (1982) find that effective rainfall for maize production at Katumani is strongly correlated with date of onset of the long rains, but only weakly with that of the short rains. Kashasha (1982) finds similar relationships between "water adequacy index" expectations for maize and date of onset, particularly of the long rains, at the other nine localities analysed.

These are illustrated in Figures 3a, b, 4a, b, and 5a, b, for the three different weather zones, using the long-term rainfall records from the Kitui Agriculture Office, the Kajiado District Office, and the Makindu Meteorological Station.

Figure 3a is a scatter diagram of the effective rainfall for maize which occurred at Kitui in each short rainy season in the record to 1980, related to the actual date of onset of the rains. As the regression line shows (Table III), there is a decline of 3.86 mm/day in expected effective rainfall as onset gets later. This represents a daily loss in potential yield approaching 100 kg/ha of maize grain.

A horizontal line crosses Figure 3a at the level of 180 mm effective rainfall, and a second line at 230 mm. The line at 180 mm comes from the maize water-production functions in Figure 2, and represents the actual evapotranspiration required for the minimum acceptable crop of maize, whether fertilized or not. As one might imagine, these yield levels have reference to the subsistence level only. The incremental yield from fertilizing maize at the minimal level of 20–20 kg/ha N and P_2O_5 amounts to about 250 kg/ha, approximately equal in market value to the fertilizer cost.

The line at 230 mm represents the minimum level of effective rainfall which justifies intercropping of maize and beans. A rough approximation of the corresponding gross rainfall would be 300 mm. Above this level intercropping is beneficial in terms of total grain production per hectare, and below this level it may cause net yield reductions (Stewart, 1982 a, b, c). From such information as shown in Figures 2 and 3a, the probabilities of successfully producing crops of interest, and at what absolute yield levels, can be estimated for different rainfall and evaporation zones.

In this instance, the regression line in Figure 3a is significant at the 1% level, even though only 15% of the variation in rainfall expectation is explained by onset date. This is shown in Table III, where findings from regression analysis are shown for both seasons at all localities. In the table one sees that there is no correlation between onset of the short rains and expectations at certain sites, and very little at most of them. Where there is none the effective rainfall analysis still evaluates the suitability of the site for different crops, and, because the correlation increases as the early season passes, practices may still be guided.

Table IV shows that the probability of successfully producing a maize crop at Kitui in the short rains is 96%, i.e., four complete failures are expected if one plants every year for 100 years. In the short rains this probability does not depend on date of onset, but, as seen in Figure 3a, the average crop yield will be less with later onset.

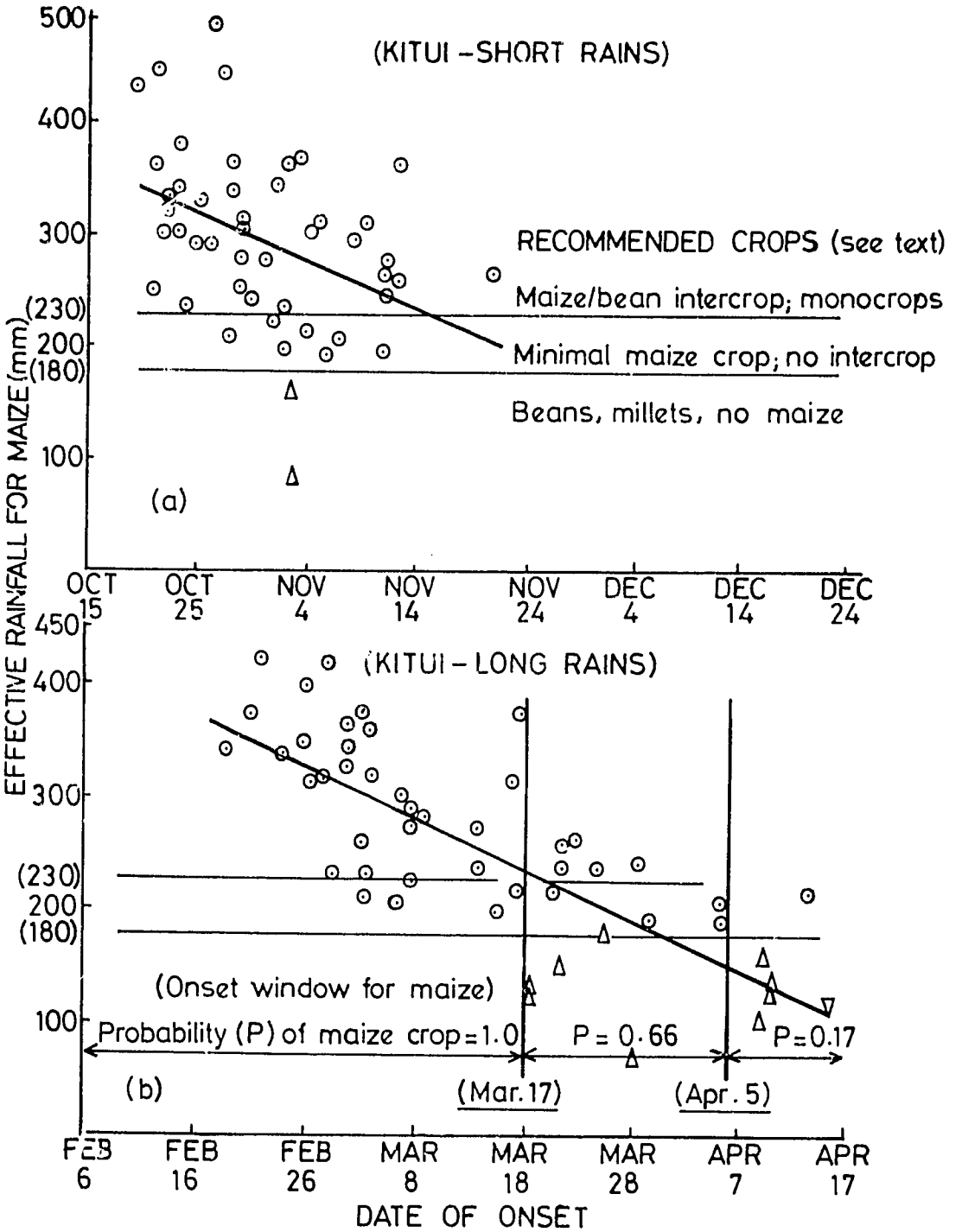

Fig. 3 a, b. Relations between date of onset of the rains and amount of effective rainfall for maize production at Kitui Agricultural Office, Kitui District, Eastern Province, Kenya, from 1926 to 1980

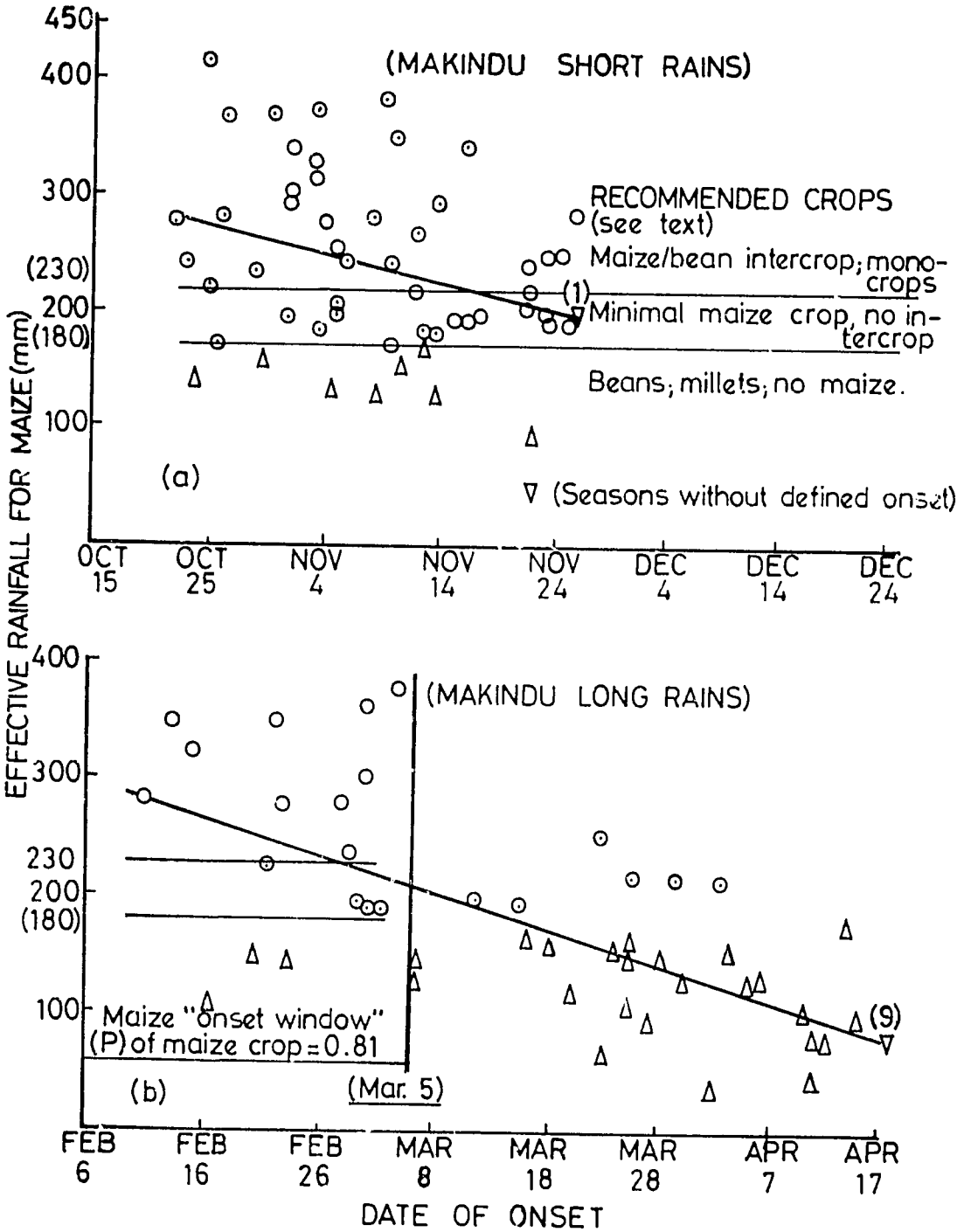

Fig. 4 a, b. Relations between date of onset of the rains and amount of effective rainfall for maize production at Makindu Meteorological Station, Machakos District, Eastern Province, Kenya, from 1926 to 1980

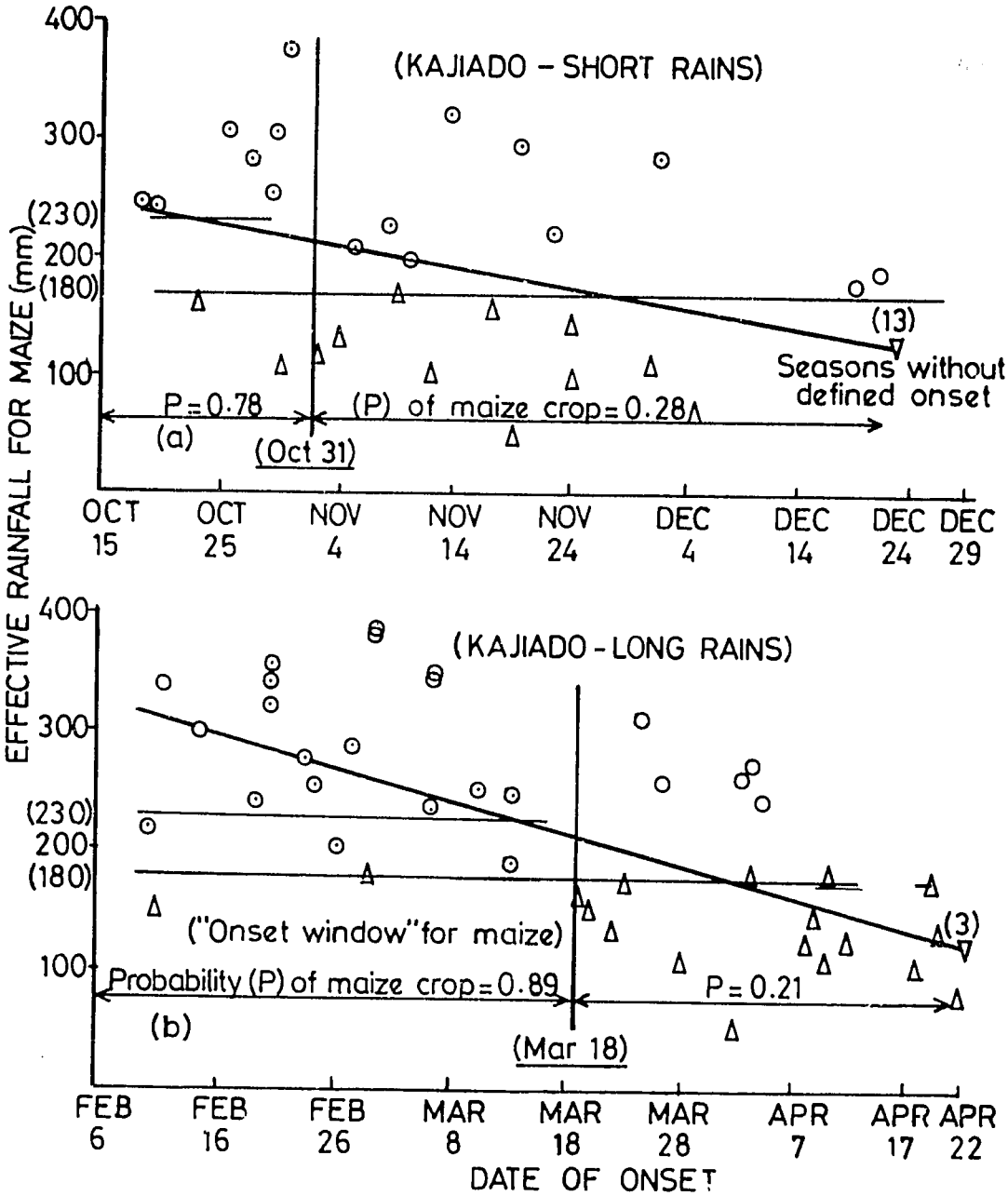

Fig. 5 a, b. Relations between date of onset of the rains and amount of effective rainfall for maize production at Kajiado District Office, Eastern Province, Kenya, from 1931 to 1980

TABLE III—REGRESSION OF EFFECTIVE RAINFALL EXPECTATIONS FOR MAIZE, ON DATE OF ONSET OF THE SHORT AND LONG RAINS (10 LOCALITIES IN MACHAKOS, KITUI AND KAJIADO DISTRICTS, EASTERN PROVINCE, KENYA)

	Short rains					Long rains				
Locality	Intercept (mm 15 Oct.)	Slope (mm/day)	C.V. R^2	Seasons (no.)	Students t	Intercept (mm 6 Feb.)	Slope (mm/day)	C.V. r^2	Seasons (no.)	Students t
Katumani	334	−2.47	.06	27	1.29ns	366	−3.37	.42	27	4.18**
Kitui	352	−3.86	.15	50	2.86**	414	−4.40	.58	51	8.31**
Potha	274	−1.12	.02	52	1.01ns	363	−3.46	.54	47	7.21**
Mwingi	260	−0.39	.00	23	0.21ns	303	−2.43	.57	21	5.01**
Makindu	291	−1.85	.06	53	1.82ns	296	−3.04	.42	46	5.63**
Ikutha	348	−4.20	.25	19	2.41*	268	−2.23	.27	17	2.34*
Kanziko	296	−3.24	.11	21	1.53ns	273	−3.05	.56	17	4.33**
Simba	344	−3.46	.13	42	2.44*	283	−2.51	.29	46	4.23**
Kiboko	277	−0.27	.00	19	0.13ns	250	−1.80	.24	20	2.41*
Kajiado	241	−1.35	.07	28	1.43ns	322	−2.63	.39	42	5.11*

*Statistical significance at 5% level.
**Statistical significance at 1% level.
ns = Not significant.

Figure 3b represents the long rains at Kitui, where a strong relationship is seen between expected rainfall and date of onset. The vertical line on 17 March denotes a rather marked change in expectations after this date, quantitatively as well as qualitatively. Table V shows how the probabilities of getting at least a minimum crop change on this date and again on 15 April.

Table V shows that if one planted maize every long rainy season at Kitui, the probability of success is 81% or 4 crops for five attempts. This is easily the highest probability among the ten localities, which fits with Kitui's higher rainfall (Table I). However, even in this favoured situation, the probability is increased, in this case to 100%, if the onset is on or before 17 March, then falls quickly thereafter. From 18 March to 5 April inclusive, in which period onset occurs in 29% of all years, the probability of a maize crop is 66%, or two years out of three. Thereafter it is 18%, or one year out of five. A point to note in Figure 3b is the large inverted triangle at the right end of the regression line with (1) above it. This indicates that one season in the record had no onset as defined here for maize production, namely a total of 40 mm of rainfall in a period not exceeding 10 days, with no dry period exceeding one day at a time. This point is not included in the regression. Figures 4 a, b and 5 a, b contain similar notations.

Figures 4 a and b show the situations respectively for the short and long rainy seasons at Makindu, where the mean annual rainfall of 560 mm is only slightly greater than half that at Kitui (see Table I). The scatter diagram for the short rains in Figure 4a shows very little correlation between rainfall and onset date; hence, the question is simply overall suitability for maize (and other crops for which production functions are determind) or not. Table IV show that the probability of success with maize is 83%, or roughly four crops from five attempts. Once again, however, at least on average, crops in seasons starting later may be expected to yield less. Table III shows an expectation of 291 mm of effective rainfall for 15 October onset, diminishing by 1.85 mm/day thereafter.

Figure 4b shows that onset of the long rains at Makindu, as at all locations, may occur over a much longer period than in the short rains, and that the correlation with expected rainfall is much greater. The importance of this may be seen in Table V, which shows that if one plants maize every long rainy season, the expected success rate is only 36% or about one season in three. This may be contrasted with the 81% success rate at Kitui. However, if onset is on or before 5 March, which happens in 31% of all seasons, the success rate rises to 81% at Makindu. After that date it falls to 16%. Such relationships, essential-

TABLE IV—SHORT-RAINS PROBABILITIES FOR SUCCESSFUL* MAIZE PRODUCTION AT 10 LOCALITIES IN MACHAKOS, KITUI AND KAJIADO DISTRICTS (PLANTING EVERY SEASON IS CONTRASTED WITH PLANTING ONLY IF ONSET OCCURS EARLY, IN A DEFINED "WINDOW")

			100-Year expectations for maize production based on planting:								
			Every year	When onset is in the window				Onset outside window			
Location	Years of available data (no.)	Eff. rain ≤180 mm	Crops expected (no.)	Last date onset window	Years in window (no.)	Crops expected (no.)	Success rate (%)	Years (no.)	Crops expected (no.)	Success rate (%)	Recommended action
Katumani	27	22	81	Not applicable, due to high and nearly equal expected success rate regardless of date of onset				Not applicable			Plant every season as desired.
Kitui	50	48	96								
Potha	54	40	74								
Mwingi	23	19	83								
Makindu	54	45	83								
Ikutha	21	14	67	11 Nov.	62	57	92	38	10	26	Plant only if onset is in window.
Kanziko	21	15	71	8 Nov.	76	62	81	24	9	37	
Simba	46	34	74	11 Nov.	57	50	88	43	24	56	
Kiboko	20	13	65	11 Nov.	60	45	75	40	20	50	
Kajiado	41	16	39	23 Oct.	22	17	78	78	22	28	

*Success, defined here for the subsistence farmer, is any yield above 200 kg/ha if not fertilizing, and above 450 kg/ha at low rates of fertilizer application. Details may be seen in Figure 2, where the production function suggests success at all effective rainfall levels from 180 mm upward.

TABLE V—LONG-RAINS PROBABILITIES FOR SUCCESSFUL MAIZE PRODUCTION AT 10 LOCALITIES IN MACHAKOS, KITUI AND KAJIADO DISTRICTS, (PLANNING EVERY SEASON IS CONTRASTED WITH PLANTING ONLY IF ONSET OCCURS EARLY, IN A DEFINED "WINDOW")

			100-Year expectations for maize production based on planting:								
			Every year	When onset is in the window				Onset ouside window			
Location	Year of available data (no.)	Years eff. rain ≤180 mm	Crops expected (no.)	Late date onset window	Years in window (no.)	Crops expected (no.)	Success rate (%)	Years (no.)	Crops expected	Success rate (%)	Recom mended action
Katumani	27	20	74	18 Mar.	59	52	88	41	22	54	Plant maize only if onset is the defined window.
Kitui	52	42	81	17 Mar.	60	60	100	29 to Apr. 5	19	66	
Potha	54	31	57	18 Mar.	52	48	93	11 Apr. 6 in the	2	18	
Mwingi	24	9	37	27 Mar.	37	33	89	48	9	19	
Makindu	55	20	36	5 Mar.	31	25	81	63	4	6	
Ikutha	23	8	35	18 Mar.	48	35	73	69	11	16	
Kanziko	23	7	30	5 Mar.	43	30	70	52	0	0	
Simba	49	23	47	2 Mar.	35	27	77	57	0	0	Kitui OK until 5 April if risk is accept-able.
Kiboko	23	8	35	13 Mar.	30	22	71	65	20	31	
Kajiado	45	24	53	18 Mar.	47	42	89	70	13	19	
								53	11	21	

ly unknown previously, have tended to obscure the boundaries within which different crops are suited for production.

The driest location analysed, with mean annual rainfall of only 504 mm, is Kajiado, for which the relations are shown in Figures 5 a and b. Table IV shows that this is the weakest location of the ten in the short rains with an overall expectation of 39% for harvesting some maize. However, this success rate is doubled to 78% in those seasons which have onset on or before 31 October. After that the rate drops to 28%.

Figure 5b and Table V show that the long rains at Kajiado are much stronger than the short rains, and stronger than the long rains at several localities with higher mean annual rainfall. The overall probability of a maize harvest is only 53%, but with onset by 18 March this rises to 89%—a crop nine times out of 10. Onset falls in this "window" in 47% of all seasons. However, with later onset, the success rate is only 21%—one harvest in five seasons.

Figures 6 a and b and 7 show how the rainfall expectations of all the localities relate to date of onset and to each other in the short rains and long rains respectively. Coefficients for the regressions are in Table III. Figure 6a, representing the short rains, is split into those localities where the probabilities of a successful maize harvest change very little with date of onset (although amount of effective rainfall may change considerably), and the other localities where an onset window exists, within which the probability of success is high, after which it is low. Table IV gives details of the dates of these windows and the pertinent probabilities.

Note that Mwingi and Kiboko show no correlation between rainfall and onset, yet the scatter diagram (not shown) for Kiboko shows 75% expected success with maize until 11 November, after which it falls to 50%. The 11 November date coincides well with the dates determined at the nearby locations of Simba, Ikutha and Kanziko.

Figure 7 confirms that in the long rains, basic rainfall versus onset behaviour is similar throughout the area, the important difference being the amount of effective rainfall with onset at any given date. Table V suggests that of the ten localities, it is only at Kitui (81%) and Katumani (74%) that one might consider planting maize every long rainy season without severe penalties. Yet observance of the onset windows at these localities, and certainly at the other localities, can markedly alter the picture. Two extreme examples occur at Ikutha and Kanziko, where all seasons in the record which would have produced maize began by 18 March at the former and 5 March at the latter. Within these windows the success rate rises to 73% and 70% respectively. At all localities the majority of seasons which could produce maize start in the defined onset windows.

Figure 8a shows the behaviour of five localities in the short rains, selected to include the extremes of high and low rainfall, and to show the differences in correlation with onset. Similarly, Figure 8b shows the behaviour of the long rains at five selected localities, to make direct comparisons between the seasons easier. All localities not shown fit between those in the figures. In Figures 8 a and b, as in Figures 6 a and b and 7, an asterisk is located by each curve denoting the date by which onset has occurred in at least 50% of seasons in the record. This includes seasons without a defined onset.

The rains are monsoonal in character, with the short rains moving down from the north and the long rains up from the south. However, the onset patterns among the ten study localities vary greatly from one short rainy season to the next, and also among long rainy seasons. Taken on average, the movement of the short rains appears more as might be expected than the long rains. Onset is earliest at Kitui, then within five days spreads both north to Mwingi and simultaneously south-west and south-east to Potha, Katumani and Kanziko, then clockwise in the next week through Ikutha, Makindu, Kiboko and Simba, then slowly west to Kajiado, arriving there 25 days after starting in Kitui.

The long rains, again on average, follow an unexpected and seemingly strange pathway among these localities. Earliest onset is at Katumani, 11 days before nearby Potha. From Katumani the movement is to Kitui (8 days), then reversing south-west through Potha to Kajiado over the next week, and simultaneously, but taking 11 days, south toward Makindu—picking up first Simba and Kanziko, then Kiboko and Ikutha, and finally Makindu. Meanwhile the expected northerly movement is slowest of all and Mwingi is reached last, four days after Makindu, and 23 days after the initial onset at Katumani.

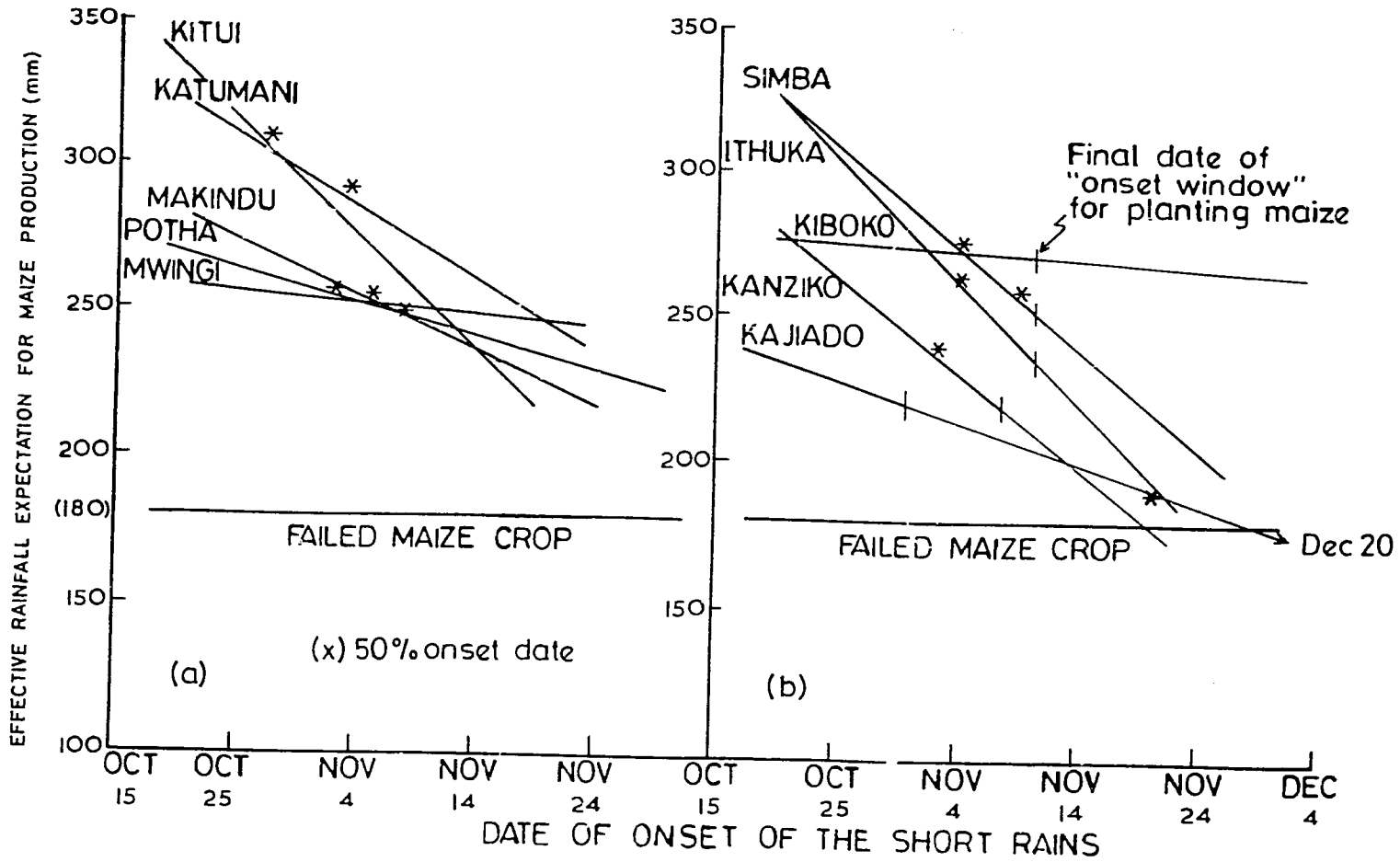

Fig. 6 a, b. Short-rains expectations for effective rainfall to produce maize, as influenced by the date of onset: 10 localities in Machakos, Kitui and Kajiado Districts, Eastern Province, Kenya

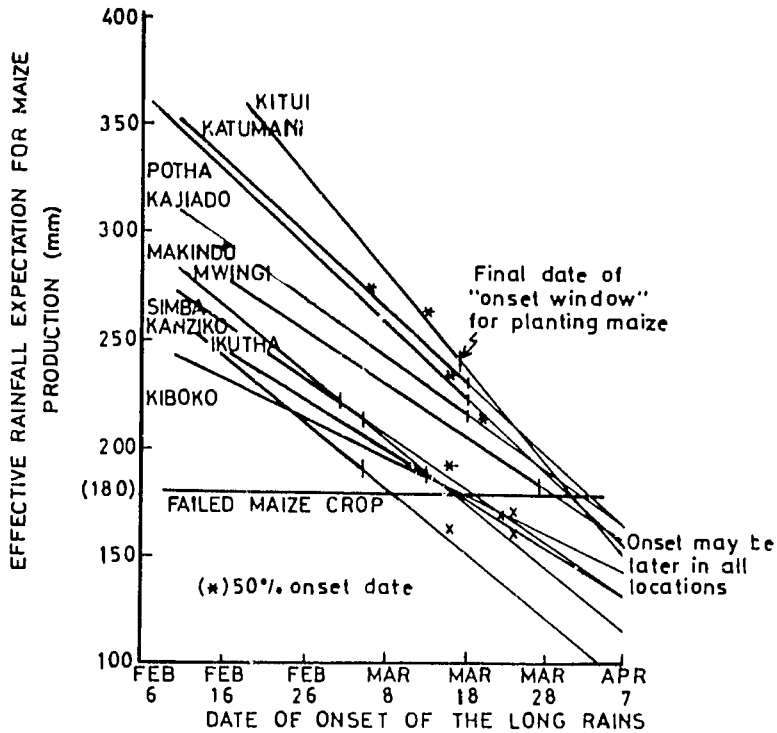

Fig. 7. Long-rains expectations for effective rainfall to produce maize, as influenced by date of onset: 10 localities in Machakos, Kitui and Kajiado Districts, Eastern Province, Kenya

ACTION SUGGESTED AND DISCUSSION OF ALTERNATIVE CROPS

The last column in Tables IV and V contains our recommendations concerning the planting of maize at the ten study localities. Basically, our conclusion is that maize to feed the family has a good (70 to 100%) chance of success in all localities studied, provided it is only planted when onset of the rains is early, as defined in the tables.

Exceptions are made in the short rains at Katumani, Kitui, Potha, Mwingi and Makindu, where the probability of harvesting at least a minimally acceptable crop is essentially constant for all onset dates. One important practical implication of this is that planting prior to the onset of the rains may be recommended, whereas at the other five sites, and all ten sites in the long rains, planting of maize is only recommended following onset. An important point here is that the farmer should stand ready to plant immediately following recognition of onset.

It is interesting to range the maize-crop expectations, i.e. numbers of crops harvested in 100 years when the recommendations are followed, against the mean annual rainfall given in Table I. This is done in Table VI.

Table VI illustrates the fact that the relative suitability of a locality for producing a certain crop cannot be accurately judged from mean annual rainfall alone. Nor can it be judged from average seasonal rainfall, because the seasons do not cover set time periods and therefore cannot be adequately defined unless the record is analysed for actual onset dates suited to the crop in question.

In Table VI the surprises overall come at Mwingi, Potha and Makindu. Although it is second highest in the list in mean annual rainfall, Mwingi's maize production potential is less than that of Potha Estate, which is sixth on the list. The latter locality looks very good in both seasons, being in fifth place in the short rains and third in the long rains, as well as third overall. Makindu also has much greater maize production potential than mean rainfall would suggest. Ninth in rainfall, it rises to fifth in production potential, primarily due to strength in the short rains. Kajiado, the driest locality examined, also

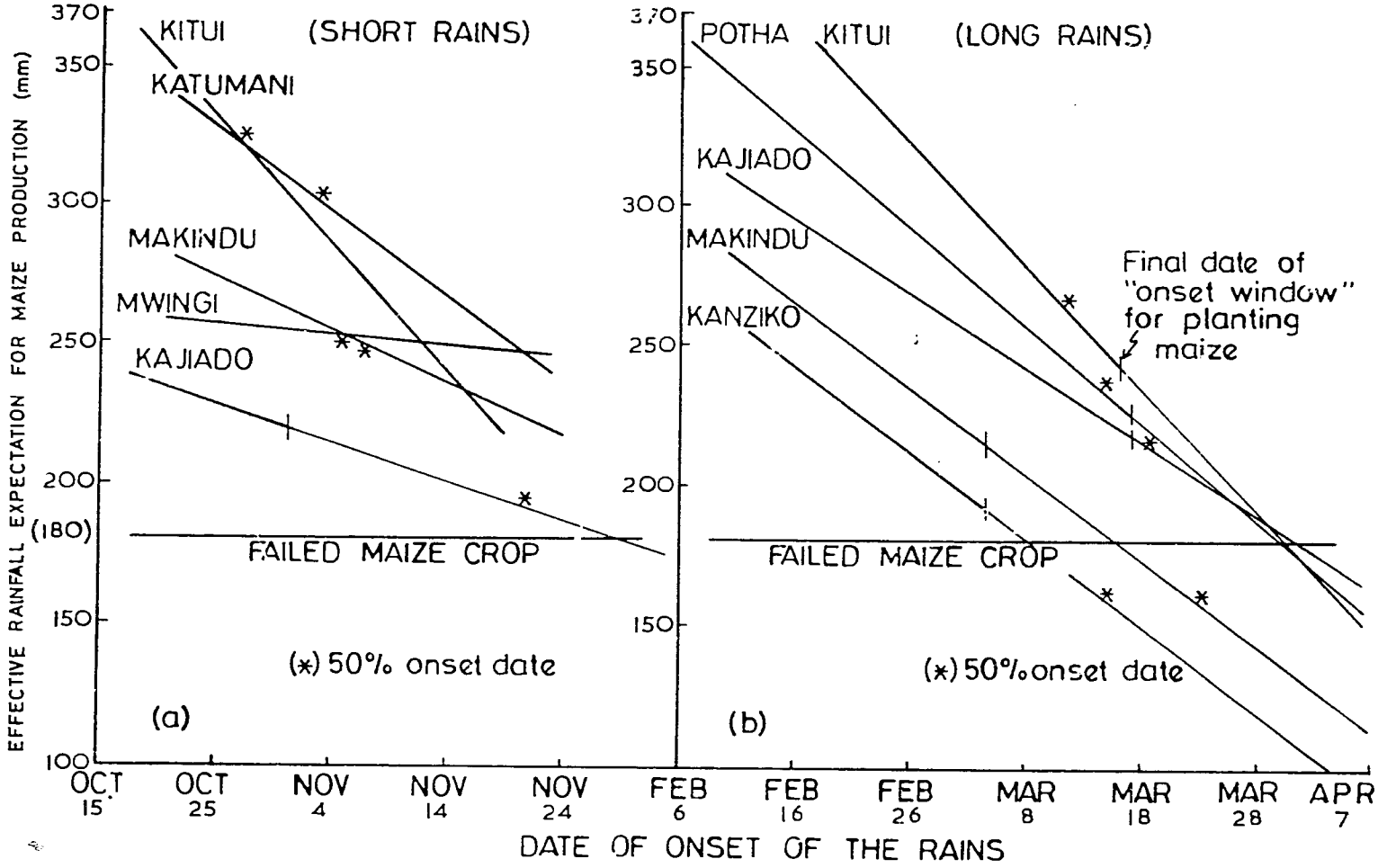

Fig. 8 a, b. Comparison of effective rainfall expectations in the short versus the long rains, and the influence of date of onset on each. Selected locations show the extremes

TABLE VI—RELATIONS BETWEEN MEAN ANNUAL RAINFALL AND NUMBERS OF MAIZE CROPS EXPECTED IN 100 YEARS AT LOCALITIES IN MACHAKOS, KITUI AND KAJIADO DISTRICTS, EASTERN PROVINCE, KENYA

			No. of maize crops expected in 100 years and ranking of locations					
	Annual rainfall		Short rains		Long rains		Total both seasons	
Location	Mean (mm)	Ranking*	Crops	Rank	Crops	Rank	Crops	Rank
Kitui	1048	(1)	96	(1)	60	(1)	156	(1)
Mwingi	783	(2)	83	(3)	33	(6)	116	(4)
Katumani	701	(3)	81	(4)	52	(2)	133	(2)
Ikutha	699	(4)	57	(7)	35	(5)	92	(6)
Kanziko	689	(5)	62	(6)	30	(6)	92	(7)
Potha	632	(6)	74	(5)	48	(3)	122	(3)
Simba	632	(7)	50	(8)	27	(8)	77	(8)
Kiboko	589	(8)	45	(9)	22	(10)	67	(9)
Makindu	560	(9)	83	(2)	25	(9)	108	(5)
Kajiado	504	(10)	17	(10)	42	(4)	59	(10)

*All ranking from high to low; 1 is high.

shows surprising potential, in this case during the long rains. However, it remains in tenth position overall due to extreme weakness in the short rains.

Table VI also offers a form of answer to the greatly debated question of the relative "reliability" of the two rainy seasons. Like the farmers themselves, at least in Machakos District, the table would choose in favour of the short rains at all localities except Kajiado, where the long rains are clearly more reliable.

Alternative crops for maize are primarily those with lower water requirements, to be grown in seasons when onset does not favour maize, and, equally, to provide food security in seasons when onset does seem to favour maize. In other words, other types of crops should be planted every season, at least sufficiently to insure the minimal food requirements.

The popular intercrop of maize and beans is an alternative system with a higher water requirement. It is widely planted in the areas where maize is grown, and arguments both pro and con may be heard about this practice. Experimental results were alluded to earlier showing increased production from intercropping when rainfall exceeds (approximately) 300 mm, but decreased production at lower rainfall levels.

On-farm trials in the 1982 short rains (very high rainfall) confirm the desirability of intercropping maize and beans in better seasons. These results, reported by Stewart (1982c), show increased grain yields per hectare of 88% on five unfertilized farm plots and 42% on 10 fertilized plots. Benefits were realized in every instance. Figures 3, 4 and 5 show that effective rainfall amounts above 230 mm, the break-even amount for intercropping, are rather randomly distributed. As a first approximation, then, we may assume that when benefits are gained from intercropping maize and beans they will average half of the above figures, i.e. 14% for farmers not using fertilizers and 21% for those who do. The remaining question is what recommendations to make concerning this practice for the ten locations analysed. Table VII provides estimates of benefits or losses to be expected from intercropping versus monocropping of maize and beans at the ten study localities.

In Table VII the first two columns (number of crops planted and number of maize crops expected) for each rainfall season are drawn from Tables IV and V, and they assume that the recommendations (actions suggested) in those tables are to be followed. The third column for each season is the number of favourable intercrops expected, and because the water requirement is greater, this number is, with the exception of Kajiado in the short rains, always less than the expected number of maize crops. The difference might be termed "unfavourable

TABLE VII—ESTIMATED LONG-TERM GAINS OR LOSSES IN GRAIN PRODUCTION FROM INTERCROPPING AS OPPOSED TO MONOCROPPING MAIZE AND BEANS (FERTILIZER EFFECTS ON PERCENTAGE OR LOSS ALSO SHOWN)

	Short rains					Long rains				
		Expected yields		Intercrop benefits			Expected yields		Intercrop benefits	
Location	Crops planted (no.)	Maize (no.)	Intercrop (no.)	Unfert. (%)	Fertilized (%)	Crops planted (no.)	Maize (no.)	Intercrop (%)	Unfert. (%)	Fertilized (%)
Katumani	100	81	59	5	(−12)	59	52	44	22	2
Kitui	100	96	82	23	3	60	60	50	20	2
Potha	100	74	50	(− 3)	(−18)	52	48	45	35	13
Mwingi	100	83	57	(− 1)	(−17)	37	33	16	(−30)	(−41)
Makindu	100	83	50	(−13)	(−27)	31	25	18	4	(−13)
Ikutha	62	57	48	21	2	48	35	22	(− 9)	(−24)
Kanziko	76	62	47	9	(− 8)	43	30	17	(−18)	(−31)
Simba	57	50	46	32	11	35	27	19	1	(−15)
Kiboko	60	45	40	28	8	30	22	17	11	(− 6)
Kajiado	22	17	17	44	21	47	42	36	23	4

intercrops", which might or might not be total failures but which would probably yield less than the same area of land equally divided among monocropped maize and beans.

The principal problem with maize/bean intercropping is that the lost (or diminished) crops occur when they are most needed, in the dry seasons. Thus risk is enhanced, but there may be instances where the benefits in the better rainfall seasons justify taking the risk. The average benefits found in farm plots of 44% for farmers not fertilizing and 21% for those who are (in favourable seasons) are used to examine this question through the equations below.

For farmers not using fertilizer

% Long-term benefit from intercropping

$$= \frac{(144 \times \text{No. intercrops})}{(\text{No. of maize crops})}$$

For farmers using fertilizer

% long-term benefit from intercropping

$$= \frac{(121 \times \text{No. intercrops})}{(\text{No. of maize crops})}$$

The percentages of long-term yield gain or loss are shown in Table VII in the final two columns for each season. There are a large number of negative percentages where obviously intercropping should not be recommended. This includes the majority of sites if using fertilizers and several sites if not fertilizing.

The senior author also believes that small percentage benefits, say those in the table of 13% or less, do not justify a recommendation for intercropping for two reasons. First, this analysis is probably not sufficiently accurate, although it is thought to be reasonable. Second, if it were exact, long-term gains of this magnitude would probably fail to compensate for the short-term difficulties resulting from yield losses in dry seasons. This leaves us with ten situations to consider where expected benefits from intercropping range from 20 to 44%.

For farmers using fertilizer it is only at Kajiado during the short rains that expected gains of 21% are likely to justify intercropping. This is somewhat anomalous because, as seen in Table VI, Kajiado ranks last in expected number of maize crops in the short rains. This is due to the short "onset window" in which the probability of a harvest is high in this locality. However, Figure 5a shows that all the seasons in the window which would have produced maize would also have favoured intercropping.

This is true equally at Kajiado for farmers not fertilizing, and the percentage benefit is still greater. Note that the absolute benefit is probably more where fertilizing, but the relative values are as shown.

For farmers not fertilizing in the short rains, long-term benefits from intercropping which reach into the 20—44% range are indicated at

Kitui, Potha and Kajiado. In these cases intercropping is recommended, but never for the entire area planted to maize and beans. This becomes a matter of judgement and the farmer's individual circumstances, with food security as the principal consideration.

Crops with a lower water requirement than maize generally also have shorter growing seasons. These would include grain sorghum, at say 90 to 110 days, millets, from 65 to 100 days, and beans, from 70 to 90 days. In both rainy seasons in the semi-arid areas of Kenya, a very high percentage of total season rainfall occurs within 65 days; hence most of the water available to maize is also available to shorter-term crops. Since they require less their needs are more nearly met, and their failure rates are reduced.

Certain crops, for example panicum millet (65 days) and Tepary bean (70 days) should almost never totally fail in the rainfall circumstances of Eastern Province, Kenya. It would seem reasonable to suggest that subsistence farmers in the drier areas should always plant such crops to assure the family food supply. This paper endeavours to guide them in ways and means of successfully widening the scope of their food production to improve their nutrition, to give them the maize they prefer, at least part of the time, and to improve their security, all by learning to respond to the rains.

CONCLUSIONS

In Eastern Province, Kenya, the date of onset of the long rains is significantly correlated with season effective rainfall for maize. Early onset bodes well for a more favourable season.

Probabilities of successfully producing maize in the long rains, at or above a defined minimum yield level, range from 70 to 100% in all 10 localities analysed in Machakos, Kitui and Kajiado Districts, which range in mean annual rainfall from 1,048 mm at Kitui to as low as 504 mm at Kajiado—provided maize is only planted when onset occurs early within "onset windows" defined for each location on the basis of an "effective rainfall analysis" of the rainfall and evaporation records. Probabilities thereafter fall within the range of 0 to 55%, except at Kitui, where in the middle onset period they are 66%, dropping thereafter to 18%.

The correlation of date of onset with season effective rainfall in the short rains is generally less, ranging from highly significant (statistically) at Kitui to non-existent at Mwingi and Kiboko. However, except for the latter two sites, effective rainfall expectations fall with later onset at rates which range from 1.12 mm/day at Potha to 4.20 mm/day at Ikutha. For farmers not fertilizing, this represents a loss of yield potential ranging from 8 to 31 kg/ha of maize for each day the rains delay. Comparable losses of potential for farmers using fertilizer are 14 to 54 kg/ha per day. This also results in reduced probabilities of a successful crop of maize as onset gets later.

At Katumani, Kitui, Potha, Mwingi and Makindu, the fall in maize production probabilities with later onset of the short rains may be ignored, with the overall probability of a crop, i.e., assuming one plants every season, ranging from 74% (Potha) to 96% (Kitui). At these sites, then, dry planting prior to the rains is feasible if desired by the farmers.

At Ikutha, Kanziko, Simba, Kiboko and Kajiado, as in the long rains, the probabilities of success with maize are high (75 to 92%) if onset occurs in defined windows, but low (26 to 56%) thereafter. Dry planting of maize is not recommended at these sites.

The popular practice of intercropping maize and beans should prove advantageous in the long run for farmers who do not fertilize (this is not a recommendation to abandon fertilizer) at Kitui in both seasons (observing onset windows throughout this list), Katumani, Potha and Kajiado in the long rains, and Ikutha, Simba, Kiboko and Kajiado in the short rains. For farmers using fertilizers, only Kajiado in the short rains. Farmers at sites not listed are advised to monocrop their maize and beans.

Shorter-term crops tolerant of water shortage, such as grain sorghums, millets and beans, are recommended for all farmers in the semi-arid areas at levels designed to assure that basic food requirements of the family are met.

SUMMARY

Response farming is based on the finding that expected effective rainfall for crop production is correlated with date of onset of the rains, and still more closely with early season rainfall. For the first time, East African farmers now have some knowledge of the current season's effective rainfall expectation, in time to respond with appropriate crops, inputs and practices.

The initial findings were based on production of maize, the preferred staple food grain, utilizing

the 24-year rainfall record at the Katumani National Dryland Farming Research Station in Machakos District. In this bimodal rainfall pattern, six seasons have now gone by since criteria were established for predicting the nature of the season at hand. During this time the criteria have, for the most part, been verified, and where indicated, modified. Production of beans and the intercrop of maize and beans have also been incorporated into the recommendations developed.

Experiment station trials to determine optimal fertilizer rates and plant populations for three categories of rainfall season (good, fair and poor) have been carried out. Farm trials, with operations carried out by the owners, have been in place for four seasons. Both station and farm trials have verified the efficacy of the method in terms of more stable and improved crop yields.

Meanwhile, the existence of the essential correlations has been firmly established on a sound statistical basis through extension of the analysis to nine additional localities, encompassing an area of 13,000 km² in Machakos, Kitui, and Kajiado Districts. Five of these have much longer rainfall records, up to 55 years or 110 seasons. Eight of the newly analysed localities are drier than Katumani, and in some of these the high risk is at present thought to preclude maize production.

The newly analysed localities, some in close proximity and some isolated, show major differences in some cases, and considerable likeness in others. This has improved our understanding of the distances over which a given set of rainfall criteria prevail. A potentially important finding is that "onset windows" are definable for any given crop for each location for one or both of the two rainfall seasons.

Taking maize as an example, in all 10 localities during the "long rains" and at five of these during the "short rains", prospects for successfully producing a crop are much greater if onset occurs by a specified date than if later. Probabilities of success if onset is in the window (early) range from 70 to 100%, versus zero to 56% if later.

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ROOTING CHARACTERISTICS OF AND WATER EXTRACTION BY KATUMANI COMPOSITE B MAIZE UNDER VARYING MOISTURE REGIMES

J. O. Mugah[1]

INTRODUCTION

The relative distribution of roots with respect to soil depth plays an important role in the water-uptake patterns of plants (Gardner, 1960). The common observation that in adequately watered soils plants normally utilize water nearest the soil surface first and in deeper layers afterwards could be interpreted as an indication of different levels of root effectiveness as well as of different root densities. Rooting depth and root ramification under given agronomic conditions vary with plants. Miller (1916), in a comparative study of the rooting characteristics of corn and sorghum, found that the two crops at the same age had different rooting patterns. Sorghum at a height of 30.1 cm had a rooting depth, lateral extent, and greatest length of a single root of 45.7, 90.3 and 102.9 cm respectively, whereas similar dimensions for corn at a height of 45.2 cm were 40.0, 82.8 and 97.8 cm respectively. The rooting depths for the two crops were not much different at the end of the growing season, but the lateral extent was always greater for sorghum. Stewart (1972) observed that sorghum performed better than maize under limiting water conditions, an observation which could be attributed, at least in part, to the difference in the rooting patterns of the two crops.

Information on crop rooting characteristics that can be related to the capacity to take up water is still scanty. This is because most quantitative studies on roots have used weight as a means of assessing the amount of root in the soil (Hendrickson and Veihmeyer, 1931; Fehrenbacher and Rust, 1956; Coley and Watson, 1966). It is generally accepted, however, that the capacity of a crop to take up water is more closely related to the surface area or total length of the root system than to its weight (Gardner, 1964; Cowon, 1965).

This paper examines the spatial rooting patterns of Katumani Composite B maize under varying moisture regimes, using Newman's (1965) line intersection method, in which root length is used to assess the amount of root in the soil. The paper also relates the rooting characteristics of the crop to its water-extraction capability.

MATERIALS AND METHODS

A field experiment was conducted on the Campbell Tract of the University of California, Davis. The soil is a deep, well-drained and relatively fertile Yolo Clay loam. Katumani Composite B maize was planted on 23 May 1980, following a pre-planting irrigation which raised the soil moisture to field capacity. The plants in the plots which were sampled for determination of root-length density were thinned to 66,700 plants per hectare on 9 June. All post-germination irrigations were applied through a line-source sprinkler irrigation system (Hanks *et al.*, 1974). With this type of irrigation set-up, it was possible to define four different water levels ranging from maximum near the sprinkler lateral and decreasing with increasing distance from the lateral so that the furthest water level from the lateral received no water. A neutron probe access tube was installed in the middle of each plot at every water level and irrigation water monitored by means of catch cans supported on these tubes (Stewart *et al.*, 1977).

Soil-moisture changes were monitored weekly at 30 cm depths through the access tubes, using a neutron probe (Gardner and Kirkham, 1952). These soil-moisture changes were used along with applied water to calculate evapotranspiration through a water-balance procedure (Stewart and Mugah, 1979).

Sampling for determination of root-length density was carried out on 23 August 1980. Composite soil samples measuring 2.2 cm in diameter and 10–25 cm long were secured from each of the four water levels. At every water level, three replicates were secured at 30 cm intervals down to 270 cm. The cores were then taken to the laboratory for determination of bulk density, after which the roots were separated from the soil using the procedure described by Torsell *et al.*, (1968). Briefly, each soil core was

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stirred with distilled water and left for the soil to settle at the bottom of the beaker, after which suspended organic matter was decanted onto a 60-mesh sieve. The process of stirring and decanting was repeated until the suspension was clear.

The organic material on the sieve was saturated with 1% aqueous solution of Congo red, rinsed with cold water, then saturated with 95% ethanol and rinsed again. This operation made it possible to discriminate living roots from dead organic matter, as the former were stained dark pink to bright red, whereas the latter remained unstained, light pink or brownish. The material was then transferred to a filter paper on a Buchmer funnel, and to distribute it uniformly over a known area, a metal cylinder 6 cm high and 12.6 cm in diameter was levelled on the filter paper so that the area over which the material spread was restricted to 124.6 cm^2. The paper was then placed between two perspex glasses with the top glass marked in 1 cm X 1 cm squares. The roots were viewed through a binocular microscope with a magnification of × 10 and their intersections with 20 randomly preselected squares counted. Volumetric root-length density, i.e., the length of root per unit volume of soil, was calculated using Newman's (1965) method.

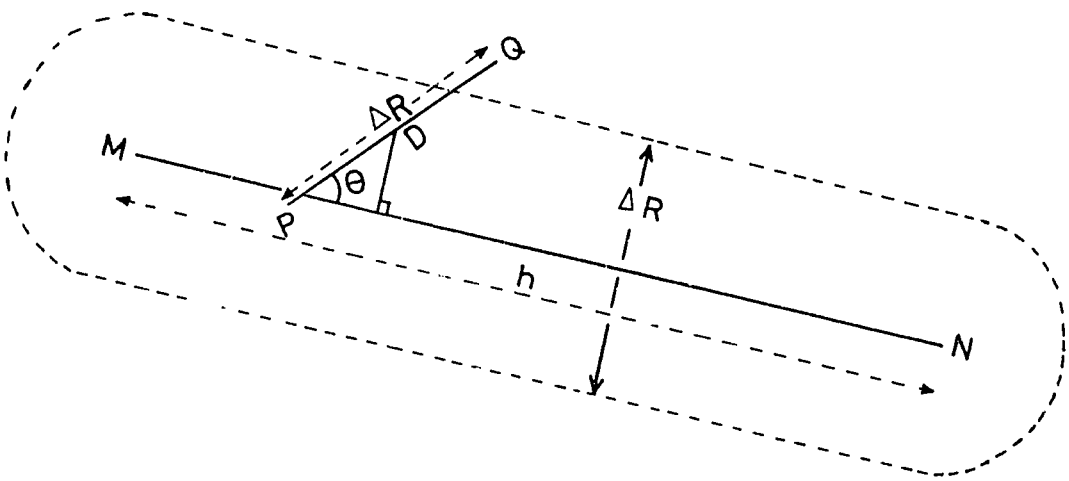

Fig. 1. Derivation of the equation $R = \frac{\Pi NA}{2H}$

Let PQ be the central axis of a portion of root of length ΔR, and short enough to be considered straight (Fig. 1). If MN, with length h, is a side of one of the squares and lies within the same plane convex region of area A as PQ, the condition for PQ and MN to intersect is that the midpoint, D, of PQ lie within an area given by $(\Delta R)h$, assuming $\Delta R/h$ to be small; the probability for PQ to intersect with MN is $(\Delta R)h/A$ if MN is positioned at random with respect to PQ. Whenever an intersection between PQ and MN occurs, the perpendicular distance of D from $MN \leqslant 1/2\,\Delta R/\sin/\theta/$, where θ is the angle between PQ and MN. Thus the probability P that there is an intersection is given by

$$\frac{\frac{1}{2}\,\Delta R|\sin\theta|\quad c = \sin\theta}{\frac{1}{2}\,\Delta R}$$

and, assuming that D lies anywhere within A,

$$\frac{P = (\Delta R)h\sin\theta.}{\frac{1}{2}\,\Delta R}$$

For several root sections intersecting with sides of more than one square, the expected total number of intersections, N, is given by

$$\frac{1}{2\Pi}\int_{0}^{2\Pi}\frac{(\Delta R)H}{A}\left|\sin\theta\right|d\theta,$$ where H = total length of sides at the squares.

$$\frac{1}{2\Pi}\int_{0}^{2\Pi}\frac{(\Delta R)H}{A}\left|\sin\theta\right|d\theta = \frac{H}{2\Pi A}\int^{\Pi/4}\Delta R\left|\sin\theta\right|d\theta + \int_{\Pi/4}^{\Pi/2}\Delta R\left|\sin\theta\right|d\theta +$$

$$\int_{\Pi/2}^{3/4\Pi}\Delta R\left|\sin\theta\right|d\theta + \int_{3/4\Pi}^{2\Pi}\Delta R\left|\sin\theta\right|d\theta.$$

$$N = \frac{HR}{2\Pi A}\left|\cos\theta\right|\Big|_{0}^{\Pi/4} + \left|\cos\theta\right|\Big|_{\Pi/4}^{\Pi/2} + \left|\cos\theta\right|\Big|_{\Pi/2}^{3/4\Pi} + \left|\cos\theta\right|\Big|_{3/4\Pi}^{2\Pi} =$$

$$\frac{HR}{2\Pi A}(1+1+1+1).$$

$$N = \frac{1}{2\Pi}\int^{2\Pi}(\Delta R)H\sin\theta\, d\theta = \frac{4RH}{2\Pi A}$$

$$N = \frac{2RH}{\Pi A}$$

Rearranging the above equation to make R the subject, $R + \frac{\Pi NA}{2H}$ = total length of root in the sample.

The volumetric root-length density, Lv, was calculated fro $Lv = \frac{\Pi NAPs}{2HM}$, in which Ps = *bulk* density and M = average mass of soil cores at 30 cm depth.

RESULTS AND DISCUSSION

Table I shows laboratory measurements of bulk density, Ps, number of root intersections counted, N, and average mass of composite soil cores per 30 cm depth, M, while Table II presents the calculated values of average total root length per 30 cm depth, R, and the corresponding root-length density, Lv. The spatial distribution of Lv is shown in Fig. 2. From Table I and Fig. 2 it is seen that the top 30 cm layer at each water level had the highest root-length density, which decreased sharply at the 60 cm layer. The percentage decrease varied with the degree of wetness of the treatments, being 28.6% at the driest treatment and 93.7% at the wettest treatment. In the two drier treatments, *WL1* and *WL2*, the variations in root-length density between layers were relatively smaller than those in the wetter treatments and the values of Lv were 1 cm/cm³ or greater down to 180 cm, whereas in the wetter treatments, *WL3* and *WL4*, root-length density fell below 1 cm/cm³ between the 120 and 150 cm depths.

Table IV shows results of an analysis of variance test which was carried out to test the significance of variations in Lv at various water levels and depths. The F values in this table show that variation of Lv with water level was significant at the 1% level, whereas no significant variation with depth was observed at any of the water levels. Lv values from the top 30-cm layer were not included in the analysis, as they were excessively high in some cases and would have strongly influenced the tests, giving erroneous results.

TABLE I—LABORATORY MEASUREMENTS OF BULD DENSITY, Ps, NUMBER OF ROOT INTERSECTIONS, N, AND MASS OF COMPOSITE SOIL CORES, M, AT 30 cm SOIL DEPTHS

	WL1			WL2			WL3			WL4		
Depth (cm)	Ps (cm/cm³)	N	M (g)	Ps (cm/cm³)	N	M (g)	Ps (cm/cm³)	N	M (g)	Ps (cm/cm³)	N	M (g)
30	1.3	62	70.5	1.3	143	57.0	1.3	222	65.0	1.3	639	67.0
60	1.0	50	60.9	1.0	58	83.3	1.0	63	51.6	1.0	62	75.9
90	1.0	91	131.0	1.0	56	97.8	1.0	88	97.3	1.0	50	111.1
120	1.0	67	116.5	1.0	74	97.8	1.0	106	104.1	1.0	31	63.7
150	1.0	55	111.0	1.0	64	120.0	1.0	27	130.5	1.0	28	112.6
180	1.0	46	112.4	1.0	62	125.8	1.0	5	120.0	1.0	5	121.1
210	1.0	26	99.7	1.0	16	127.5	1.0	5	109.5	1.0	0	98.1
240	1.0	13	103.3	1.0	5	116.2	1.0	0	109.1	1.0	0	115.7
270	1.0	4	86.9	1.0	4	101.2	1.0	0	103.4	1.0	0	119.4

TABLE II—TOTAL ROOT-LENGTH, R, AND THE CORRESPONDING ROOT-LENGTH DENSITY, Lv, AT 30 cm DEPTHS AS CALCULATED FROM THE FORMULAE $R = \frac{\Pi NA}{2H}$ and $Lv = \frac{\Pi NA\ Ps}{2HM}$

	WL1		WL2		WL3		WL4	
Depth (cm)	R	Lv	R	Lv	R	Lv	R	Lv
30	151.6	2.8	349.6	8.0	542.8	10.9	1,562.4	30.3
60	122.3	2.0	124.7	1.7	154.0	3.0	151.6	2.0
90	222.5	1.7	136.9	1.4	215.2	2.2	122.3	1.1
120	163.8	1.4	180.9	1.4	259.2	2.5	75.8	1.2
150	134.5	1.2	161.4	1.3	66.0	0.5	68.5	0.6
180	112.5	1.0	151.6	1.2	12.2	0.1	12.0	0.1
210	63.4	0.6	39.1	0.3	12.0	0.1	0.0	0.0
240	31.8	0.3	12.2	0.1	0.0	0.0	0.0	0.0
270	9.8	0.1	9.8	0.1	0.0	0.0	0.0	0.0

Spatial water extraction patterns at 30 cm depth intervals at each of the four water levels are shown in Table III and plotted against Lv in Fig. 3 a, b, c and d for water levels 1, 2, 3 and 4 respectively. Data from the top 30 cm layer at each water level were not included in the figures. The values of ET in this layer did not match the high values of Lv, and were also much lower than those in the underlying 60 cm layer. The relatively lower values of ET in the 30 cm layer are typical of experimental findings at Davis (Stewart, personal communication) resulting from soil compaction and subsequent reduction of water flow towards the roots.

The shapes of the curves shown in Fig. 3 are

TABLE III—SPATIAL WATER-EXTRACTION PATTERNS FOR KATUMANI COMPOSITE B MAIZE

Depth (cm)	WL1 ET (mm)	WL2 ET (mm)	WL3 ET (mm)	WL4 ET (mm)
30	33	38	17	6
60	47	51	34	23
90	44	47	38	19
120	40	43	29	13
150	34	34	22	8
180	22	15	6	5
210	7	7	7	2
240	1	1	2	1
270	0	0	0	0

TABLE IV—SUMMARY OF ANOVA TABLE FOR VARIATIONS IN Lv WITH WATER LEVEL AND DEPTH INTERVALS

Source of variation	D.F.	S.S.	M.S.	F
Water level	7	7,106.218	1,015.174	26.001
Depth	3	1,304.343	434.781	11.135
Error	21	819.906	39.043	
Total	31	9,230.468		

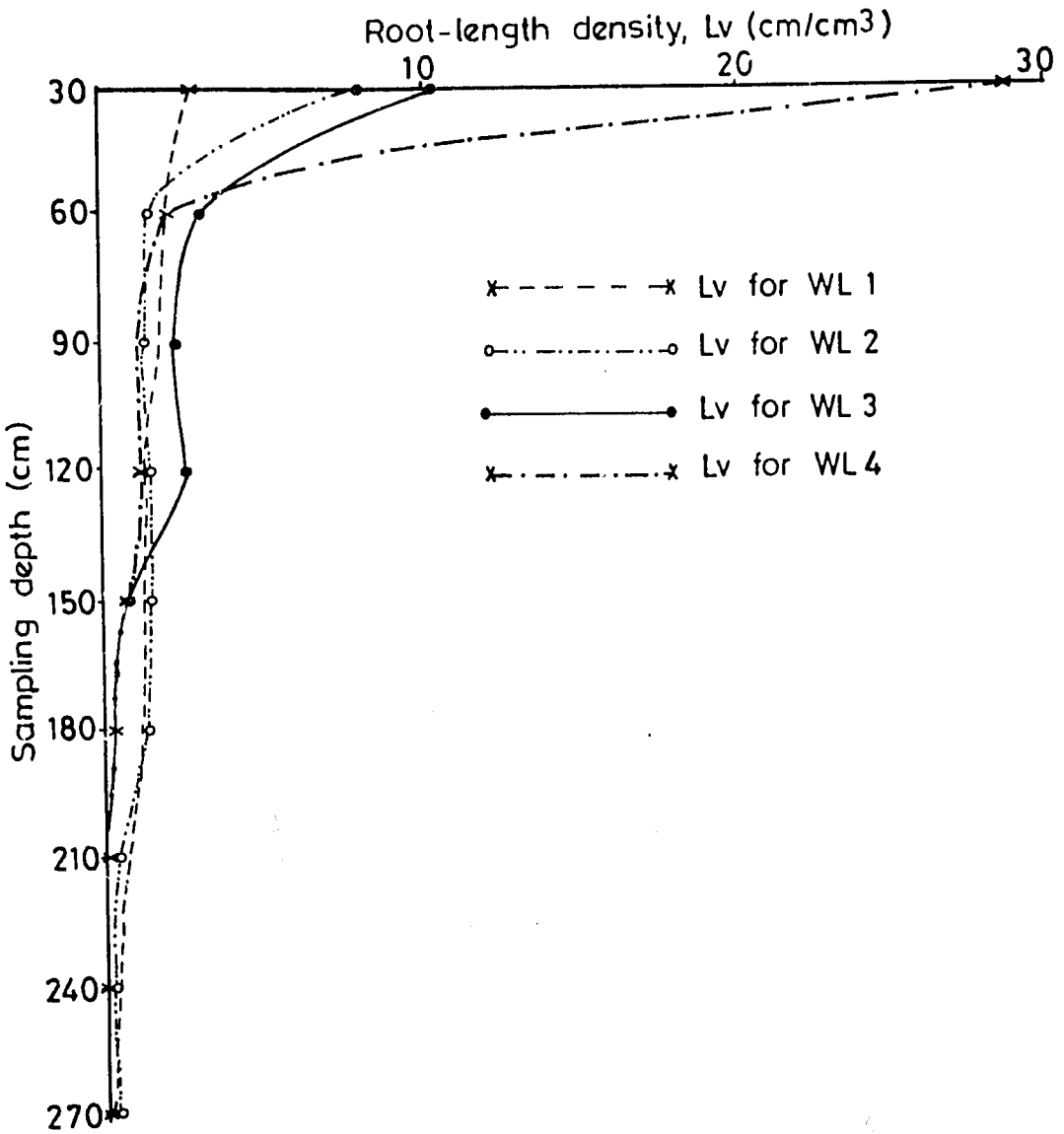

Fig. 2. Spatial distribution of root-length density for Katumani Composite B maize

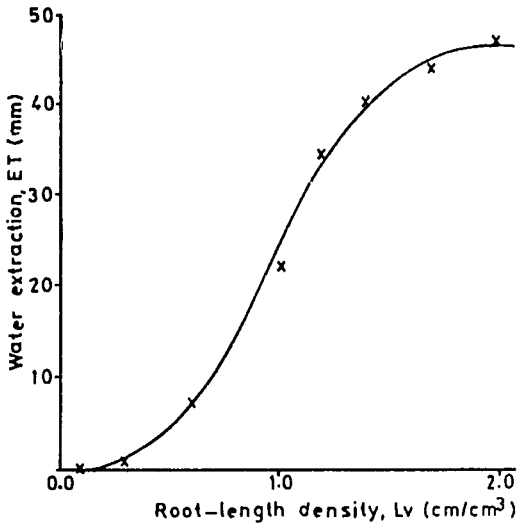

Fig. 3a. Relationship between root-length density, Lv, and water extraction, ET, for the driest treatment, WL_1

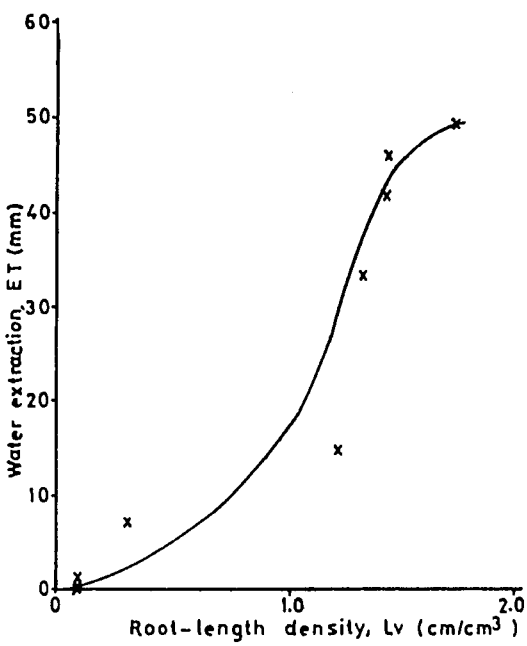

Fig. 3b. Relationship between root-length density, Lv, and water extraction, ET, for a dry treatment, WL_2

fully explicable by times of exposure to moisture in each layer since the soil was last wetted and depletion began. In the wettest treatment, the exposure time was practically uniform at all depths, due to the relatively more frequent irrigations. At any one time, a given length of root had an adequate supply of water in its vicinity and an increase in root-length density therefore necessarily resulted in proportionately higher water extraction rates, giving a constant slope in the *Lv* versus water-extraction curve; hence the strong linearity shown in Fig. 3d. In the drier treatments, the time of exposure varied from one layer to another. In the driest treatment, *WL1*, for instance, the roots in the 60 to 90 cm layer had been in place during most of the season and had depleted virtually all the extractable water in this layer. The amount of moisture in the vicinity of any length of root was small and continued to decrease as root-length density increased. The *Lv* versus water-extraction curve was therefore levelling off at the 60 and 90 cm depths, where *Lv* was 2.0 and 1.7 cm/cm³ respectively. In the middle 120 to 210 cm layer, the roots had attained a root-length density between 0.6 and 1.4 cm/cm³. The time of exposure to moisture in this layer was shorter than that in the 60 to 90 cm layer, and the amount of extractable water was still relatively higher. A given increase in *Lv* therefore resulted in a higher water withdrawal rate; hence the sharp rise in the *Lv* versus *ET* curve at the 210 to 120 cm layer. The time of root exposure to moisture was shortest in the 240 to 270 cm layer, where root-length density was also lowest. Water extraction was therefore low, giving the mild slope observed at the lowest end of the curve in Fig. 3a.

Eighty-five days after planting, the total rooting depth for the driest treatments in this experiment was approximately the same as that reported for an adapted maize variety, Pioneer 3773 (Gutierez, 1972), but the average root-length density per layer was always lower for the unadapted Katumani Composite B maize. The total water extracted by Katumani Composite B maize was 228 mm in the driest treatments, much lower than the 317 mm reported by Stewart (1972) for the unirrigated and adapted maize variety, Pioneer 3775, 87 days after planting. Soil-moisture extraction patterns found by Stewart and his colleagues in the USAID/KARI Dryland Cropping Systems Research Project indicate that when under stress, Katumani Composite B maize can extract water down to a

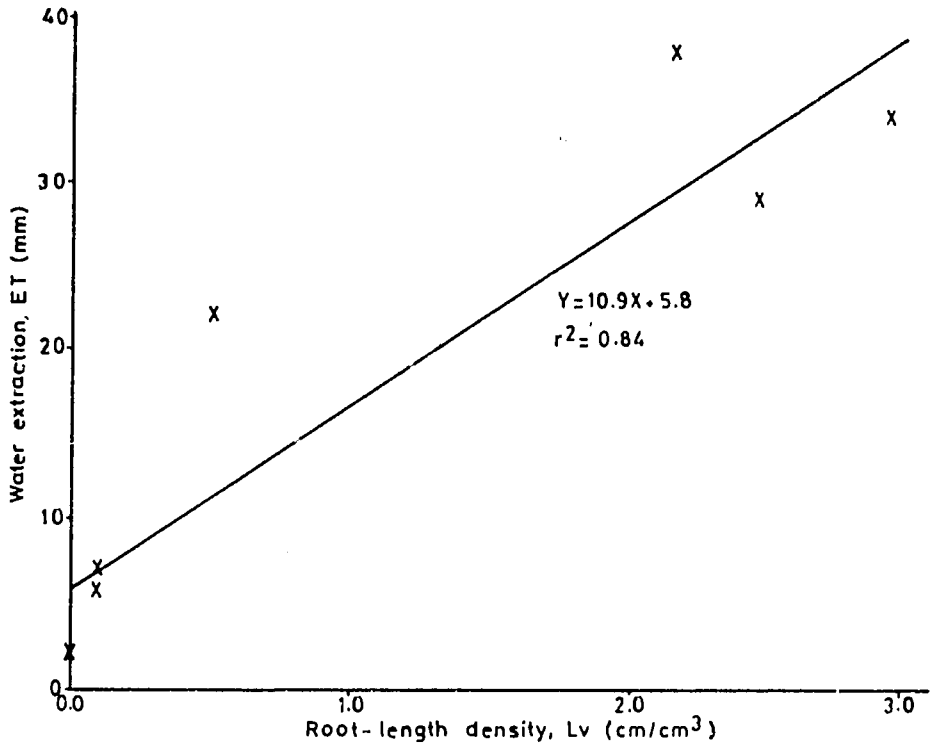

Fig. 3c. Relationship between root-length density, Lv, and water extraction, ET, for a wet treatment, WL_4

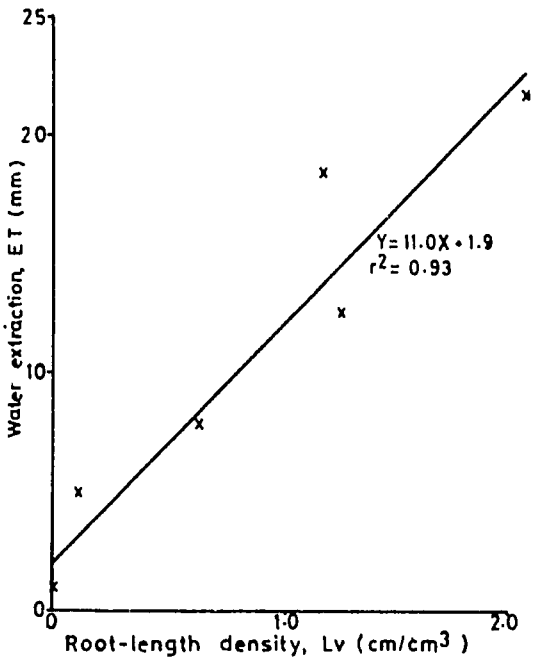

Fig. 3d. Relationship between root-length density, Lv, and water extraction, ET, for the wettest treatment, WL_4

depth of 2.0 m in the marginal rainfall areas of Kenya where the variety is adapted.

SUMMARY

Spatial rooting patterns of Katumani Composite B maize were studied under varying soil-moisture regimes, using Newman's (1965) line-intersection method. Root-length densities at 30 cm depth intervals were then related to the water-extraction capability of the crop. A strong linear relationship was found for the wettest treatment, *WL4*. The relationship became curvilinear with decreasing soil moisture, and was strongly curvilinear at the driest treatment, *WL1*. The total rooting depth for the driest treatments was approximately the same as that reported for an adapted maize variety, pioneer 3773 (Gutierez, 1972) but the average root-length density per layer was always lower for the unadapted Katumani Composite B maize. The total water extracted by Katumani Composite B maize in the driest treatments was 228 mm, which was much lower than the 317 mm reported by Stewart (1972) for unirrigated Pioneer 3775, an adapted variety.

ACKNOWLEDGEMENTS

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LYSIMETER MEASUREMENTS OF BEAN WATER REQUIREMENTS VERSUS ESTIMATES BASED ON CLIMATIC PARAMETERS

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INTRODUCTION

Considerable international scientific effort has been and is still being directed towards ways of determining crop water requirements, i.e. maximum evapotranspiration or ETm (Aboukhaled, 1972; Dilly and Shephard, 1972; Doorenbos and Pruitt, 1977; etc.). This effort is justified in view of the applicability of ETm in managing irrigated as well as rainfed agriculture (Pereira, 1957; Dagg, 1965; Mugah, 1981). The common practice of using water-balance relationships to decide when to irrigate and how much water to apply is a major management strategy in irrigated agriculture as it maximizes net returns (Stewart, 1972). More recent application of the water-balance relations of selected crops to analysis of rainfall records from selected sites offers a basis for assessing the suitabilities of the crops for those sites, and for guiding farm practices to maximize their yields (Stewart and Hash, 1982; Kashasha, 1982). These relationships, whether used in an irrigated or a rainfed context, have ETm as a major component (Stewart and Mugah, 1979; Mugah, 1981).

Crop water requirements may be determined by direct measurement using lysimeters (Forsgate *et al.*, 1965), neutron-scatter techniques (Gardner and Kirkham, 1952), and gravimetric sampling, or estimated by predictive methods based on climatic and crop parameters (Jensen *et al.*, 1969; Doorenbos and Pruitt, 1977). Lysimeters and neutron-scattering equipment are prohibitively demanding in costs and skill, factors which have confined their applicability largely to research. Gravimetric sampling is unsuitable for routine determination of crop water requirements because it is destructive and time-consuming. Climatic parameters, notably wind speed, temperature, humidity, sunshine duration, and pan evaporation, can be used to estimate water requirements through appropriate meteorological formulae. This paper compares estimates of the water requirement of Mwezi Moja bean made using three such formulae with direct lysimetric measurements from the hydraulic pillow lysimeter at Muguga. The formulae tested are the revised Penman formula, the radiation formula, and the pan-evaporation formula as modified and described by Doorenbos and Pruitt (1977).

MATERIALS AND METHODS

An experiment was conducted from 7 September to 30 November 1980 at the Kenya Agriculture Research Institute, Muguga. Mwezi Moja bean was planted on and around a 2.74 × 2.74 × 1.83 m hydraulic lysimeter containing soil with a textural composition of 52% clay, 20% silt, 28% sand and a pH of 7.0 (Stewart and Mugah, 1979). The climatic parameters that were measured from planting to harvesting are summarized in Table 1, in which the second, third, and fourth columns for *Tm*, *Tdb* and *Twb* show 10-day averages of air temperatures and dry-bulb temperatures respectively. The sixth, seventh and eighth columns show the 10-day mean relative humidity (*RH*), hours of bright sunshine (*n*), and the maximum possible sunshine duration (*N*). *U* is the 24-hour wind run at a 2-metre height. The eleventh column shows the saturation vapour pressure (*es*), as calculated from the expression

$$es$$

formulated by Murray (1967). In this expression, *T* is the mean air temperature, *Tm*, and *e* the base of the Naperian system of logarithms, *A*, *b*, and *c* are constants with values of 6.107, 17.2964 and 237.30 respectively for *T* greater than 0°C, and 6.1078, 21.8746 and 265.50 for *T* less than 0°C. In the twelfth column *ea* is actual vapour pressure as obtained from psychrometric tables using *Tdb* and the corresponding wet-bulb depression, *Tdb-Twb*.

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TABLE 1—CLIMATIC PARAMETERS FOR THE PERIOD 7 SEPTEMBER TO 30 NOVEMBER 1980

Days after 6 Sept. 1980	Tm (°C)	Tdb (°C)	Twb (°C)	Tdb-Twb (°C)	R.H. (%)	n (hr/day)	N (hr/day)	n/N	U (km/day)	es (mb)	ea (mb)	Ra (mm/day)	RS (mm/day)	Rns (mm/day)	Rni
1 – 10	15.3	17.2	13.0	4.2	65	7.5	12.0	0.6	239	17.4	13.3	15.2	8.4	6.3	1.7
11 – 20	15.4	18.4	13.0	5.4	57	8.6	12.0	0.7	296	17.5	10.0	15.2	9.1	6.8	2.0
21 – 30	15.4	18.4	12.7	5.7	55	9.8	12.0	0.8	325	17.5	9.6	15.2	9.9	7.4	2.3
31 – 40	16.5	19.0	16.4	2.6	79	7.7	12.0	0.6	307	18.8	14.9	15.4	8.5	6.4	1.5
41 – 50	17.2	20.3	15.4	4.9	63	10.0	12.0	0.8	364	20.0	15.5	10.1	7.6	2.1	2.1
51 – 60	16.1	17.8	13.9	3.9	68	7.1	12.0	0.6	358	18.3	12.4	15.5	8.5	6.4	1.7
61 – 70	16.0	17.7	14.2	3.2	74	6.4	12.0	0.5	337	18.2	13.5	15.4	7.7	5.8	1.4
71 – 80	15.9	17.3	14.6	2.7	76	6.3	12.0	0.5	304	18.1	13.8	15.4	7.7	5.8	1.4
81 – 85	15.7	18.3	14.5	3.8	69	8.9	12.0	0.7	368	17.8	12.3	15.2	9.1	6.8	1.9

Rs, *Rns* and *Rnl* represent solar radiation, net short-wave radiation, and net long-wave radiation respectively, and were calculated from

$$Rs = (0.25 + 0.50\, n/N)\, Ra$$
$$Rns = (1 - a)\, Rs,$$
$$Rnl = (\sigma\, Tk\, (0.35 - 0.044\sqrt{ea})\, (0.1 + 0.9\, n/N)$$

Ra is extraterrestrial radiation and a the reflectiveness of the crop surface, assumed to be 0.25. σ is the Stefan Boltzman constant with a numerical value of 1.98×10^{-9} mm/day/K^{-4}, while *Tk* is temperature in Kelvins.

The Modified Penman Formula

Penman (1948) proposed a combination aerodynamic-energy balance approach for predicting water loss from an open water surface for weekly of longer periods. Doorenbos and Pruitt (1977) suggested a slightly modified form of the Penman equation, which is given below:

$$ETO = c\left[\frac{\Delta}{\Delta+\gamma}\, Rn + \frac{\gamma}{\Delta+\gamma}\, f(u).\ (es - ea)\right]$$

where

ETO = reference-crop evapotranspiration, defined as "the rate of evapotranspiration from an extensive suface of 8 to 15 cm tall, green cover of uniform height, actively growing, completely shading the ground and not short of water". It is expressed in units of mm/day;

c = an adjustment factor to compensate for the effect of day and night wind and humidity conditions;

Δ = the slope of the saturation vapour pressure versus mean air temperature, expressed in millibars per °C;

γ = psychrometric constant;

Rn = net radiation in equivalent evaporation in mm/day.

Determination of c, Δ, γ and Rn in the Expression for Penman ETO

The magnitude of *c* is determined by day and night wind as well as *Rs* and *RH*. Appropriate wind data for the experimental station were not available, but an examination of similar data from the Kenya Meteorological Department, approximately 20 km away, indicated that for all the 10-day intervals covered in the study, *c* was essentially 1.

Δ was obtained by differentiating $e_s = Ae^{bT/(T+c)}$ with respect to temperature as follows:

$$\frac{de_s}{dT} = A \times \frac{d}{dt} e^{bT/(T+c)} + e^{bT/(T+c)} \times \frac{dA}{dT}$$

But A is a constant, so $\frac{dA}{dT} = 0$

$$\frac{de_s}{dT} = A \times e^{bT/(T+c)} \times \frac{dbT}{dT} / (T + c)$$

$$= A \times e^{bT/(T+c)} \times$$

$$\frac{(T+c) \times \frac{dbT}{dT} - bT \times \frac{d(T+c)}{dT}}{(T+c)^2} \quad T + c \neq 0$$

$$= A \times e^{bT/(T+c)} \times \frac{(bT + bc - bT)}{(T+c)^2}$$

$$= A \times e^{bT/(T+c)} \times \frac{bc}{(T+c)^2}$$

Numerical values for Δ were obtained by substituting for A, b, c, and T in the above expression.

The psychrometric constant, γ, was calculated from the expression $\gamma = \frac{0.386p}{L}$, which is due to Brunt (1952), and in which P is the average station barometric pressure in millibars and L the latent heat of vaporization. P for the experimental station was 800 mb. L was obtained from the relationship $L = 595 - 0.51T$, also due to Brunt (1952).

Over the range of temperatures that prevailed between the planting and harvesting dates, γ was invariably 0.53.

The Radiation Formula

The radiation formula developed by Makkink (1957) was adapted by Doorenbos and Pruitt (1977) for calculating ETO. The relationship recommended is:

$$ETO = c\left(\frac{\Delta}{\Delta+\gamma} \times Rs\right),$$

in which all the terms retain the definitions given earlier, except for the adjustment factor, c, which in this formula depends on mean humidity and daytime wind conditions.

The procedure for determining Δ, γ, and Rs has already been outlined. The contribution of c was incorporated into the above relationship through a graphical relationship between $\frac{\Delta}{\Delta+\gamma} \times Rs$ and ETO as described by Doorenbos and Pruitt (1977).

The Pan-Evaporation Formula

The pan used in this study was similar to the U.S.A. Class A pan described by Houston (1973), except that the study pan was covered with a 1-inch-square wire mesh to avoid losses due to birds or animals; it was also painted black inside. To adjust readings from this pan to the U.S.A. Class A pan evaporation, each value of 10-day mean evaporation was multiplied by a factor of 0.98 during the drier period of the season from 7 September to 31 October, and by a factor of 1.05 during the wetter periods from 1–30 November (Kaila, 1982). The adjusted value was then multiplied by a pan coefficient, Kp, to include corrections for humidity, wind and a 200-metre windward-side distance of grass to obtain ETO (Doorenbos and Pruitt, 1977; Kaila, 1982).

Development of Crop Coefficient Curve and Determination of ETm

Maximum crop evapotranspiration, ETm, is related to ETO by a crop coefficient, Kc, as follows:

$$ETm = Kc \times ETO.$$

Kc reflects the effect of crop characteristics on ETm, and is dependent upon crop type and growth stage. Kc values for different growth stages in this study were derived using the procedure described by Doorenbos and Pruitt (1977).

The duration of the initial stage was 30 days. The average recurrence interval of irrigation or significant rain during this stage was 3 days. The corresponding values of Kc from Fig. 1 are 0.77, 0.8, and 0.83 respectively, for the Penman, radiation, and pan-evaporation methods. The duration of the crop-development stage was 30 days, and Kc values for this period were obtained by interpolation between the initial stage and the mid-season stage. The value found for the latter was 1.05 for all three formulae, as shown below:

Duration of mid-season stage	= 16 days
Wind (Tables I and V)	= 0–5 m/s
Humidity (Tables I and V)	= 70% (high)

Kc (Table V)	= 1.05
Duration of late-season stage	= 9 days
Wind (Tables I and V)	= 0–5 m/s
Humidity	= 69%.

Kc at mid-point of the final interval, which lasted only 9 days, was 0.85 (Table V).

The *Kc* values were plotted and connected with straight lines as shown in Fig. 2. From this figure, a crop coefficient was read at the mid-point of every 10-day interval and multiplied by the corresponding *ETO* to obtain *Etm* for that interval.

ETm from Lysimetric Measurements

Daily measurements of applied water, *AW*, deep percolation *DP*, and changes in soil water storage, Δ *SW*, obtained from the lysimeter were used to calculate *ETm* through the water-balance relationship:

$$ETm = AW - DP \pm \Delta SW.$$

The daily *ETm* rates were then averaged over successive 10-day intervals.

RESULTS AND DISCUSSION

Tables II and III show numerical values for each of the components used in calculating *ETm*

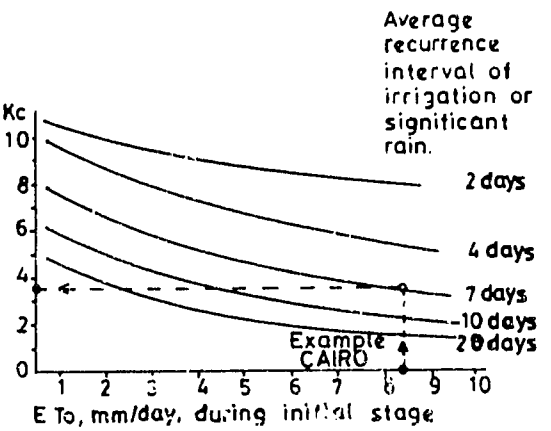

Fig. 1. Average Kc value for initial crop development stage as related to level of ETO and frequency of irrigation and/or significant rain (after Doorenbos and Pruitt, 1977)

TABLE II—NUMERICAL VALUES FOR THE COMPONENTS USED IN CALCULATING *ETm* BY THE PENMAN METHOD

Days after 6 Sept 1980	C	Δ	γ	$\frac{\Delta}{\Delta+\gamma}$	Rn (mm/day)	$\frac{\Delta}{\Delta+\gamma}$	f(u)	es-ea
1–10	1	1.12	0.53	0.68	4.6	0.32	0.92	6.1
11–20	1	1.12	0.53	0.68	4.8	0.32	1.07	7.5
21–30	1	1.12	0.53	0.68	5.1	0.32	1.15	7.9
31–40	1	1.19	0.53	0.69	4.9	0.31	1.10	3.9
41–50	1	1.26	0.53	0.70	5.5	0.30	1.25	7.4
51–60	1	1.17	0.53	0.69	4.7	0.31	1.24	5.9
61–70	1	1.16	0.53	0.69	4.4	0.31	1.18	4.7
71–80	1	1.15	0.53	0.68	4.4	0.32	1.09	4.3
81–85	1	1.14	0.53	0.68	4.9	0.32	1.26	5.5

by the Penman, radiation, and pan-evaporation formulae. Table IV summarizes and compares the estimates of *ETO*, *Kc*, and *ETm* by the three methods for each 10-day period and for the season as a whole. It also shows *ETm* values from the lysimeter. Duncan's Multiple-Range and Least Significant Difference tests showed no significant differences among the mean *ETm* rates. A closer examination of Table IV, however, reveals that the *ETm* rates from the three predictive formulae were rather consistently above those from the lysimeter during the first 60 days and generally below during the last 25 days. The apparent overestimation of *ETm* by the predictive formulae during the initial and crop-development stages could be attributed in part to the fact that the *Kc* values used in these formulae were based on a maximum leaf-area index of 3 or above, whereas the maximum leaf-area index actually attained in this experiment was only 1.6.

TABLE III—NUMBERICAL VALUES FOR THE COMPONENTS USED IN CALCULATING ETm BY THE RADIATION AND PAN-EVAPORATION METHODS

	Radiation method					Pan-evaporation method		
Days after 7 Sept. 1980	RS (mm/day)	Δ	γ	$\frac{\Delta}{\Delta+\gamma}$	$\frac{\Delta}{\Delta+\gamma}$	Epan, Muguga (mm/day)	Epan, U.S.A. standard class A pan (mm/day)	Kp
1–10	8.4	1.12	0.53	0.68	5.7	5.3	5.2	0.77
11–20	9.1	1.12	0.53	0.68	6.2	6.3	6.2	0.77
21–30	9.9	1.12	0.53	0.68	6.7	6.7	6.6	0.77
31–40	8.5	1.19	0.53	0.69	5.9	6.1	6.0	0.81
41–50	10.1	1.26	0.53	0.70	7.1	7.9	7.7	0.78
51–60	8.5	1.17	0.53	0.69	5.9	5.5	5.4	0.77
61–70	7.7	1.16	0.53	0.69	5.3	4.7	5.0	0.80
71–80	7.7	1.15	0.53	0.68	5.2	4.7	5.0	0.80
81–85	9.1	1.14	0.53	0.68	6.2	5.3	5.6	0.76

TABLE IV—COMPARISON OF ESTIMATES OF *ETO*, *Kc* AND *ETm* BY THE PENMAN, RADIATION AND PAN-EVAPORATION METHODS, AND OF *ETm* ESTIMATES WITH THOSE OBTAINED FROM LYSIMETRIC MEASUREMENTS

	Penman method				Radiation method				Pan-evaporation method				Lysimeter method	
Days after 7 Sept. 1980	ETO (mm/day)	Kc	ETm (mm/day)	Cumulative ETm (mm)	ETO (mm/day)	Kc	ETm (mm/day)	Cumulative ETm (mm)	ETO (mm/day)	Kc	ETm (mm/day)	Cumulative ETm (mm)	ETm (mm/day)	Cumulative ETm (mm)
1–10	5.0	0.77	3.9	39	5.0	0.80	4.0	40	4.0	0.83	3.3	33	3.1	31
11–20	6.0	0.77	4.6	85	5.2	0.80	4.2	82	4.8	0.83	4.0	73	3.2	63
21–30	6.5	0.77	5.0	135	5.8	0.80	4.6	128	5.1	0.83	4.2	115	4.4	107
31–40	4.7	0.81	3.8	173	4.5	0.84	3.8	166	4.8	0.87	4.2	157	3.4	141
41–50	6.3	0.90	5.7	230	6.0	0.92	5.5	221	5.9	0.94	5.5	212	5.2	193
51–60	5.6	1.00	5.6	286	4.8	1.10	5.3	274	4.2	1.02	4.3	255	4.3	236
61–70	4.8	1.05	5.0	336	3.9	1.05	4.1	315	4.0	1.05	4.2	297	5.3	289
71–80	4.5	1.03	4.6	382	3.9	1.03	4.0	355	4.0	1.03	4.1	338	5.3	342
81–85	5.6	0.90	5.0	407	5.2	0.90	4.7	379	4.3	0.90	3.9	358	4.0	352
1–85	5.4	0.89	4.8	407	4.9	0.92	4.5	379	4.6	0.92	4.2	358	4.2	362

TABLE V—CROP COEFFICIENT (KC) FOR FIELD AND VEGETABLE CROPS FOR DIFFERENT STAGES OF CROP GROWTH AND PREVAILING CLIMATIC CONDITIONS (AFTER DOORENBOS AND PRUITT, 1977

	Humidity		RHmin	>70%	RHmin	<20%
Crop	Wind (m/sec)		0–5	5–8	0–5	5–8
	Crop stage					
All field crops	Initial	1	Use Fig. 2 by			
All field crops	crop dev.	2	interpolation			
Artichokes	Mid-season	3	.95	.95	1.00	1.05
Perennial	At harvest	3				
clean cultivated	or maturity	4	.90	.90	.95	1.00
Barley		3	1.05	1.10	1.15	1.20
		4	.25	.25	.20	.20
Beans (green)		3	.95	.95	1.00	1.05
		4	.85	.85	.90	.90
Beans (dry)		3	1.05	1.10	1.15	1.20
Pulses		4	.30	.30	.25	.25

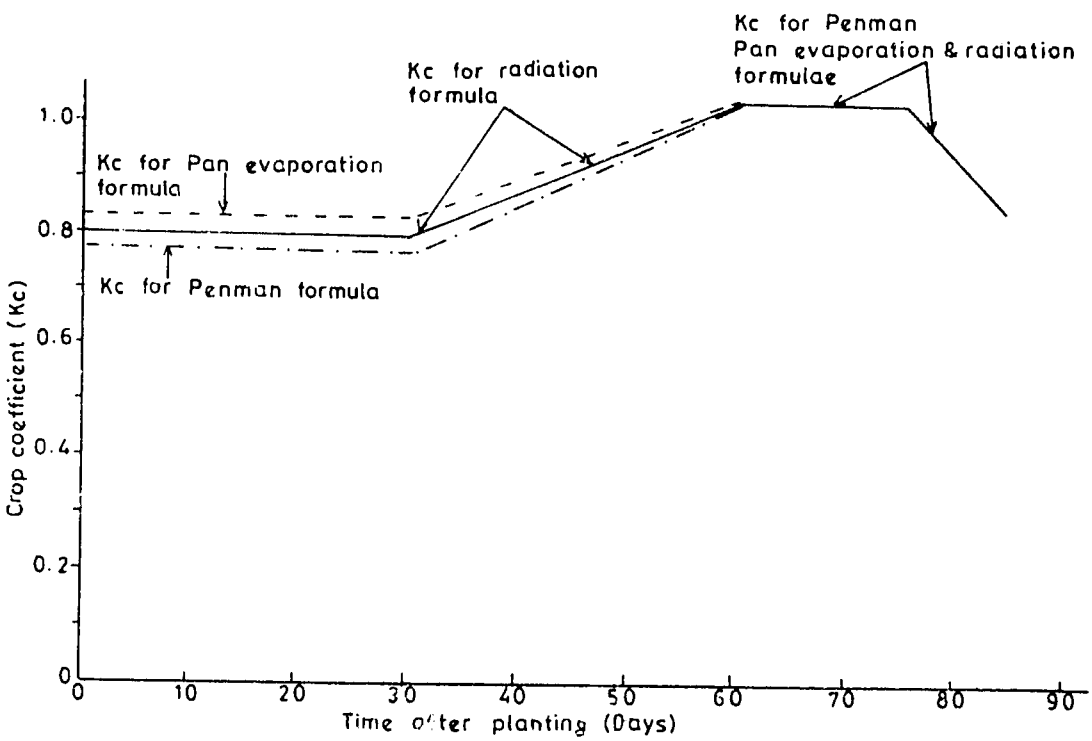

Fig. 2. Crop coefficient curves for Penman, Radiation and Pan Evaporation methods

This leaf-area index would be expected to be proportionately lower than that used in the formulae, both during the initial and crop-development stages. The apparent underestimation by these formulae during the mid-season and maturation stages is most likely due to the relatively higher frequency of rainfall during these two stages.

Significant rainfall occurred on 14 of the last 25 days of the season, with minor amounts on 7 additional days. This factor must have increased the evaporation component of *ETm* from the lysimeter above that from each of the formulae. The predictive formulae do not consider frequency of wetting during the main growth period, due to the assumption of full canopy conditions.

Whereas it can be concluded from the foregoing considerations that each of the three predictive methods approximated the lysimeter method reasonably closely over all the 10-day intervals, the pan-evaporation method approximated the lysimeter method most closely. As seen in Table IV, the total *ETm* for the season was determined as 407, 379, 358 and 362 mm respectively for the Penman, radiation, pan-evaporation, and lysimetric methods. It is also noteworthy that the pan-evaporation method requires the least number of input variables and the calculations involved are fairly straightforward. The Penman and radiation methods, on the contrary, require much more input data and have more involved calculations, factors which frequently lead to uncertainties and errors in applying the equations, and to geographical limitations due to scarcity of complete meteorological stations.

SUMMARY

Water requirements, *ETm*, of Mwezi Moja bean averaged over successive 10-day intervals from planting to harvesting were calculated from three predictive meteorological formulae, the modified Penman formula, the radiation formula, and the pan-evaporation formula. The capability of each of the three formulae in estimating *ETm* was examined by using *ETm* determined from lysimetric measurements as a check. The three predictive formulae all approximated the lysimetric method reasonably closely, with the pan-evaporation formula coming closest. The *ETm* for the season was 407, 379, 358, and 362 mm respectively as determined by the Penman, radiation, pan-evaporation, and lysimetric methods.

ACKNOWLEDGEMENTS

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LYSIMETER EXAMINATION OF THE FIELD-CAPACITY CONCEPT UNDER FALLOW AND CROPPED CONDITIONS (ABSTRACT)

J. Ian Stewart[1] *and J. O. Mugah*[2]

In February 1977 a hydraulic bolster-type weighing lysimeter was installed at Muguga in preparation for the agrometeorological research programme within the project now known as the USAID/KARI Drying Cropping Systems Research Project. From 28 July 1978 to 1 May 1979, a period of 278 days, the water balance within the lysimeter was monitored daily.

For the first 145 days the lysimeter and its surrounds were maintained free of vegetation; that is, a bare soil or fallow condition obtained. On 19 December maize was planted in and around the lysimeter. It reached physiological maturity 133 days later, on 11 May, where the record ends. Readings were made each day on a manometer connected through a hydraulic line to the bolsters supporting the lysimeter soil tank. These registered gain or loss of water to the nearest millimetre. Drainage from the tank was also measured, as were rainfall, irrigation depths, and class-A pan evaporation.

The entire water-balance record is presented in the paper, with both the bare soil and cropped periods subdivided into irregular subperiods of 1 to 9 days ea .., when the water content of the lysimeter soil was clearly increasing or decreasing. Additionally, four selected periods are presented to illustrate how the division of water loss between evapotranspiration and drainage is altered by stage of crop growth. Situations presented are fallow (two periods), rapid leaf expansion, and maximum canopy development.

The four periods all follow heavy rainfall or irrigation, with water content well above field capacity and drainage rapid. Water balances are then shown first for the few days (3 to 6) required in each case to return to field capacity, then separately for the next 10 days.

The term "effective field capacity" is used to mean water usefully evapotranspired plus the total soil water remaining in the profile when drainage has essentially ceased, that is, been reduced to 0.1 mm/day. This amount was found to be 619 mm when the maize crop was undergoing rapid leafing, and 626 mm with maximum canopy development. It fell to 589 mm in fallow conditions due to extra (slow) drainage plus wasted soil-surface evaporation.

A marked slowing of drainage after wetting the soil occurred in 3 to 6 days when the profile water totalled 620 mm. This was taken to be field capacity. The findings indicate that the field-capacity concept is useful as a practical approach to soil-water management under cropped conditions. It is concluded that, when being cropped, the extra loss to slow drainage is compensated by utilization of a portion of the excess water in evapotranspiration before it can be lost to drainage.

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EFFECT OF LEAF-AREA INDEX ON WATER REQUIREMENTS OF KATUMANI COMPOSITE B MAIZE

J. O. Mugah[1] *and J. Ian Stewart*[2]

INTRODUCTION

Inadequate soil moisture is often a major limiting factor in agricultural production in many parts of the world, including much of Kenya, in which approximately 85% of the total land area suffers soil-moisture inadequacy with respect to crop production. This situation calls for an exhaustive investigation of the factors governing crop water use under conditions of limiting soil water. One such factor is the leaf-area index (LAI), defined as the total photosynthetic surface area of the plant per unit land area.

The effects of leaf-area index on water use of crops have been recognized by many research workers. Tanner and Lemon (1962), using data from the work of Shaw and Fritschen (1960) on corn, showed that water use from a short crop was less than one half that from a tall crop with a higher leaf-area index. Johns and Lazenby (1973 a, b) observed that water use of irrigated swards was sensitive to the manipulation of leaf-area index by defoliation. At a leaf-area index of 1, a 1% decrease in LAI was associated with a 1% decrease in water use. The sensitivity of water use to changes in LAI decreased as LAI increased, and at an LAI of 3 and above, water use was insensitive to changes in LAI.

Knowledge of the water requirements of crops grown under dryland farming conditions is a key requirement in any method of predicting the crops' performance. Many dry-farming management strategies take advantage of the fact that water requirements of crops are reduced significantly by reduced plant populations, which reduce radiation interception per unit land area. Shaw (1959) observed that early in the growing season of a maize crop, when leaf-area index was still low, Rn at the ground surface was close to 100% of its value at the top of the canopy. When the crop attained a height of 1.52 m, soil surface Rn had fallen and was between 60 and 65%, and at a height of 2.29 m, had decreased to 14%.

The maximum LAI attained by a crop is not necessarily the optimum, and the latter value should be such that the lowest leaves are barely above the compensation point, i.e. the point at which the photosynthetic rate equals the respiration rate and the leaves can support themselves with metabolites manufactured within them without losing weight. When leaf-area index exceeds the optimum level, the lower leaves will be below the compensation point and either dry up or derive metabolites from the upper leaves. Conversely, if LAI is below the optimum level, the crop will not be able to take maximum advantage of the net radiation and the yield will fall short of the potential. Black (1963) conducted an experiment with subterranean clover, in which he examined the effect of varying levels of LAI and radiation on dry-matter production. He observed that as LAI varied from 0 to 9, for a given radiation intensity, the growth rate rose to a maximum at an optimum value of LAI, and as LAI increased further, the growth rate started declining. His results also show that the higher the radiation intensity, the higher the growth rate for a given level of LAI.

The variation of leaf-area index during the growing season has important implications for cultural practices and can serve as a useful guide. The planting date, for example, should be selected in such a way that the optimum leaf-area index occurs at a time when climatic conditions (mainly rainfall and sunshine) are most favourable for photosynthesis. Determination of planting date by relation to leaf area index is illustrated by Watson (1947) for sugar beet and potatoes.

Hardly any attempts to quantify the relationships between LAI and crop water requirement, i.e. maximum evapotranspiration, ETm, have been made, yet such quantification is essential for purposes of prediction and offering guidance in management practices. This paper will therefore develop, for Katumani Composite B maize, the sorely needed functional relationships between ETm and LAI.

MATERIALS AND METHODS

The experiment from which this work is reported was conducted at the University of California, Davis. The soil and climatic characteristics of the

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experimental site are described by Stewart *et al.* (1977). Katumani Composite B maize was planted on 23 May 1980, three days following a pre-planting irrigation of 100 mm. The winter rains preceding the planting date were heavy and had fully charged the entire soil profile; the pre-planting irrigation replaced any water that had been lost from the upper soil layers by weeds and/or evaporation, so that the soil was at field capacity at the time of planting.

The seeds were planted at a rate of about 80,000 per hectare. Twenty days after planting, the plants in the plots in which LAI and ETm measurements were to be made were thinned to form a 4 × 4 latin square design with populations of 16,700, 33,300, 50,000, and 66,700 plants/ha. Four weeks after planting, a neutron probe access tube was installed in the middle of each plot to a depth of 315 cm; soil-moisture changes were monitored weekly by means of a neutron probe at 30 cm intervals. The access tubes also supported catch cans for measuring applied irrigation water (Stewart *et al.*, 1977), which was used along with the soil-moisture changes to calculate ETm through a water balance procedure (Stewart and Mugah, 1979). The irrigations were applied through two parallel sprinkler laterals which were set to give a uniform irrigation depth that would meet the requirements of the crop at each of the four populations without draining substantially beyond the root zone, as this would have invalidated calculation of ETm through the water-balance relationship. A total of 204 mm of water was applied in 6 irrigations. One irrigation was applied every week, immediately following a soil-moisture measurement.

Leaf-area measurements were made weekly from 2 to 30 July 1980. A final measurement was made on 14 August when the experiment was terminated at the blister kernel stage of development. To determine leaf-area index for a given population, three plants were randomly picked from every replicate. The leaves were removed and fed into an electronic planimeter which measured the total leaf area for the three plants, from which an average leaf area per plant was calculated for that replicate. Green-stem area was also measured and added, and leaf-area indices were then calculated for each plot and for each plant-population treatment level. LAI values thus obtained were plotted against time (Fig. 1) so that for each soil-moisture measurement day, a LAI value could be selected from the graph to match the calculated rate of ETm, since LAI and ETm measurements were carried out on different days of the week.

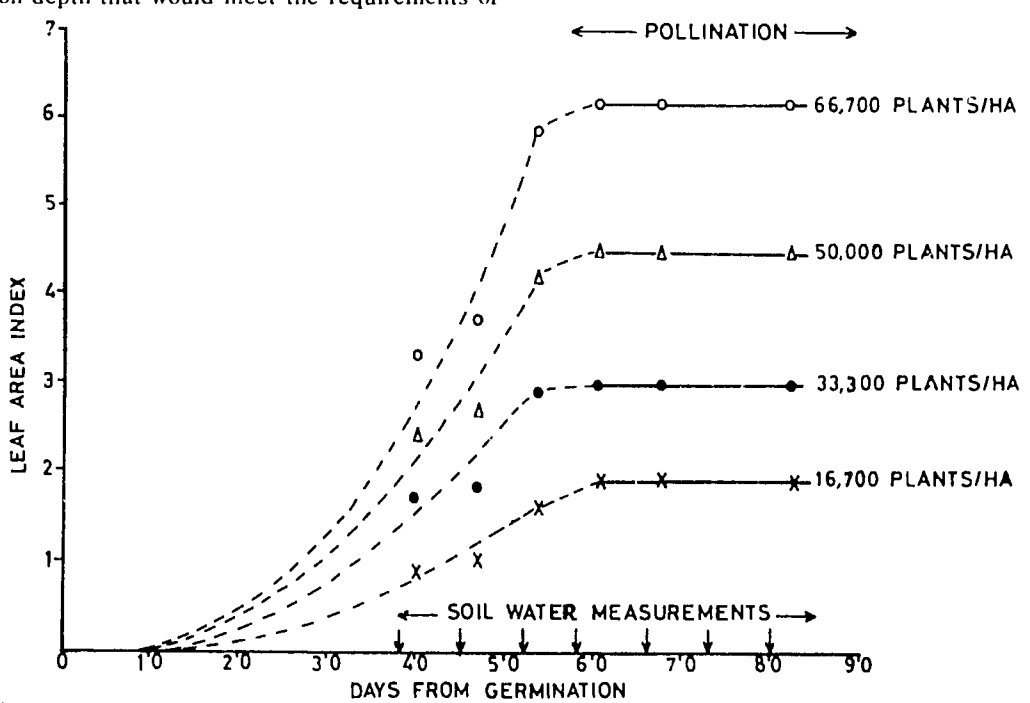

Fig. 1. Development of leaf area index with time for four population densities of Katumani Composite B maize grown at the University of California, Davis

Estimates of leaf-area index from germination to the first day of leaf-area measurement were obtained from Fig. 1 by extrapolation.

To develop a functional relationship between LAI and ETm, both parameters were first averaged over appropriate day-intervals. The first interval selected comprised 38 days and covered the period between germination on 23 May to the first day of soil-moisture measurements on 30 June. Thereafter, both LAI and ETm were averaged over two-week intervals. A regression analysis was then run using the LAI and ETm averages to determine the functional relationship between the two parameters.

RESULTS AND DISCUSSION

LAI measurements made from 2 July (40th day after germination) to 14 August 1980 (83rd day after germination) are shown in Table I, along with weekly estimates from Fig. 1 for the 28 May to 2 July period. To determine if the variations in LAI and ETm among the four populations during the final two weeks of the experiment were significant, an analysis of variance (ANOVA) test was carried out for each of the parameters. The results are presented in Table III, which shows a highly significant variation in LAI ($F = 3967.57$) but no significant variation in ETm ($F = 1.89$). An analysis of variance was also carried out for LAI and ETm over the two-week interval from 15 to 28 July 1980 (days 53 to 66 inclusive after germination). As shown in Table IV, a highly significant variation was found for both LAI and ETm, with F values of 676.78 and 274.43 respectively.

TABLE I—MEASURED AND EXTRAPOLATED VALUES OF LAI FOR FOUR POPULATION DENSITIES OF KATUMANI COMPOSITE B MAIZE DURING THE ESTABLISHMENT, VEGETATIVE AND POLLINATION PERIODS

Population (plants/ha)	Days from germination										
	Extrapolated						Measured				
	5	12	19	26	33	40	47	54	61	68	83
16,700	0.0	0.0	0.1	0.3	0.5	0.9	1.0	1.6	1.9	1.9	1.9
33,300	0.0	0.0	0.2	0.5	0.9	1.7	1.8	2.9	3.0	3.0	3.0
50,000	0.0	0.1	0.3	0.8	1.3	2.4	2.7	4.2	4.5	4.5	4.5
66,700	0.0	0.2	0.4	1.0	1.7	3.3	3.7	5.9	6.2	6.2	6.2

From the data presented in Table II, it can be seen that the minimum level of LAI that resulted in the maximum daily ETm rate of 9.0 mm/day was 3.0. As shown in Fig. 1, this minimum threshold level of ETm was attained on 2 July by the population with 66,700 plants per hectare, and approximately on 10 July by the population with 50,000 plants per hectare. The population with 33,300 plants per hectare reached LAI 3 on 21 July, whereas the maximum LAI with 16,700 plants per hectare was 1.9. The maximum water-use rate for the latter population was 7.9 mm/day, which fell short of the potential of 9.0 mm/day.

The pollination stage, which is the most stress-sensitive stage for maize, started eight weeks after planting and lasted 4 weeks for all the populations. As shown in Fig. 1, the population with 66,700 plants per hectare started extracting water at the maximum rate of 9.0 mm/day approximately 5½ weeks after planting, i.e. 3½ weeks before the beginning of the pollination stage, whereas the population with 50,000 plants per hectare attained this maximum water-use rate approximately 7 weeks after planting. Had soil moisture been limiting, as is usually the case under dryland farming conditions, the population with 66,700 plants per hectare, and to a lesser extent that with 50,000 plants per hectare, would have used up a considerable amount of water from the soil for vegetative growth by the time pollination started, and grain productivity would most likely have been impaired. Plants at 33,300 per hectare attained the maximum water-use rate approximately 8 weeks after planting, at the beginning of the pollination stage, and yield reductions in this instance should be less than those of the two denser populations. As noted, the lowest population, of 16,700 plants per

TABLE II—AVERAGE LAI AND ETm VALUES OVER SELECTED TIME INTERVALS DURING THE GROWING PERIOD OF KATUMANI COMPOSITE B MAIZE

Population (plants/ha)	16,700				33,300				50,000				66,700			
Interval from germination (days)	0–38	39–52	53–66	67–80	0–38	39–52	53–66	67–80	0–38	39–52	53–66	67–80	0–38	39–52	53–66	67–80
Average LAI	0.2	1.1	1.8	1.9	0.3	2.1	2.8	3.0	0.6	2.8	3.8	4.5	0.7	3.8	6.1	6.2
Average ETm (mm/day)	0.9	3.4	5.0	7.9	1.8	6.2	7.6	9.0	1.9	8.0	9.0	9.0	2.7	8.4	8.1	9.0

hectare, attained a maximum leaf-area index of 1.9 approximately 9 weeks after planting, and the corresponding maximum ETm rate was 7.9 mm/day. Thus a reduction by 37% in LAI below the threshold required for attaining maximum ETm resulted in a 12% reduction in the maximum Etm rate.

The maximum leaf-area index of 6.2 attained by the unadapted Katumani Composite B maize variety used in this experiment exceeded that of 5.5 reported by Acevedo (1975) for an adapted variety, hybrid Dekalb SL2Z. Acevedo carried out his experiment in the same Yolo Clay loam at the Experiment Station of the University of California, Davis. His population density was 69,800 plants per hectare, and the treatment that gave the highest LAI of 5.5 was irrigated with 50 mm of irrigation water per week. The LAI of 5.5 was attained 10 weeks after planting, whereas that of 6.2 for Katumani Composite B was attained within nine weeks of planting. Earlier studies with Katumani Composite B maize at the Katumani Dryland Farming Research Station, where the variety is adapted, show that the highest LAI that has been attained in this environment is 4, 64.5% of that attained at Davis. The common planting practices by farmers in the marginal rainfall areas result in plant populations of less than 40,000 plants per hectare (often 20,000 or less), giving a maximum leaf-area index of approximately 2; this falls short of the LAI of 3 required for maximum water use.

From the foregoing results and discussion, it can be concluded that the farmers' planting practices can and should be modified in a manner that would take maximum advantage of net radiation and rainfall in a season with an adequate water supply, and minimize yield reductions due to stress in a season with an inadequate water supply. This can be accomplished for a given rainfall situation by manipulating the planting date so that the most stress-sensitive growth stage, i.e. the pollination stage, coincides with the time of maximum soil-water availability, from both rainfall and prior soil-water storage. A high plant population should be established and should maximize yield in high-rainfall seasons. But if early-season rainfall is low the plant population should be reduced, effectively reducing the crop water requirement.

Fig. 2 shows a strongly linear relationship between LAI and ETm for values of LAI below 3.0 ($r^2 = 0.94$). The figure further shows that ETm is insensitive to changes in LAI above 3.0.

TABLE III—SUMMARY OF ANOVA TABLE FOR TESTING VARIABILITY OF LAI (IIIa) AND ETm (IIIb) AMONG TREATMENTS FOR TWO-WEEK INTERVAL INCLUSIVE FROM 29 JULY TO 11 AUGUST 1980

(a)

Source	D.F.	S.S.	M.S.	F
Row	3	0.035	0.011	4.81
Column	3	0.063	0.021	8.62
Treatment	3	29.360	9.785	3967.57
Residual	6	0.014	0.002	
Total	15	29.474		

(b)

Source	D.F.	S.S.	M.S.	F
Row	3	11.914	3.971	1.59
Column	3	5.304	1.768	0.71
Treatment	3	14.106	4.702	1.89
Residual	6	14.948	2.491	
Total	15	46.273		

TABLE IV—SUMMARY OF ANOVA TABLE FOR TESTING VARIABILITY OF LAI (IVa) AND ETm (IVb) AMONG TREATMENTS FOR TWO-WEEK INTERVAL BETWEEN 14 AND 28 JULY 1980

(a)

Source	D.F.	S.S.	M.S.	F
Row	3	0.042	0.014	1.55
Column	3	0.058	0.019	2.12
Treatment	3	18.510	6.170	676.78
Residual	6	0.054	1.009	
Total	15	18.665		

(b)

Source	D.F	S.S.	M.S.	F
Row	3	0.175	0.058	0.81
Column	3	0.495	0.165	2.30
Treatment	3	59.000	19.666	274.43
Residual	6	0.430	0.071	
Total	15	60.100		

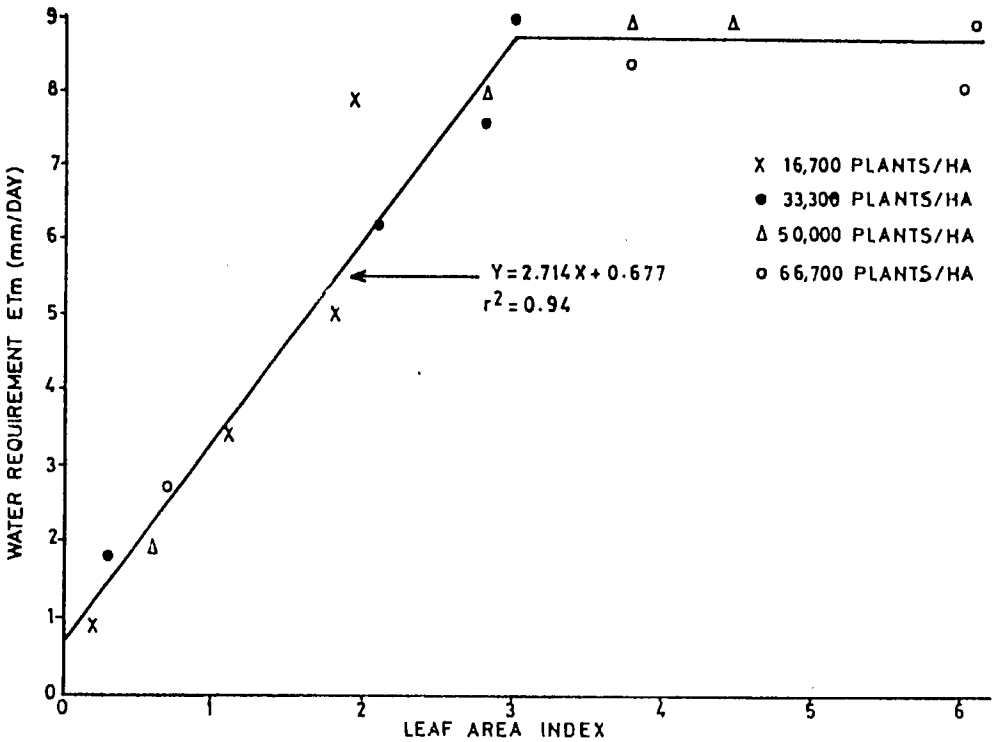

Fig. 2. Relationship between LAI and ETm for Katumani Composite B maize grown at the University of California, Davis

SUMMARY

An experiment was conducted to study the effect of varying levels of leaf-area index, LAI, on the water requirements, ETm, of Katumani Composite B maize. Leaf-area index was varied by thinning the plants to four different population densities, of 16,700, 33,300, 50,000 and 66,700 plants per hectare. The corresponding maximum leaf-area indices were 1.9, 3.0, 5.5 and 6.2. The maximum ETm rate was 9.0 mm/day and the minimum threshold level of LAI required to reach this rate was 3.0. The highest population of 66,700 plants per hectare reached its maximum water-use rate 2½ weeks before pollination started, whereas the population with 33,300 plants per hectare reached the maximum water-use rate when pollination was just starting.

A strong, linear relationship was observed between LAI and ETm for values of LAI below 3.0 (r^2 was 0.94). ETm was insensitive to LAI at values above 3.0.

ACKNOWLEDGEMENTS

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TECHNICAL SESSION 1: REPORT ON DISCUSSION

Chairman (Dr C. L. Coulson): Farming in semi-arid areas is faced with a whole range of uncertainties and accompanying risks, the chief ones being:

a. uncertainty of exact date of onset of rainfall;
b. the amount and distribution of rainfall;
c. what crops to grow and what cropping systems to adopt.

Provided the first two questions can be determined with a certain degree of certainty then the third problem can be solved. The questions raised during the discussion session relate to these basic issues and closely related problems. I notice that on your graph of maize yield against evapotranspiration the grain yield and total DM yield lines are parallel—does this indicate that there is an effect on DM partitioning with reduced water?

Dr J. I. Stewart: When *N* fertility was adequate, both *TDM* and grain were produced at approximately 22 kg/ha per mm of water evapotranspired, but with *TDM* effectively beginning production at 58 mm *ET*, while grain began at 218 mm *ET*, thus requiring each plant to reach roughly 69 g *TDM* before producing grain. With additional water use by the crop, it seems all new photosynthates (or an equivalent quantity) were partitioned to the grain. Therefore, at *ET* 220 mm grain would be a minuscule portion of total *TDM*, while at 378 mm *ET*, which is about maximum, grain would approximate 50% of *TDM*. This suggests that partitioning of *DM* is rather different at each water level.

Mr M. Karachi: Could we use the differences in physiological water-use requirements for plant selection, that is, selecting for dryland pasture species? But additional factors such as production per unit of water used and ability to survive long periods without rainfall also require consideration.

Mr J. K. Mavua: Does the arrangement of crops in an intercrop affect the yields of the various crops in the intercrop?

Dr Stewart: I believe it does, but my experience with different arrangements is limited to a single replicated experiment in which maize and beans were placed in alternate rows 75 cm apart, in the same rows, again spaced at 75 cm, and in alternate rows, 37.5 cm apart. The latter two arrangements appeared better, especially for the maize, than the first. Observation trials (not replicated) on farms in Machakos District seem to support the finding that same-row planting on 75 cm rows is superior to alternate row planting on 75 cm rows.

Mr P. L. Ulsaker: How far are recommendations for response farming appropriate from the location of meteorological data collection upon which the recommendations are based?

Dr Stewart: There is no set distance I can state because it is much influenced by terrain features and all the factors causing the considerable spatial variability found in rainfall in the semi-arid areas. Mr D. Kashasha's analysis of effective rainfall at nine sites plus the original Katumani analysis indicates that in some instances recommendations can cover rather large areas, say a circle 50 km in diameter, while in others this might shrink to a 10 km circle. However, the newly simplified analytical procedures will make it possible to perform individual analysis for localized areas quickly and easily.

Mr Mavua: The presentation shows that farmers stand to gain if they adopt the medium- and high-level management, but what are the reasons why farmers have not adopted—or are not adopting—them?

Dr Stewart: High-level management requires considerable cash outlay—beyond the reach at present of most smallholders in the semi-arid areas. Medium-level management involving rotation of maize and beans in the study presented, and improved weeding practices, are in fact already practised by perhaps 5 to 10% of the farmers. But these area have only been cropped recently and there is little or no long-term experience factor working. Hence the urgent need for research to point the way.

Mr P. Whiteman: Where early onset permits sowing high populations, there are still extra advantages if farmers have to subsequently thin: (i) fodder for livestock; and (ii) extra protection against splash erosion through the temporarily uncovered ground cover.

Dr Stewart: Mr Whiteman is certainly correct in both of his suggestions.

Dr F. H. C. Scott: (1) The inevitable question—what have you to say about the present short rains season (short rains 1983)? (2) If we are going to make practical use of your work we will have to know more about the different soils. Have you related the probabilities of the seasons to soil type and rainfall conservations?

Dr Stewart: (1) In the areas of Katumani 50% of short rainy seasons begin on or before 2 November. The latest recorded is 23 November. So the present season is clearly late but not as yet hopeless. (2) Yes, the "effective rainfall" analysis is based on water-balance calculations which consider soil depth and water-holding capacity, rainfall amount, duration, and pattern, and the sequence of crop water needs throughout the growing season of the crop, that is, in each growing stage.

TECHNICAL SESSION 2

CROP PRODUCTION AND PLANT NUTRITION

EVALUATION OF EFFECTS OF *RHIZOBIUM PHASEOLI* STRAINS ON NODULATION, DRY-MATTER AND GRAIN YIELD OF TWO BEAN (*PHASEOLUS VULGARIS*) VARIETIES

J. N. Chui[1] *and H. M. Nadar*[2]

INTRODUCTION

Bean (*Phaseolus vulgaris* L.) is one of the most common legume crops incorporated in different cropping systems in Kenya. As a legume, it provides dietary protein and contributes to the maintenance of soil fertility. It is important, therefore, to investigate ways of improving bean production. Use of inorganic nitrogen fertilizers has been shown to improve seed yield and has prompted the recommendation of their application to beans (Stephens, 1969; Spurling, 1973; Bazan, 1975). However, inorganic nitrogen has had contradictory results; it has been reported to decrease both nodulation and N_2 fixation in legumes (Dart, 1974; Lie, 1974). Also, with the high prices of inorganic nitrogenous fertilizers and their limited availability, their application in the developing countries, and especially by subsistence farmers generally, is not feasible. Hence there is need for research on the application of available and cheaper technology to sustain high legume-food-crop production. The rhizobia inoculants, which have been shown to be relatively cheaper when applied to legumes (Singh and Chowbey, 1971), could offer an alternative to N fertilizers.

Unfortunately, bean yield response to inoculation has been variable, ranging from yield decreases where N is not limiting (Pessanha *et al.*, 1970) to substantial increases (Habish and Ishag, 1974). Also, beans have shown no yield response to inoculation on soils where beans had previously been grown (MaCartney and Watson, 1966).

Although beans have been found to nodulate without inoculation when grown on many Kenyan soils, Keya (1975) found that bean rhizobia were lacking in some soils. Using appropriate commercial inoculants on friable Kikuyu loam soil of pH 6.2 and lacking bean rhizobia, Keya obtained good nodulation and increased seed yields of beans. Munns (1977) stated that the absence of proper rhizobium strains is one of the barriers to yield increase of legumes on many tropical soils. Rhizobium strains and host specificities, as well as environmental factors, could also reduce the potential yield of legumes (Franco and Dobereiner, 1977; Graham and Hubbell, 1975). These findings warrant research on the compatibility of different legume species and varieties with various rhizobium strains where legumes are grown in different ecological zones of Kenya.

This study was conducted to determine the availability of indigenous rhizobia and to compare the effectiveness of known rhizobium strains on two *P. vulgaris* bean varieties, using a field soil under greenhouse conditions.

MATERIALS AND METHODS

A greenhouse experiment was conducted at the National Agriculture Laboratories, Nairobi, between October 1982 and January 1983. The greenhouse temperatures ranged between 15.3°C (minimum) and 33.8°C (maximum) during the growing period.

The soil used was collected from an experimental field at the National Dryland Farming Research Station, Katumani, Machakos District. The soil taken was previously occupied by cowpeas (*Vigna unguiculata* L.). The preceding crop, before the cowpeas, was beans. The type of soil was a well drained, dark reddish-brown and sandy clay, classified as Oxic Paleustalf. The soil pH was 5.0. Soil was mixed with fine gravel at the ratio of 2:1, respectively. The mixture was then put into plastic pots holding 5.5 kg. Two bean varieties, Mwezi Moja and Zebra, were used.

The bean seeds were inoculated with two rhizobium strains, NU 405 and NU 439, obtained from the University of Nairobi, and their combination 2-NU, and a 3-strain rhizobia mix, 3-NS,

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2. Agronomist, USAID, Nairobi.

for *Phaseolus vulgaris* obtained from the NifTAL Project, Hawaii. The inoculants were in powdered peat form and gum arabic was used as the sticker. A control treatment without inoculant was included. Before planting, pots of soil were watered and left overnight. Seeds were planted three in a pot immediately after the inoculant coating was dry. Two weeks after emergence, seedlings were thinned to one per pot and phosphorus was applied in the form of triple superphosphate at the rate of 110 kg/ha. Plants were watered every other day.

Data were collected at different growth stages: at flower initiation (32 days), pod-filling (49 days) and maturity (88 days). Plants were washed out of the soil, bagged in plastic bags, and stored in the refrigerator for nodule count. Shoots and nodules were dried at 65°C for 48 hours for dry-weight determination. At maturity, seeded pod dry weight and seed yield expressed as grams per plant were measured.

A split-plot design was used with the two bean varieties forming the main plots and four inoculant treatments plus a control comprising the five subplots. Each treatment had four plots and was replicated three times. The Wang 2200 MVP computer was used for statistical analysis.

RESULTS AND DISCUSSION

The nodulation response of *Phaseolus vulgaris* bean varieties to inoculation is shown in Table I.

TABLE I—EFFECT OF VARIETY AND TREATMENT ON THE NUMBER OF NODULES PER PLANT AT TWO PLANT GROWTH STAGES

Variety	Treatment	Flower initiation	Pod-filling
Mwezi Moja	NU 405	81.83 a[1]	138.00 ab
	NU 439	109.67 a	97.80 b
	2-NU	92.33 a	136.50 ab
	3-NS	100.33 a	145.00 ab
	Control	62.80 a	167.00 a
Zebra	NU 405	75.20 a	69.23 a
	NU 439	89.80 a	102.50 a
	2-NU	83.00 a	142.17 a
	3-NS	72.80 a	85.00 a
	Control	91.70 a	55.80 a

1. Any two means within a variety followed by the same letter do not differ at the 5% level of probability.

The control (uninoculated) results indicated that there were effective indigenous rhizobia in the soil for nodulating the two bean varieties. At flower initiation, neither variety responded significantly to inoculation. However, inoculation increased the nodule number of Mwezi Moja beans by 53% on the average and decreased that of Zebra beans by 12.5%. On the other hand, at pod-filling Mwezi Moja had a greater response to indigenous rhizobia than to the inoculation by 22.6%, whereas Zebra beans showed a better response to inoculation (78.7%) than the control. It seemed that Mwezi Moja beans responded to inoculants in their earlier growth stage, but that later, during the pod-filling, the indigenous rhizobia had become more effective in promoting nodulation. A converse response to treatments at both growth stages was observed in Zebra beans. At pod-filling, the 2-NU strain increased the nodule number of Zebra by 155% above the control. These response variations to treatments could be attributed to varietal differences. Graham and Halliday (1977) showed that ability to nodulate varied between determinate and indeterminate *P. vulgaris* bean cultivars.

There were negative correlations between seed yield and nodule number both at flower initiation ($r = -0.24$) and at pod-filling ($r = -0.44$). Nodule dry weight at pod-filling (Table IV) was also negatively correlated with seed yield ($r = -0.61$) but positively correlated with nodule number ($r = 0.80$). These results agree with the findings of Sartain *et al.* (1982), who had planted beans at four different locations in El Salvador.

There were no significant varietal differences on shoot dry weight at pod-filling or maturity (Table II), although each variety responded to inoculation differently at both growth stages. Inoculation of Mwezi Moja had produced greater shoot dry weight than the control at maturity. The best rhizobium strain, NU 439, increased the shoot dry weight of Mwezi Moja by 36% more than the poorest strain, NU 405, and 5.6% more than the control. Shoot dry weight at pod-filling showed that only Zebra beans had a significant response to inoculation; at this growth stage, NU 439 increased shoot dry weight of Zebra by 98.7% over the control. Comparison of the average dry weight of the seeded pod of the two bean varieties showed that Zebra had significantly higher seeded pod dry weight than Mwezi Moja (Table II). Although in Mwezi Moja the inoculation was not significantly different from the control on seeded pod dry weight, there were

TABLE II—EFFECT OF VARIETY AND INOCULATION ON SHOOT DRY WEIGHT AND SEEDED PODS DRY WEIGHT

Variety	Treatment	Shoot dry wt (g/plant) at pod-filling	Shoot dry wt (g/plant) at maturity	Seeded pods dry wt at maturity (g/plant)
Mwezi Moja	NU 405	7.08 a[1]	12.09 b	8.02 b
	NU 439	5.23 a	16.42 a	11.15 a
	2-NU	5.60 a	12.48 ab	7.75 b
	3-NS	6.23 a	12.96 ab	8.56 ab
	Control	5.32 a	15.55 ab	10.78 ab
Zebra	NU 405	4.35 b	13.25 a	9.37 a
	NU 439	9.28 a	13.41 a	9.37 a
	2-NU	4.21 b	14.26 a	9.51 a
	3-NS	6.96 ab	16.91 a	12.40 a
	Control	4.57 b	14.40 a	11.33 a

1. Any two means within a variety followed by the same letter do not differ at the 5% level of probability.

TABLE III—EFFECT OF INOCULATION ON TOTAL DRY MATTER (g/plant) OF TWO BEAN VARIETIES

Treatment	Variety: Mwezi Moja	Variety: Zebra
NU-405	12.70 b[1]	13.65 a
NU-439	17.04 a	14.22 a
2-NU	13.55 b	14.90 a
3-NS	13.08 b	17.67 a
Control	16.17 ab	16.14 a

1. Any two means within a variety followed by the same letter do not differ at the 5% level of probability.

TABLE IV—EFFECT OF INOCULATION ON NODULE DRY WEIGHT AT POD-FILLING STAGE AND SEED YIELD AT MATURITY

Variety	Treatment	Nodule dry weight (g/plant)	Seed yield (g/plant)
Mwezi Moja	NU 405	0.23 a[1]	6.04 b
	NU 439	0.14 a	8.44 a
	2-NU	0.18 a	5.87 b
	3-NS	0.26 a	6.42 b
	Control	0.19 a	8.26 a
Zebra	NU 405	0.08 a	6.90 a
	NU 439	0.19 a	7.18 a
	2-NU	0.16 a	7.32 a
	Control	0.09 a	8.67 a

1. Any two means within a variety followed by the same letter do not differ at the 5% level of probability.

significant differences among the inoculants. The NU 439 strain had increased the seeded pod dry weight of Mwezi Moja beans more than NU 405 and 2-NU had done—by 39% and 44% respectively.

Table III illustrates the effect of inoculation on total dry matter at maturity. No significant varietal difference was observed. Total dry-matter production of Zebra beans was not significantly affected by inoculation. With Mwezi Moja, although the results of inoculation did not differ significantly from the control, the NU 439 strain led to significantly higher total dry matter than the other inoculants—by 37% on average. Except for one rhizobium strain in each bean variety, which produced higher total dry matter than the control, total dry matter decreased by between 11.7 and 20% as a result of inoculation. There were negative correlations between total dry matter and both nodule number ($r = -0.33$) and nodule dry weight ($r = -0.54$) at pod-filling.

In regard to nodule dry weight at pod-filling, the bean varieties did not respond significantly to inoculation. However, a comparison of the mean nodule dry weight of both varieties showed a significant difference in response to their treatments. On the average, Mwezi Moja gave 64% more nodule dry weight than Zebra (Table IV). There was no significant linear relationship between nodule dry weight and seed yield, and on the average Zebra beans showed 10.5% greater seed yield than Mwezi Moja. Seed yield of Zebra was not significantly influenced by inoculation (Table IV). For Mwezi Moja, three inoculants out of four significantly lowered seed

yields below the control. These results were similar to those obtained at Makerere, Uganda, by Keya (1982), where two bean varieties, K20 and Banja Z, showed no increase in yield due to inoculation but actually showed a reduction.

SUMMARY AND CONCLUSIONS

Bean varieties responded differently to each inoculant for every parameter measured. However, there was a tendency to inoculant preference by each variety. Although there were no significant differences, Mwezi Moja interacted better with the locally prepared inoculant NU 439, and Zebra showed better response to the NifTAL inoculant 3-NS, on shoot dry weight, pod dry weight, total dry matter at maturity and seed yield, relative to indigenous rhizobia in the soil.

Although bean yield was not significantly affected by inoculation, it was observed that a small yield increase of between 2 and 5% was caused by the two inoculants, NU 439 and 3-NS, which had shown bean variety preference on some of the other parameters measured. The data seem to indicate that there could have been bean variety and rhizobia strain specificity, and further work should be done to confirm this, using these two rhizobium strains, NU 439 and 3-NS, on both bean varieties under field conditions.

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EFFECT OF PLANTING TIME RELATIVE TO THE BEGINNING OF THE SHORT RAINS ON EFFICIENCY OF WEED CONTROL AND MAIZE YIELDS

H. M. Nadar[1] *and W. A. Faught*[2]

INTRODUCTION

Weeds constitute a constant and important problem for farmers in the Machakos area, especially in the short-rains season. The short rains begin after five dry months, during which weed seeds are transported to the fields by wind, as well as by domestic and wild animals which feed on the crop residues left in the fields after harvest. Effective weeding would help conserve moisture for crop use and reduce or eliminate competition from weeds for available nutrients in the soil. From rainfall analysis and maize phenology studies (Nadar, 1983a) it was found that during the short-rains season the only way to ensure maximum water availability for the high water requirement of the 40-day growth period, which usually starts 40 to 50 days after planting, was to conserve as much of the soil stored moisture as possible. One important method of water conservation, early in the season, is efficient weed control. Chemical weed control is not yet feasible in the target area, and is not expected to be widely used in the near future. Weed-control chemicals are expensive, water for mixing the chemicals is not always available, and the farmers are not trained in the safe use of these chemicals. Weeds are controlled at present by mechanical means such as ploughing, hoeing, and hand pulling. Ploughing after the beginning of the short rains and the germination of the first flush of weeds appears to be the most effective and at the same time the cheapest method for early weed control, because no extra ploughing is needed for seed-bed preparation. Planting after this process allows the crop a chance to grow in a relatively weed-free environment until it is strong enough to compete with later-emerging weeds and can withstand mechanical weeding. This method of planting is expected to help conserve moisture, as moisture loss due to inefficient weeding is much higher than that lost delaying planting until after controlling the first flush of weeds. Conserving moisture that would have been consumed by weeds can make the difference between success and failure, especially in seasons of very limited rainfall.

This report discusses the effect of planting time for the short rains on the efficiency of weed control and maize yields as influenced by population, intercropping, and ridging methods.

MATERIALS AND METHODS

This experiment was carried out during the 1980/81 short rains at the National Dryland Farming Research Station, located at Katumani, 10 km south of Machakos town, Machakos District, in the Eastern Province of Kenya. Its centre co-ordinates are 01°35′ S and 37°14′ E and it lies at an elevation of 1,575 m. The soil is well drained, dark reddish-brown sandy clay. It is hard when dry, friable when moist, and sticky plastic when wet. This soil is classified as Oxic Paleustalf (Chromic Luvisol). It has a relatively low water-storage capacity and medium depth. Average depth is 120 cm with a total water-storage capacity of 100 mm.

Total rainfall during the short rains of 1980/81 was 185 mm; the rain started on 4 November and had stopped by 20 December, thus lasting less than 50 days. From 20 December until harvest no measurable rainfall was recorded.

Maize (*Zea mays* L., Katumani Composite B) was planted either as a sole crop or intercropped with beans (*Phaseolus vulgaris* L., var. Mwezi Moja). The sole-crop maize was thinned to either 1 plant or 2 plants per hill, while the intercrop was all thinned to 1 plant per hill. Beans were planted at 1 plant per hill between the maize plants in the same row. The planting was in plots of 10 rows, 0.60 m apart and 10 m long. The spacing between maize plants within the rows was 0.30 m in all cases, resulting in a spacing of 0.15 m between a maize plant and a bean next to it in the same row. Considering the one-plant-per-hill sole crop to be the base population, then the population would be doubled either by doubling the number of plants per hill in the sole-crop system or by adding an equal population of beans in the intercrop system. Planting before the beginning of the rains took place on 26

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October 1980, while the after-rains planting was performed, after ploughing to control the first flush of weeds and at the same time preparing the seed-bed, on 14 November 1980. Ridging and weeding were performed by hand labour, a practice generally followed in the area. The labour inputs are substantially higher than would be required if oxen and ploughs had been used for ridging and weeding. The plots were weeded either once or twice. All plots were weeded for the first time 15 days after germination. The plots which received two weedings were weeded for the second time three weeks later.

The experimental design was 3×2×2 factorial within a split plot. The main plots tested time of planting and, within them, ridging methods (either ridged or non-ridged), population, and number of weedings were also tested.

Yields were determined by harvesting 6 rows 8 m long from plot. Maize yields were adjusted to 15.5% moisture, and bean yields adjusted to 14%. Bean yields were further multiplied by 3.5/1.5 to convert them to the equivalent for maize. This conversion facilitated adding, averaging statistically analysing, and comparing the intercrop and sole-crop data. The calculation of gross field returns was based on avarage yields and on estimated prices of KSh. 1.5 per kilogram for maize and KSh. 3.5 for beans. The gross market values calculated in this manner were reduced by 10% to approximate costs and losses incurred in moving crops from the field to markets and thus provided an estimate of gross field values. Labour costs have been estimated on the basis of the recorded labour input in carrying out each practice at an average charge of KSh. 16.10 per man-day. Although most labour is provided by the family and no cash cost is incurred, the value placed on the labour inputs appears to be a reasonable estimate of the opportunity cost of such labour. It was the minimum cost of labour established for the Machakos area and a large number of workers were employed at this wage.

RESULTS AND DISCUSSION

The number of man-days (md) of labour per hectare used for ridging and weeding of the after-rains (AR) and before-rains (BR) planting at the different populations and cropping systems is listed in Table I. Within each planting time, there were no significant differences in labour requirements for weeding the plots which were planted to sole-crop maize at 1 plant per hill or 2 plants per hill, or those planted to maize/bean intercrop. This is an indication that doubling the population per unit area, either by doubling the number of plants per hill or by planting an equal bean population between the maize plants in the same row, had no effect on labour requirements for weeding, whether the planting was before or after the rains.

Labour required for ridging averaged almost the same for BR and AR plantings. Labour used for ridging the BR plots averaged 27.5 md/ha, compared with 32 md/ha for ridging the AR plots. This is as would be expected, as ridging by hand is an activity which is not supposed to be influenced by the time of planting. Ridging by hand is usually done after the crop has germinated and grown tall enough to withstand gathering the soil around it in the process of building the ridges.

The only significant differences were between the weeding requirements of the AR plots and those of the BR plots. While weeding the AR plots required, on the average, 16.3 md/ha for the first weeding and 11.9 md/ha for the second, the BR plots required 28.7 and 22 md/ha respectively. The increase in labour requirements for weeding the BR plots from that required for the AR plots averaged 76% in the first weeding and 85% in the second. Despite the higher labour input, the BR plots at the end of the season were much weedier than the AR plots. This is an indication that turning the weeds under by ploughing before planting was a more efficient method of mechanical weed control than hoeing after emergence. Controlling the first flush of weeds by ploughing before planting seemed to have caused a substantial reduction in weed population throughout the season, especially in the drill, which resulted in easier control of later emerging weeds by hoeing and lower labour requirements than in the case of BR plantings. Even if there were no yield differences between the two plantings, an average saving of 80% in labour required for weeding would justify the adoption of the AR planting method over BR planting. Under high rainfall and high soil-fertility conditions, yields realized from the two planting methods would not be expected to differ, as long as the weeds were kept under control. The only expected difference would be in the labour required to do so.

Rainfall during the short rains of 1980/81 was low in amount and short in duration. These conditions were not suitable for maize production, but were more suitable for beans. Beans have lower water requirements than maize and a shorter

TABLE I—TOTAL LABOUR IN MAN-DAYS (md) PER HECTARE, AND OPPORTUNITY COST IN KENYA SHILLINGS (KSh) PER HECTARE USED IN WEEDING AND RIDGING ALTERNATIVE PLANTINGS AND CULTURAL PRACTICES DURING SHORT RAINS 1980/81

Ridging method	Number of weedings		Sole-crop maize											
			1 Pl/hill			2 Pl/hill			Maize/bean intercrop			Averages		
			BR	AR	AR/BR	BR	AR	AR/BR	BR	AR	AR/BR	BR	AR	AR/BR
Ridged	1	md	58.0	43.0	0.741	57.0	45.0	0.789	62.0	62.0	1.000	59.0	50.0	0.847
		KSh.	934.0	692.0	—	918.0	724.0	—	998.0	998.0	—	950.0	804.0	—
Ridged	2	md	72.0	57.0	0.792	77.0	60.0	0.779	77.0	59.0	0.766	75.3	58.7	0.780
		KSh.	1,159.0	918.0	—	1,240.0	996.0	—	1,240.0	950.0	—	1,213.0	945.0	—
Non-ridged	1	md	29.0	12.0	0.414	22.0	21.0	0.955	35.0	16.0	0.457	28.7	16.3	0.568
		KSh.	467.0	225.0	—	354.0	338.0	—	564.0	258.0	—	462.0	274.0	—
Non-ridged	2	md	54.0	24.0	0.444	36.0	29.0	0.806	62.0	31.0	0.500	50.7	28.0	0.552
		KSh.	869.0	386.0	—	582.0	470.0	—	998.0	499.0	—	816.0	452.0	—
Ridged avge.		md	65.0	50.0	0.769	67.0	52.5	0.784	69.5	60.5	0.871	67.0	54.3	0.810
		KSh.	1,047.0	805.0	—	1,079.0	845.0	—	1,119.0	974.0	—	1,082.0	875.0	—
Non-ridged avge.		md	41.5	18.0	0.435	29.0	25.0	0.862	48.5	23.5	0.485	39.7	22.0	0.554
		KSh.	668.0	305.0	—	467.0	404.0	—	781.0	378.0	—	638.0	363.0	—

growing season. Because of the rainfall conditions weed competition for moisture affected maize yields more than it did bean yields. As a result, the effect of time of planting on maize yields was highly significant, whereas on bean yields it was not. Planting both sole and intercrop maize after the beginning of the rains and control of the first flush of weeds gave significantly higher yields than plantings before the rains. In the intercrop (Table II), the average maize yield of AR was 128% higher than that of the maize component of the BR intercrop, while average bean yields were only 12% higher, which was not significant. While the overall differences between bean yields were not significant, ridging and number of weedings had a significant effect on bean yield in the BR plantings. Yields of beans from the ridged plots were significantly higher than those from the flat plots, and plots that were weeded twice yielded significantly higher than those weeded only once. In AR plantings, ridging had no significant effect on bean yield, but the effect of number of weedings was significant. These results indicated that, under the low-rainfall conditions of the 1980/81 short-rains season, the effect of ridging was not directly on water conservation *per se*, but was rather an indirect effect on water conservation by more efficient weed control. Rainfall intensity during that season, beyond the first week of November, was not conducive to water runoff, which could have been reduced or eliminated by the ridges that were constructed by the end of that month. This would explain the difference in the effect of ridging on bean yields in the different planting methods. In AR plantings weeds were efficiently controlled before planting, giving an almost weed-free drill, while the weeds in the drill which could not be efficiently removed by regular hoeing were buried in the process of constructing the ridges. When weeds were efficiently controlled either by ploughing before planting in the AR method, or by ridging in the BR method, yields of beans were almost equal for the two planting methods. Maize response in the intercrop was different from bean response. Maize was more affected by the competition for available water by the bean component than by ridging. Higher maize yields were associated with lower bean yields and vice versa. On the other hand, maize yields in the intercrop were significantly affected by both number of weedings and planting time.

TABLE II—YIELDS OF INTERCROP MAIZE AND BEANS, BEAN YIELD EQUIVALENT OF MAIZE (BEAN YIELD × 2.4) AND TOTAL YIELDS (kg MAIZE/ha) IN RESPONSE TO TIME OF PLANTING AS AFFECTED BY RIDGING METHOD AND NUMBER OF WEEDINGS DURING SHORT RAINS 1980/81

Number of weedings	Ridging method	Yields (Kg/ha)				Maize equivalent of bean yield (kg maize/ha)		Total yields (kg maize/ha)		
		BR		AR						
		Maize	Beans	Maize	Beans	BR	AR	BR	AR	AR/BR
1	Ridged	42	230	204	230	537	537	579	741	1.28
1	Ridged	143	483	480	392	1,127	915	1,270	1,395	1.10
1	Non-ridged	48	124	270	230	289	537	337	807	2.39
2	Non-ridged	252	387	150	521	903	1,216	1,155	1,366	1.18
Avge.	ridged	93	357	342	311	832	726	925	1,068	1.15
Avge.	non-ridged	150	256	210	376	596	877	746	1,087	1.46
Overall average		121	306	276	343	714	801	835	1,077	1.29

Comparing these results with those of the sole crop (Table III), it was found that average BR maize yields in the intercrop were similar to those of the two-plants-per-hill arrangement in the sole crop, but substantially lower than those of the one-plant arrangement. This is an indication that increasing plant population, whether the extra plants were maize plants or bean plants, had an adverse effect on maize yields under the low-rainfall conditions of the 1980/81 short rains.

TABLE III—SOLE-CROP MAIZE YIELDS AND INTERCROP TOTAL YIELDS AND THEIR VALUES IN KENYA SHILLINGS (GROSS FIELD RETURNS (GFR)) IN RESPONSE TO TIME OF PLANTING AS INFLUENCED BY RIDGING METHOD AND NUMBER OF WEEDINGS DURING SHORT RAINS 1980/81

Ridging method	Number of weedings		Sole-crop maize											
			1 Pl/hill			2 Pl/hill			Maize/bean intercrop			Averages		
			BR	AR	AR/BR	BR	AR	AR/BR	BR	AR	AR/BR	BR	AR	AR/BR
Ridged	1	Yield	380.0	974.0	2.56	130.0	839.0	6.45	579.0	741.0	1.28	363.0	851.0	2.35
		GFR	513.0	1,315.0	—	175.0	1,133.0	—	781.0	1,000.0	—	489.0	1,149.0	—
Ridged	2	Yield	303.0	1,255.0	4.14	274.0	513.0	1.87	1,270.0	1,395.0	1.10	616.0	1,054.0	1.71
		GFR	409.0	1,694.0	—	370.0	692.0	—	1,716.0	1,884.0	—	832.0	1,423.0	—
Non-ridged	1	Yield	140.0	1,103.0	7.88	12.0	470.0	39.20	337.0	807.0	2.39	163.0	793.0	4.87
		GFR	189.0	1,490.0	—	16.0	634.0	—	465.0	1,089.0	—	223.0	1,071.0	—
Non-ridged	2	Yield	158.0	590.0	3.73	23.0	477.0	20.70	1,155.0	1,366.0	1.18	445.0	811.0	1.82
		GFR	213.0	797.0	—	31.0	643.0	—	1,559.0	1,843.0	—	601.0	1,094.0	—
Ridged avge.		Yield	342.0	1,115.0	3.26	202.0	676.0	3.35	925.0	1,068.0	1.15	490.0	953.0	1.94
		GFR	461.0	1,505.0	—	272.0	912.0	—	1,248.0	1,442.0	—	660.0	1,286.0	—
Non-ridged ave.		Yield	149.0	847.0	5.68	18.0	474.0	26.33	746.0	1,087.0	1.46	304.0	802.0	2.64
		GFR	201.0	1,143.0	—	23.0	638.0	—	1,012.0	1,466.0	—	412.0	1,083.0	—

Maize yields at the lower population were more than double those at the higher populations. In AR planting, maize yields were generally much higher. They were 4 to 5 times that of the BR planting in the sole crops, but only twice that of BR in the intercrop. This is an indication that the effect of bean competition on maize was more severe than that between the maize plants, at the same population levels. This is in agreement with earlier findings that intercrop competition was more severe than intracrop competition (Nadar, 1982).

Total yields of the intercrops were between 12% and 680% higher than those of sole-crop maize. The greatest increases were over the BR two-plants-per-hill population. These increases were entirely due to the relatively high yields and values of the bean component in both BR and AR plantings.

In the maize sole-crop systems, the advantages of AR plantings over BR, as represented by maize yields, were much greater than those in the intercrop system. They ranged between 300%, in the one-plant-per-hill population, and 423%, in the two-plant arrangement. Effect of ridging was significant, while that of weeding was not. In some cases, the second weeding had a negative effect on yield. This was the reverse of the effect of ridging and weeding in the intercrop and was probably brought about by the difference of efficiency in weed control between the two crop systems. Spacing between the plants within the row was 0.30 m in the sole crop, while it was 0.15 m in the intercrop. The within-row spacing as well as the possible missing of weeds covered by the bean plants may have resulted in more efficient first weeding in the sole-crop plots than in the intercrop plots. As a result, by the time of the second weeding there were more weeds in the intercrop plots than in the sole-crop plots, and the soil moisture lost due to the hoeing process was less than what might have been consumed by the weeds removed from the intercrop plots, whereas it was much larger in the sole-crop plots.

From these results it can be concluded that while yields from all plots were extremely low, the AR plantings significantly out-yielded the BR plantings in all cases. On the other hand, doubling the maize population or adding extra bean population by intercropping did not affect labour requirements for weeding and ridging, while it significantly reduced maize yields. Labour requirements for ridging were almost the same for both planting methods, whereas those for weeding were significantly different.

Economic interpretations of results from plots on experimental stations, under conditions that differ markedly from those prevailing on farms, may be misleading. This is particularly true for estimates involving total costs and returns. However, relative benefits can be calculated with considerable accuracy where only yields and a limited number of variable inputs are involved, as in the present experiment, where the only significant input-cost item varying among practices being evaluated was labour inputs for weed control.

Gross field returns for all plantings made after the onset of the rains and emergence of weeds averaged KSh. 1,184 per hectare, compared with an average of only KSh. 536 for plantings before the onset of the rains (Table III). The variable cost for labour (Table I) averaged KSh. 618 per hectare for AR, compared with KSh. 860 for BR plantings. Net returns to other factors of production (Table IV) averaged KSh. 890 more on AR plots than on BR plots, reflecting the KSh. 648 greater field return and KSh. 242 lower labour cost per hectare.

Ridging increased yields, which resulted in gross returns that exceeded returns on non-ridged plots by KSh. 225 per hectare. However, labour required for ridging was much greater and the associated costs exceeded the average of non-ridged plots by KSh. 477. The net effect was returns to other factors for the non-ridged plots that exceeded those for the ridged plots by KSh. 252 per hectare.

The cost of a second weeding was more than offset by increased field returns when applied to ridged or non-ridged plots planted before the rains, and also to ridged plots planted after the rains. However, net returns were reduced on the non-ridged after-rains plantings. Overall, a second weeding increased labour costs on the average from KSh. 622 to KSh. 856, but the increase in yields and gross field returns more than offset the added cost of labour and net returns increased from KSh. 111 to KSh. 132.

Intercrop maize and beans yielded net returns substantially larger than sole-crop maize (plus KSh. 478 compared to negative KSh. 58). Under the conditions prevailing, one-plant-per-hill sole-crop maize yielded substantially better returns than two plants per hill (a net return of KSh. 122 compared with a net loss of KSh. 237).

In summary, the greatest increase in net returns was due to planting after the onset of rains and first emergence of weeds. The better control

TABLE IV—RETURNS, OTHER FACTORS AND TOTAL SPREADS (AR-BR) IN KENYA SHILLINGS PER HECTARE OF CROPS PRODUCED UNDER THE DIFFERENT PLANTING, RIDGING, AND WEEDING METHODS FOR SHORT RAINS 1980/81

Ridging method	Number of weedings	Sole-crop maize						Maize/bean intercrop			Averages		
		1 Pl/hill			2 Pl/hill								
		BR	AR	AR-BR	BR	AR	AR-BR	BR	AR	AR-BR	BR	AR	AR-BR
Ridged	1	−421	623	1,044	−743	409	1,152	−217	2	219	−461	345	806
Ridged	2	−750	766	1,526	−870	−274	596	476	934	458	−381	478	859
Non-ridged	1	−278	1,265	1,543	−338	292	630	−99	831	930	−239	797	1,036
Non-ridged	2	−656	411	1,067	−549	173	722	561	1,344	783	−215	642	857
Ridged avge.		−586	700	1,286	−807	67	874	129	468	339	−422	411	838
Non-ridged avge.		−467	838	1,305	−444	234	678	231	1,088	1,319	−227	720	947
Average	1	−350	944	1,294	−540	937	1,377	−158	417	575	−399	733	1,082
Average	2	−703	594	1,297	−709	−50	659	518	1,139	621	−298	561	859
Overall average		−526	769	1,295	−625	151	776	178	778	600	−324	566	890

of weeds associated with this practice appears to have reduced the competition for moisture and plant nutrients and resulted in increased yields. Likewise, the better control of weeds, particularly in the drill, reduced the labour requirement. Ridging by hand was not profitable. Although increasing production, this practice increased the labour requirements to the point of reducing net returns. Second weeding also appeared to increase production, but increased the labour requirements only moderately and resulted in a small increase in net returns. For sole-crop maize, a single plant per hill resulted in better returns, in this very low rainfall season, than two plants per hill. However, intercropped maize and beans provided much better returns than sole-crop maize at the relative prices assumed in these estimates. The combination providing the highest returns among all those tested was intercrop maize and beans, planted after the onset of rains and the emergence of weeds, non-ridged, and weeded twice. The combination of practices resulting in the greatest loss was sole-crop maize with two plants per hill, planted before the rains, ridged, and weeded only once.

The absolute costs and returns to be realized from these alternatives would probably differ in other seasons from those reported, due to variations in rainfall, temperature, opportunity costs for labour, or prices of products. An analysis was made assuming opportunity costs for labour at only one-half that used in the analysis described above, which might more closely approximate the opportunity costs of labour for some families in the area. In this instance, the same combinations of practices yielded the highest and lowest net returns. Likewise, if all yields were assumed to increase proportionally, the most profitable and the least profitable combinations of practices would remain the same. However, in a more normal season with more adequate rainfall, yields probably would not have increased proportionally. As pointed out in a previous discussion (Nadar, 1983b), a population of about 70,000 plants per hectare would provide the highest yield in a relatively good season. Therefore, in a good season, the yields from the plots of sole-crop maize with two plants per hill would be expected to increase proportionately more than the yields from plots with only one plant/hill, and the relative returns associated with these practices might be reversed. Also, in a good season the yields of maize might be expected to increase proportionally more than the beans, and thus decrease the advantage of the intercrop over the sole crop, if the same relative prices were maintained. Of course, a reversal of the relative prices would be expected to reverse the relative advantages of sole crops and intercrops.

SUMMARY

An experiment was conducted during the short rains of 1980/81, designed to study the effect on weeding efficiency and final maize yields of dry planting before the start of the rains (BR) as compared with the effect of planting after the beginning of the rains and ploughing to prepare the seed-bed and control the first flush of weeds at the same time (AR). For each time of planting, the effects of population, ridging, and number of weedings were also tested. The results indicated that labour required for ridging averaged almost the same for BR and AR plantings. Ridging using hand labour was not found profitable. Time of planting had a significant effect on labour requirements for weeding, with AR planting requiring 80% less labour than BR planting. Increasing the plant population per unit area had no effect on labour requirements for weeding, while significantly decreasing maize yields. Total yields of the intercrops were up to 630% higher than those of sole-crop maize. These increases were entirely due to the relatively high yields and values of the bean component in both BR and AR plantings. The advantage of AR over BR plantings as represented by maize yields averaged 128% in the intercrop system, while it was between 300% and 423% in the sole-crop system. The greatest increase in net returns was due to planting after the onset of rains and first emergence of weeds. The better control of weeds associated with this practice appeared to have reduced the competition for moisture and plant nutrients, and resulted in higher yields and decreased labour requirements for subsequent weedings. The combination which provided the highest returns was maize/bean intercrop, AR planting, non-ridged, and weeded twice. In more normal rainy seasons, sole-crop maize might produce higher returns, and no yield differences between AR and BR plantings might be expected. However, AR planting would still be better than BR because it would still require significantly less labour for keeping weeds under control.

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EFFECT OF RELAY PLANTING ON MAIZE YIELD AS INFLUENCED BY CROPPING SYSTEMS, ROW SPACINGS AND POPULATIONS

H. M. Nadar[1]

INTRODUCTION

Relay cropping is planting a new crop while the maturing crop is still standing in the same piece of land. This system of planting does not allow for conventional seed-bed preparation (i.e. ploughing and disc-ing) before planting. Although the objectives are not the same, relay planting is very similar to minimum or no-tillage systems in that no seed-bed preparation takes place. The objective of minimum and no-tillage planting is to do away with seed-bed preparation as a means of saving energy and keeping soil disturbance to a minimum. On the other hand, the main objective of relay planting is to meet an optimum planting date which occurs while the land is still occupied by a maturing crop. In such a case, no seed-bed preparation is possible except for hand hoeing between the standing plants. Maize yields produced under no-tillage have been found to be equal to or higher than those produced under conventional tillage (Kang and Yunusa, 1977; Legg *et al.*, 1979; Shear and Moschler, 1969). Under conditions of relatively short rainy seasons, like those prevailing in the Machakos area, the results of studies have indicated that double cropping results in more grain production and more efficient use of annual precipitation and soil-stored moisture than growing one crop per year. This double cropping was achieved either by planting directly after harvesting the previous crop, utilizing the no-tillage method (Crabtree and Rupp, 1980; Widstrom and Young, 1980; Nelson *et al.*, 1977; Camper *et al.*, 1972) or by interplanting the second crop within the maturing crop (Chan *et al.*, 1980; Triplett *et al.*, 1976). For the Machakos area it has been suggested that relay planting of maize before 1 March for the long rains would bring the most sensitive growth stage of the crop to a time where water stress can be avoided. By following such a practice, most of the crop's water requirements can be satisfied, and thus maize production in the area can be improved (Nadar, 1983).

This report discusses the results of a study conducted to determine maize yield response to relay planting and conventional planting as affected by population, row spacing, and cropping systems under Katumani conditions.

MATERIALS AND METHODS

This study was undertaken at the Dryland Farming Research Station during the long rains of 1978. The station is located 10 km south of Machakos town, Machakos District, in the Eastern Province of Kenya. It has centre co-ordinates 01° 35′ S and 37° 14′ E and lies at an altitude of 1,575 m. The soil is well drained, dark reddish-brown sandy clay. It is classified as Oxic Paleustalf (Chromic Luvisol). It has a relatively low water-storage capacity and medium depth. The average depth is 120 cm, with a total water-storage capacity of 100 mm. The long rains of 1978 started by the middle of February and ended by mid-May. Total rainfall was 463 mm.

Maize (*Zea mays* L., Katumani Composite B) was planted on 2 March 1978. It was either relay planted within the maturing short-rains maize (no-till), or planted after removing the short-rains crop and preparing the seed-bed by ploughing and disc-ing (till). The planting was in rows spaced 0.06, 0.75 or 0.90 m apart, with 0.30 m spacing within the row. Maize plants were thinned to either 1 or 2 plants per hill. The one-plant-per-hill populations were either grown as sole crops or intercropped with beans (*Phaseolus vulgaris* L., var. Mwezi Moja). The two-plants-per-hill populations were grown as sole crops only.

A split-plot experimental design was chosen for testing planting methods. Within the main plots, a 3 × 3 factorial design was used to test row spacing, population, and cropping systems. Plots were of 6 rows 0.90 m apart, 8 rows 0.75 m apart, or 10 rows 0.60 m apart. All plots were 10 m long. Yields were determined by harvesting 4, 4, and 6 rows 8 m long from the 0.90, 0.75, or 0.60 m row-spacing plots respectively. Maize yields were adjusted to 15.5% moisture, and bean yields adjusted to 14%. Bean yields were further converted to maize-yield equivalent by multiplying

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bean yields by the bean:maize price ratio at the time, which was 1.44:0.71. This conversion allowed the addition of maize and bean harvests obtained from the intercrop plots, as well as making direct comparison and analysis of variance possible.

RESULTS AND DISCUSSION

The overall response of maize yield to planting methods was not statistically significant. However, relay-planted maize yielded, on the average, about 4% less than that planted by the conventional method. Average yield of relay planting was 5,007 kg/ha while that of conventional planting was 5,213 kg/ha. Response to planting method seemed to be influenced by row spacings and cropping systems. In the sole-crop maize system, either at 1 or 2 plants per hill, yields realized from relay-planted maize were consistently lower than those from maize planted by the conventional method, at all row spacings. The level of yield reduction varied with the variation in row spacing and number of plants per hill. The percentage yield reduction was greater at 1 plant per hill than at 2 plants per hill, and also greater at 75 cm row spacing than at 60 or 90 cm spacing (Tables I and II). In the intercrop system, total yields (maize yield + bean yield) of the relay plantings were higher than those of the conventional plantings, except in the case of the 75 cm row spacing, where the yield of the relay-planted crop was lower than that of a crop planted by the conventional method (Table III). However, yield reduction caused by the relay planting in the intercrop at 75 cm was very much lower than that in the sole crop. Yield was reduced by 4% in the intercrop as compared with 17% in the sole crop at 1 plant per hill and 11% in the two-plants-per-hill sole crop.

TABLE I—YIELDS OF ONE-PLANT-PER-HILL MAIZE SOLE CROP AT THREE DIFFERENT ROW SPACINGS, AS INFLUENCED BY PLANTING METHOD, TOGETHER WITH PERCENTAGE YIELD DEVIATION OF THE RELAY-CROPPING FROM THAT PLANTED CONVENTIONALLY

Row spacing	Yields (kg/ha)		Percentage deviation of relay
	Coventional planting	Relay planting	
60 cm	4,748	4,663	− 2
75 cm	5,248	4,337	−17
90 cm	3,946	3,423	−13
Average	4,646	4,144	−10

TABLE II—YIELDS OF TWO-PLANT-PER-HILL MAIZE SOLE CROP AT THREE DIFFERENT ROW SPACINGS, AS INFLUENCED BY PLANTING METHOD, TOGETHER WITH PERCENTAGE YIELD DEVIATION OF THE RELAY-CROPPED FROM THAT PLANTED CONVENTIONALLY

Row spacing	Yields (kg/ha)		Percent deviation of relay
	Conventional planting	Relay planting	
60 cm	5,757	5,658	− 1
75 cm	6,657	5,983	−11
90 cm	5,199	4,905	− 6
Average	5,861	5,515	− 6

TABLE III—YIELDS OF INTERCROPPED MAIZE AND BEANS AT THREE DIFFERENT ROW SPACINGS, AS INFLUENCED BY PLANTING METHOD, TOGETHER WITH PERCENTAGE DEVIATION OF THE RELAY-CROPPED FROM THAT PLANTED CONVENTIONALLY

Row spacing	Yields (kg/ha)		Percent deviation of relay
	Conventional planting	Relay planting	
60 cm	5,403	5,772	+ 1
75 cm	5,240	5,033	− 4
90 cm	4,753	5,281	+11
Average	5,132	5,362	+ 5

Although yield differences between planting methods were not significantly different at the 5% level, they were too high and consistent to ignore (Tables I and II). This is an indication that, if planted on the same date, conventional planting, after preparing the seed-bed by ploughing and disc-ing, would be expected to produce heavier maize yields in the sole-crop systems than that produced by relay planting within the previous season's maturing crop, especially at the 75 cm row spacing.

Planting by both methods for this study took place on 2 March. In practice, the short-rains maize or cowpea crops would not be harvested before the middle of March. The earliest time to plant using the conventional method would be 3 to 7 days after the middle of March, which gives the relay-planting method an advantage of 2 to 3 weeks as regards earliness over the conventional method. A 2 to 3 weeks' delay in the planting of maize beyond 1 March could be expected to cause reduction in maize yields substantially greater than those caused by relay planting.

Relay planting could have other advantages, such as the saving of draught power required for seed-bed preparation before planting by the conventional method. Another advantage could be that in the relay system the planting could take place during a period when labour requirements are at their minimum. When using the relay-planting method, the harvest of the short-rains crop, which is very labour-demanding, takes place 2 to 3 weeks after finishing planting for the long rains.

In the intercrop, total yields were generally higher than those of a one-plant-per-hill sole crop, and those of the relay planting were mostly higher than total yields of conventional plantings. However, maize yield responses to intercropping were influenced by row spacings. While maize yields were not affected by intercropping with beans at 60 and 90 cm row spacings, yields were substantially reduced at 75 cm row spacing (Fig. 1). Yield responses to row spacings and number

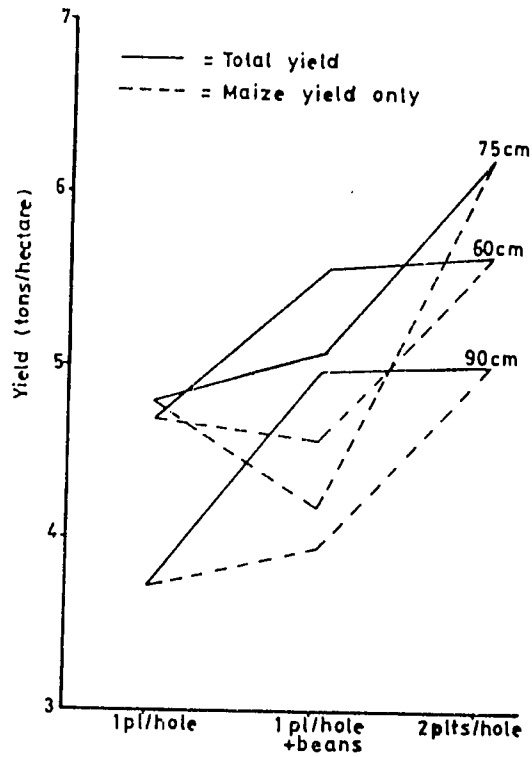

Fig. 1. Effect of Intercropping with Beans on Maize Yields and Total Yields During Long Rains 1978

of plants per hill were significant. Maize yields (Table IV) increased significantly with the decrease in row spacings at 1 plant per hill. At 2 plants per hill, maize planted at 75 cm row spacing, with about 70,000 plants per hectare, yielded higher than that planted at 60 or 90 cm spacings. As intrarow spacing was constant (30 cm), change in row spacings or number of plants

TABLE IV—MAIZE COMBINED YIELD RESULTS OF BOTH PLANTING METHODS ($\times 10^3$ kg/ha) AND POPULATION COUNTS ($\times 10^3$ plants/ha) AT DIFFERENT ROW SPACINGS, NUMBER OF PLANTS PER HILL, AND CROPPING SYSTEMS DURING LONG RAINS 1978

	1 Plant		1 Plant + beans		2 Plants	
Row spacing	Population	Yield	Population	Yield	Population	Yield
60 cm	51.9	4.705[c]	46.0	5.587[a,b] (4.636 + 0.951)	92.4	5.693[ab]
75 cm	41.5	4.95[c]	39.8	5.136[b,c] (4.195 + 0.942)	70.7	6.320[a]
90 cm	33.4	3.801[d]	36.1	4.937[b,c] (3.970 + 0.967)	53.8	5.052[b,c]
Average	42.3	4.430	40.6	5.247	72.3	5.688

1. Maize population only; bean population was not counted.
2. Numbers in brackets: first = maize yield; second = bean yield corrected to equivalent maize yield.
3. Letters following yield value indicate that it is significantly different from values followed by different letters at the 10% confidence level, according to the LSD mean comparison test.

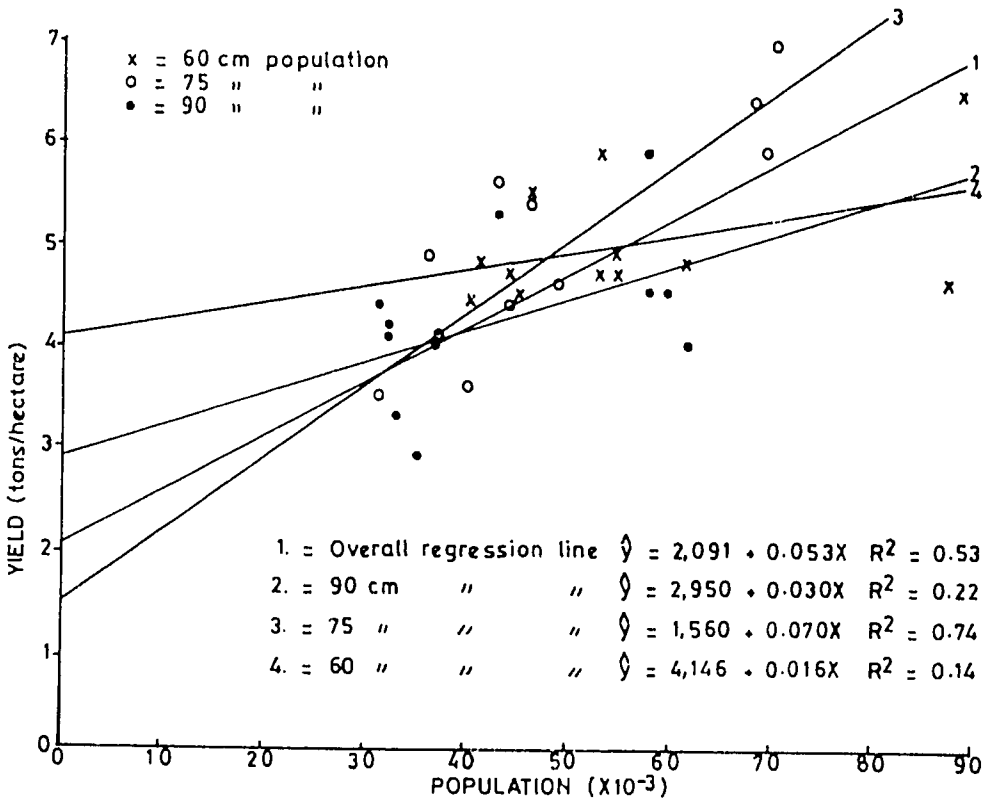

Fig. 2. Regression of Maize Yields on Plant Numbers at the Different Row Spacings During Long Rains 1978

per hill would be expected to affect number of plants per unit area. As a result, it was not possible to separate the effect of row spacing on maize yield from that of population. Fig. 2 presents the linear regression of maize yields over population at the different row spacings. While the R value for the overall regression was 0.53, it was 0.22, 0.74 and 0.14 for 60 cm, 75 and 90 cm respectively. This may be an indication that the effect of the 75 cm row spacings on maize yields was more than just the direct effect of the increase in plant numbers. It may have provided a better population geometry by changing the distance relationships between the plants. Field observations indicated that 60 and 75 cm row spacings provided better plant arrangements than 90 cm spacings. They gave faster land coverage and better light interception. Further studies on row spacing and plant populations would shed more light on their interactions.

From these results it can be concluded that under the conditions of the experiment, within both planting systems, population had a significant effect on maize yields, with 75 cm at 2 plants per hill producing the highest yields. Although intercropping beans with maize caused a decrease in maize yields, the total yield realized from a unit area was higher than that of one-plant-per-hill sole-crop maize at all row spacings, and was not different from that of 2 plants per hill at 60 and 90 cm row spacings. Relay planting can be considered a feasible agronomic practice when it is desired to meet optimal planting dates before the previous season's crop is ready for harvest. If the previous season's crop was already harvested, the conventional method of planting would be expected to be superior to relay planting and would result in better yields, especially under sole-crop systems.

SUMMARY

This study was conducted during the long rains of 1978 to test maize yield response to relay planting and conventional planting as affected by population, row spacings, and cropping systems. The results indicated that maize response to planting methods was influenced by row spacing and cropping systems. While yields of relay-planted crops were lower than those of conventionally planted crops in the sole-crop systems, they were mostly higher in the intercrop systems. Under both planting systems, row spacing, like population, had a significant effect on maize yields, with 75 cm row spacing producing the highest yields. Although intercropping beans with maize caused a decrease in maize yields, total yields were generally higher. On the average, the yield reduction caused by relay planting was minimal (4%) as compared to the yield reduction which might be caused by delaying planting until after harvest of the short-rains crops. Relay planting can be considered a feasible agronomic practice to be employed to meet the recommended planting dates when the previous season's crop is not yet ready for harvest. If the previous season's crop is already harvested before the recommended planting date, conventional planting would be expected to result in higher yields. Studies on planting dates for the long-rains seasons are needed to quantify the relative advantages of the two planting methods.

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EFFECT OF LEGUMES ON THE YIELD OF ASSOCIATED AND SUBSEQUENT MAIZE IN INTERCROPPING AND ROTATION SYSTEMS WITHOUT NITROGEN FERTILIZER

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INTRODUCTION

Maize (*Zea mays* L.) is the main subsistence crop in Kenya. Nitrogen is an important nutrient requirement for maize production and needs to be supplied in some form to obtain economical maize production. The omission of no other nutrient results in such drastic decrease in growth and yield of maize as nitrogen. Studies of the response of maize to commercial nitrogen fertilizer (Nadar and Faught, 1983) have clearly demonstrated the economic feasibility of using such fertilizer to increase yields and net returns to farmers. However, the practical feasibility of using this approach to improve productivity is sharply restricted by the lack of cash or credit to purchase the fertilizer, the limited availability of supplies in local trading centres at appropriate times, and the difficulties of transporting the fertilizer to farms where it is to be used. In April 1980, the USAID-funded Dryland Cropping Systems Research Project developed agronomic practices to improve maize production in eastern Kenya (Nadar *et al.* 1983). These practices were not fully adopted by the subsistence farmers in the area because of the high nitrogen fertilizer input required for maize production.

An alternative to commercial nitrogen fertilizer, which is practically out of the reach of subsistence farmers, is farmyard manure. The farmyard manure available to these farmers is only enough to fertilize a very small percentage of the areas they usually plant to maize each season. Hence, viable alternatives to these two sources of nitrogen need to be identified.

Another alternative is rotating of crops, particularly rotations including legumes. Rotations have been employed to control weeds, insects, plant diseases, and soil erosion, as well as to improve soil fertility (Battese and Fuller, 1972). After a 39-year rotation study, Hays and Thatcher (1955) found that the average maize yield in a maize-alfalfa rotation was 3.4 times that of continuous maize. At the end of the study they found that total nitrogen in the rotation plots was increased by 484 pounds per acre, while that in the continuous maize plots was decreased by 923 pounds per acre. Fleming *et al.* (1981) reported that maize following clover produced 318% more grain than that following fallow. Lombin (1981) found that sorghum following groundnuts yielded consistently higher than continuous sorghum. The beneficial effect of the legumes on the subsequent cereals was mainly explained by their nutrient contribution to the system. Triplett *et al.* (1979) found that meadows containing an excellent stand of legumes were capable of supplying most, if not all, of the N needs of the cereal crop that followed. Baldock and Musgrave (1980) estimated the contribution of alfalfa to be equivalent to 134 kg N/ha. Mitchell and Teel (1977) estimated the contribution of hairy vetch (*Vicia velosa* Roth) and crimson clover (*Trifolium incarnatum* L.) to be 112 kg N/ha. Clegg (1982) reported a contribution equivalent to 76 kg N/ha by soybeans (*Glycine max* (L.) Merr.) to a soybean-sorghum rotation system.

Subsistence farmers in the study area do not usually grow forage crops in the areas reserved for food crops, but rather intercrop their maize with other grain legumes. Intercropping was reported to be an old practice of subsistence farmers, especially under rainfed conditions (Jodha, 1981). Cordero and McCollum (1979), Okigbo (1981), and Osiru and Kibera (1981) suggested that intercropping was superior to sole crops. Singh (1981) reported increases in sorghum yields up to 34% as a result of intercropping with legumes. Nadar (1982) reported an LER advantage of about 15% for maize/bean intercrops. The beneficial effect of the associated legumes was found to be influenced by the spatial arrangement of the intercrop components (Nadar *et al.*, 1983; Chui, 1982).

This study was undertaken to determine the

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agronomic and economic feasibility of using the grain legumes usually grown by the farmers in the researched area, in either rotation or intercropping systems as practical alternatives to commercial nitrogen fertilizers for maize.

MATERIALS AND METHODS

The experimental site was located at the National Dryland Farming Research Station at Katumani, 10 km south of Machakos town, Machakos District, Eastern Province of Kenya, with centre co-ordinates 01°35′ S and 37°14′ E and at an altitude of 1,575 m. The soil is well drained, dark reddish-brown, sandy clay. It is classified as Oxic Paleustalf (Chromic Luvisol). The average depth was 120 cm with total water-storage capacity of 100 mm. The rainfall is bimodal with two rainy seasons called short rains (October to December) and long rains (March to May). Total rainfall and its distribution are highly variable. Total rainfall per season during the duration of this experiment ranged between 175 mm and more than 500 mm (Fig. 1).

Permanent plots were established in the short rains of 1981/82 for rotating and/or intercropping maize (*Zea mays* L., Katumani Composite B) and the grain legumes beans (*Phaseolus vulgaris* L., var. Mwezi Moja), cowpeas (*Vigna unguiculata* L., var. Machakos 68), tepary beans (*Phaseolus acutifolius* A. Gray), and a two-season local variety of pigeonpeas (*Cajanus cajan* L.). The plots were 10 rows 0.6 m apart and 10 m long. No nitrogen fertilizer or farmyard manure was used and 17.5 kg P/ha were applied to all crops each season.

Seventeen cropping systems were included in this study. These systems represent as closely as possible those practised by the farmers or can be easily adopted by them. They were divided into four groups as follows:

I. *Continuous cropping systems*

- IA. Continuous sole-crop: maize
- IB. Continuous intercrop systems:
  - IB1. Maize/bean intercrop
  - IB2. Maize/cowpea intercrop.

II. *Rotation between sole-crop maize and maize/legume intercrops*

- IIA. Sole-crop maize in the short rains and intercrops in the long rains:
  - IIA1. Maize followed by maize/bean intercrop
  - IIA2. Maize followed by maize/cowpea intercrop.
- IIB. Maize/legume intercrops in the short rains and sole-crop maize in the long rains:
  - IIB1. Maize/bean intercrop followed by sole-crop maize
  - IIB2. Maize/cowpea intercrop followed by sole-crop maize.
- IIC. Two-season maize/pigeonpea intercrop followed by two seasons of sole-crop maize.

III. *Rotation between sole-crop maize and sole-crop legumes*

- IIIA. Maize in the short rains and legumes in the long rains:
  - IIIA1. Maize followed by beans
  - IIIA2. Maize followed by cowpeas
  - IIIA3. Maize followed by tepary beans.
- IIIB. Legumes in the short rains followed by maize in the long rains:
  - IIIB1. Beans followed by maize
  - IIIB2. Cowpeas followed by maize.
- IIIC. Sole-crop pigeonpeas for two seasons followed by two seasons of sole-crop maize.
- IIID. Sole-crop cowpeas for two seasons followed by sole-crop maize for one season.

IV. *Maize and one-season legume intercropped with a two-season pigeonpea crop*

- IVA. Maize/pigeonpea followed by bean/pigeonpea
- IVB. Maize/pigeonpea followed by cowpea/pigeonpea.

To reduce the soil nitrogen residue, no nitrogen fertilizer was applied to any of the crops grown during the long rains of 1981 (the season preceding the start of the experiment). The crops grown during the long rains of 1981 and those grown during the duration of the experiment are listed in Table 1 for each cropping system. The cropping systems were assigned randomly to the plots. The experimental design was a randomized complete block with three replications. All crops were seeded in excess and thinned to final populations of 55,000 pl/ha for maize and cowpeas and 22,500 pl/ha for pigeonpeas in both sole-crop and intercrop systems. For beans, the population was 110,000 pl/ha in sole-crop and

TABLE I—CROPS GROWN DURING LONG RAINS 1981 (BEFORE THE START OF THE STUDY) AND THOSE GROWN DURING THE COURSE OF THE EXPERIMENT, LISTED BY CROPPING SYSTEM

Cropping system	Crop or combination of crops planted during the season*									
	Long rains 1981		Short rains 1981/82		Long rains 1982		Short rains 1982/83		Long rains 1983	
IA	Maize	SC	Maize	SC	Maize	SC	Maize	SC	Maize	SC
IB1	Maize	SC	M/B	IC	M/B	IC	M/B	IC	M/B	IC
IB2	Cotton	SC	M/Cp	IC	M/Cp	IC	M/Cp	IC	M/Cp	IC
IIA1	Cp/PP	IC	Maize	SC	M/B	IC	Maize	SC	M/B	IC
IIA2	Cassava	SC	Maize	SC	M/Cp	IC	Maize	SC	M/Cp	IC
IIB1	Maize	SC	M/B	IC	Maize	SC	M/B	IC	Maize	SC
IIC	PP	SC	M/PP	IC	M/PP	IC	Maize	SC	Maize	SC
IIIA1	Cp/PP	IC	Maize	SC	Bean	SC	Maize	SC	Bean	SC
IIIA2	Cotton	SC	Maize	SC	Cowpea	SC	Maize	SC	Cowpea	SC
IIIA3	Cp/PP	IC	Maize	SC	Tepary	SC	Maize	SC	Tepary	SC
IIIB1	Maize	SC	Bean	SC	Maize	SC	Bean	SC	Maize	SC
IIIB2	Maize	SC	Cowpea	SC	Maize	SC	Cowpea	SC	Maize	SC
IIIC	Maize	SC	PP	SC	PP	SC	Maize	SC	Maize	SC
IIID	Maize	SC	Cowpea	SC	Cowpea	SC	Maize	SC	Bean	SC
IVA	Cp/PP	IC	M/PP	IC	B/PP	IC	M/PP	IC	B/PP	IC
IVB	Maize	SC	M/PP	IC	Cp/PP	IC	M/PP	IC	Cp/PP	IC

*SC = Sole crop, M = Maize, B = Beans, IC = Intercrop, Cp = Cowpeas, PP = Pigeonpeas, Tepary = Tepary beans

55,000 in intercrop systems. Yields were determined by harvesting 6 rows 8 m long from each plot. Maize yields were adjusted to 15.5% moisture, while legume yields were adjusted to 14%. The adjusted yields were further adjusted to variations in final population counts using the covariance analysis method.

Data are for the seasons short rains 1981/82, long rains 1982, and short rains 1982/83. Land-equivalent ratios (LERs) were calculated for each crop and cropping system by assuming a value of 1 for the yields of the sole crops, except in the case of maize, where the value of 1 was assigned to the yields of the continuous sole-crop. Yields of sole-crop maize in other systems would have LER values different from 1 if their yields were different from that of continuous sole-crop maize. Determining one LER value for each cropping system would allow a meaningful procedure for comparing these systems.

Analysis of variance and mean comparisons were applied to total LERs. Partial LERs of maize were compared to those calculated for the continuous maize fertilizer trial (Nadar and Faught, 1983). LERs for the continuous maize fertilizer trial were calculated by first applying second-order polynomial regression analysis to the yield response to nitrogen fertilizer levels, assigning a value of 1 to the yield corresponding to 0 N/ha and then determining the LER values corresponding to other values of N. A continuous function line was developed (Fig. 2), and the nutrient contributions of legumes were quantified by determining the amount of nitrogen which corresponded to the LER of the maize produced in the cropping system.

Use of LERs provides one basis of comparison, but comparison of benefits or advantages of alternative cropping systems involving a variety of crops cannot be made directly in terms of physical production. Therefore, economic evaluations which express production of several crops in common terms must be used. Economic evaluations are complicated for subsistence areas such as the Eastern Province of Kenya by the absence of reliable market-price information. Volumes of all crops sold are very limited and no market-price information is systematically collected. Informal observations in trading centres in the area indicated that the prices of legumes generally are two to three times the price of maize, and greatly exceed prices set by the National Cereals and Produce Board. Even the price of maize often departs substantially from the minimum

prices established by the National Cereals and Produce Board, but this minimum price for maize appears to be the best approximation of market price available, and the most appropriate base for the economic evaluations. Estimates of gross values of returns have been used for the evaluation, since labour for harvest, usually provided by the family, is the only major variable cost.

Prices of all legumes are assumed to be double the price of maize in estimating gross values. Systems involving four-season rotation have not been included in the economic evaluation, since the study period did not encompass their full cycle and comparisons with other systems would by biased. The rotation including tepary beans has also been omitted, since it is a completely new crop in the area and no relative value, either as a subsistence or a cash crop, has been established.

Production of the two-season rotations involving the same legume in alternate seasons was averaged, since a farmer following one of those rotations would have half his land under maize and half under the sole-crop or intercrop legume each season. Because of the probable inaccuracy in prices used in the evaluations, sensitivity analysis has been done to determine if varying relative prices of the several crops would affect the conclusions of the study.

RESULTS AND DISCUSSION

The differences between seasons were highly significant. Rainfall was the major factor influencing these differences. Total and distribution of the rainfall (Fig. 1) varied greatly from one season to the other. Although rainfall conditions ranged from extremely poor to very good, with accompanying variations in results, the overall results suggest that the incorporation of legumes in the cropping system, either as intercrop or as part of a rotation, generally resulted in a higher value of production than that obtained from continuous maize production.

Because of the drought conditions during the short rains of 1981/82, there was no maize harvest (Table II). The yields of sole-crop beans and cowpeas were reasonably good. In the intercrop systems, the legume yields were very poor because of the competition between the components for available moisture. The decrease in intercrop bean yields was between 76 and 78%, while that in cowpeas was between 94 and 96%. These results agreed with earlier findings that under drought conditions beans are better competitors for available moisture in intercrop systems than cowpeas, and intercropping is more economical than sole-crop maize (Nadar *et al.*, 1983). Economic analysis showed that when maize production failed completely, legumes as intercrops provided modest returns, and as sole crops provided gross returns ranging from about KSh. 2,000 to KSh. 2,500.

The results of the long rains of 1982 (Table III) were influenced by the late start and early end of the rainy season (Fig. 1). Maize, cowpea, and pigeonpea yields were generally low, while bean and tepary bean yields were not affected because their growing seasons are much shorter than those of other crops. Yields of intercrop maize (IB1, IB2, IIA1, IIA2 and IIC) were lower than that of continuous sole-crop maize (IA). If there was any beneficial effect to the associated legume, it was confounded by the rainfall conditions. Under these conditions, eight cropping systems produced total yields higher than that of continuous maize. Only two of these systems resulted in actual significant increase in maize yields. Both were sole-crop maize-legume rotation systems (IIIB1 and IIIB2). When LERs of these two systems were compared to those of the continuous maize fertilizer trial in the long rains of 1982 (Fig. 2), it was possible to estimate the contribution of cowpeas as equivalent to 12.5 kg N/ha, valued at KSh. 136, while beans contribution was estimated as equivalent to 80 kg N/ha, with a value of KSh. 872. Gross returns from cropping systems that included legumes averaged 11% higher than the returns from continuous maize. However, there was great variation in returns among the several systems. Those including beans as a continuous intercrop or as a sole crop in a rotation had an average return 52% above the returns from continuous maize. Those including cowpeas in the same combinations had average returns 17% below those from continuous maize.

Rainfall conditions were more favourable during the short rains of 1982/83. The beneficial effects of associated cowpeas and pigeonpeas were reflected in the maize yields of this season (Table IV). On the other hand, yields of maize intercropped with beans were 28 and 44% lower than that of continuous sole-crop maize. Total gross values of all cropping systems were higher than that of continuous maize, except in the case of sole-crop beans, the value of which was 4% lower. The increase in total LERs ranged between 6% for the continuous maize/bean intercrop (IB1) and 109% for maize following beans (IIIA1). By using the short-rains-1982/83 curve in Fig. 2 and maize partial LERS, it was possible

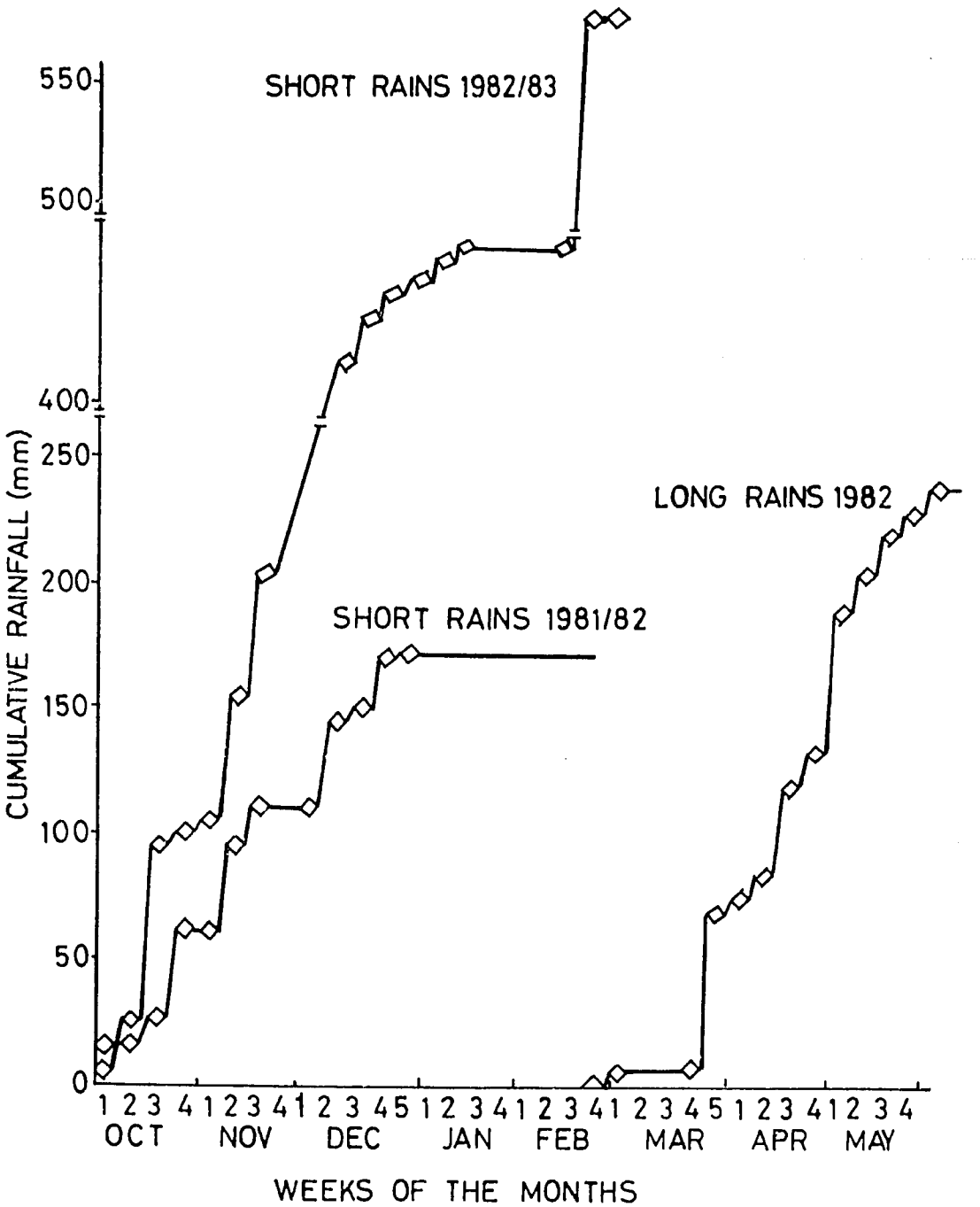

Fig. 1. Cumulative Weekly Rainfall for Short Rains 1981/82, Long Rains 1982, and Short Rains 1982/83 at Katumani Meteorological Station

TABLE II—YIELDS, LAND EQUIVALENT RATIOS (LERs), AND GROSS VALUES OF CROPS PRODUCED BY THE DIFFERENT CROPPING SYSTEMS DURING SHORT RAINS 1981/82

Cropping system	Yields ($\times 10^3$ kg/ha		Partial LERS		Total LERs	Gross value KSh.[1]
	Legumes	Maize	Legumes	Maize		
IA	—	0.0	—	0.0	0.0	0
IB1	0.191	0.0	0.22	0.0	0.22	547
IB2	0.039	0.0	0.06	0.0	0.06	112
IIA1	—	0.0	—	0.0	0.0	0
IIA2	—	0.0	—	0.0	0.0	0
IIB1	0.208	0.0	0.24	0.0	0.24	596
IIB2	0.026	0.0	0.04	0.0	0.04	75
IIC	—	0.0	—	0.0	0.0	0
IIIA1	—	0.0	—	0.0	0.0	0
IIIA2	—	0.0	—	0.0	0.0	0
IIIA3	—	0.0	—	0.0	0.0	0
IIIB1	0.856	—	1.0	—	1.0	2,453
IIIB2	0.726	—	1.0	—	1.0	2,081
IIIC	—	—	—	—	—	—
IIID	0.687	—	—	—	1.0	1,949
IVA	—	0.0	—	0.0	0.0	0
IVB	—	0.0	—	0.0	0.0	0

[1]KSh. = Kenya shilling
$US 1.00 = KSh. 13.1

TABLE III—YIELDS, LAND EQUIVALENT RATIOS (LERs), AND GROSS VALUES OF CROPS PRODUCED BY THE DIFFERENT CROPPING SYSTEMS DURING THE LONG RAINS 1982

Cropping system	Yields ($\times 10^3$ kg/ha)		Partial LERs		Total LERs	Gross value KSh.[1]
	Legumes	Maize	Legumes	Maize		
IA	—	1.852	—	1.0	1.0	2,653
IB1	0.713	0.949	0.35	0.51	0.86	3,403
IB2	0.248	0.440	0.36	0.24	0.60	1,342
IIA1	0.899	0.451	0.44	0.24	0.68	3,223
IIA2	0.249	0.752	0.36	0.41	0.77	1,792
IIB1	—	1.933	—	1.04	1.04	2,770
IIB2	—	1.736	—	0.94	0.94	2,488
IIC	0.120	1.319	0.18	0.71	0.89	2,234
IIIA1	2.033	—	1.0	—	1.0	5,827
IIIA2	0.694	—	1.0	—	1.0	1,989
IIIA3	1.367	—	1.0	—	1.0	3,917
IIIB1	—	3.460	—	1.87	1.87	4,958
IIIB2	—	2.373	—	1.28	1.28	3,400
IIIC	0.661	—	1.0	—	1.0	1,894
IIID	0.725	—	1.0	—	1.0	2,078
IVA	1.329	—	0.99	—	0.99	3,809
IVB	0.731	—	1.08	—	1.08	2,095

[1]KSh. = Kenya shilling
$US 1.00 = KSh. 13.1

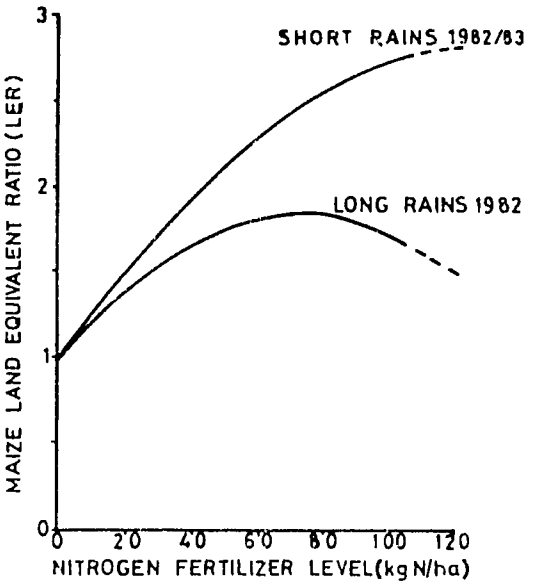

Fig. 2. Function Lines of Second-order Polynomial Regression of Maize Yields on Nitrogen Fertilizer Rates for Results of Continuous Sole-Crop Maize Fertilizer Studies during Long Rains 1982 and Short Rains 1982/83. Data are Transformed to LER Values with Yield Responses to Zero Fertilizer Level Given a Value of One.

to estimate the legume contributions to the several systems (Table V). Beans were the highest contributors to the sole-crop rotation system, while pigeonpeas were the highest contributors to the intercrop system. The percentage maize increases in yield and LERs were higher for the short rains of 1982/83 than those for the long rains of 1982, while the estimated legume contributions in terms of nitrogen were the reverse. This was probably because of the expected higher efficiency of the maize crop in utilizing nitrogen fertilizer when rainfall conditions are favourable. In this season, the relative benefits from beans and cowpeas in the intercrop systems were reversed. Value of products from systems incorporating beans exceeded value from the continuous maize by 36%, while those incorporating cowpeas exceeded continuous maize by 58%.

For the three seasons as a whole (Table VI), total value of products from systems including beans or cowpeas as the legume exceeded that from continuous maize by 43%. For the same period, returns from systems that included beans exceeded continuous maize returns by 58%, but those systems that included cowpeas exceeded continuous maize by only 29%. Intercropping, either continuous or as part of a rotation, resulted in substantially better returns than continuous

TABLE IV—YIELDS, LAND EQUIVALENT RATIOS (LERs), AND GROSS VALUES OF CROPS PRODUCED BY THE DIFFERENT CROPPING SYSTEMS DURING SHORT RAINS 1982/83

Cropping systems	Yield ($\times 10^3$ kg/ha)		Partial LERs		Total LERs	Gross value KSh.[1]
	Legumes	Maize	Legumes	Maize		
IA	—	1.776	—	1.0	1.0	2,545
IB1	0.426	0.987	0.50	0.56	1.06	2,635
IB2	0.526	2.053	0.56	1.16	1.62	4,445
IIA1	—	2.285	—	1.29	1.29	3,274
IIA2	—	3.011	—	1.70	1.70	4,314
IIB1	0.600	1.280	0.70	0.72	1.42	3,554
IIB2	0.521	1.986	0.56	1.12	1.68	4,626
IIC	—	2.515	—	1.42	1.42	3,604
IIIA1	—	3.709	—	2.09	2.09	5,315
IIIA2	—	2.913	—	1.64	1.64	4,174
IIIA3	—	2.172	—	1.22	1.22	3,112
IIIB1	0.854	—	1.0	—	1.0	2,447
IIIB2	0.932	—	1.0	—	1.0	2,671
IIIC	—	2.412	—	1.36	1.36	3,456
IIID	—	2.893	—	1.63	1.63	4,146
IVA	—	2.242	—	1.26	1.26	3,212
IVB	—	2.063	—	1.16	1.16	2,956

[1]KSh. = Kenya shilling
$US 1.00 = KSh 13.1

TABLE V—CONTRIBUTION OF LEGUMES TO THE DIFFERENT CROPPING SYSTEMS IN TERMS OF NITROGEN AS kg N/ha AND THEIR MONETARY VALUES IN SHILLINGS (ONE KILOGRAM OF NITROGEN COSTS KSh. 10.9) FOR THE RESULTS OF THE SHORT RAINS 1982/83 EXPERIMENT

Cropping system	Legume component		Partial LER of maize	Legume contribution to the system	
	Present season	Previous season		kg N/ha	Value (KSh.)[1]
IA	—	—	1.0	0.0	.0
IB1	Beans	Beans	0.56	0.0	0.0
IIA1	—	Beans	1.29	10.0	109.0
IIB1	Beans	—	0.72	0.0	0.0
IIIA1	—	Beans	2.09	44.0	479.6
IVA	Pigeonpeas	Beans & PP	1.26	9.0	98.1
IB2	Cowpeas	Cowpeas	1.16	5.0	54.5
IIA1	—	Cowpeas	1.70	26.0	283.4
IIB2	Cowpeas	—	1.12	4.0	43.6
IIIA2	—	Cowpeas	1.64	24.0	261.6
IIID	Cowpeas	Cowpeas	1.63	23.0	250.7
IVB	Pigeonpeas	Cowpeas & PP	1.16	5.0	54.5
IIC	—	Pigeonpeas	1.42	15.0	163.5
IIIC	—	Pigeonpeas	1.36	13.0	141.7
IIIA3	—	Tepary beans	1.22	8.0	87.2

[1]KSh. = Kenya Shilling
$US 1.00 = KSh. 13.1

TABLE VI—ESTIMATED VALUES OF PRODUCTION PER HECTARE FROM ALTERNATIVE CROPPING SYSTEMS DURING SHORT RAINS 1981/82, LONG RAINS 1982, AND SHORT RAINS 1982/83

Cropping systems	Estimated values in Kenya shillings			Total	Relative values (per cent)
	S.R. 81/82[1]	L.R. 82	S.R. 82/83		
Continuous sole-crop maize (IA)	0	2,653	2,545	5,198	100
Continuous maize/beans inter-crop (IB1)	547	3,403	2,635	6,585	127
Maize/bean intercrop rotated with sole-crop maize. (Ave. of IIA1 & IIB1)	298	2,996	3,414	6,708	129
Maize-bean sole-crop rotation (Ave. of IIIA1 & IIIB1)	1,227	5,392	3,881	10,500	202
Continuous maize/cowpea inter-crop (IB2)	112	1,342	4,445	5,899	113
Maize/cowpea intercrop rotated with sole-crop maize (Ave. of IIA2 & IIB2)	38	2,140	4,470	6,648	128
Maize-cowpeas sole-crop rotation (Ave. of IIIA2 & IIIB2)	1,040	2,695	3,422	7,158	138
Average of all cropping systems including beans	719	4,036	3,445	8,200	158
Average of all cropping systems including cowpeas	454	2,202	4,046	6,702	129

[1]S.R. = Short rains
L. R. = Long rains

maize. Intercropping of maize and beans sharply lowered the yields and returns from the intercrop maize compared with continuous sole-crop maize, so that the higher total value of the intercrop was entirely due to the value of the bean component. In contrast, intercropping maize and cowpeas in several instances raised the yields and value of the intercropped maize above those of the continuous sole-crop maize. Although intercropping provided better returns than continuous maize, benefits were substantially less than those of sole-crop maize-legume rotations. Average return for the three seasons from the several systems incorporating maize-bean intercrop was 28% greater than the average return from continuous maize, while the comparable average from sole-crop maize-bean rotation was 102% greater. Returns from maize-cowpea intercrops averaged 23% greater than the average returns from continuous maize, while the increase in returns from sole-crop maize-cowpea rotation averaged 38%.

As indicated earlier, a possible alternative approach to increasing maize yields by including legumes in the cropping system is the application of commercial nitrogen fertilizer to continuously cropped maize. For example, continuous maize yields might have been increased to a level equalling that of sole-crop maize following beans by the application of 80 kg N/ha in the long rains or 44 kg N/ha in the short rains of 1982. Also, the continuous maize yields might have been increased to a level equalling that of sole-crop maize following cowpeas by applying 12.5 or 24 kg N/ha in the two seasons respectively. However, these nitrogen fertilizer applications would have required cash outlays for fertilizer alone of KSh. 872 for the bean substitute or KSh. 136 for the cowpea substitute in the long rains. Comparable figures for the short rains would be KSh. 480 or KSh. 262. Net returns would be reduced by equal amounts. Additional costs would be incurred for applying the fertilizer, interest on capital required, and for risk involved. The benefit in the form of increased returns from applying fertilizer in a continuous maize system would be five to six times the cash outlay, but the same benefits could be attained without this outlay by adopting the maize-legume rotation systems. The risk involved in applying commercial fertilizers becomes particularly significant in seasons such as the short rains of 1981/82, when such outlays, rather than bringing benefits, would have resulted in an increase in net losses equalling the cost of applying the fertilizer. Many subsistence farmers would not be able to absorb such losses in a single year, even though the practice would be profitable over the three-season period.

Shifts in relative values among the commodities included in the several systems would cause shifts in the relative benefits over continuous maize production. An increase in the price of maize from the 1982 minimum to the minimum for maize planted in 1983 of about 22%, with legume prices constant, would narrow the relative benefits of systems including legumes over continuous maize. However, all systems including a legume would still be more profitable than continuous maize. Rotations would still provide greater returns than continuous intercrops, and the largest returns would still be obtained from sole-crop maize-legume rotation systems. The maize-bean sole-crop rotation would continue in the number one position. An increase in the relative price of maize of 50% would about eliminate the advantage of continuous maize-legume intercrops, and further narrow the relative advantage of rotations. However, the rotations would still retain a substantial advantage over continuous maize, and the sole-crop maize-bean rotation would still occupy the number one position. If the minimum prices established by the National Cereals and Produce Board for all commodities should prevail, the price of beans would be raised to a level equal to 2.4 times the price of maize, while the price of cowpeas would be lowered to 0.90 that of maize and the price of pigeonpeas would be equal to 1.15 times the price of maize. At these relative price levels, the advantage of intercrops and rotations including beans would be substantially strengthened and the advantage of intercrops or rotations including other legumes would disappear.

SUMMARY

Maize (*Zea mays* L.), the main subsistence crop in Kenya, needs to be supplied with nitrogen in order to obtain economical production. Commercial nitrogen fertilizers are expensive and becoming out of reach of subsistence farmers. This study was undertaken for three seasons without nitrogen fertilizer on a typical Oxic Paleustalf soil in Machakos District of eastern Kenya. The purpose of this study was to determine the possibility of using the grain legumes, beans (*Phaseolus vulgaris* L.) cowpeas (*Vigna unguiculata* L.), tepary beans (*Phaseolus acutifolius* A. Gray), and pigeonpeas (*Cajanus cajan* L.) in either rotation or intercrop systems with

maize, as alternatives to commercial nitrogen fertilizers. Sixteen maize-legume cropping systems were compared with continuous sole-crop maize and with each other. Results from the long rains of 1982 were generally influenced by the late start and early end of the rainy season. This resulted in intercrop maize yields lower than that of continuous sole-crop maize. Yields of maize following cowpeas and beans were significantly higher than that of continuous sole crop. The legume contributions to the rotation systems were estimated to be equal to 12.5 kg N/ha for cowpeas and 80 kg N/ha for beans. If there was any beneficial effect to the associated legumes in the intercropping systems, it was confounded by the rainfall conditions. When rainfall conditions were more favourable during the short rains of 1982/83, LERs and gross values of all cropping systems were higher than that of continuous sole-crop maize, except in the case of sole-crop beans, which was 4% lower. Legume contributions to sole-crop rotation systems were found to range between 8 kg N/ha for tepary beans and 44 kg N/ha for beans. In the intercrop systems, pigeonpeas were the highest contributors (15 kg N/ha). From these results it can be concluded that under favourable rainfall conditions, the legumes studied have a beneficial effect on yields and returns of both associated and subsequent maize. Under less-than-adequate rainfall, the beneficial effect of legumes can only be observed in the sole-crop maize-legume rotation systems. To improve maize production as well as total crop production under the rainfall conditions of the study area, it is recommended to use a maize-bean sole-crop rotation system. This system was found, under the experiment conditions, to increase maize yields by 98% and total three-season gross returns by 102% without nitrogen fertilizer application.

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EFFECT OF SPATIAL ARRANGEMENTS ON THE YIELD AND OTHER AGRONOMIC CHARACTERS OF MAIZE AND LEGUME INTERCROPS

J. N. Chui and[1] *H. M. Nadar*[2]

INTRODUCTION

The growing of two or more crop species simultaneously on the same piece of land is a common cultural practice that dominates tropical subsistence agriculture (Willey, 1979). This practice of intercropping has often shown yield advantages over monocropping and has other agronomic values attached to it (Okigbo, 1978; I.R.R.I., 1974, 1975; Litsinger and Moody, 1976) which have been demonstrated both by research and in actual practice. In the maize (*Zea mays* L.)-legume system, the usual aim of a small-scale farmer is to get full production of the maize plus an additional grain yield from the intercropped legume. The additional yield depends upon the extent of the interspecific competition for the available environmental resources and is normally less than monocrop potential (Agboola and Fayemi, 1971; Dalal, 1974). Because of the meagre legume yields obtained from intercropping systems and the high nutritional value attached to legume crops, there is interest in improving the legume performance in this system. Also, the alleged beneficial effects of the legume in terms of additional nitrogen made available to companion cereal crops needs further investigation, for this might reduce dependence on chemical nitrogen fertilizers, which are often not available and are always expensive.

In intercropping systems the intensity of the interaction between the component crops depends upon the extent of interplant contacts between individuals of the different components. A factor of major importance in the performance of intercrops, therefore, is their spatial arrangement, which affects edaphic interactions and light penetration into the canopies of both the taller and shorter components. Hence, a relevant question is how intimate intercrops should be (Willey, 1979). Reports have indicated that the spacing of the taller cereal crop can be adjusted without reducing its yield while providing a more favourable environment for the associated legume. Freyman and Venkateswarlu (1977) reported that using paired 30 cm sorghum (*Sorghum bicolor* L. Moench) rows to allow wider interrow space for intercropped pigeon pea (*Cajanus cajan* L. Mill.) improved the yield of the legume.

Intercropping maize and soybeans (*Glycine max* L. Merr.), using double rather than single alternating rows of each species, improved the intercrop legume yield without affecting the performance of the maize relative to monocropping (Singh *et al.*, 1973; Mohta and De, 1980). But intercropping these species in the same row reduced yields of both compared to single or double alternating rows, which gave maize yields similar to those of a monocrop (Dalal, 1977).

The question of intimacy is also pertinent where legume contribution to the cereal crop is desired because mingling of legume and cereal roots has been said to have beneficial effects (Trenbath, 1974). Research has revealed that tropical legumes are capable of excreting nitrogen during growth (Agboola and Fayemi, 1971), and non-legume crop yields have been increased when intercropped with a legume compared to the yield when monocropped, even when high levels of nitrogen have been applied (CIAT, 1974).

The main objectives of this work were to find out whether altering maize spatial arrangements would reduce the competition between the intercrops and consequently improve the yield of an associated legume without reducing maize yield significantly; assess the beneficial effects of legumes on maize; and determine the advantages of the intercropping system compared to monocropping.

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MATERIALS AND METHODS

Experimental sites and soil types

The experiments were conducted in both tropical and temperate environments. In the tropics, the experiment was carried out at the National Dryland Farming Research Station at Katumani, Kenya, situated at 1°35′ S and 37°14′ E at an altitude of 1,575 m. It was conducted during the long rains of 1981. The total precipitation during the long rains of 1981 was 441 mm. The area has a bimodal rainfall regime known as the long rains (March-May) and the short rains (October-December). The duration of rainy seasons and amounts of rainfall are variable and unpredictable. This area is semi-arid. The soil type is Oxic Paleustalf, a well drained, dark reddish-brown, sandy clay. The temperate experiment was conducted in the 1980 and 1981 summer seasons at the Iowa State University, U.S.A., at 42°2′ N and 93°33′ W. The soil was Nicollet sandy clay loam with a pH of 6.0.

Crop species and their combinations

Maize was used as the main crop in both experimental sites. In the U.S.A., a short-statured maize, Pioneer 3780, was intercropped with a semideterminate soybean line, A75D29. In Kenya, a 120-day maize, Katumani Composite B, was intercropped with an 80-day bean variety, Mwezi Moja. These crops were planted in both sole and intercrop systems. There were maize (M), soybean (S) and bean (B) sole crops planted at their optimum populations. The intercropping of maize and soybeans was on the same row at either 70, 87 or 105 cm spacings. Intercropped soybean was either at half optimum (S1) or optimum (S2) population density. At 87 and 105 cm row spacings, one maize plant alternated with one soybean plant in spatial arrangements designated 87 × 24S1 and 105 × 20S1. At 70 cm row spacing, maize was planted one or more seeds per hill, and soybeans, planted at half or optimum population density, were distributed evenly in the same row. Three maize intrarow spacings of 30, 60 and 90 cm were used in 70 cm interrows. At 70 cm row spacing, therefore, one maize plant per hill intercropped with S1 or S2 were in spatial arrangements designated 70 × 30S1 and 70 × 30S2; two maize plants per hill intercropped with S1 or S2 were designated 70 × 60S1 and 70 × 60S2; three maize plants per hill intercropped with S1 or S2 were designated 70 × 90S1 and 70 × 90S2. Maize and beans were planted in 60 cm interrows in sole and intercrop systems (MB). Monocrop maize and soybeans were planted at 70 × 30 cm and 70 × 15 cm row spacing respectively. Maize plants were grouped, two or three in a hill at 70 × 60 and 70 × 90 cm and in wider rows (87 and 105 cm) to alleviate the shading effect of maize on soybeans.

Planting and management

In the U.S.A., maize and soybeans were planted heavily on the same row and were thinned two weeks after seedling emergence. The maize population remained constant at 48,000 plants/ha in all spatial arrangements. The monocrop soybean population was 96,000 plants/ha (S). Two soybean population densities, 48,000 (S1) and 96,000 (S2) plants/ha, were used in the intercrop system. Urea fertilizer was the source of N and was applied 5 cm to one side of the plant rows at two rates, 0 and 135 kg/ha, three weeks after emergence. Phosphorus and potassium were broadcast the previous autumn at the rates of 33 and 66 kg/ha respectively.

In Kenya, maize and beans were also planted in both sole and intercrop systems. Intercrops were planted in three spatial arrangements, that is, in the same hole, in the same row, and in alternate rows at 60 cm row spacing. The maize population remained the same at 55,000 plants/ha in both the sole and intercrop systems. Thinning was done 15 – 20 days after planting. Two bean populations of approximately 55,000 and 110,000 plants/ha were left in the intercrop and sole-crop systems respectively. Fertilizer in the form of single superphosphate at the rate of 40 kg/ha P_2O_5 was applied to both crops immediately after thinning. No N fertilizer was applied. Hand hoeing was the means of weeding in both experimental sites.

Experimental Design and Data Collection

In the U.S.A., the experimental design was a split plot replicated three times. Two levels of N fertilizer, 0 (N_0) and 135 (N_{135}) kg/ha, characterized the two main blocks. A block was made up of monocrop maize and soybean and five intercropping systems in 1980 and eight in 1981. The area harvested was 7.56 m² for both monocrops and intercrops.

In Kenya, three spatial arrangements were studied in a randomized complete block design, replicated three times. In both sites, the yield was expressed as kg/ha at 15.5% moisture for maize, 14% for soybeans, and 13% for beans. The data developed included growth and develop-

ment, yield and yield components, and land equivalent ratios (LER).

Statistical treatment of data was by analysis of variance. Orthogonal contrasts were used to test for mean differences.

RESULTS AND DISCUSSION

Crop growth and development

These parameters were measured on maize and soybean monocrops and intercrops planted on the same row.

The blooming of soybean was not importantly influenced by either intercropping or N fertilizer. Intercropping delayed maize tasselling and silking by up to 2 days, especially at the optimum population density of the soybean (S2). N fertilizer hastened tasselling and silking by 2 and 4 days, respectively. Treatments without applied N showed a greater time difference, up to 6 days, between tasselling and silking.

Intercropping significantly reduced soybean growth attributes. That is, the number of leaves per soybean plant was reduced by 61%, leaf area index (LAI) by 67%, and phytomass per m^2 at seedfill by 78% (Table I). These findings correspond with the observations of others. Natarajan and Willey (1980) reported that pigeon-pea LAI was greatly reduced when it was interplanted with sorghum, and Wiggans (1934) showed that soybean dry weight was reduced when it was grown in combination with maize. N fertilizer did not influence these variables. Intercropping the S2 resulted in 7.5% fewer leaves per plant than the half population density (S1). However, the S2 had 59% more leaves per m^2 due to the population increase, resulting in a greater LAI of 17.5% and phytomass of 12% compared with S1 (Table I). Highly significant linear relationships between LAI and phytomass at seedfill in the two seasons were observed (r^2 = 0.87 and r^2 = 0.97 for the 1980 and 1981 seasons respectively).

TABLE I—EFFECT OF SPATIAL ARRANGEMENTS ON SOME GROWTH ATTRIBUTES OF SOYBEANS AVERAGED OVER THE 1980 AND 1981 SEASONS, AT IOWA STATE UNIVERSITY, U.S.A. DATA TAKEN AT BEGINNING SEEDFILL STAGE

Cultural practice	Leaves per plant (number)	Leaf area index	Phytomass (g/m^2)
Sole soybean	37.0	3.3	342.9
Intercrop[a]			
70 × 30S1	14.7	0.7	49.1
70 × 60S1	16.1	0.8	56.9
70 × 90S1	18.4	0.9	66.1
87 × 24S1	13.4	0.7	48.4
105 × 20S1	11.6	0.6	40.9
70 × 30S2	12.0	1.3	77.7
70 × 60S2	12.7	1.5	98.7
70 × 90S2	16.7	1.9	137.8
Intercrop mean	14.5	1.1	73.9

[a]The intercrop with S2 represents data of 1981 season alone.

Reduction of intimacy between maize and soybeans by widening intrarows of maize (achieved by grouping maize plants two or three in a hill) diminished interspecific competition. This was revealed by increased soybean leaves per plant by 27 and 39%, LAI by 38 and 46%, and phytomass by 35 and 77% at S1 and S2 respectively, where maize plants were planted three to a hill as against conventional planting of one maize plant per hill at 70 × 30 cm. Widening maize interrows to 87 or 105 cm did not improve soybean growth attributes.

Nitrogen fertilizer did not affect the height of soybean monocrop but both the maize monocrop and intercrops were significantly taller, 33 cm and 12 cm when N fertilizer was applied. Intercropping without N generally did not affect maize

height, but where N was applied intercropping significantly reduced the height of maize, by 21 cm. The shortest intercrop maize was that where maize was grouped three to a hill, probably due to intensification of intraspecific competition. Intercropping significantly increased length of soybean stems, by 13 and 22 cm under N_0 and N_{135} respectively. Competition for light obviously increased soybean internode elongation. There was a positive relationship between intercrop soybean height and height of maize ($r^2 = 0.50$) and the taller the intercrop soybean plants the more they lodged ($r^2 = 0.80$). There was no lodging in soybean monocrop. The soybeans in maize grouped three to a hill were the shortest and least lodged of the intercropped soybeans. Probably, grouping maize plants, which reduced interspecific intimacy, resulted in a reduced shading effect of maize on soybeans.

Seed yield and yield components

Maize

Application of N fertilizer significantly increased the yield of maize intercropped with soybeans, by 91 and 40%, and of maize monocrop by 97 and 49% in 1980 and 1981 respectively (Table II). This yield increase was attributable to the increased ear weight (92%), hundred-kernel weight (26%) and harvest index (19%) (Table III). The effect of legumes on maize due to the proximity of the component crops was observed. Planting maize one, two, or three seeds in a hill in a soybean intercrop did not reduce maize yield significantly, although maize-yield reduction below the monocrop ranged from 7% to 12% in 5 out of 13 intercrops and from 1 to 14% in 11 out of 13 intercrops under 0 and 135 kg/ha N, respectively (Table II). Intercropping maize and beans in alternate rows without applied N fertilizer at Katumani caused maize-yield reduction of 33% below the monocrop, mainly due to a decrease of 29% in average ear weight (Table IV). Other workers have observed both similar and contrasting results. Dalal (1977) found maize yields reduced by 15 and 17% under 0 and 100 kg/ha N when intercropped in the same row with soybean. Groot (1982) reported a 35% maize-yield reduction when maize was interplanted with beans on alternate rows of 75 cm, but when maize was intercropped with soybeans on alternate 45 cm (Dalal, 1977) and 60 cm (Mohta and De, 1980) rows, the maize yields were not significantly reduced.

Although intercropping maize and beans in alternate rows without N fertilizer showed a significant depressive effect on maize yield, planting maize and beans in the same hole and in alternate holes in the same row indicated beneficial effects on maize by increasing maize yield

TABLE II—EFFECT OF SPATIAL ARRANGEMENTS AND N FERTILIZER ON THE YIELD OF MAIZE AND SOYBEANS AT IOWA STATE UNIVERSITY, U.S.A. (kg/ha)

	Maize				Soybeans			
	1980		1981		1980		1981	
Cultural practice	N_0	N_{135}	N_0	N_{135}	N_0	N_{135}	N_0	N_{135}
Sole maize	4,547	8,944	6,151	9,158				
Sole soybean					2,765	3,545	3,400	3,416
Intercrop								
70 × 30S1	5,252	9,570	5,824	9,083	347	254	432	372
70 × 60S1	4,827	8,508	5,384	8,465	420	332	549	432
70 × 90S1	4,713	8,647	6,535	8,682	424	407	600	521
87 × 24S1	4,236	8,635	6,239	8,920	368	253	313	322
105 × 20S1	4,230	9,137	7,527	8,765	327	216	296	245
70 × 30S2			5,428	8,532			575	419
70 × 60S2			6,353	7,840			792	508
70 × 90S2			5,714	8,112			888	757
Intercrop mean	4,652	8,900	6,126	8,550	377	292	556	447

TABLE III—EFFECT OF SPATIAL ARRANGEMENT AND N FERTILIZER ON THE YIELD COMPONENTS OF MAIZE, AT IOWA STATE UNIVERSITY, U.S.A., 1980

Cultural practice	Ear weight (kg/7.56 m²)		100-kernel wt. (g)		Harvest Index	
	N_0	N_{135}	N_0	N_{135}	N_0	N_{135}
Maize	4.0	8.2	22.6	28.7	0.43	0.48
Intercrop						
70 × 30S1	4.6	8.1	23.2	27.9	0.42	0.52
70 × 60S1	4.4	8.1	24.5	28.7	0.48	0.48
70 × 90S1	3.7	7.5	20.9	27.9	0.48	0.49
87 × 24S1	4.3	8.3	21.1	28.7	0.36	0.50
105 × 20S1	4.0	7.8	22.7	28.1	0.43	0.51
Intercrop mean	4.2	8.0	22.5	28.3	0.43	0.50

TABLE IV—YIELDS AND YIELD COMPONENTS OF MAIZE AND BEANS IN SOLE AND INTERCROP SYSTEMS WITH NO N FERTILIZER APPLIED DURING LONG RAINS 1981, AT KATUMANI

Cropping system	Spatial arrangement	Maize			Bean		
		Ears/ plant	Ear wt. (g)	Yield (kg/ha)	Pods/ plant	Seeds/ pod	Yield (kg/ha)
Sole maize		0.93	76.0	2730			
Sole bean					7.51	3.15	1082
Intercrop							
MB	Same hill	0.94	78.3	3,470	5.25	2.87	361
MB	Same row	0.84	79.3	2,920	4.63	2.53	351
MB	Alternate row	0.86	54.0	1,820	4.82	2.51	366

by 27 and 7% (Table IV). A similar effect was observed in the U.S.A. during the 1980 season where maize alternated with soybeans in the same row in a 70 × 30 cm spatial arrangement (Table II). In this case, the maize yield was significantly increased, by 16 and 7% under 0 and 135 kg/ha N. These results correspond well with the findings of Singh *et al.* (1973), who found that maize yields were enhanced by 5 to 12% over monocrop levels (2,800 to 3,800 kg/ha) by intercropping with soybean in alternate single and double rows.

Although some of these results indicate that maize may have benefited from legume intercrops, probably in terms of transferred N as was reported by Agboola and Fayemi (1971), it is difficult to generalize the effect on yield of maize in a legume intercropping system because of the diversity in results and environments tested. However, there is enough evidence that there exist maize-legume spatial arrangements by which, under each environmental condition, it would be possible to intercrop the two species and sustain only a small loss in maize yield while still obtaining the benefits of the additional legume yield.

Soybeans

Intercropping soybeans with maize significantly and severely reduced the soybean yields. The reduction averaged 87% over the two years for all spatial arrangements and fertility levels. Dalal (1977) obtained a 90 and 75% reduction in soybean yields by intercropping with maize in the same row and in alternate rows. The yield of full soybean population density (S2) was generally

reduced less by intercropping and averaged about a third more than the half soybean population density (S1). Grouping maize two or three plants to a hill and increasing soybean population to S2 improved soybean yields. In the S2 and maize grouped three to a hill (70 × 90 S2), soybean yields were significantly greater than in the ungrouped spatial arrangement (70 × 30 S2), 888 and 757 compared with 575 and 419 kg/ha under 0 and 135 kg/ha of N respectively (Table II).

Grouping maize plants three to a hill reduced intimacy between maize and soybeans planted in the same row and this probably resulted in reduced interspecific competition, as was indicated by increased LAI and phytomass at seedfilling (Table I). Application of N fertilizer to the intercrops reduced the yield of soybean by 12.0 and 19.5 in 1980 and 1981. The increased height of maize due to N fertilizer, averaging 15 cm, probably enhanced maize competition, resulting in curtailed light interception by soybeans, which, in turn, reduced the potential of soybean yield. Grouping two or three maize plants to a hill diminished the competitive effects of fertilized maize on the soybean intercrop (Table II).

The two-years average yield reduction of 87% of intercropped soybeans was associated with a 61% reduction in number of leaves, a 67% reduction in LAI, and a 78% reduction in dry-matter accumulation at seedfilling. Hence, soybean yield reductions caused by intercropping with maize were clearly related to canopy development. Competition of maize with soybean reduced number of soybean branches by 90%, nodes by 56% and pods by 76% (Table V).

TABLE V—EFFECT OF SPATIAL ARRANGEMENTS ON THE YIELD COMPONENTS OF SOYBEANS, AT IOWA STATE UNIVERSITY, U.S.A. 1980

Cultural practice	Branches per plant	Nodes per plant	Pods per plant
Sole soybean	11.8	40.8	79.3
Intercrop			
70 × 30S1	0.8	16.5	16.7
70 × 60S1	0.9	18.4	19.7
70 × 90S1	3.0	22.0	24.5
87 × 24S1	0.9	17.4	17.9
105 × 20S1	0.5	14.4	15.0
Intercrop mean	1.2	17.7	18.8

Soybean seed-yield variation was attributable largely to number of pods per plant ($r^2 = 0.76$ for N_0, 0.96 for N_{135}) and hence to seed number. Because number of pods per plant was essentially determined by number of nodes ($r^2 = 0.98$ for both N treatments) and because of the strong relationship of seed yield with phytomass at the beginning of seedfilling ($r^2 = 0.88$ to 0.98) and leaf number, which is a function of node number ($r^2 = 0.90$ and 0.98 both seasons), we conclude that maize competition in this study reduced associated soybean yield largely by curtailing growth. Hence, any manipulation or practice that facilitates greater growth by soybeans at the vegetative stages should improve the yield of that intercrop. Widening intrarow spacing of maize by grouping two or three plants in a hill and distributing soybean plants evenly on the same row did just that. It diminished interspecific competition, probably mostly for light, and improved canopy development, increased LAI by 37 and 46% and phytomass at the beginning of seedfilling by 35 and 77% at S1 and S2. Improved growth resulted in reduced lodging and greater seed yield.

Beans

Intercropping beans with maize was conducted in an attempt to find out whether close intimacy between the component crops would be beneficial to the cereal crop. The yield of beans that resulted from different spatial arrangements with maize is shown in Table IV. The intercropping systems severely reduced the bean yield, by an average of 67%. The bean-yield reduction was mainly due to a decrease in pods per plant, which ranged from 31 to 38%, and reduced number of seeds per pod, which ranged from 9 to 20%. Except for the number of pods and seeds,

which were reduced differently, the yield reduction was similar when beans were planted in the same hole, in alternate holes in the same row, or in alternate rows with maize. It seems that if the farmer's criterion is to get the full yield of the main crop, then planting maize and beans in the same hole and alternate holes on the same row justified the bean-yield sacrifice, since higher maize grain yields were obtained in these intercrops than in sole crops. In these two intercropping systems, therefore, the yield of beans, which averaged 33%, was additional.

Land productivity

One way of evaluating the productivity of intercrop systems relative to monocultures is by considering the total land productivity. Many scientists evaluate land productivity by calculating land equivalent ratio (LER) which is the sum of separate ratios of yields of crop in association to yields in monoculture. LER is defined as the relative land area under sole crops required to produce the yields achieved in intercropping. A LER greater than unity indicates a better land-utilization efficiency by the intercrop, and the larger its value the greater the efficiency.

In both experimental locations, intercropping maize with soybeans and beans provided greater LERs than unity (Fig. 1 and Table VI). Averaged over the two seasons, the largest LER in maize-soybean intercrops was 1.19 from a 70 × 90 cm spatial arrangement. In maize-bean intercrops, the largest LER was 1.65. The largest LER in maize-soybean intercrops where no N was applied was 1.34 and where N was applied it was 1.14. The magnitude of LERs was observed, therefore, to depend upon the spatial arrangement and nitrogen-fertilizer level. Intercropping maize in different spatial arrangements generally did not reduce the relative yields (RYs) of maize significantly. In fact, in some cases the maize RYs were enhanced by intercropping by up to 0.32 above unity (Fig. 1 and Table VI). On the other hand, intercropping soybean and beans in various spatial arrangements severely reduced their RYs. Application of N fertilizer significantly lowered the RYs of soybeans and tended to reduce that of maize, resulting in lower LERs than where N was not applied. Grouping maize plants two or three per hill at 70 × 60 cm and 70 × 90 cm respectively, to reduce interspecific intimacy, and intercropping soybean optimum population density (S2) improved the soybean RYs and finally the LERs, since maize RYs were not significantly reduced by these intercropping systems (Fig. 1). Planting beans in alternate rows did not improve the RYs nor, therefore, the LERs. Widening the interrows of maize to 87 and 105 cm did not improve the RYs of soybeans, probably because the intensified interspecific interaction brought about increased intimacy between the two species intercropped in the same row.

However, intercropping systems showed greater yield advantages (LERs) over monocropping. This was because of the insignificant depression of the maize yield and in some cases the actually enhanced maize-grain yields observed in association. This intercropping effect on maize caused the yields obtained from the intercropped legumes to compensate for the yield depression of maize, and in cases where maize yield was improved to greater than unity, the yield of the legume in association was a bonus in the intercropping systems.

SUMMARY AND CONCLUSIONS

The data at these two locations illustrate the effects of the interactions between maize and intercropped soybeans and beans in different spatial arrangements. The research had assumed the need for improved intercropped-soybean yield without diminishing the yield of maize importantly, and had also attempted to improve the yield of maize intercropped with beans through the reported beneficial effects of a legume.

Intercropping maize and soybeans did not affect maize yield significantly. Planting maize and beans in the same row increased maize yields, but planting them in alternate rows significantly reduced the yield of maize.

Application of nitrogen fertilizer resulted in the highest maize yield, since it was associated with increased 100-kernel weight, ear weight, and harvest index. Competition between maize and soybeans was enhanced by N application in favour of maize growth through the increased height of the maize.

Intercropping systems reduced the yields of beans and soybeans significantly. The yield reduction of legumes was related to the reduced growth attributes and yield components. Increasing intimacy of maize and legumes by intercropping them in the same hole or in the same row in alternate holes enhanced interspecific competition, which was detrimental to the yield of legumes. Intercropping maize with soybeans in the same row in wider interrows and with beans on alternate rows did not improve the yield of the legumes.

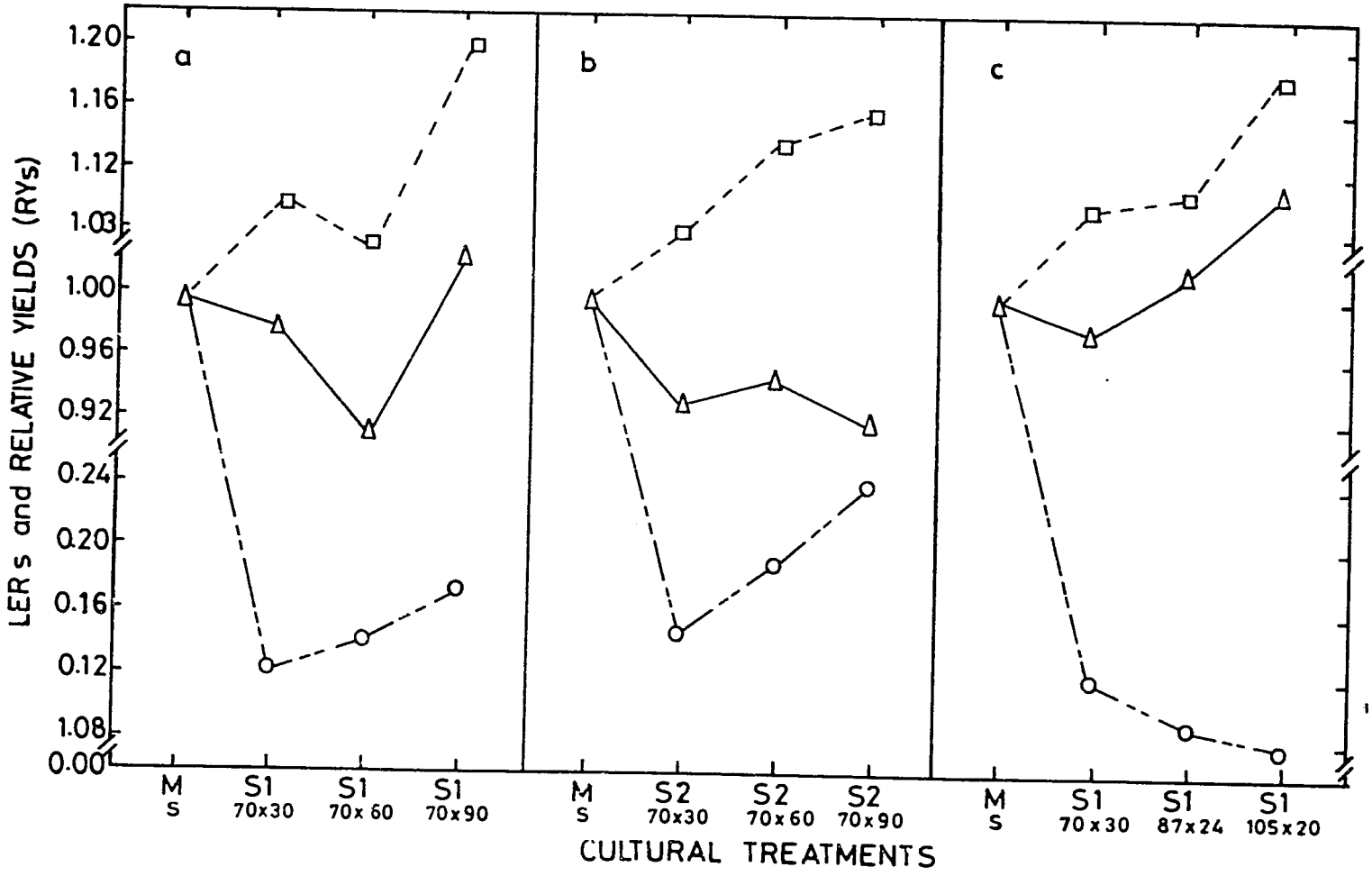

Fig. 1. Effects of maize intrarow spacings (a) and (b) and maize interrow spacings (c) on the total LERs (□) and RYs. of maize (Δ) and soybeans (○) in the 1981 season. M, S, S1 and S2 are as described in the Materials and Methods section.

TABLE VI—EFFECT OF SPATIAL ARRANGEMENTS ON THE RELATIVE YIELDS (RYs) AND TOTAL LAND EQUIVALENT RATIO (LERs) IN SOLE AND INTERCROP SYSTEMS DURING THE LONG RAINS 1981, AT KATUMANI

Cropping system	Spatial arrangement	Maize RYs	Bean RYs	Total LERs
Sole maize		1.00		1.00
Sole soybean			1.00	1.00
Intercrop				
MB	Same hill	1.32	0.33	1.65
MB	Same row	1.10	0.32	1.42
MB	Alternate row	0.67	0.34	1.01

However, with regard to the objectives, grouping maize plants three in a hill in a 70 × 90 cm row spacing and distributing soybean plants evenly in the same row did not affect maize yield significantly but provided the legumes with the best environment. This spatial arrangement improved growth attributes, node number, pod set and seed yield of the intercropped soybeans, even where N fertilizer was applied. Planting an intercrop soybean population equal to that of a sole crop while grouping maize plants three to a hill in a 70 × 90 cm row spacing significantly out-yielded half the soybean population intercropped in a similar spatial arrangement, by 36%. Grouping two or three maize plants to a hill reduced the intimacy between the species and probably this allowed the legume to exploit both edaphic and light conditions with less interspecific competition.

With regard to the second objective, planting maize and legumes in close proximity was beneficial to maize, although it proved detrimental to the legumes. Intercropping maize and soybeans in the same row at 70 × 30 cm and beans in the same hole and same row at 60 cm rows significantly increased the yield of the intercropped maize relative to monoculture.

Intercropping showed greater yield advantages than monocropping in terms of total grain yield per unit area and land use efficiency (LER).

In view of this, it can be concluded that manipulation of plant spatial arrangements, total component-plant densities and soil fertility levels could improve the yield of the intercrop legume without reducing the yield of maize significantly. Also, some spatial arrangements can sacrifice the yield of a legume to some extent while improving the yield of maize, consequently producing a greater yield advantage (LER) overall. The maize seed-yield increase where maize-legume proximity was increased was an indication that there exists a potential intimate intercrop association that could maximize the yield of the cereal crop. In our experiment there was probably an advantageous underground interaction in the cereal-legume mixtures, since the mingling of legume and cereal roots has been reported to have beneficial effects (Agboola and Fayemi, 1971; Trenbath, 1974).

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MAIZE YIELD RESPONSE TO DIFFERENT LEVELS OF NITROGEN AND PHOSPHORUS FERTILIZER APPLICATION: A SEVEN-SEASON STUDY

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INTRODUCTION

Subsistence farmers in eastern Kenya plant maize, their main staple diet, twice a year. Average yields realized are usually around 500 kg/ha, which is considered very low. When this study began there was no information available on long-term soil fertility studies in the area. Marimi (1975) concluded from the results of a one-season fertility study that the maize cultivar used in this experiment (Katumani Composite B) was more responsive to soil-moisture levels than to applied nitrogen. This conclusion appears to be contrary to other findings concerning maize response to fertilizers, and especially to nitrogen-fertilizer applications. It is a well documented fact that maize usually responds positively to nitrogen fertilizer applications in most areas where it has been grown (Bandel *et al.*, 1980; Ritchey and Naderman, 1976). Although increasing nitrogen rates from 112 to 280 kg/ha had no effect on leaf area, upon which grain yield was found to be dependent, the efficiency of a given leaf area in producing grain was higher as nitrogen rates increased (Nunez and Kamprath, 1969). Under certain unusual soil or other environmental conditions, maize yield response to nitrogen-fertilizer applications may be masked. Oelsligle *et al.* (1976) did not obtain any significant maize yield response to application of nitrogen fertilizer on a soil which was planted to annual food crops for the first time. They ascribed their results to the masking effect of residual soil nutrients which might have been accumulated during the period of several years when the land was under native pasture. Broadbent (1980) suggested that substantial quantities of residual nitrogen would reflect over-fertilization and/or insufficient water supply for the crop during its growing season in previous years. Shukla (1972) reported that maize yield was highly correlated with the total nitrogen content of the soil, and found that maize did not respond to nitrogen-fertilizer application on soils with relatively high total nitrogen (0.32%). In the study area, the frequent occurrence of drought conditions and the use of land newly introduced to crop production after several years of native pasture are common features. Even in seasons when there is no drought, the rainfall is in some cases barely sufficient for crop survival, and not enough for efficient utilization of the higher levels of fertilizers applied. This will usually end up with a nutrient-residue build-up in the soil. The moderate temperatures and low rainfall do not allow for nutrient degradation or leaching from the soil. Another explanation for the results obtained by Marimi (1975) might be that the failure of the maize cultivar Katumani Composite B to respond to nitrogen-fertilizer applications was due to the masking effect of the already existing soil-nitrogen residue, rather than to the cultivar's genetic make-up.

Time and method of fertilizer application have been reported to influence the efficiency of its utilization. Stevenson and Baldwin (1969) found that under Ontario climatic conditions, spring fertilizer application produced higher grain yields than autumn application, while there was no difference between pre-planting and side-dressing methods of application. On the other hand, Rhoads *et al.* (1978) reported that applying fertilizers after plant emergence produced about 30% more grain than pre-planting applications. Belcher and Ragland (1972) found that applying all the phosphate fertilizer on the soil surface was equally as effective as banding part of the phosphate in the rows and applying the remainder to the soil surface. Fertilizer efficiency was reported to be higher when surface-applied for no-tillage than for conventionally tilled maize with an equal disked-in application (Legg *et al.*, 1979; Moschler *et al.*, 1972; Triplett and Van Doren, 1969). Stewart has suggested that on the basis of the date of onset of the rains and the performance during the first 35 to 50 days of the season, the quality of a rainy season can be predicted with a relatively high probability of success, and that adjustment in fertilizer rate can be made accordingly. This procedure, depending on the success of the prediction, may offer an opportunity of optimizing fertilizer application

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levels each season. However, it might result in a sizeable loss in potential yield in cases of failure to predict a good rainy season and consequent failure to apply the required amounts of fertilizer. Also, fertilizer applied later is not expected to be as efficiently utilized by the plant as that applied in the early stages of growth.

Maize yield response to nitrogen-fertilizer application can also be influenced by the nutrient source. Bandel *et al.* (1980) reported that maize yields were significantly higher in response to ammonium nitrate applications than to nitrogen in urea form.

This study was conducted for seven successive seasons to determine the optimum levels of nitrogen and phosphate fertilizers for maximum maize production and economic returns under the soil and rainfall conditions prevailing at Katumani.

MATERIALS AND METHODS

The experimental site was located at the National Dryland Farming Research Station at Katumani, 10 km south of Machakos town, Machakos District, Eastern Province of Kenya. Its centre co-ordinates are 01° 35′ S and 37° 17′ E and its altitude 1,575 m. The soil is well drained, dark reddish-brown sandy clay, classified as Oxic Paleustalf (Chromic Luvisol). The average depth is 120 cm, with total water-storage capacity of 100 mm. The rainfall is bimodal, with two rainy seasons, referred to as the short rains (October to December) and the long rains (March to May). Total rainfall and its distribution are highly variable. Total rainfall per season during the duration of the study ranged between less than 200 mm and more than 500 mm (Fig. 1).

Permanent plots were established in the short rains of 1979/80 to test the yield responses of a 120-day maize (*Zea mays* L., Katumani Composite B) to the application of five levels each of phosphate and nitrogen fertilizers. The phosphate fertilizer was applied in the form of single superphosphate at rates of 0, 8.75, 17.5 26 25, and 35 kg/ha. These levels of application are equal to 0, 20, 40, 60, and 80 kg P_2O_5/ha. Nitrogen fertilizer was applied in the form of calcium ammonium nitrate at rates of 0, 26, 52, 78, and 104 kg/ha. Phosphate fertilizer was banded along the rows, while nitrogen fertilizer was applied at the base of each plant one week after germination. Fertilizers were applied at the planned rates regularly each season except for the long rains of 1982. This season followed severe drought conditions during the short rains of 1981/82, which resulted in near crop failure. The very low yields of the short-rains 1981/82 crop suggested that most of the applied fertilizers were not utilized, and it was decided to grow the crop in the long rains of 1982 without any fertilizer application. Yield results of both seasons were combined to represent yield responses to one application of fertilizers. The plots were of 5 rows, 0.60 m apart and 5 m long. The fertilizer treatments were assigned randomly to the plots within each block at the start of the experiment, and then continued to occupy the same plot throughout the study. The experimental design was a 5 × 5 factorial within a randomized complete block with three replications. At the time of planting, maize was seeded in excess and then thinned to a final population of 55,000 pl/ha. Yields were determined by harvesting 3 rows 3 m long and yields were adjusted to 15.5% moisture, then further adjusted to variations in final population counts using the covariance analysis method.

The analysis of variance was applied to the yield results of each season as well as to all seasons combined. Second-order polynomial regression of yields on nitrogen application rates was determined. For economic analysis, the incremental variable cost and incremental net benefits were calculated for each fertilizer combination, by considering the 0–0 treatment as having a value of zero variable cost and zero benefits. The treatments will be identified throughout by two numbers separated by a hyphen. The first number will represent the nitrogen fertilizer application level in kilograms of N per hectare, and the second number the phosphate fertilizer application level in kilograms of P_2O_5 per hectare. Hence, 0–20 represents the treatment where 0 kg N/ha and 20 kg P_2O_5/ha (8.75 kg P/ha) were applied.

RESULTS AND DISCUSSION

This study was initiated to determine the optimum combination or combinations of nitrogen and phosphate fertilizers to be applied to a maize crop to get maximum yields under the conditions prevailing at Katumani. The economic fertilizer levels were then to be determined. These economic levels do not necessarily have to be those producing maximum yields, but rather those providing maximum net returns. Maize yield levels varied significantly from one season to another. The overall yield averaged 653 kg/ha for the season with the lowest rainfall (short rains 1981/82) and more than 3,000 kg/ha for the seasons with adequate rainfall. This is an indication that rainfall conditions are the major factors in-

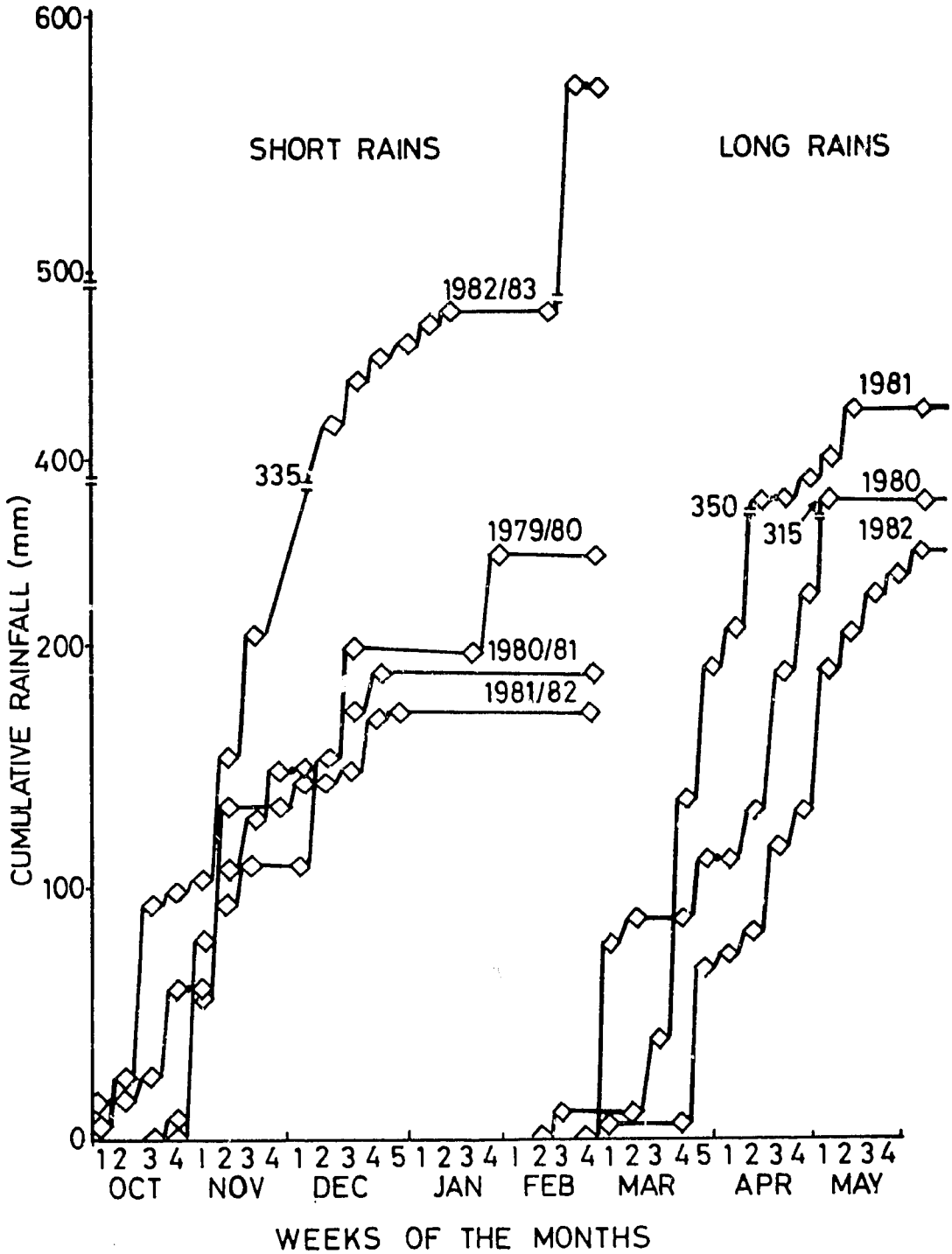


Fig. 1. Weekly rainfall and cumulative seasonal totals at Katumani meteorological station, for the short-rains seasons of 1970/80, 1980/81, 1981/82, and 1982/83, and for the long-rains seasons of 1980, 1981, and 1982

fluencing maize yield response to fertilizer application. Drought conditions were prevalent during the short-rains seasons of 1980/81 and 1981/82, and the amount of rain which fell during the long rains of 1982 was not adequate (Fig. 1). During these three seasons yields were extremely low, and the crop was not expected to utilize the higher levels of fertilizer applications, especially of nitrogen. Following each of the two drought seasons, a test was made with one level of nitrogen fertilizer application to determine the residual effect of the unutilized fertilizer. During the long rains of 1981 and 1982 maize was planted following short-rains maize which had received 70 kg N/ha. One-half of the area planted to maize during the long rains received 70 kg N/ha, while the other half did not receive any nitrogen fertilizer. In the long rains of 1981, maize which did not receive any nitrogen yielded an average of 4,289 kg/ha, while that which received 70 kg N/ha yielded 4,505 kg/ha. In the long rains of 1982 the non-fertilized maize yields averaged 1,928 kg/ha, while maize that had received 70 kg/ha averaged 1,960 kg/ha. In both seasons there was no significant difference between the yields of the maize which received fertilizer and that which did not, while there was a highly significant difference between seasons. These results indicated that nitrogen fertilizer unutilized due to drought conditions is not subjected to degradation or leaching in the soil, but stays almost intact, and could be utilized by a following maize crop to produce a yield almost equal to that of maize which received 70 kg/ha. This is also an indication that applying nitrogen fertilizer to maize following a drought season will result in a build-up in the soil of residual nitrogen without any benefits to the current maize crop. Also, continuous application of nitrogen fertilizer each season, regardless of the rainfall conditions, is not to be considered an economically feasible practice. One alternative is not to apply fertilizers to a crop grown during the season following a drought season. By following such a practice the soil-nutrient residues would be maintained at a minimum and crop production levels would not be reduced. Another alternative would be that suggested by Stewart, which calls for the pre-planting application of 20—20 regardless of the expected season, which might result in a saving of 50 kg of nitrogen per hectare in the case of a successful prediction of a drought season. In such a case, in the following season the first method would call for no fertilizer application, while the latter would call for the application of 20—20 again. If the season following the drought turned out to be a good season, no fertilizer would be needed in the first method, while the second method would call for the addition of 40 more kilograms of nitrogen per hectare. A comparative economic analysis of the two methods of fertilizer use can provide a better basis for choosing one method rather than the other. In the four seasons of the study period with adequate rainfall, seasonal yield averages were above, 3,000 kg/ha. The difference between the seasonal averages can be ascribed to the soil-nitrogen residual effect. This can be clearly seen in Fig. 2.

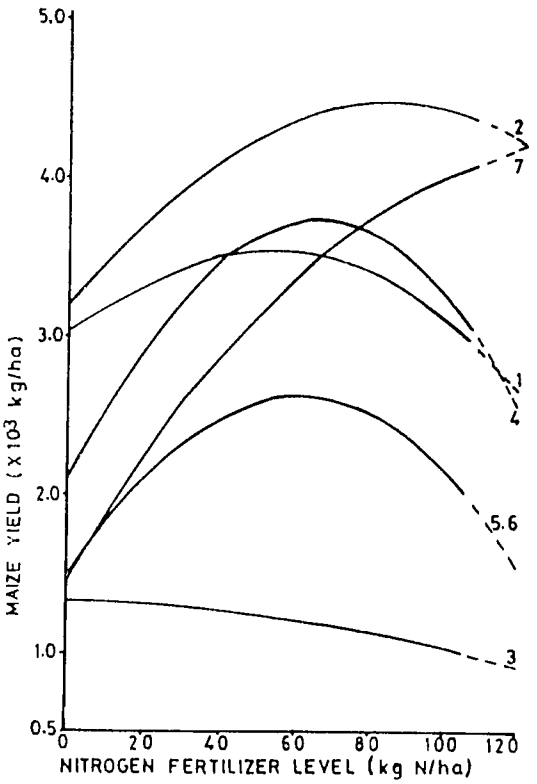


Fig. 2. Maize-yield responses to the applied nitrogen-fertilizer levels for the seasons (1) short rains 1979/80, (2) long rains 1980, (3) short rains 1980/81, (4) long rains 1981, (5) short rains 1981/82, (6) long rains 1982, and (7) short rains 1982/83

Yields with higher levels of application for the second and seventh seasons are almost equal, while yields at zero application for the second season were more than double those of the seventh season, which is an indication that the residual nitrogen in the soil was substantially reduced over a period of five seasons. Soil-nutrient residues influenced the experimental

results by masking maize yield response to applied fertilizers. Response to nitrogen fertilizer was masked in the first season, while that to phosphate fertilizer continued to be masked throughout the duration of the study. Drought conditions affected the results of the study by confounding maize yield responses to the applied fertilizers, because of the inhibitory effect of moisture stress on the overall biological activities of the plant. As a result, the crop would have a very low efficiency in utilizing the applied fertilizer, and new nutrient residues would be built up in the soil. This nutrient residual build-up would, in turn, confound the results of subsequent seasons.

Maize-yield response to phosphate-fertilizer levels was not significant (Table I). Nevertheless, there was a constant and positive yield response to phosphate fertilizer application, especially at 8.75 kg/ha. The only exception was in the short rains of 1981/82, when zero application yielded the highest, probably because of the confounding effect of the severe drought during that season. When the yields of both short rains 1981/82 and long rains 1982, which received only one fertilizer application, were combined, the 8.75 kg P/ha level of application yielded higher than the zero application. Although not significant, this constant and positive trend of maize yield response to phosphate application is an indication that

TABLE I—MAIZE YIELDS ($\times 10^3$ kg/ha) IN RESPONSE TO THE SEVERAL LEVELS OF PHOSPHATE APPLICATIONS, AVERAGED OVER ALL NITROGEN APPLICATION LEVELS, DURING THE SEVEN SEASONS OF THE FERTILIZER STUDY WITH CONTINUOUS SOLE-CROP MAIZE

	Phosphate fertilizer level (kg/ha)					
Season	0	8.75	17.5	26.25	35.0	Avge.
Short rains 1979/80	3.197	3.539	3.171	3.453	3.276	3.327
Long rains 1980	4.060	4.224	4.053	4.234	4.130	4.140
Short rains 1980/81	1.009	1.185	1.266	1.296	1.289	1.210
Long rains 1981	2.851	3.336	3.240	3.376	3.288	3.218
Short rains 1981/82	0.710	0.666	0.655	0.499	0.738	0.653
Long rains 1982	1.422	1.668	1.578	1.534	1.645	1.569
Short rains 1982/83	2.816	3.382	2.949	3.354	3.096	3.119
Average all seasons	2.295	2.571	2.416	2.535	2.495	2.462

under Katumani conditions 8.75 kg P/ha is an essential nutrient requirement for optimum maize production. Hooker *et al.* (1983) found that the application of 8.75 kg P/ha is required for optimum maize production and maintenance of soil phosphate levels at two locations in western Kansas.

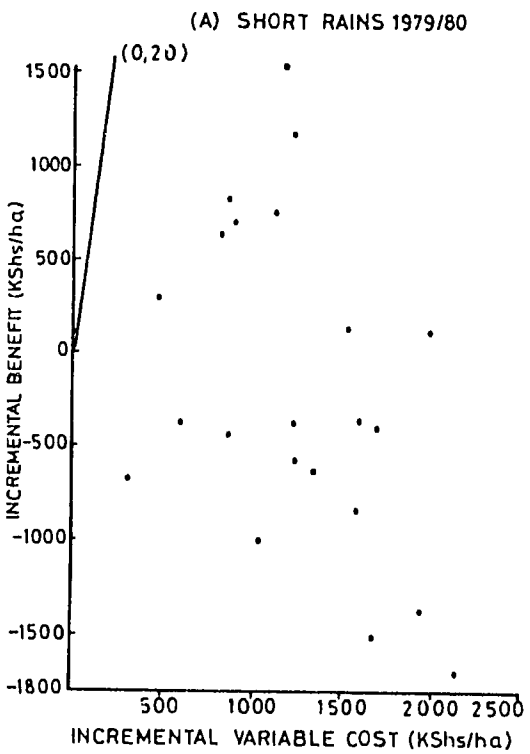
The non-significant results of maize yield response to phosphate-fertilizer applications allowed the pooling of the nitrogen-fertilizer data over all phosphate levels. The relationship between maize yields and nitrogen-fertilizer levels of application seems to be curvilinear (Fig. 2). The degree of correlation between the two variables varied greatly from one season to another (Table II) and was again influenced by the rainfall conditions and the level of residual nitrogen in the soil.

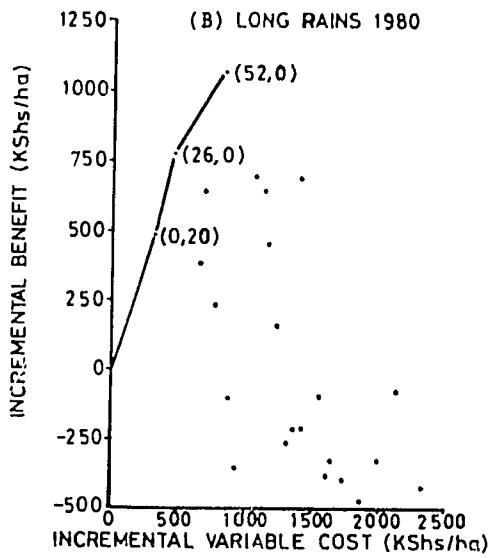
Although fertilizer applications had no significant effect on maize yields in the short rains of 1979/80, the 52—20 treatment produced the highest yields. However, maximum net benefit was obtained with the application of 0—20 (Fig. 3A). No other treatment would have been economically feasible, since all other treatments not only resulted in lower net benefits, but were also associated with higher costs and greater risks. The optimum treatment would have increased net benefits above the no-fertilizer treatment (control) by KSh. 1,604, with an added cost of KSh. 412. This resulted in a 389% rate of return for the risk involved in making the added investment.

In the long rains of 1980, nitrogen-fertilizer application had a significant effect on maize yields. The 52—0 treatment resulted in both

TABLE II—PREDICTION EQUATIONS AND COEFFICIENTS OF MULTIPLE DETERMINATION (R^2) FOR THE POLYNOMIAL REGRESSIONS OF YIELD (Y) ON NITROGEN FERTILIZER APPLICATION LEVELS (X) DURING THE SEVEN-SEASON STUDY

Season	Prediction equation	R^2
Short rains 1979/80	$Y = 3.0342 + 0.02188X - 0.000208X^2$	0.0392
Long rains 1980	$Y = 3.2490 + 0.03211X - 0.00192X^2$	0.2729
Short rains 1980/81	$Y = 1.3282 + 0.000339X - 0.0000246X^2$	0.3351
Long rains 1981	$Y = 2.1485 + 0.05211X - 0.000407X^2$	0.02581
Short rains 1981/82 & long rains 1982	$Y = 1.5172 + 0.03805X - 0.0003144X^2$	0.4104
Short rains 1982/83	$Y = B1.5004 + 0.04407X - 0.000169X^2$	0.5802





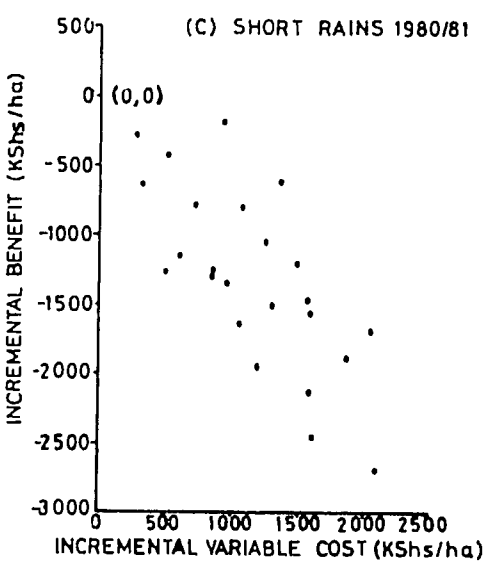
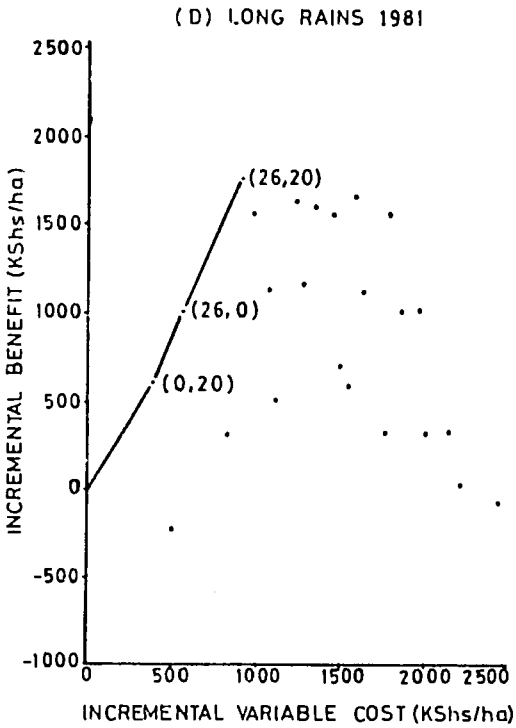
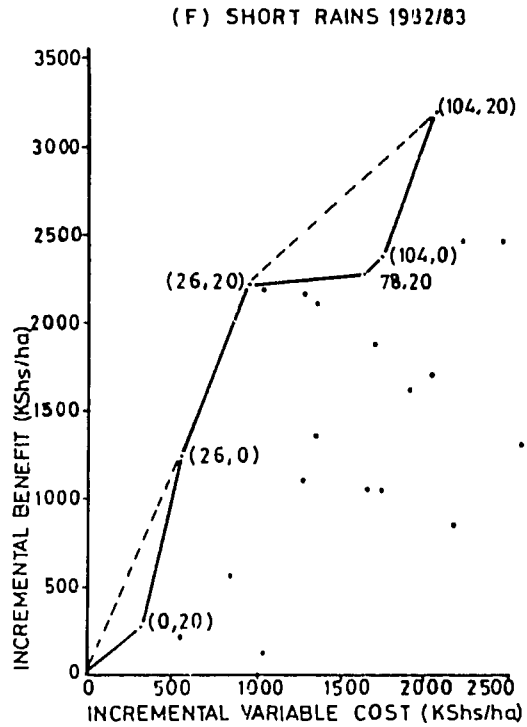
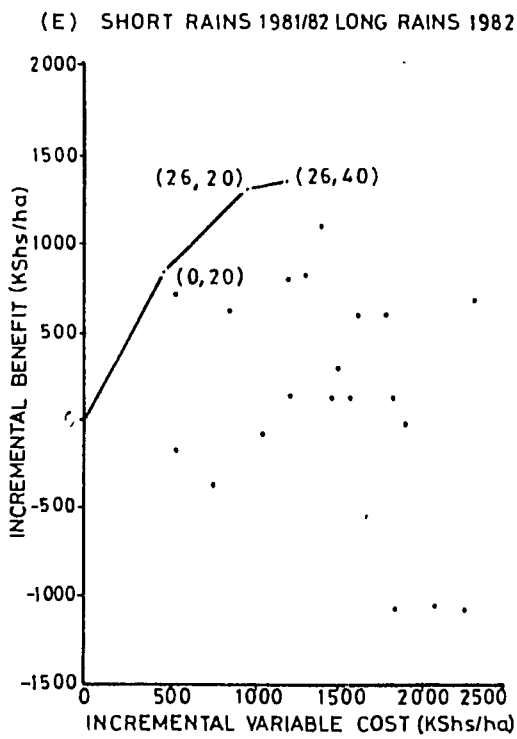
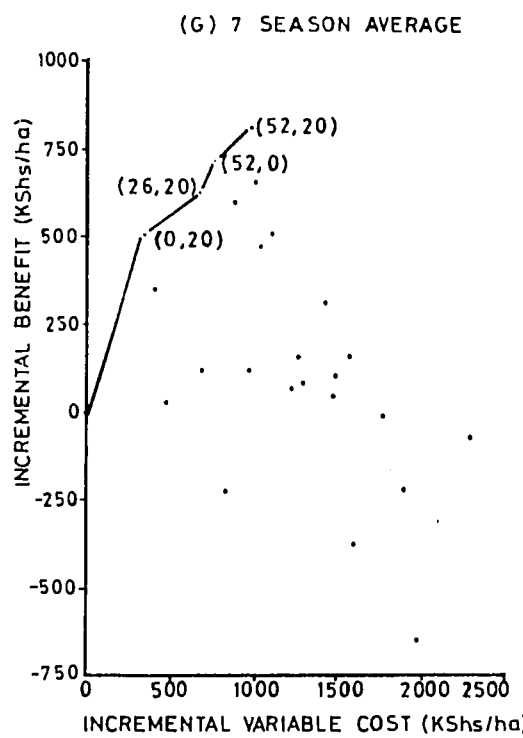


Fig. 3. Net benefits realized and incremental variable costs incurred each season from applying the different combinations of nitrogen and phosphorus fertilizers to maize during the seasons (A) short rains 1969/80, (B) long rains 1980, (C) short rains 1980/81, (D) long rains 1981, (E) short rains 1981/82 + long rains 1982, (F) short rains 1982/83, and (G) the average of all seven seasons


(D) LONG RAINS 1981
INCREMENTAL BENEFIT (KShs/ha)
INCREMENTAL VARIABLE COST (KShs/ha)
(26,20)
(26,0)
(0,20)
2500
2000
1500
1000
500
0
-500
-1000
0
500
1000
1500
2000
2500


(F) SHORT RAINS 1982/83
INCREMENTAL BENEFIT (KShs/ha)
INCREMENTAL VARIABLE COST (KShs/ha)
(104,20)
(104,0)
78,20
(26,20)
(26,0)
(0,20)
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500


(E) SHORT RAINS 1981/82 LONG RAINS 1982
INCREMENTAL BENEFIT (KShs/ha)
INCREMENTAL VARIABLE COST (KShs/ha)
(26,20)
(26,40)
(0,20)
2000
1500
1000
500
-500
-1000
-1500
0
500
1000
1500
2000
2500


(G) 7 SEASON AVERAGE
INCREMENTAL BENEFIT (KShs/ha)
INCREMENTAL VARIABLE COST (KShs/ha)
(52,20)
(52,0)
(26,20)
(0,20)
1000
750
500
250
0
-250
-500
-750
0
500
1000
1500
2000
2500

maximum yields and maximum net benefits (Fig. 3B). The increase in benefits over the control was KSh. 1,078, with a 136% rate of return on added cost of KSh. 794. Other economically viable options for farmers with limited capital resources would have been 26–0 and 0–20. The rates of return on these two treatments would have been 180 and 164% respectively. Certainly, these are adequate returns for the risks involved in the small additional outlay required for either of the treatments.

The very great risks involved in applying commercial fertilizers is vividly illustrated by the results in the short rains of 1980/81. In that season of very limited rainfall, the application of any combination of fertilizers would have reduced net benefits below those obtained with no fertilizer (Fig. 3C). Nine of the 24 treatments would have failed to provide gross returns equal to the variable cost for the treatment and actual net losses would have occurred. Net benefits on the average declined consistently and sharply with increased applications of nitrogen, and consistently but not as sharply with increased applications of phosphates.

In the long rains of 1981, the treatment giving the highest net benefits was 26–20 (Fig. 3D). The yield from this treatment was 13% below the maximum yield, which was obtained from applying 78–40, but the variable cost was 43% below that of the maximum yield treatment. Application of 26–0 or 0–20 would again have been viable options for some farmers, since they have substantially lower costs as well as lower net benefits than the optimum treatment. The 0–20 treatment, at an incremental variable cost over the control of KSh. 347, would have yielded an incremental net benefit of KSh. 619, and a rate of return of 178%. The 26–0 treatment had a slightly higher incremental cost of KSh. 511, but its incremental net benefit of KSh. 1,018 yielded a 199% rate of return. The optimum treatment, incorporating both of the alternatives, had an incremental cost of KSh. 848, an incremental benefit of KSh. 1,801, and a rate of return of 212%. All other treatments would have yielded lower net returns and had higher costs than the three options noted.

Results in the short rains of 1981/82 largely duplicated those in the short rains of 1980/81. In this very dry season, no treatment would have produced a net return as great as that from the control. Again, many of the heavier applications did not produce gross returns sufficient to cover even the added cost of applying the fertilizer. Since little of the fertilizers applied in the short rains had been used by the short-rains crop, or was likely to have been lost before the next season, it was decided not to apply any fertilizer in the long rains and to combine the results of the two seasons in the analysis. Maximum net benefits for the two seasons were derived from the single 26–40 application (Fig. 3E). Benefits would have been increased by KSh. 1,395 over the control and the rate of return on the investment in the one fertilizer application would have been 127%. Net benefits from the 26–20 treatment were only slightly lower than the maximum, but costs were substantially lower and the rate of return would have been 160%. The 0–20 treatment would have yielded an increase in benefits over the control of KSh. 851 and provided a rate of return of 217% on the small additional outlay of KSh. 393.

The short-rains season of 1982/83 was a very favourable one, and the residual effects that may have confused results in the preceding seasons appeared to have been substantially reduced. Therefore there was a better response to fertilizer than had been experienced in preceding seasons. Increases in yields in response to the heavier fertilizer applications were more than sufficient to cover the costs. Both maximum yields and maximum net benefits were obtained from the 104–20 treatment (Fig. 3F). Net benefits were increased by KSh. 3,298 at a cost of KSh. 2,170, yielding a return of 152% for the added risk. The 104–0 and 78–20 treatments were feasible alternatives but net benefits were sharply lower and costs only slightly less than the optimum. The latter two options yielded returns of 145 and 133% respectively. The 26–20 treatment produced net benefits only moderately lower than the 104–0 and 78–20 treatments, but costs were substantially lower and the rate of return was 245%. The 26–0 and 0–20 treatments would be feasible options for farmers with limited resources.

Most farmers who are not restricted by available capital or credit and who can absorb considerable risk will prefer the combination of fertilizer that will produce maximum net benefits. However, many farmers who have very limited capital or credit available and who cannot afford the risks of substantial losses in a single season may prefer, or be forced to choose, a level of fertilizer application that is considerably below that which would return the maximum net benefit. The great variation in the optimum fertilizer application from season to season indicates the difficulty confronting a farmer in deciding on the

best application for his own situation. In the two seasons of very limited rainfall, any application of fertilizer would have reduced net benefits. In the very favourable season of the short rains of 1982/83, the application of 104—20 would have produced maximum net benefits.

The application of 52—20 each season would have produced the maximum net benefits for the entire period (Fig. 3G). Losses in net benefits of KSh. 1,242 would have occurred from the application of this treatment in the short rains of 1980/81, and of KSh. 574 in the short rains of 1981/82. This latter loss was more than offset in the following season, when no fertilizer was applied and only residual benefits were derived. However, for the seven seasons as a whole, net benefits would have averaged KSh. 826 more than the control and would have yielded a rate of return of 89%. In contrast, if the maximum optimum application for the short rains of 1982/83 of 104—20 had been applied in each of the seven seasons, incremental net benefits would have averaged only KSh. 61 more than the benefits derived from the control, and the rate of return would have been 4% for the very substantial risk involved.

The 52—0 and 26—20 treatments would be viable options for farmers with limited cash resources or who preferred somewhat lower risks. Costs would have been 20 or 25% lower than the optimum, but net benefits would have been reduced only 12 or 23%. For farmers with extremely limited cash and wishing for the maximum return for a very limited investment, the 0—20 treatment would be the preferred alternative. In all but the two very dry seasons, the application of only 8.75 kg of P gave a substantial increase over no fertilizer, which may be an indication of incomplete removal of residual nitrogen. Net benefits averaged KSh. 508 for the seven-season period, and costs averaged only KSh. 283, with the rate of return averaging 180%.

An increase in the relative price of maize by 50% would almost double the rate of return, but the same combinations of applications would continue to be the only economically viable options to no fertilizer application. A reduction of 50% in the relative price would reduce net benefits of all applications, except for the 0—20 treatment, to about the level of no fertilizer application.

SUMMARY

This study was conducted for seven seasons to determine the optimum levels of nitrogen and phosphorus fertilizer applications for maximum maize production and economic returns under the soil and environmental conditions prevalent at Katumani. The experimental results indicated that rainfall conditions are the factors most influencing maize yield response to fertilizer applications. Maize yields varied significantly from one season to another in response to variations in rainfall conditions. The overall yield averaged more than 3,000 kg/ha for seasons with adequate rainfall, and only 653 kg/ha for drought seasons. During drought seasons, the maize crop did not utilize all the applied fertilizer and most of it was left behind in the soil after harvest. It was found that the nitrogen fertilizer left behind in the soil was not subjected to degradation or leaching and stayed almost intact until it was utilized by the following maize crop. These findings suggest that it is not necessary to apply fertilizers to crops grown in the rainy season following a drought. By not applying fertilizers following a drought, the soil-nutrient residues could be maintained at a minimum and at the same time crop-production levels would not be reduced. Soil-nutrient residues and drought conditions, which caused a new accumulation of nutrients in the soil, affected the experimental results by confounding the response of maize yields to the applied fertilizers; maize yield responses to applied nitrogen-fertilizer levels were masked in the first season. The residual effect of nitrogen in the soil was continually reduced in the following seasons, except when new residues were built up following a drought season. On the other hand, maize yield responses to applied levels of phosphate fertilizer continued to be masked throughout the duration of the study. Although yield responses to phosphate fertilizer levels were not significantly different from the control, there was a constant and positive yield response to phosphate application, especially at 8.75 kg/ha. This may be an indication that under Katumani conditions 8.75 kg P/ha was an essential nutrient requirement for optimum maize production. Economic analysis showed that the application of 52—20 each season would have produced the maximum net benefits for the entire period of the study. For the seven seasons as a whole, net benefits would have averaged KSh. 826 more than the control and would have yielded a rate of return of 89%. The 52—0 and 26—20 treatments would be viable options for farmers with limited cash resources. For farmers with extremely limited finances, the 0—20 treatment would be the preferred

alternative. The positive response to the application of phosphate fertilizer without nitrogen application may be an indication that the soil-nitrogen residue was still high enough to be mobilized by the addition of the phosphate fertilizer. An increase of 50% in the relative price of maize would almost double the rate of return, but the same combinations of fertilizer applications would continue to be the only economically viable options to applying no fertilizer. A reduction of 50% in the relative price would reduce the net benefits of all applications, except for the 0—20 treatment, to about the level of no fertilizer application.

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MAIZE YIELD RESPONSE TO ROW SPACINGS AND POPULATION DENSITIES UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

H. M. Nadar[1]

INTRODUCTION

Maize yield per unit area of land is highly dependent upon plant population, plant geometry, and fertility levels. Average maize yields produced by the farmers in the Machakos area are very low. A survey conducted by the Integrated Agriculture Development Programme (IADP) in the Kenya Ministry of Agriculture during the long rains of 1977, when rainfall was not limiting for maize production, indicated that average maize yield in the area ranged between 240 and 750 kilograms per hectare. The average maize population planted by the farmer in the area was around 20,000 pl/ha. Giesbrecht (1969) reported that row spacings between 50 and 95 cm had no significant effect on maize yield, while increasing the population from 30,000 to 75,000 plants per hectare resulted in a substantial increase in yield under adequate moisture conditions. Under less than adequate moisture conditions, peak production occurred at 60,000 plants per hectare. Mannering and Johnson (1967) reported that soil erosion on fields of maize planted at narrow row spacing (51 cm) was 24% below that on fields planted on widely spaced rows (102 cm). Nunez and Kamprath (1969) reported optimum maize production at 51,750 plants per hectare. They found no significant effect of row spacing on yield except under drought conditions, when 53 cm rows gave higher yields than 106 cm rows. Moll and Kamprath (1977) found that increased population density resulted in higher yields. In a previous study, conducted in the long rains of 1978, it was found that maize yields increased significantly with decrease in row spacing at one plant per hill (Nadar, 1983). At two plants per hill, maize planted at 75 cm row spacings with about 70,000 plants per hectare yielded the highest. As population was not constant at the different row spacings, it was not possible to separate the effect of row spacings from that of population.

This report will discuss the results of population studies conducted in three localities in three seasons to evaluate the effect of population densities and row spacings on maize yields under different environmental conditions.

MATERIALS AND METHODS

The first phase of this study was undertaken during the short rans of 1978–79 at both the Dryland Farming Research Station at Katumani and the substation at Kampi ya Mawe. The Katumani station is located 10 km south of Machakos town in the Machakos District of eastern Kenya, with centre co-ordinates 1°35′S and 37°14′ E and an altitude of 1,575 m. The Kampi ya Mawe substation is located 5 km south-east of Makueni town in the same District, with centre co-ordinates 1°50′ S and 37°40′ E at an altitude of 1,125 m. Because of its lower altitude, the Kampi ya Mawe substation has a mean temperature 5°C higher than that at Katumani. The soil in both localities is well drained dark reddish-brown, sandy clay. It is classified as Oxic Paleustalf (Chromic Luvisol). It has relatively low water-storage capacity and medium depth; the average depth is 120 cm with a total water-storage capacity of 100 mm. The rainfall during the 1978–79 short rains in both localities was relatively high (more than 500 mm) and of even distribution. Maize (*Zea mays* L., Katumani Composite B) was planted on 30 October 1978 in rows either 0.60, 0.75, or 0.90 m apart and 10 m long. The spacing within rows was 0.30 m. At the time of planting, maize was seeded in excess and then thinned to either one or two plants per hill.

During the long rains of 1982 and the short rains of 1982–83, this study was repeated at Katumani station only, and was modified in such a way as to allow the separation of the row-spacing effect from that of population. Within each row spacing the population was varied by varying the spacing within the row. The rainfall during the long rains of 1982 was low, of short duration and uneven distribution, while that of the short rains of 1982–83 was the reverse (Fig. 1).

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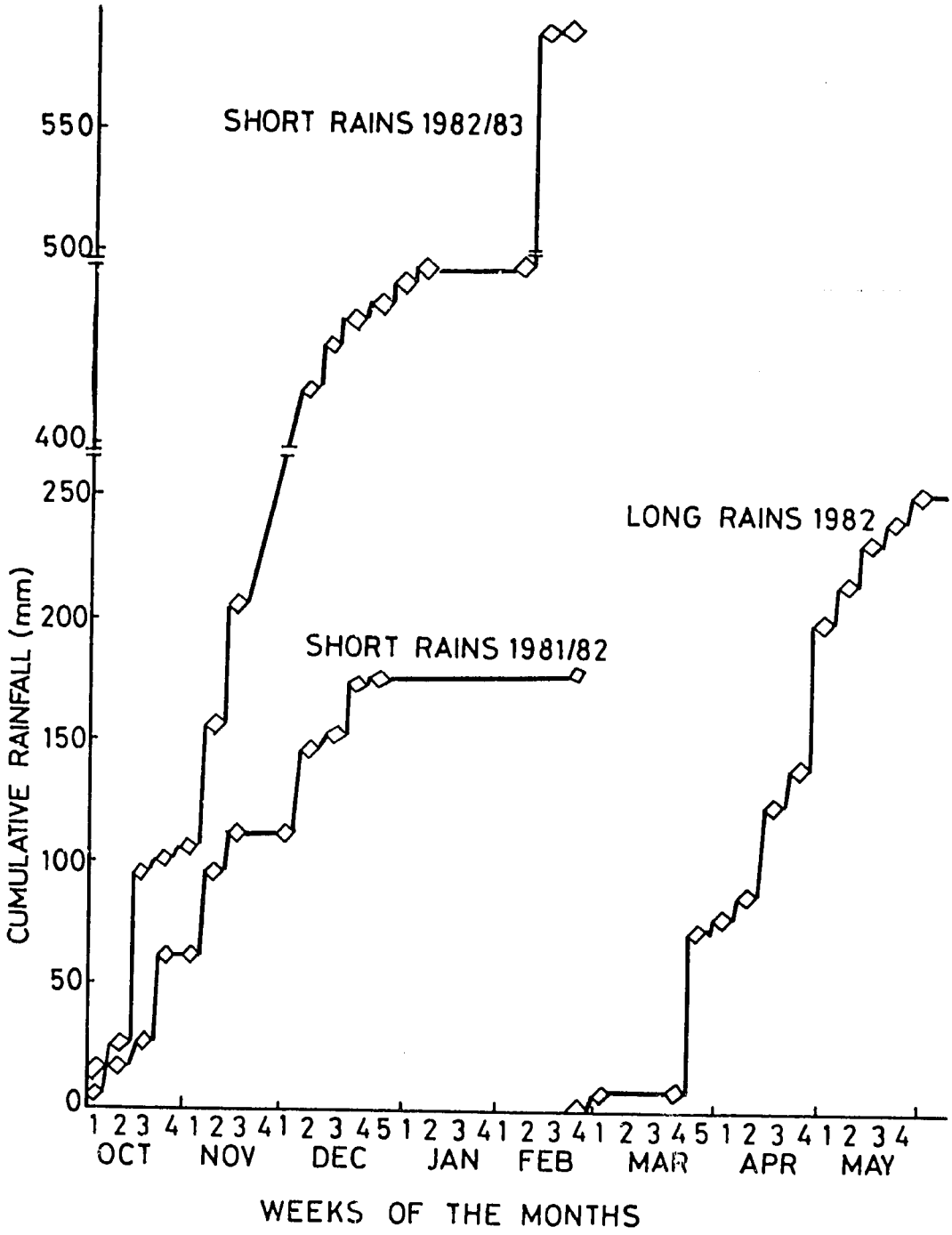

Fig. 1. Rainfall weekly totals and cumulative seasonal totals at Katumani meteorological station for the short-rains seasons of 1978/79 and 1982/83 and long-rains season of 1982

During the long rains of 1981 the response of the cultivar Katumani Composite B to population density under Muguga conditions was compared with that of a local cultivar widely grown in the area as well as with an Embu hybrid recommended for the Muguga environment (HI512). This experiment was planted at the experimental farm of the Kenya Agriculture Reseach Institute at Muguga, 40 km west of Nairobi, with centre co-ordinates 1°13′ S and 36°38′ E and at an elevation of 2,085 m, or 490 m higher than the Katumani station The mean temperature at the Muguga farm is lower than that at Katumani. Rainfall was relatively high, almost evenly distributed, and of relatively long duration (Table I).

TABLE I—MONTHLY RAINFALL TOTALS AND MEAN TEMPERATURES AT MUGUGA METEOROLOGICAL STATION DURING THE YEAR 1981

Month	Rainfall (mm)	Mean temperature (°C)
January	4.5	16.6
February	2.3	17.7
March	81.6	17.2
April	412.0	15.8
May	212.5	14.9
June	18.1	13.9
July	22.1	12.3
August	39.3	13.6
September	43.0	14.5
October	34.9	15.8
November	32.7	15.9
December	61.9	15.7

Each different population was harvested separately, the population count was converted to plants per hectare and the yields were converted to tons/ha at 15.5% moisture content. Both linear and second-order polynomial regressions of yields on population were determined for each row spacing.

RESULTS AND DISCUSSION

The results of the row-spacing and number-of-plants-per-hill studies during the short rains of 1978/79 at both Katumani and Kampi ya Mawe (Table II) were similar to those of the previous study during the long rains of 1978 (Nadar, 1983). Both row spacing and number of plants per hill had a significant effect on maize yield, while the locality effect was not significant. Maize planted at 60 and 75 cm row spacing yielded significantly higher than that planted at 90 cm row spacing, and two plants per hill yielded significantly higher than one per hill. There was no significant difference in yield of maize planted at 60 or 75 cm spacing. Yield was highly correlated with population and the relationship was almost linear. The difference between this correlation relationship and that of the experiment during the long rains of 1978 may result from the fact that the maize population in the 60 cm row spacing was not as high as it was during the long rains of 1978. The highest population in the short rains of 1978—79 was 75,200 plants per hectare, while it was 92,400 in the long rains of 1978. Seventy thousand plants per hectare probably represents the optimum population under the conditions of the experiments and the non-linear relationship would be expected to show itself beyond this point. The consistent increase in yields of maize planted at 60 or 75 cm row spacings over that planted at 90 cm row spacing might be ascribed to either population or to the change in population geometry caused by the change in row spacing, or perhaps both. Field observations indicated that 60 and 75 cm row spacings provided better population geometry than 90 cm spacing, giving faster ground cover and better light interception.

When the data from both seasons were combined, which offered 3 times as many data points as were available from the long-rains 1978 results, and the second-order polynomial regression of maize yield on population was determined, it was found that the relationship between yield and population was curvilinear, with relatively high coefficients of determination (R^2). The highest R^2 was that of 75 cm row spacing (0.691) followed by 90 cm (0.524), while the R^2 of 60 cm row spacing was 0.291. Their prediction equations were as follows:

90 cm $Y = -0.3788 + 0.1668X - 0.0012X^2$
75 cm $Y = 2.3912 + 0.2186X - 0.0013X^2$
6 cm $Y = -2.8431 + 0.2296X - 0.0015X^2$

The points of deflection of the regression lines were all beyond the 65,000 plants per hectare count and were different for each row spacing. While the point fell between 65 and 70 thousand plants per hectare for 90 cm spacing, it was between 75 and 85 thousand plants for the 60 cm spacing and between 80 and 90 thousand for the 75 cm row spacing (Fig. 2). It was also observed that the 90 cm row spacing was best for populations lower than 40,000 plants per hectare.

TABLE II—YIELD RESULTS IN TONS PER HECTARE AND POPULATION COUNTS IN THOUSAND PLANTS PER HECTARE OF MAIZE ROW-SPACING AND NUMBER-OF-PLANTS-PER-HILL TRIALS AT KATUMANI AND KAMPI YA MAWE STATIONS DURING SHORT RAINS 1978/79

	Katumani				Kampi ya Mawe					
	One plant		Two plants		One plant		Two plants		Average yields	
Row spacing	Pop.	Yields	Pop.	Yields	Pop.	Yields	Pop.	Yields	1 Pl. yields	2 Pl. yields
60 cm	52.0	5.472	75.2	6.391	48.6	5.329	62.6	6.107	5.396[b]	6.270[a]
75 cm	43.3	5.193	64.1	6.387	42.9	4.993	52.5	6.158	5.107[bc]	6.288[a]
90 cm	41.3	4.615	53.5	5.805	33.0	4.490	48.9	5.153	4.581[c]	5.526[b]

*Letter following yield value indicates that it is significantly different from other values followed by different letters at the 10% level of confidence according to LSD mean comparison test.

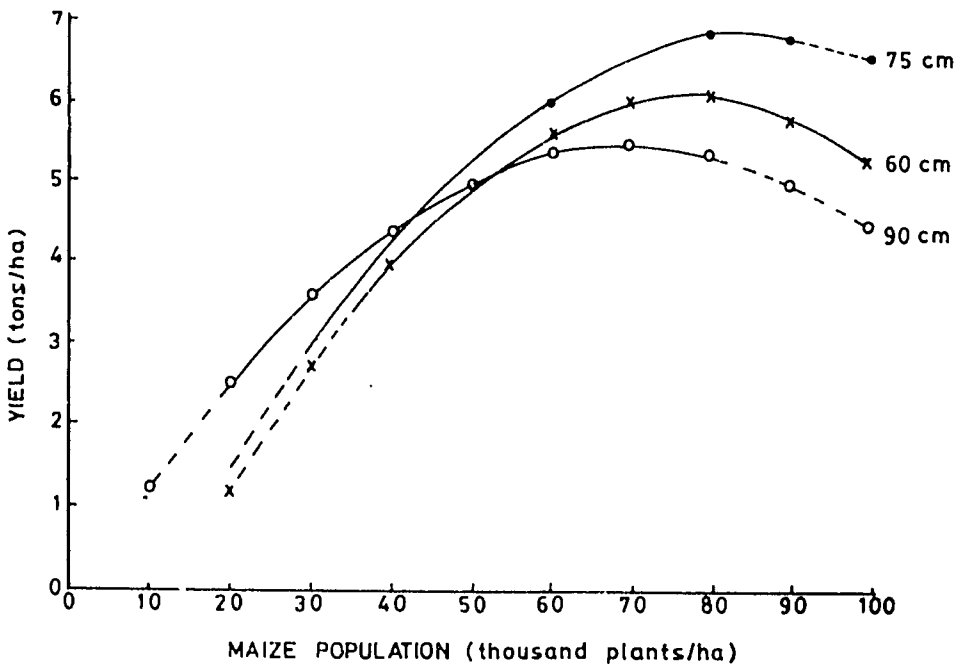

Fig. 2. Second polynomial regression lines of maize yields on poulations at three row spacings of the experiments conducted during long rains 1978 and short rains 1978/79 at Katumani and Kampi ya Mawe research stations

At forty thousand plants per hectare or higher, 75 cm row spacing was best, while 60 cm spacing was always poorer than 75 cm. It was better than 90 cm only at populations higher than 50,000 plants per hectare. When the homogeneity of the regression coefficients was tested they were found significantly different, with a calculated F value of 5.917 with 2 and 114 degrees of freedom.

This study was conducted under favourable conditions, with the rainfall during both seasons totalling more than 500 mm. The range of popula-

tion was not wide enough to cover both ends of the population spectrum, as can be seen from the broken lines in Fig. 2. These lines are an extrapolation of the part of the population spectrum not covered in the study. During the long rains of 1982 this study was repeated, using the same row spacings but with a wider range of populations at each row spacing. The population range was from 10,000 plants to more than 130,000 plants per hectare. During this season, total rainfall was low (245 mm) and the rains were too late for good maize production (start on 29 March). The results (Fig. 3) indicated that under the conditions of the long rains of 1982 at the Katumani station, the maize yield response to population was mainly negative. Only the R^2 for the 90 cm yield regression on population was increased significantly when the second polynomial regression was determined. Both linear and second-order polynomial prediction equations and R^2s are listed in Table III. It is of interest to note that while 90 cm row spacing was favourable to low populations under adequate rainfall, and 75 cm row spacing was favourable to higher populations, it was the reverse under less than adequate rainfall. At 90 cm spacing, yields increased with the increase in population up to 40,000 plants per hectare, where the regression line reached its point of deflection. Beyond that point the decrease in yield was much slower than that of the 60 or 75 cm regression lines. The regression coefficients were significantly different, with a calculated F value of 4.792 with 2 and 139 degrees of freedom.

During the short rains of 1982—83, although amounts were high, there was virtually no rain during the six weeks preceding the middle of February. After this drought period and about two weeks before the crop reached physiological maturity, 86 mm of rain fell on 15 February, followed by an unusually strong wind. This resulted in the lodging of most of the maize plants. The lodged plants did not benefit from the rains and had to be harvested prematurely, and yields were lower than expected as compared with those of previous seasons with similar rainfall conditions. It was not possible to quantify the yield losses which may have resulted due to that weather situation. These yield losses may have

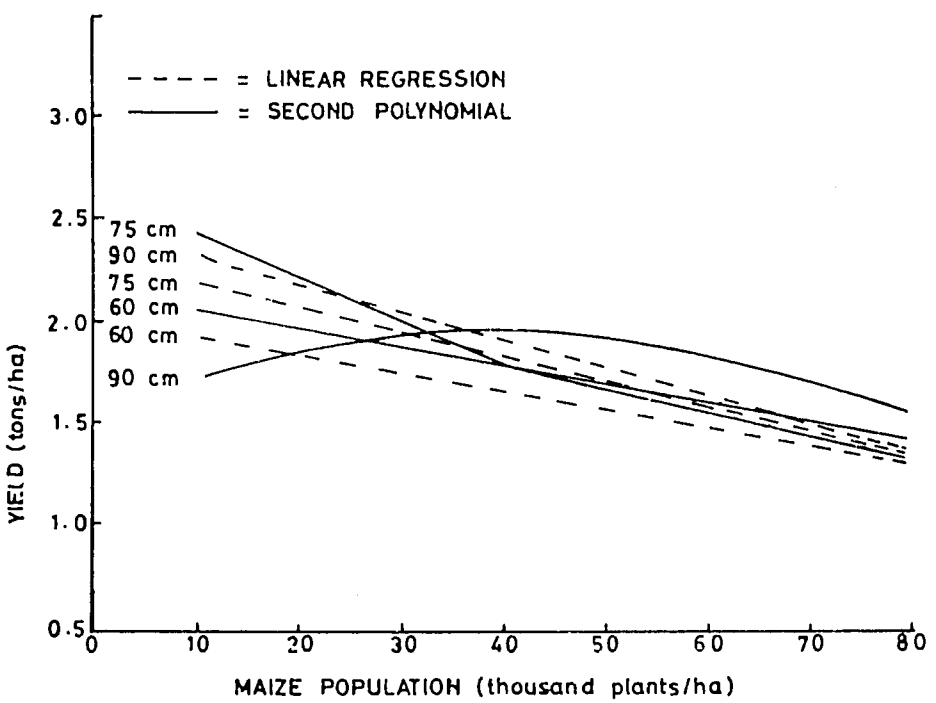

Fig. 3. Linear and second-order polynomial regression lines of maize yields on populations at three row spacings of the study conducted at Katumani Research Station during the long rains of 1982

TABLE III—PREDICTION EQUATIONS AND THEIR RESPECTIVE COEFFICIENTS OF DETERMINATION (R^2) OF LINEAR AND SECOND-ORDER POLYNOMIAL REGRESSIONS OF MAIZE YIELDS ON POPULATIONS FOR THE ROW SPACING BY POPULATION STUDY DURING THE LONG RAINS OF 1982

	Linear regression		Second-order polynomial regression	
Row spacing	Prediction equation	R^2	Prediction equation	R
90 cm	$y = 2.4502 - 0.0132X$	0.315	$y = 1.5464 + 0.0196X - 0.0003X^2$	0.438
75 cm	$y = 2.3145 - 0.0116X$	0.333	$y = 2.6782 - 0.0253X - 0.0001X^2$	0.365
60 cm	$y = 1.9819 - 0.007X$	0.130	$y = 2.1874 - 0.0111X + 0.00002X^2$	0.172

been responsible for the relatively low yields and coefficients of determination (R^2). They were 0.231, 0.330, and 0.350 for 90, 75, and 60 cm row spacings respectively. The prediction equations are:

90 cm $Y = 1.124 + 0.0653X - 0.000416X^2$
75 cm $Y = 1.229 + 0.0698X - 0.000379X^2$
60 cm $Y = 2.333 + 0.0085X - 0.000056X^2$

Yields at the 60 cm row spacing continued to increase with the increase in population, but at a rate which was much slower than that at 75 or 90 cm spacings up to 80 thousand plants per hectare, where yields started to decrease with the increase in population, except at 60 cm row spacing, when they continued to increase (Fig. 4). The 90 cm curve deflected at 80,000 plants per hectare, while the 75 cm curve deflected at 90,000. This was similar to previous results under favourable rainfall conditions (short rains of 1978–79). Yields at 75 cm row spacing were higher than those at 90 cm spacing at all population levels, and the gap between the two curves increased with the increase in population counts.

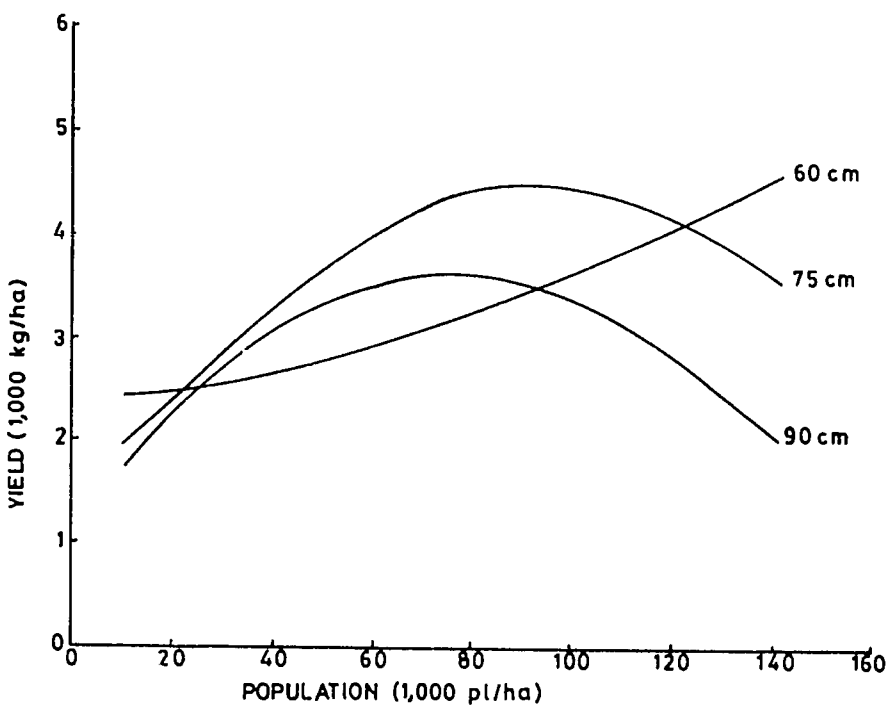

Fig. 4. Second-order polynomial regression lines of maize yields on populations at three row spacings of the study conducted at Katumani Research Station during the short rains of 1982/83

The results of the studies conducted during the seasons long rains 1978, short rains 1978–79, long rains 1982, and short rains 1982–83 indicated that there was a significant effect of row spacings on maize yields at any given population level. The effect of row spacing on yield was influenced by population levels, as well as by the rainfall conditions. Under favourable rainfall conditions, and at population levels below 40,000 plants per hectare, either there was no difference between yields of maize planted at 90 or 75 cm spacings, or those planted at 90 cm yielded higher. At populations higher than 40,000 plants per hectare, maize planted at 75 cm produced significantly higher yields. Under unfavourable rainfall conditions, maize planted at 75 cm produced higher yields than that planted at 90 cm when the population was below 40,000 plants per hectare. At populations higher than 40,000 plants per hectare, maize planted at 90 cm spacing yielded higher. Considering the overall results, it can be concluded that planting maize at 75 cm row spacing would optimize yields under almost all rainfall conditions tested. The optimum population to be planted at 75 cm row spacing under favourable rainfall conditions would be between 70 and 80 thousand plants per hectare. Under less-than-favourable conditions, 20,000 plants per hectare or less would produce the highest yields. These findings suggest that if the quality of the rainy season could be predicted with a 100% probability of success, reducing plant population from 70 to 20 thousand plants per hectare in the season with rainfall conditions similar to that of the long rains of 1982 would result in an increase in yield of 0.45 tons per hectare, or an increase of about 30%. If the prediction of a drought season was wrong, the expected losses from reducing the population would be substantial. Under the conditions of the short rains of 1978–79, reducing the population from 70,000 to 20,000 plants per hectare would have reduced yields from 6,000 kg/ha to 1,500 kg/ha, or a loss of 4,500 kg/ha. Under the conditions of the short rains of 1982-83, the loss would have been 2,000 kg/ha. Under both rainfall conditions, maize yields at 20,000 pl/ha were approximately 2,000 kg/ha. Planting maize at 20,000 pl/ha might be one way of stabilizing yields under a wide range of rainfall conditions, but it is doubtful whether it would be economical in the long run. From the information accumulated during this study, it seems to be more economical to plant at the higher populations, even if unfavourable rainfall conditions occurred 50% of the time. In two seasons, one with favourable rainfall conditions and the other unfavourable, we would get 2 + 2 = 4 tons of maize from one hectare if we planted 20,000 plants per hectare in both seasons. If we planted 70,000 plants per hectare in both seasons, we would get 5.25 + 1.55 = 6.8 tons with almost the same farm inputs. That is an increase of 2,800 kg, or an average of 1,400 kg/ha per season. Another alternative is predicting the quality of the rainy season and reducing the population if an unfavourable season is predicted. For the population-adjustment method to have an advantage over planting 70,000 plants per hectare each season, the prediction of the quality of rainfall has to have a 100% probability of success. Using the data accumulated from these experiments it was estimated that if the quality of the rainy season was predicted successfully 100% of the time, adjusting the population would give a 9% advantage over planting constant populations. If the prediction failed once in six times, the two systems would have equal production. If the failure was once every three times, which is more realistic, planting 70,000 plants per hectare constantly would yield 11% higher than the total production if the populations were adjusted according to the prediction of the quality of the rainfall. If the success of the prediction was 50%, total production from the varied population would be 31% less than that from the constant population.

The results of the population study at Muguga during the long rains of 1981 (Fig. 5) indicated that the Katumani maize was not adapted to higher-elevation environments, and was outyielded by both HI512 and the local cultivar. The yield of HI512 exceeded that of Katumani Composite B by about 700 kg/ha at all population levels, which indicated that both cultivars responded in the same manner to population changes and attained their maximum yields at about 70,000 pl/ha. The local cultivar yielded higher than both the other two at population levels between 30 and 50 thousand pl/ha. Above 50,000 pl/ha, the yield of the local cultivar started to drop sharply, until it reached a level 1,400 kg/ha below that of HI512 and 700 kg/ha below that of Katumani Composite B at the 80,000 pl/ha level. The local cultivar response indicated that it was less tolerant of population pressure than the other two tested cultivars. This is an indication that each maize cultivar has an optimum population level at which its yield will be highest. This optimum population level may not be the same for all cultivars, and should be

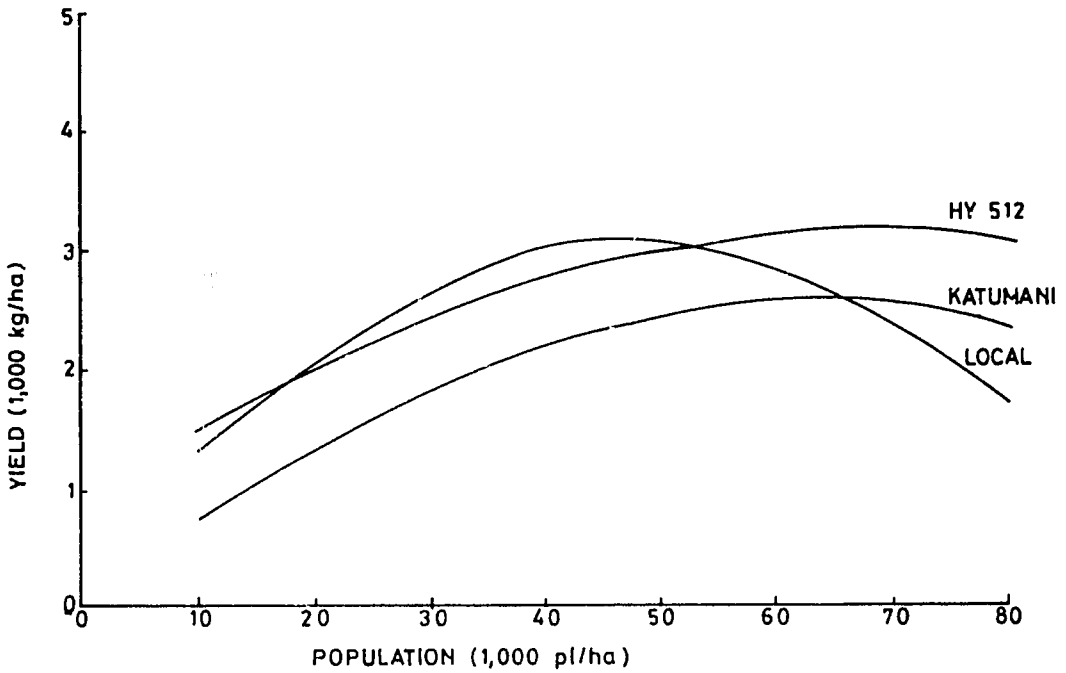

Fig. 5. Second-order polynomial regression lines of maize yield on populations of the study conducted at Muguga Research Station during the long rains of 1981 with three different cultivars

determined before comparing the yield performance of different cultivars. These differences in response to population pressure may have been due to the populations and environments under which the original selection of the cultivar was done. While yields of both Katumani Composite B and HI512 peaked at 70,000 pl/ha, yields of Katumani Composite B were significantly lower than those of HI512. Probably because Katumani Composite B was developed under the relatively higher temperatures of the Katumani area, it lacked the ability to tolerate the higher elevation and colder temperatures of the Muguga area, while the other two cultivars tested were more adapted to Muguga conditions at their optimum populations. It can also be concluded that there was no significant yield difference between the local cultivar and HI512 at their respective optimum populations. Planting the local cultivar at 45,000 pl/ha and HI512 at 70,000 pl/ha is expected to result in almost equal yields. The advantage of HI512 over the local cultivar would show only if both cultivars were planted at higher levels than 50,000 pl/ha. If both were planted at populations less than 50,000 pl/ha, the local cultivar would yield higher. This clearly indicates that maize-variety selection should be performed under the actual conditions the selection is meant for, whether for sole cropping, intercropping, tolerance of population pressure, or any other adverse environmental condition for that matter.

SUMMARY

This study was conducted in three localities for several seasons with different rainfall conditions, in order to study the effect of population densities and row spacings on maize yields as influenced by the different environments. The results indicated that there was a significant effect of row spacings on maize yields at any given population density. These effects were influenced by population levels as well as by the rainfall conditions. It was found that planting maize at 75 cm row spacing would optimize maize yields under almost all rainfall conditions tested. The optimum population to be planted under favourable rainfall conditions was found to be around 70,000 plants per hectare. Under less-than-favourable conditions, 20,000 plants or less would produce the highest yields. Prediction of

the quality of the rainy season and reduction of the plant population would help maximize the farmers' income. Based on the data accumulated from this study, it was found that there would be no benefit to be gained from predicting the quality of the rainy season and reducing the populations from 70 to 20 thousand plants per hectare except in the case of 100% probability of success. If the prediction failed more than one season in every six, substantial losses would occur. The results of the study at the Muguga station showed that each maize cultivar had an optimum population level and optimum environment at which its performance would be best. These optimum levels may be different for different cultivars, and should be determined before comparing cultivars in yield-performance studies.

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INTERCROPPING AND INTERCROP COMPONENT INTERACTION UNDER VARYING RAINFALL CONDITIONS IN EASTERN KENYA. I: MAIZE/BEAN INTERCROP

H. M. Nadar [1]

INTRODUCTION

Intercropping is an old practice of subsistence farmers, especially under rainfed conditions, and the farmers in the Machakos area of eastern Kenya are no exception. An economic survey of the area (M.O.A., 1981) reported that almost all farmers practised mixed cropping, especially during the short rains. Intercropping was reported to provide several crops and thus to result in a balanced diet. It also reduces peak labour demand and minimizes crop-failure risks (Jodha, 1981). Okigbo (1981) suggested that intercropping reduced the adverse effects of pests, provided higher returns, and protected soil against erosion. Research on intercropping presents a challenge in the developed countries, where chemical weed control and mechanical harvesting are integral parts of successful farming. These problems do not confront intercropping research in Kenya and are not likely to in the near future, since farming in Kenya depends mainly on animal power and hand labour.

Many recent reports have indicated the superiority of intercropping over sole crops. Francis (1978) reported that maize-and-bean associated cropping systems provided the highest net incomes. Singh (1981) reported 8 to 34% sorghum yield increases in sorghum/legume intercrop systems over the sole crop. Lima and Lapes (1981) reported land equivalent ratios (LERs) in maize/bean intercrops higher than those of sole crops at all populations and spatial arrangements tested. Gardiner and Craker (1979) found that bean yields were decreased in maize/bean intercrop, mainly due to reduction in the number of pods per plant. Crookston and Hill (1979) found that Minnesota land-use efficiency was not improved by intercropping.

Several methods have been used to evaluate intercrop yield advantages over sole crops. None of these methods individually can evaluate all the factors involved, such as competitive effects, relative production potentials of the intercrop components, labour requirements, water- and nutrient-use efficiency, or social and economic impacts. All these factors have to be taken into consideration, and this requires a team effort involving agronomists, crop physiologists, soil scientists, agricultural economists, and social scientists. Snaydon and Harris (1981) focused on below-ground interactions to evaluate plant competition for water and nutrients. Willey (1981) used LERs as measures of intercrop yield advantages and as indicators of competition effects. LERs provide a basis for comparing different crops and crop mixes. Hiebsch (1978) argued that LER was not an accurate technique for comparing the relative production potentials of the intercrop and sole-crop systems because it did not take into account the variations in the length of the growing seasons of the different crops. He suggested the use of what he called an area/time equivalency ratio (ATER), redefining yield as quantity/unit area/unit time. Okigbo (1981) suggested the use of LERs, competition coefficients, relative yields, calorie equivalents, and gross returns as indices for selecting efficient crop mixtures.

The present study was started in the short-rains season of 1978/79 with the object of studying the performance of both maize and beans in sole-crop and intercrop systems with different populations, spatial arrangements, and fertility levels as influenced by the varying rainfall conditions prevalent in the study area.

MATERIALS AND METHODS

The experimental site was located at the National Dryland Farming Research Station, Katumani, 10 km south of Machakos Town, in the Machakos District of Eastern Province, Kenya. It has centre co-ordinates 1° 35′ S and 37° 14′ E and an altitude of 1,575 m. The soil was a well drained, dark reddish-brown sandy clay. It is classified as Oxic Paleustalf (Chromic Luvisol). The average depth was 120 cm, with a total water-storage capacity of 100 mm. The rainfall is

1. USAID/Kenya Agricultural Research Institute, Muguga

bimodal, with two rainy seasons known as the short rains (October to December) and the long rains (March to May). Total rainfall and its distribution are highly variable. Total rainfall per season during the duration of this study ranged between 175 mm and more than 500 mm (Fig. 1).

Maize (*Zea mays* L., Katumani composite B) and beans (*Phaseolus vulgaris* L., var. Mwezi Moja) were planted in plots of either 6, 8 or 10 rows spaced 0.90, 0.75 or 0.60 m apart and 10 m long, and were either intercropped or planted separately as sole crops. The intrarow spacings were 0.30 m for maize in both sole-crop and intercrop systems. For beans, it was 0.15 m in both systems except when beans were intercropped on the same row with maize, in which case the spacing between two bean plants was 0.30 m and between a maize plant and a bean plant next to it 0.15 m. Ten to 15 days after emergence, plants were thinned to either 1 or 2 plants per hill.

In the short rains of 1978/79 maize and beans as sole crops were tested at the three row spacings and at 1 or 2 plants per hill. In the intercrop systems maize and beans were planted at the three row spacings at populations equal to those of 1 plant per hill sole crop. The maize arrangements in the intercrops were either 1 plant per hill, 0.30 m apart on each row or 2 plants per hill, 0.30 m apart on every other row. Bean arrangements in the intercrop systems were 2 plants per hill, either 0.30 m apart on each row or 0.15 m apart on rows alternating with the maize rows. In subsequent seasons intercropping experiments were planted at 0.75 m row spacing only. During the short rains of 1978/79 and the long rains of 1979, maize was planted in the intercrop systems at half the two-plant-per-hill sole-crop populations, or the maize/bean population relationship was 0.5:0.5. This population relationship between the intercrop components will be referred to as substitution (Sub). During the short rains of 1979/80 the population relationship in the intercrop systems was either Sub or the maize was planted at 2 plants per hill on each row (the same population as in the sole crop) and the beans at half the sole-crop population, resulting in a 1.0:0.5 maize:bean population relationship in the intercrop system. This population relationship will be referred to as addition (Add). In subsequent seasons intercrops were tested at only the Add population relationships.

The fertilizer application rates were 17.5 kg P/ha for all crops and 70 kg N/ha for sole-crop and intercrop maize, except during the short rains of 1979/80 and the long rains of 1981, when intercropping was also tested with no nitrogen fertilizer. In that case maize received only phosphate fertilizer at the above rates. Fertilizers were side dressed immediately following thinning at 10 to 20 days after emergence.

The experimental design was a randomized complete block with three replications. Where other variables were tested, it was a factorial within the randomized complete block. Maize yields were adjusted to 15.5% moisture content, while bean yields were adjusted to 14%. Yields were then adjusted to variation in actual counts of population using the covariance method, except in the case where variation in population was intentional. Land equivalent ratios were calculated as described by Willey (1981). These LERs were subjected to analysis of variance and mean comparisons.

RESULTS AND DISCUSSIONS

Results of the short rains 1978/79 (Table I) indicated that under the same environmental and cultural conditions, when rainfall is not limiting sole-crop maize yields can be increased on the average by 21% by planting 2 plants per hill instead of 1. The increase ranged between 17% at 0.60 m row spacing and 26% at 0.75 m. These results are similar to those from maize population studies (Nadar, 1983). In the same-row intercrop systems maize and bean yields were significantly higher than those in the alternate-rows system, except at the 0.60 m row spacing, where there was no significant difference between yield in the two systems.

In both systems the same populations were planted, and the difference was only in the spatial arrangements. While changing the relative distance between the plants did not cause much difference at the 0.60 m row spacings because of the closeness of the rows, it made a significant difference at the wider row spacings, which was expressed in the final yields. This is probably an indication that intracrop competition is much more severe than intercrop competition, especially at the 0.75 and 0.90 m row spacings. Partial LERs of the intercrop components were calculated as proportions of the sole-crop optimum yields. Optimum yields were found to be those of maize planted at 2 plants per hill, which is almost double the maize population in the intercrop. This resulted in about a 19% increase in total relative yields of the same-row intercrop over the sole crop, while the alternate-rows intercrop had a 7% yield advantage.

TABLE I—MAIZE AND BEAN YIELD RESPONSES TO ROW SPACING, NUMBER OF PLANTS/HILL AND INTERCROPPING AND THEIR RESPECTIVE LAND EQUIVALENT RATIOS DURING SHORT RAINS 1978/79

Row Spacings	60 cm			75 cm			90 cm			Average		
	Yield × 10^3 kg/ha			Yield × 10^3 kg/ha			Yield × 10^3 kg/ha			Yield × 10^3 kg/ha		
Treatment	Maize	Beans	LERs	Maize	Beans	LERs	Maize	Beans	LERs	Maize	Beans	LERs
Maize 2 pl/hill	6.392	—	1.00	6.387	—	1.000	5.806	—	1.00	6.195	—	1.00
Maize 1 pl/hill	5.472	—	0.86	5.069	—	0.790	4.749	—	0.82	5.097	—	0.82
Beans 2 pl/hill	—	2.138	1.00	-	1.788	1.000	—	1.825	1.00	—	1.917	1.00
Beans pl/hill	—	1.992	0.93	—	1.938	1.080	—	1.792	0.98	—	1.907	1.00
Maize + bean same row	4.477	0.992	1.16	4.447	0.933	1.180	3.973	0.921	1.19	4.299	0.949	1.18
Maize + bean alternate rows	4.556	0.937	1.15	3.838	0.743	1.101	3.674	0.758	1.05	4.023	0.812	1.06

Actually what was done was that to a given maize population, a certain population was added, of either maize or beans. The effect of the added population was to reduce yields per thousand plants of the original population, while nevertheless ending up in a higher yield per unit area because of the increase in the number of plants in that area. Comparing the effect of increasing the population by adding extra maize in the sole crop or adding a population of beans sheds some light on intra- versus inter-plant competition and can provide a more accurate measure of the intercrop advantage. Analysis of the 75 cm row-spacing results (Table II) indicated

TABLE II—A COMPARATIVE ANALYSIS OF THE SOURCE OF POPULATION INCREASE ON THE FERFORMANCE OF THE ORIGINAL MAIZE POPULATION IN THE SOLE-CROP AND SAME-ROW INTERCROP SYSTEMS AT 75 cm ROW SPACING DURING SHORT RAINS 1978/79

	Population × 10^1/ha				Relative yields		
Treatment	Original population	Added population	% Increase	Source of added population	Original population	Added population	Total
Maize sole-crop 1 pl/hill	43.5	—	—	—	1.00	1.00	1.00
Maize sole-crop 2 pl/hill	43.5	25.4	58	Maize	0.80	0.46	1.26
Intercrop with beans	42.3	93.0	220	Beans	0.88	0.48	1.36

that an increase in maize plant population of 58% resulted in decreasing the potential yield of the original populations by 20% but ended up in an overall relative yield increase of 26%. On the other hand, adding a population of beans equalling more than 200% of the original maize population reduced its potential yield by only 12% and ended up in an increase in relative yield of 36%. This indicated that the rate of competition between individuals of the same crop is much higher than that between plants of different crops, and increasing the population by intercropping resulted in competition levels about 10% lower than that caused by higher maize populations. Although this method of comparison seems to be more accurate in quantifying competition effect than the LER method, it is more laborious and requires the planting of two or more populations of sole-crop maize each time an intercrop experiment is conducted. LER provided an overall indication of the intercrop performance which was considered sufficient for the purpose of our study. The results of this study showed clearly the superiority of intercropping in the same row as compared to intercropping in alternate rows. This may be an indication either that the spatial arrangement of plants in the same-row system provided better light interception and reduced competition between the two crops, or that the same-row arrangement brought the maize and bean roots close enough together for the maize to benefit from the nitrogen fixed by the beans, or perhaps both. Agboola and Fayemi reported in 1972 that the three legumes, cowpea, calapo, and green gram were capable of excreting nitrogen into the soil, and the amounts excreted by cowpeas were estimated to be equal to 6.7 kg N/ha. Beans would be expected to have the same capabilities, and the effect of excreted nitrogen would be expected to express itself in the same-row intercropping spatial arrangement more than in the alternate-row arrangement. The excreted nitrogen would be expected to be localized, and the maximum distance the roots had to travel to benefit from the excreted nitrogen would be 15 cm in the same-row arrangement, as against 60 to 90 cm in the alternate-row arrangement. It is suspected that at least part of the maize yield difference between the two spatial arrangements may be caused by the effect of nitrogen excreted by the legume into the soil. An attempt to quantify the beneficial effect of the associated beans in different spatial arrangements under low-fertility conditions indicated that the rate of beneficial effect was positively associated with the proximity of the roots of the two intercrop components (Chui and Nadar, 1983). When maize and beans were planted in the same hill maize yields were 27% higher than those of the sole crop. When the maize and beans were 15 cm apart in the same row the yield increase was only 7%, but when planted in alternate rows maize yield was lower than that of the sole crop. This is a clear indication that the excreted nitrogen was almost immobile, and that the maize could not benefit from it if the site of excretion was more than 15 cm away from the maize plant.

Bean response to population change in the sole crop was not significant. It yielded almost the same when planted at either 1 or 2 plants per hill. A separate study of the effect of bean population on yield gave the same results. Bean response to population was tested at the row spacings 0.30, 0.40, 0.50, 0.60, and 0.75 m and at 0.05, 0.10, and 0.15 m intrarow spacings. These arrangements resulted in bean populations ranging between 114.5 and 638.9 thousand plants per hectare. Bean yields at these different population levels were not significantly different (Table III). Bean plants compensated for the decrease in population by a corresponding increase in both the number of pods per plant and the number of seeds per pod. Regression analysis of yield and number of pods per plant on population showed that there was no significant correlation between yield and population ($R^2 = 0.017$), while the correlation between number of pods per plant and population was negative and highly significant ($R^2 = 707$). The prediction equations given population X were:

$$Y_1 \text{ (yield)} = 1.4136 - 0.000289X$$
$$Y_2 \text{ (number of pods/plant)} = 9.7984 - 0.01406X$$

These results indicated that, within a certain range of population levels, bean plants do not significantly respond to changes in population and can counteract the change in population by an opposite change in the number of pods per plant, which keeps the potential bean yields at relatively constant values if no other environmental factors are limiting.

Yields of the long-rains 1979 experiment (Table IV) were generally lower and the intercrop advantage over the sole crop was very low (3%). The decrease in both maize and bean yields in the intercrop was very high. This was probably due to the spatial arrangement, which was in alternate rows, and to the competition between the intercrop components due to the long drought period which occurred during February and early March (Figure I). The experiment was relay planted on 8 February and no measurable rain

TABLE III—BEAN HARVEST RESULTS OF POPULATION STUDY DURING SHORT RAINS 1979 SHOWING POPULATION (THOUSAND PLANTS/HECTARE), AVERAGE NUMBER OF PODS/PLANT, AVERAGE NUMBER OF SEEDS/POD, YIELDS (× 10^3 kg/ha) AS AFFECTED BY ROW SPACING AND INTRAROW SPACING

	Intrarow spacings															
	5 cm				10 cm				15 cm				Averages			
Row spacing	Pop.	Pods/ Pl.	Sds/ Pod	Yield	Pop.	Pods/ Pl.	Sds/ Pod	Yield	Pop.	Pods/ Pl.	Sds/ Pod	Yield	Pop.	Pods/ Pl.	Sds/ Pod	Yield
30 cm	638.9	2.6	2.4	1.235	338.9	3.9	2.8	1.444	311.1	4.8	2.8	1.367	441.3	3.8	2.7	1.349
40 cm	468.8	3.3	2.6	1.436	304.2	4.7	2.5	1.371	206.3	6.9	3.3	1.535	326.4	5.0	2.8	1.447
50 cm	369.0	3.7	2.8	1.335	211.7	5.7	3.1	1.357	191.7	7.0	3.0	1.407	25.7.5	5.5	3.0	1.366
60 cm	286.1	4.7	3.0	1.310	175.0	7.4	3.1	1.315	169.4	7.8	3.1	1.472	210.2	6.6	3.1	1.366
75 cm	264.4	5.2	2.8	1.401	133.3	9.3	3.1	1.371	114.5	9.5	3.6	1.251	170.7	8.0	3.2	1.341
Ave.	405.4	4.3	2.7	1.343	[illegible]	6.2	2.9	1.372	193.6	7.2	3.2	1.406	282.2	5.8	3.0	1.374

TABLE IV—YIELDS AND LAND EQUIVALENT RATIOS OF MAIZE AND BEANS IN BOTH SOLE-CROP AND INTERCROP SYSTEMS PLANTED DURING LONG RAINS 1979

	Yields × 10^3 kg/ha		Partial LER		
Treatment	Maize	Beans	Maize	Beans	Total LER
Sole-crop maize	3.465	—	1.00	—	1.00
Sole-crop beans	—	0.807	—	1.00	1.00
Maize/bean intercrops	2.135	0.332	0.62	0.41	1.03

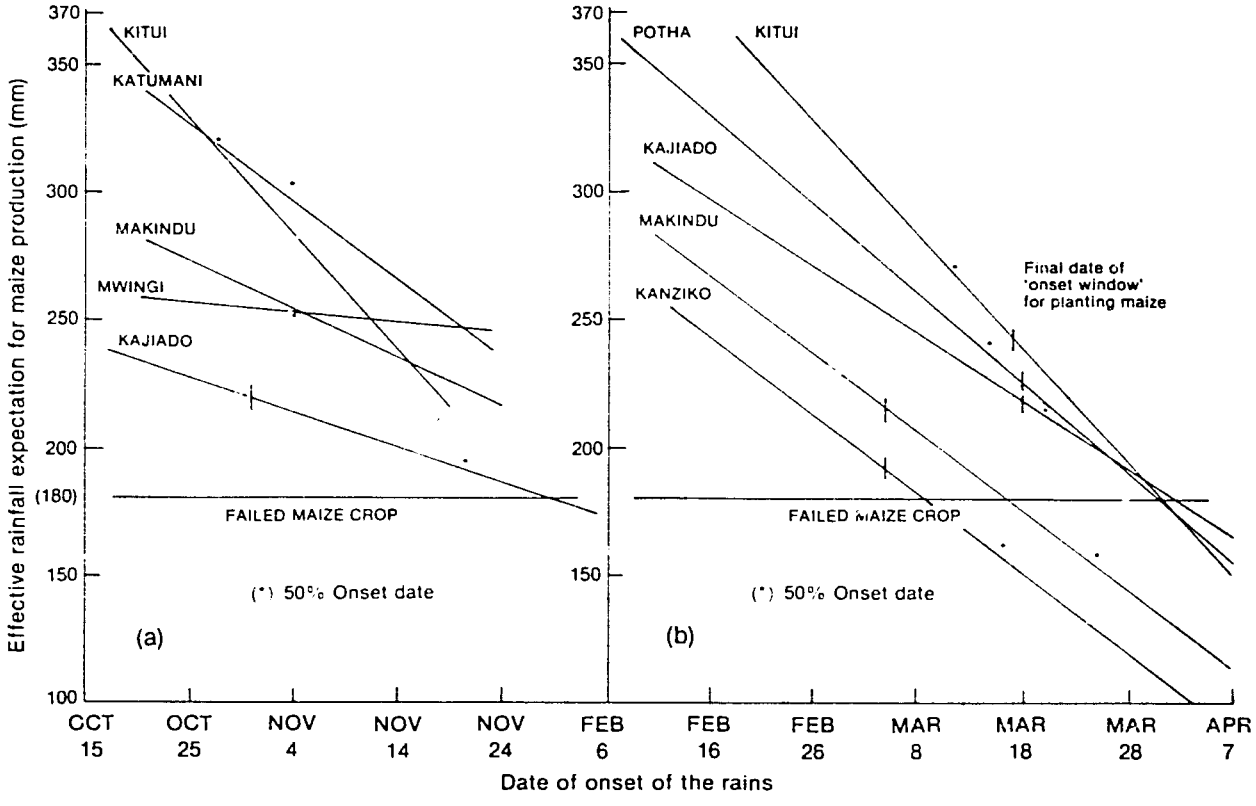
Effective rainfall expectation for maize production (mm)
370
350
300
250
200
(180)
150
100
KITUI
KATUMANI
MAKINDU
MWINGI
KAJIADO
FAILED MAIZE CROP
(*) 50% Onset date
(a)
POTHA
KITUI
KAJIADO
MAKINDU
KANZIKO
Final date of 'onset window' for planting maize
FAILED MAIZE CROP
(*) 50% Onset date
(b)
OCT 15
OCT 25
NOV 4
NOV 14
NOV 24
FEB 6
FEB 16
FEB 26
MAR 8
MAR 18
MAR 28
APR 7
Date of onset of the rains

TABLE V—YIELDS AND LAND EQUIVALENT RATIOS OF MAIZE AND BEANS IN BOTH SOLE-CROP AND INTERCROP SYSTEMS PLANTED DURING SHORT RAINS 1979/80 WITH AND WITHOUT NITROGEN FERTILIZER

	With nitrogen fertilizer						With no nitrogen fertilizer					
	Maize population	Yields × 10³/ha		Partial LERs			Maize population	Yield × 10³/ha		Partial LERs		
Treament ment	× 10³/ ha	Maize	Bean	Maize	Bean	LER	ha	Maize	Bean	Maize	Bean	Total LERs
Maize S.C.	54.9	5.026	—	1.00	—	1.00	36.1	3.230	—	1.00	—	1.00
Bean S.C.	—	—	1.106	—	1.00	1.00	—	—	1.077	—	1.00	1.00
M/B Add	53.6	3.257	0.554	0.65	0.50	1.15	34.7	2.669	0.512	0.83	0.48	1.31
M/B Sub	35.6	2.640	0.554	0.53	0.50	1.03	—	—	—	—	—	—

fell until the third week of March. The degree of the drought effect on beans was higher than that on maize. Beans are more sensitive to early drought conditions than maize.

During the short rains of 1979/80 maize and beans were intercropped with and without nitrogen fertilizer. The results (Table V) indicated that the maize/bean additional population relationship in the intercrop system was more beneficial than substitution. The Add yield advantage was 15%, while that of Sub was only 3%. The difference between the two systems was due to the difference in the partial LERs of the maize component; there was no difference in the LER of the bean component. Without fertilizer, although the population relationship in the intercrop was addition, the sole-crop maize population was lower than that in the fertilized plots. The yield of sole-crop maize in the non-fertilized plots was relatively high, which indicated the presence of a high level of nitrogen residue in the soil. Maize yield in the low-fertility intercrop was 83% of the sole crop, which was significantly higher than that in the fertilized plots for both the Sub and Add population relationships. Intercrop maize yield in the low-fertility plots was slightly higher than that with equal population (M/B Sub) which received 70 kg N/ha. This is an indication that the associated beans had a beneficial effect on maize yield. This beneficial effect substantially reduced the effect of the competition between the intercrop components, resulting in a maize partial LER significantly higher than those in the high-fertility plots.

The drought during the short rains of 1980/81 provided an opportunity to evaluate maize and bean responses to less than adequate rainfall conditions in the intercrop systems. Total rainfall during that season was less than 200 mm (Fig. 2). Yield results (Table VI) indicated that, under drought conditions, the two intercrop components adversely affected each other. While in previous seasons, when rainfall was adequate, total LERs were higher than unity, the LER was significantly below unity during the short rains of 1980/81. The maize partial LER was 0.38 and that of beans 0.34, a total LER of 0.72. It can be concluded that, under drought conditions, the intercrop of maize and beans was 28% less productive than if maize and beans were grown separately as sole crops. Because of the price relationship of maize and beans, it was found that although maize yields were subtantially reduced in the intercrop under the conditions of the short-rains season of 1980/81, the maize/bean intercrop was more economically feasible than sole-crop maize. On the other hand, sole-crop beans would have been more economically feasible than either sole-crop maize or the maize/bean intercrop. Because of the shorter growing season of beans and consequent lower water requirements, bean yields were not reduced as much as maize yields in either the sole-crop or the intercrop systems. These results clearly indicate that under conditions of upredictable rainfall, such as prevail in the Machakos area, maize and bean intercropping would not be the best practice. It would be to the farmer's advantage to grow maize and beans as sole crops.

SUMMARY

Subsistence farmers in eastern Kenya practise intercropping on most of their crop land, but the yields realized are generally low. To improve

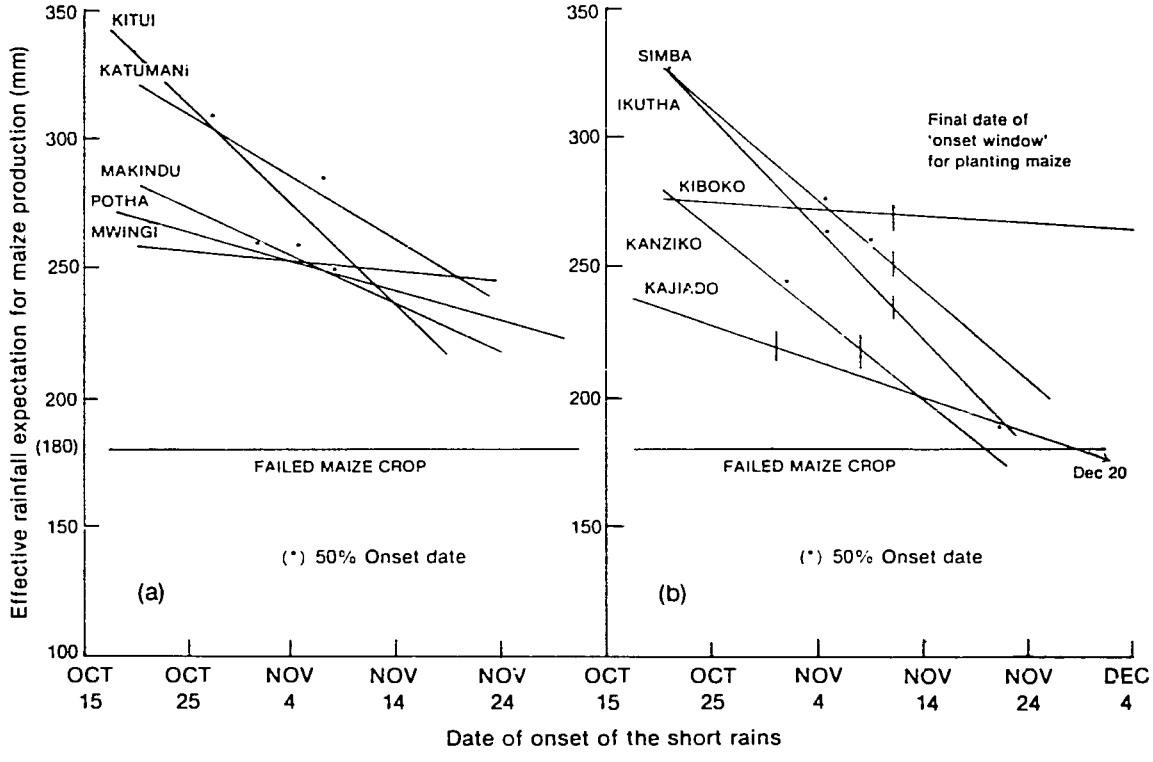
Effective rainfall expectation for maize production (mm)
350
300
250
200
(180)
150
100
KITUI
KATUMANI
MAKINDU
POTHA
MWINGI
FAILED MAIZE CROP
(*) 50% Onset date
(a)
SIMBA
IKUTHA
KIBOKO
KANZIKO
KAJIADO
Final date of 'onset window' for planting maize
Dec 20
(b)
OCT 15
OCT 25
NOV 4
NOV 14
NOV 24
DEC 4
Date of onset of the short rains

TABLE VI—YIELDS AND LAND EQUIVALENT RATIOS OF MAIZE AND BEANS IN THE SOLE-CROP AND INTERCROP SYSTEMS PLANTED DURING SHORT RAINS 1980/81

Treatment	Yields × 10^3 kg/ha		Partial LERs		Total LERs
	Maize	Beans	Maize	Beans	
Sole-crop maize	0.775	—	1.00	—	1.00
Sole-crop beans	—	0.771	—	1.00	1.00
Maize/beans intercrops	0.293	0.259	0.38	0.34	0.72

their production, a study was started in the short-rains season of 1978/79 at Katumani on a typical Oxic Paleustalf soil with the objective of evaluating the performance of both maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) in sole-crop and intercrop systems with different populations, spatial arrangements, and fertility levels as influenced by the varying rainfall conditions prevalent in the study area. The results of this study indicated that the rate of intracrop competition was much higher than that of intercrop. Increasing the population by intercropping resulted in competition levels 10% lower than that caused by higher maize populations. Intercropping in the same row was superior to intercropping in alternate rows. This might be due to better spatial arrangements or to the closeness of the maize and bean plant roots in the same-row arrangement resulting in the maize plants benefiting from the nitrogen fixed by the bean plants. This beneficial effect was found to be positively correlated with the proximity to each other of the roots of the two intercrop components. Land equivalent ratios of intercrop experiments under adequate rainfall conditions were always more than unity, which indicated the superiority of intercropping under those conditions. On the other hand, under drought conditions LER values were lower than unity, probably because of the competition between the intercrop components for the available moisture. Because of the maize/bean price relationship, the intercrop would be more economical than sole-crop maize under drought conditions, while sole-crop beans would be more economical than either sole-crop maize or a maize/bean intercrop. It was also found that within a certain range of population levels, bean plants do not significantly respond to changes in population and can counteract the change by an opposite change in the number of pods per plant. This keeps the potential bean yields at relatively constant values if no other environmental factors are limiting. These results clearly indicate that under unpredictable rainfall conditions, such as prevail in the Machakos area, maize and bean intercropping would not be the best practice. It would be to the farmers' advantage to grow maize and beans as sole crops.

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INTERCROPPING AND INTERCROP COMPONENT INTERACTION UNDER VARYING RAINFALL CONDITIONS IN EASTERN KENYA. II: MAIZE/COWPEA INTERCROP

H. M. Nadar[1]

INTRODUCTION

Almost all farmers in the researched area practise mixed cropping. The results of a study on maize/bean intercropping indicated that (a) intercropping on the same row was superior to that on alternate rows, (b) land equivalent ratios (LERs) of the intercrops, when the rainfall conditions were adequate, were always more than unity, while under drought conditions LER values were less than unity, and (c) within a certain range of population levels, bean plants do not significantly respond to changes in plant numbers (Nadar, 1983a). It was concluded that, under the unpredictable rainfall conditions of the study area, it would be to the farmers' advantage to grow maize and beans as sole crops rather than in intercrop systems.

Cordero and McCollum (1979) realized 20 to 40% increases in total production from intercropping maize with soybeans or snapbeans. They related the higher productivity to the longer leaf-area durations of the intercrop systems. Remison found that when maize was sown 2 to 4 weeks later than cowpeas, in the same plots, LERs and total yields were reduced, while when the cowpeas were the later-sown crop total yields and LERs were not affected. Agboola and Fayemi (1972) reported that cowpeas fixed nitrogen under both sole-crop and intercrop conditions. They found also that cowpeas did not benefit the associated maize, but were found to be an important source of nitrogen as green manure; the amount of nitrogen fixed by cowpeas during 12 weeks was estimated to be equal to 354 kg N/ha when inoculated and grown under optimal conditions.

May and Misangu (1982) found that intercropping maize and cowpeas or soybeans in the same hole resulted in consistently larger grain yields than intercropping in alternate holes. They suggested that these yield advantages may have occurred through the stimulation of additional nitrogen fixation or the creation of a better soil environment. These findings were similar to results obtained from studies with maize/bean intercrops (Chui and Nadar, 1983).

This study was started in the short-rains season of 1979/80 with the objective of studying the performance of both maize (*Zea mays* L.) and cowpeas (*Vigna unguiculata* L.) in sole-crop and intercrop systems at different populations and fertility levels, as influenced by the varying rainfall conditions prevalent in the study area.

MATERIALS AND METHODS

The experimental site, soil type, and rainfall conditions were described in a previous report (Nadar, 1983a).

Maize (*Zea mays* L., Katumani Composite B) and the Machakos 68 variety or a local variety of cowpea (*Vigna unguiculata* L.) were planted in plots of 8 rows 0.75 m apart and 10 m long, either as sole crops or in intercrop systems. The intra-row spacings were 0.30 m for both maize and cowpeas in both sole-crop and intercrop systems. Maize and cowpeas were always intercropped in the same row, except during the long rains of 1981, when they were intercropped with no nitrogen fertilizer application at three different spatial arrangements: in the same row 15 cm apart, or seeds of both crops planted in the same hole, or planted in alternate rows. In the same-row arrangement the spacing between two plants of the same kind was 0.30 m, while that between plants of different kinds was 0.15 m. In alternate rows the spacing was 0.30 m within the row, with the plants thinned to 2 plants per hill to keep the population constant. Ten to fifteen days after emergence plants were thinned to 1 or 2 plants per hill. During the short rains of 1979/80 the population relationships between the intercrop components were either addition (Add) or substitution (Sub). Add means that the intercrop components were planted at their optimum population in the sole crops, resulting in a 1.0: 1.0 maize:cowpea population relationship in the intercrop system. Sub means the substitution for half the maize population of a full population

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of cowpeas or a 0.5:1.0 maize:cowpea population relationship in the intercrop system. In subsequent seasons maize/cowpea intercrops were only tested at the Add population relationship.

Fertilizer application rates were 17.5 kg P/ha for all crops and 70 kg N/ha for sole-crop and intercrop maize, except during the short rains of 1979/80 and the long rains of 1981, when intercropping was also tested with no nitrogen fertilizer. In this case maize received only phosphate fertilizer at the above rate. Fertilizers were side dressed immediately following thinning.

The experimental design was a randomized complete block with three replications. Maize yields were adjusted to 15.5% and cowpea yields to 14% moisture content. Yields were then further adjusted to variations in final population counts using the covariance analysis method (Steel and Torrie, 1976). Land equivalent ratios (LERs) were calculated as described by Willey (1981). These LER values were subjected to analysis of variance and mean comparison tests.

RESULTS AND DISCUSSION

Yield results of the short rains of 1979/80 (Table I) showed that planting sole-crop maize at 2 plants per hill resulted in a 25% yield increase over one-plant-per-hill sole-crop maize. This rate of increase was higher than that realized during the short rains of 1978/79. Results of the maize/bean intercropping study during that season (Nadar, 1983a) indicated that under the same environmental and cultural conditions, when rainfall was not limiting, sole-crop maize yields were increased by an average of 21% by planting 2 plants per hill instead of one. The actual increase in plant numbers was found to be from 53.3 thousand plants per hectare to 67.1 during the short rains of 1978/79, or 26%. In the short rains of 1979/80 the increase was 39%, from 35.4 to 49.2 thousand. Also, as the relationships between yields and population was found to be curvilinear (Nadar, 1983b), the yield increase in response to increases in population would be expected to be higher at lower populations than at higher populations. The increase in sole-crop maize population resulted in a decrease in average ear weight, but a net increase in total grain yield of 25% was realized.

In the intercrop, cowpeas competed strongly with the maize component. Maize yields in the intercrop were reduced by 46 to 57%, mainly due to a severe reduction in average ear weight..

TABLE I—YIELDS, POPULATIONS AND LAND EQUIVALENT RATIOS (LERs) OF MAIZE AND COWPEAS IN SOLE-CROP AND INTERCROP SYSTEMS FOR THE STUDY CONDUCTED DURING THE SHORT RAINS OF 1979/80

Cropping system*	No. of Maize Pl/Hill	Population (× 10³ pl/ha)			Yield (× 10³ kg/ha)		Partial LERs			% increase over 1 pl/hil S.C	
		Maize	Cowpeas	Total	Maize	Cowpeas	Maize	Cowpeas	Total LERs	Pop.	LERs
Maize SC	1	35.4	—	35.4	3.662	—	1.0	—	1.0	—	—
Maize SC	2	49.2	—	49.2		—	1.25	—	1.25	39%	25%
M/Cp. IC	1	36.3	70.0	106.3	1.976	0.643	0.54	0.45	0.99	200%	=1%
M/Cp. IC	2	52.5	80.0	132.5	1.985	0.640	0.54	0.45	0.99	274%	=1%
Cowpea SC	—	—	65.6	65.6	—	1.436	—	1.0	—	—	

*SC = sole crop; M = maize; Cp. = Cowpeas; IC = intercrop.

Actually, the reduction in yield was much higher than the reduction in average ear weight. Percentage of seeds per ear was also reduced. Maize response to intercrop competition, in this case, was the reverse of that in the case of maize/bean competition (Nadar, 1983a). This may be due to differences between the competitive abilities of beans and cowpeas, or possibly this severe competitiveness is specific to the cowpea variety used in the study. The local cowpea variety used during that season was of the climbing type and a fast starter. With its long taproot it was expected to compete with maize for available moisture. This expected effective competition as well as its climbing habit, which caused the lodging of a large number of maize plants, may have had a devastating effect on yields of the maize component in the intercrop system.

When maize and the same local variety of cowpeas were intercropped under low-fertility conditions, maize yields (Table II) were higher than those under high-fertility conditions, resulting in a total LER of 1.16, or a 16% advantage over the sole crops. The increase in LER was mainly due to the increase in the maize partial LER, which was 0.68 as compared to 0.54 under high-fertility conditions. The partial LER of the legume component was 0.48, as compared to 0.45 under high-fertility conditions, an increase of 0.03, which was not significant. These results were very similar to those of maize/bean intercrop studies with and without nitrogen fertilizer (Nadar, 1983a), which supports the idea that beans and cowpeas, and perhaps other legumes, have a beneficial effect on the associated maize in a maize/legume intercrop system. This beneficial effect, which can be more easily detected under low-fertility conditions, caused a substantial reduction in the competition effect and resulted in a maize partial LER significantly higher than that under high-fertility conditions. On the other hand, the competition effect of maize on the cowpea component in the intercrop system was essentially the same under both fertility conditions. Reduction in intercrop cowpea yields was around 50% of the sole-crop yield, and can be accounted for by a similar reduction in average number of pods per plant, though there was no significant change in number of seeds per pod (Table III).

TABLE II—MAIZE AND COWPEA (LOCOAL VARIETY) YIELDS AND LAND EQUIVALENT RATIOS (LERS) GROWN IN BOTH SOLE-CROP AND INTERCROP SYSTEMS WITHOUT NITROGEN-FERTILIZER APPLICATION DURING THE SHORT RAINS OF 1979/80

Cropping system	Yields ($\times 10^2$ kg/ha)		Partial LERs		Total LERs
	Maize	Cowpeas	Maize	Cowpeas	
Maize SC	3.230	—	1.00	—	1.00
Cowpeas SC	—	1.462	—	1.00	1.00
M/Cp. IC	2.207	0.703	0.68	0.48	1.16

TABLE III—COWPEA HARVEST DATA FOR THE SHORT RAINS OF 1979/80 INTERCROPPING EXPERIMENT AT KATUMANI, SHOWING YIELDS, AVERAGE NUMBER OF PLANTS PER PLOT (24 m²), AND AVERAGE NUMBER OF SEEDS PER POD

Treatment	Yields ($\times 10^3$ kg/ha)	Ave no. of plants/plot	Ave. no. of pods/pl.	Ave. no. of seeds/pod
Cowpea SC	1.436	157	18.6	13.7
M/Cp.	0.645 (−55)*	192 (+22)	7.9 (−58)	13.5
½ M/Cp.	0.643 (−55)	168 (+7)	8.4 (−55)	13.7

*Numbers in brackets represent percentage variation from CP values.

Because of the climbing habit of the local cowpea variety and its adverse effect on maize plants, it was replaced by the variety Machakos 68 in subsequent experiments. Machakos 68 was found to be more adapted to intercropping than the local variety. It was found that the inhibitory effect of the maize component on the new variety was closely similar to that on the local one, while the inhibitory effect of Machakos 68 on the maize component was much less severe than that of the local variety.

The experimental results from the long rains of 1980, when the cowpea component in the intercrop was the variety Machakos 68 (Table IV), showed that while the partial LER of the cowpea component was 0.51 (almost equal to that in the short rains of 1979/80 experiment, when the cowpea component was the local variety), the maize component partial LER was 0.91 as compared to 0.54, which accounted for most of the difference between the total LERs of 1.42 and 0.99. By changing the cowpea variety, a 42% advantage over the sole crops was realized as well as a 16% advantage over the maize/bean intercrop system, which was superior when the local cowpea variety was used. These results indicated that different varieties perform differently under sole-crop and intercrop conditions. Hence, variety selection should be done under the actual conditions the selected variety is meant to be used for. If the intention is to use the variety for intercropping, the initial selection should be performed under intercropping conditions.

The drought during the short rains of 1980/81 provided an excellent opportunity to evaluate the crop responses, under both intercrop and sole-crop conditions, to less than adequate rainfall when competition for moisture would be a major factor. During that season, total rainfall was less than 200 mm, which was far less than adequate for maize or cowpea production. Yield results for the short rains of 1980/81 (Table V) showed that, in the intercrop, the maize-component yield was less than the sole-crop maize yield by a percentage not much greater than that under adequate rainfall conditions. In other words, the competition effect of the legume component on maize yield in the intercrop was almost the same under both adequate and less-than-adequate rainfall conditions. On the other hand, the cow-

TABLE IV—MAIZE AND COWPEA (MACHAKOS 68) YIELDS AND LAND EQUIVALENT RATIOS (LERS), IN BOTH SOLE-CROP AND INTERCROP SYSTEMS OF THE STUDY CONDUCTED DURING THE LONG RAINS OF 1980

Cropping system	Yields ($\times 10^3$ kg/ha)		Partial LERs		Total LERs
	Maize	Cowpeas	Maize	Cowpeas	
Maize SC	3.970	—	1.00	—	1.00
Cowpea SC	—	1.436	—	1.00	1.00
M/Cp. IC	3.614	0.730	0.91	0.51	1.42

TABLE V—MAIZE AND COWPEA (MACHAKOS 68) YIELDS AND LAND EQUIVALENT RATIOS (LERS) IN BOTH SOLE-CROP AND INTERCROP SYSTEMS OF THE EXPERIMENT CONDUCTED DURING THE SHORT RAINS OF 1980/81

Cropping system	Yields ($\times 10^3$ kg/ha)		Partial LERs		Total LERs
	Maize	Cowpeas	Maize	Cowpeas	
Maize SC	0.775	—	1.00	—	1.0
Cowpea SC	—	0.620	—	1.00	1.0
M/Cp. IC	0.565	0.170	0.73	0.27	1.0

pea component was much more severely affected by maize competition for moisture, and its yields were greatly reduced. The maize partial LER in the short rains of 1980/81 was 0.73, or about 80% of that in the long rains of 1980 (0.91). On the other hand, the cowpea partial LER in the short rains of 1980/81 was 0.27, or only 52% of that in the long rains of 1980. This is an indication of the poor competitiveness of cowpeas for moisture in a maize/cowpea intercrop system when the rainfall conditions are limiting. These results were the opposite of those of maize/bean intercrop, where beans were the better competitors and the partial LER of the maize component was greatly reduced, while that of the bean component was relatively not affected (Nadar, 1983a).

The results of the experiment in the long rains of 1981, which was conducted with no nitrogen fertilizer application at three different spatial arrangements (Table VI) further supported the theory that in the absence of chemical nitrogen fertilizer, maize can utilize some of the nitrogen fixed by the associated legume component in an intercrop system. The amount of fixed nitrogen which can be utilized by the maize component may be directly influenced by the proximity of the maize roots to the nitrogen-fixing sites on the legume roots. While the highest maize partial LER was achieved in the maize/cowpea intercrop system when the two components were 15 cm apart, it was only achieved in the maize and bean intercrop when the component species were planted in the same hole. Probably the nitrogen-fixing sites on the roots of the two legume crops are different. While the bulk of the nodules are expected to be close to the crown of the bean plant, they are expected to be on the secondary roots of the cowpea plant.

TABLE VI—YIELDS AND LAND EQUIVALENT RATIOS (LERS) OF MAIZE AND COWPEAS GROWN AS SOLE CROPS AND INTERCROPS AT THREE DIFFERENT SPATIAL ARRANGEMENTS WITHOUT NITROGEN-FERTILIZER APPLICATION DURING THE LONG RAINS OF 1981

Cropping system*	Yields ($\times 10^3$ kg/ha)		Partial LERs		Total LERs
	Maize	Cowpea	Maize	Cowpea	
Maize SC	2.731	—	1.00	—	1.00
Cowpeas SC	—	1.306	—	1.00	1.00
M/Cp. ICSH	2.735	0.670	1.00	0.51	1.51
M/Cp. IC15	3.056	0.670	1.12	0.51	1.63
M/Cp. ICAL	2.546	0.670	0.93	0.51	1.44

*SC = sole crop; M = maize; Cp. = cowpeas; ICSH = intercrop in the same hole; IC15 = intercrop in the same row with 15 cm intrarow spacings; ICAL = intercrop in alternate rows.

It can be concluded that, in general, the performance of maize/cowpea intercrop is much better than that of maize/bean intercrop under both adequate and less-than-adequate rainfall conditions. In another study during three seasons with different rainfall conditions (Nadar and Faught, 1983) it was found that intercropping maize with cowpeas without nitrogen fertilizer, either continuous or as part of a rotation, resulted in substantially better returns than those from continuous maize, while intercropping of maize and beans sharply lowered the yields and returns from the intercrop maize. The higher total value of the maize/bean intercrops was entirely due to the value of the bean component. These findings support the results of the present study and lead to the conclusion that contrary to the recommendations concerning the planting of maize and beans given in Nadar (1983a), it is advantageous to the farmers in the study area to plant maize and cowpeas in intercrop systems rather than as sole crops. It is also recommended to plant maize and cowpeas 15 cm apart in the intercrop system, to provide the best spatial arrangement for the maize component to derive the highest possible benefit from the ambient nitrogen fixed by the cowpea component.

SUMMARY

A study was started in the short rains of 1979/80 with the objective of improving the intercrop

production of maize and cowpeas and evaluating their performance under both sole-crop and intercrop conditions at different populations, spatial arrangements, and fertility levels. The results of this study indicated that although the increase in sole-crop-maize population resulted in a decrease in average ear weight, a net increase in total grain yield of 25% was realized. Different cowpea varieties performed differently under intercropping conditions. While the partial land equivalent ratios (LERs) of the two cowpea varieties used in the study (Machakos 68 and a local climbing variety) were almost equal, the maize partial LER was 0.54 when it was intercropped with the local variety and 0.91 when intercropped with Machakos 68. This is an indication that crop varieties intended for intercropping should be selected under intercropping conditions. When maize was intercropped with cowpeas without nitrogen fertilizer, maize partial LER was higher than that under high-fertility conditions. The maize partial LER was highest when maize and cowpeas were planted 0.15 m apart. Probably this spatial arrangement provided conditions where the maize roots were closest to the nitrogen-fixing sites on the cowpea roots. These findings indicate that maize can benefit from the nitrogen fixed by the associated legume in an intercrop system at the proper spatial arrangement and fertility level. The competition effect of cowpeas on maize in the intercrop system was found to be similar under both adequate and less-than-adequate rainfall conditions. All these findings lead to the conclusion that it is advantageous to the farmers in the study area to plant maize and cowpeas in intercrop systems rather than as sole crops. It is also recommended to plant maize and cowpeas, in the intercrop system, in the same row at 0.15 m intrarow spacing between a maize plant and a cowpea plant.

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TABLE II—YIELDS AND LERs OF MAIZE, BEANS, AND PIGEONPEAS SOLE CROPS AND INTERCROPS DURING THE SHORT RAINS OF 1978/79 AND THE LONG RAINS OF 1979 (PARTIAL LER OF MAIZE IN THE MAIZE/PIGEONPEA INTERCROP IS CALCULATED AS A FRACTION OF SHORT-RAINS MAIZE SOLE CROP)

	Short rains 1978			Long rains 1979				
	Yield (tons/ha)			Yield (tons/ha)				
Treatment	Maize	Beans	LER	Maize	Beans	Pigeon-peas	LER	Ave. LER/ Season
Maize S.C.	5.982	—	1.00	3.465	—	—	1.00	1.00
Beans S.C.	—	1.477	1.00	—	0.807		1.00	0.50
Pigeonpeas S.C.	—	—	—	—	—	2.704	1.00	1.50
Maize/bean intercrop	3.749	0.655	1.06	2.155	0.322	—	1.03	1.05
Maize/P.P. intercrop	5.719	—	0.96	—	—	2.704	1.00	0.98

TABLE III—COMPARISON BETWEEN LAND EQUIVALENT RATIOS (LERs) AND MONETARY ADVANTAGES OF THE INTERCROPS OVER SOLE-CROP MAIZE AND COMBINED SOLE-CROP YIELDS DURING THE SHORT RAINS OF 1978/79 AND THE LONG RAINS OF 1979, FOR BOTH MAIZE/BEANS AND MAIZE/PIGEONPEA INTERCROPS

Treatment	LERs	Net income* (KSh.)	Advantage over combined sole crop (%)	Advantage over maize (%)
Combined maize/beans SR[1]	1.06	3,869	+18.8	−8.8
Maize SR	1.00	4,242	+30.0	—
Beans SR	1.00	2,270	−7.2	−17.7
Combined maize/beans SR	0.5 + 0.5	3,256	—	−23.0
Maize/pigeonpeas SR & LR[2]	1.60	6,300	+49.0	+3.3
Maize SR & LR	1.00	6,097	+44.0	—
Combined maize and pigeonpeas SR & LR	0.5 + 0.5	4,233	—	−31.0
Pigeonpeas SR & LR	1.00	2,370	−44.0	−61.0

[1]SR = Short-rains 1978 crop
[2]SR & LR = Short-rains 1978 + Long-rains 1979 crops
*Adopted from economic analysis by G. E. Rodewald, Agricultural Economist of the project until the end of 1979.

intercrop would have a 3% monetary advantage over sole-crop maize. Its advantage over combined sole crops was 49%, while that over the pigeonpea sole crop was 61% (Table III). That explains why pigeonpeas are almost never grown as a sole crop in the study area. While LER relationships would have stayed the same, monetary advantages would have been different if the maize/legume price relationships had been different.

During 1980, when rainfall during the short rains was less than adequate, yields of intercrop maize and pigeonpeas were reduced much more than in 1979, but the yield reduction was much less than that in the maize/bean intercrop (Table IV). Comparing the competition effects of beans, cowpeas, and pigeonpeas on maize in the intercrop systems (Table V) showed that the most competitive intercrop was the local variety of cowpeas. Cowpeas reduced maize yields by 57%

TABLE IV—YIELDS AND LERS OF MAIZE, BEANS, AND PIGEONPEAS SOLE CROPS AND INTERCROPS AS ADDITIONS (1.0:0.5) OR SUBSTITUTIONS (0.5:0.5) DURING THE SHORT RAINS OF 1979/80 AND THE LONG RAINS OF 1980

	Short rains 1979/80			Long rains 1980				
	Yields ($\times 10^3$ kg/ha)			Yields ($\times 10^3$ kg/ha)				
Treament	Maize	Beans	LERs	Maize	Beans	P. Peas	LERs	Average LER per season
Maize sole-crop	5.026	—	1.00	3.970	—	—	1.00	1.00
Beans sole crop	—	1.106	1.00	—	0.929	—	1.00	1.00
Pigeonpea sole-crop	—	—	—	—	—	2.478	1.00	0.50
Maize/beans Add.	3.257	0.554	1.15	3.497	0.399	—	1.22	1.19
Maize/beans Sub.	2.640	0.554	1.03	Not planted during the long rains seasons				
Maize/P.P. Sub.	4.137	—	0.80	—	—	1.999	0.81	0.81

TABLE V—MAIZE HARVEST DATA FOR THE SHORT RAINS OF 1978/79 AND SHORT RAINS OF 1979/80 OF THE INTERCROPPING EXPERIMENT AT KATUMANI, SHOWING YIELDS, AVERAGE EAR WEIGHTS AND AVERAGE NUMBER OF PLANTS PER PLOT (24 m^2)

	Short Rains 1978			Short Rains 1979		
Treatment	Maize yield ($\times 10^3$ kg/ha)	Ave. ear weight (g)	No. of maize plts./plot (24 m^2)	Maize yield ($\times 10^3$ kg/ha)	Ave. ear weight (g)	No. of maize plts./plot (24 m^2)
Maize	6.195	123	161	4.582	123	118
½ Maize[a]	5.097	141	128	3.662	148	85
Maize/beans	—	—	—	3.257 (−29)	80 (−35)	129 (+9)
½ Maize/beans	4.299 (−16)[b]	134 (−5)	115 (−10)	3.395 (−7)	140 (−5)	85 (0)
Maize/½ P.P.	5.850 (−6)	126 (+2)	157 (−2)	4.410 (−4)	123 (0)	113 (−4)
Maize/P.P.	—	—	—	4.229 (−8)	110 (−11)	127 (+8)
½ Maize/P.P.	—	—	—	3.940 (+7)	150 (+1)	85 (0)
Maize/cowpeas	—	—	—	1.985 (−57)	55 (−56)	126 (+7)
½ Maize/cowpeas	—	—	—	1.976 (−46)	69 (−53)	87 (+2)

a. ½ preceding a crop name indicates that the population planted was meant to equal ½ the optimum population in the sole-crop system.

b. Numbers in brackets are the % deviation from the sole crop with similar population.

in the MCP system and 46% in the ½MCP system, mainly due to a severe reduction in average ear weight. Actually the reduction in yield was higher than the reduction in ear weight, because the percentage of seeds per ear was also reduced. Cowpea was a fast starter, and with its strong tap root may have competed effectively with maize for available moisture at all soil depths. This effective competition had a devastating effect in 1979, when moisture was a limiting factor. Maize yield reduction in the MB system was 29%, and can be accounted for by the reduction in average ear weight (35%). Some ear-weight reduction was compensated for by an increase in maize-plant population in the intercrop. In the ½MB system the reduction in ear weight was 5% in both seasons and accounted for most of the yield reduction. These results indicate that the yield of lower maize populations, as compared with that of high populations, was not significantly reduced by bean competition in the intercrop. The maize/pigeonpea intercrop did not

intercrop maize and produce yields equivalent to 80–100% of the sole crop.

Under drought conditions the partial LER of maize was not affected, while that of pigeonpeas was drastically reduced. Because the pigeonpeas have a long growing season, it was possible to correct for the severe reduction in intercrop-pigeonpea yield by planting cowpeas after the harvest of the intercrop maize. Cowpea yields compensated for the reduction in pigeonpea yields. The maize/pigeonpea intercrop was demonstrated to be the best intercrop system for the unpredictable rainfall conditions of the study area. Pigeonpeas had virtually no competition effect on the maize component under all tested rainfall conditions, and it was possible to correct for an expected pigeonpea crop failure due to inadequate rainfall during the short-rains season by re-intercropping it with another one-season crop during the following long rains. Also, the study results indicated that, in an intercrop system, the associated maize component can benefit from the nitrogen fixed by the pigeonpeas if the intercrop components are planted at the proper spatial arrangements and fertility levels.

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DEVELOPING AN AGRONOMY RESEARCH PROGRAMME TO SERVE THE NEEDS OF SUBSISTENCE FARMERS: THE KENYAN EXPERIENCE (ABSTRACT)

H. M. Nadar[1]

Concentrated efforts are needed to develop technologies suitable for subsistence farmers. Developing a successful research programme to cater for the needs of those farmers, is not an easy process. Many technologies were developed with the intention of improving farm production in developing countries, but few of them were adopted by the farmers. The main idea behind the planning of the agronomy research programme was to have it compatible with the farming systems followed by the farmers it was developed to serve. We call this the farming-systems approach (FSA), to distinguish it from other research programmes which do not take into consideration the overall farming system in the process of planning research. In our opinion, any kind of research can be called applied or adaptive research so long as its results can directly fit within a known farming system. FSA is a method of planning any kind of biological research with the specific purpose of solving an identified farm-production problem. The solution to that problem has to be compatible with the farming system(s) it was developed to serve. These results should also fit within that system without disturbing other farm activities of the system. The first step in developing an FSA-oriented research programme is to identify the socio-economic status of the target farmers. This requires the early involvement of the agricultural economist and social scientist with the biological scientist in the process of research planning. All the specialists must be involved in setting the research priorities, determining the economic and social feasibility of the research findings, and determining the compatibility of these findings with the existing farming systems under actual farm conditions. Through a successful relationship between the Agronomist and the Agricultural Economist of the Dryland Cropping Systems Project, it was possible to adapt the agronomic research programme to FSA. Many research results were subjected to economic analysis and their economic feasibilities determined. Determination of the compatibility of new technologies found to be economically feasible has already started on several farms in the Machakos area. The results of those tests, so far, have been very promising and are discussed elsewhere. It is our hope that through these studies large and long-lasting farm-production improvements will be realized in the near future.

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(Table I). With the increase in gross value of maize averaging only KSh. 144 and the cost of applying fertilizer totalling KSh. 1,113/ha the farmer would have suffered a net loss of KSh. 969. On the experimental plots at the Katumani station in the same season, plots which had been in continuous maize and had had no fertilizer applied for four seasons had an average yield of only 454 kg/ha, while the equivalent yield associated with fertilizer applications equal to that on the trial farms was 916 kg/ha. The gain in gross value would have been KSh. 620, but a net loss of KSh. 493 would still have occurred.

With the extremely limited rainfall, it was expected that the yields from the plots with the recommended higher populations would be lower than those of the conventional planting, particularly if the recommended 75 cm row spacing had been followed. However, the planting with the higher populations, which averaged 38,000 plants per hectare, had an average yield of 988 kg/ha, while the plantings at a lower level averaged only 19,000 plants and had an average yield of 590 kg/ha. This apparent reversal may be due to the wider row spacing. One experiment indicated that in dry years yield response to plant

TABLE I—MAIZE POPULATION AND YIELDS BY CROPPING SYSTEMS AND TREATMENT: VERIFICATION ON-FARM TRIALS, SHORT RAINS 1981–82, MACHAKOS DISTRICT

	Not fertilized		Fertilized	
Cropping system	Local maize	Katumani maize	Local maize	Katumani maize
Intercrop: Farmers' method				
Population (thousand)	19.0	19.2	20.5	16.5
Yield (kg/ha)	467.0	717.0	586.0	591.0
Intercrop: Recommended method				
Population (thousand)	33.1	33.2	41.0	44.8
Yield (kg/ha)	859.0	900.0	1,239.0	956.0

numbers differed significantly between 75 cm and 90 cm row spacings. The former declined significantly and in a linear manner throughout its range, but the latter response was curvilinear, increasing from 10,000 to about 35,000 and falling thereafter.

The average yields from the Katumani and local seed were almost identical: 791 kg/ha and 788 kg/ha respectively. However, the planting of Katumani would have increased costs by KSh. 107/ha and reduced net returns by an equal amount.

As indicated previously, most of the data for the long rains of 1982 were lost. However, the limited data available illustrated the substantial carry-over effect of fertilizer applied in the preceding season. Because the rainfall and response to fertilizer were so limited during the short rains of 1981–82, no fertilizer was applied during the long rains. However, the planting receiving fertilizer in the preceding season had average yields that exceeded unfertilized plantings by 1,020 kg/ha (Table II). The increase in gross returns of KSh. 1,371 would have slightly more than offset losses in the preceding seasons. Surprisingly, the yields from local-seed planting exceeded that from the Katumani planting by 358 kg/ha, resulting in a net return for the local planting of about KSh. 575 more than the return for the Katumani planting.

The short rains of 1982–83 started in mid-October, reached a total of 172 mm at the Katumani station within 30 days, and ended in late February with a total effective rainfall for the season of 466 mm. The on-farm trials in that season were the most successful in the three-season

TABLE II—MAIZE AND BEAN YIELDS BY TYPE OF MAIZE SEED PLANTED AND FERTILIZER TREATMENT IN PRECEDING SEASON: VERIFICATION ON-FARM TRIALS, LONG RAINS 1982, MACHAKOS DISTRICT (kg/ha)

	Not fertilized preceding season		Fertilized preceding season	
Crop	Local	Katumani	Local	Katumani
Maize	2,000	1,556	2,933	2,662
Beans	301	276	409	351

series, reflecting not only the very good growing conditions but also refinements in the procedures for conducting the trials based on the experience of the two preceding seasons. The trials provided results for comparing yields and returns from fertilized and non-fertilized plots, from local and Katumani maize, and from plots planted in the conventional manner and those planted with the recommended higher population and different planting configuration. In addition, sole-crop maize and beans, planted at a recommended higher rate than conventional plantings, were in the trials. Gross returns, costs, and net returns were calculated in the same manner as that followed in the preceding seasons. The economic results have been expressed as increments from those obtained from what is described as the conventional planting used as the base. These practices included planting intercrop maize and beans in alternate rows, using the farmers' maize seed and applying no fertilizer.

Yields in the favourable short rains of 1982—83 more than doubled or tripled those of the very dry 1981—82 season (Table III). The recommended intercropping method, with 28 to 32 thousand maize plants per hectare, produced 845 kg more maize and 184 kg more beans than the conventional intercrop with only 16 to 20 thousand plants per hectare. The LER for the recommended method of intercropping averaged 1.68, compared with 1.08 for the conventional method.

The response to fertilizer was quite marked in the 1982—83 short rains. Overall (sole and intercrop, local and Katumani seed) there was an average increase of 1,570 kg/ha in maize yields and 208 kg/ha in beans in response to the fertilizer application. The response of Katumani maize

TABLE III—YIELDS OF MAIZE AND BEANS BY CROPPING SYSTEM AND TREATMENT: VERIFICATION ON-FARM TRIALS, SHORT RAINS 1982—83 MACHAKOS DISTRICT (kg/ha)

	No fertilizer		Fertilized	
Cropping system	Local maize	Katumani maize	Local maize	Katumani maize
Intercrop: Farmers' method				
Maize	1,007	1,373	2,119	2,146
Beans	162	276	296	477
Intercrop: Recommended method				
Maize	1,620	1,554	3,369	3,544
Beans	391	393	532	632
Sole-crop maize	1,644	3,266	4,152	
Sole-crop beans	519		844	

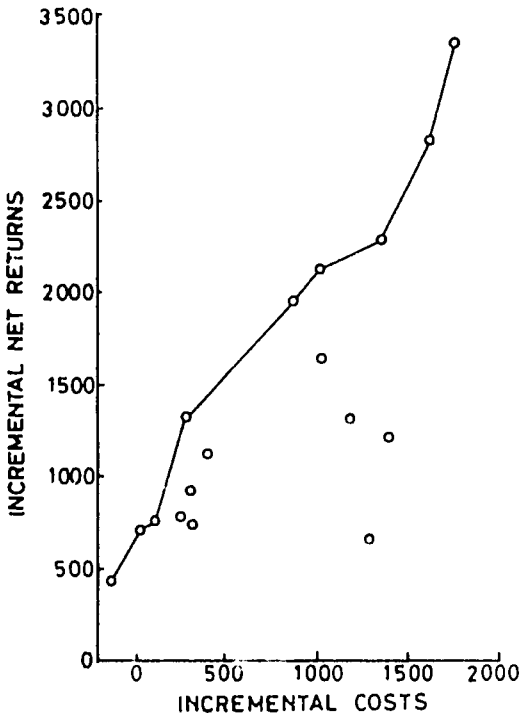

Fig. 1. Relation of incremental net returns and incremental costs of alternative cropping/treament combination verification on-farm trials—short rains 1982--83, Machakos District

lower costs and/or higher returns—are those connected by the solid lines on the chart. These include, from the highest to the lowest and including estimates for a sole-crop maize and bean rotation:

1. recommended intercrop systems; fertilized and planted with Katumani seed;
2. same as number 1 except using local seed;
3. sole-crop Katumani maize with high population and fertilized;
4. rotation of sole-crop Katumani maize and beans fertilized;
5. sole-crop beans fertilized;
6. recommended intercrop with local seed and no fertilizer;
7. sole-crop Katumani maize not fertilized;
8. sole-crop local maize not fertilized.

Costs of these viable economic options range from KSh. 122/ha less than the conventional method for local sole-crop maize not fertilized to KSh. 1,820/ha more than conventional for the recommended intercrop with Katumani seed and fertilized. Comparable net returns range from KSh. 426/ha to KSh. 3,194. An individual farmer's choice among these options will depend on his access to available capital, his managerial ability, and his willingness to undertake risks.

SUMMARY

Experiments conducted under carefully controlled conditions may lead to recommendations that farmers, because of various physical or institutional constraints, are unable to implement. Even if the farmer is able to implement the recommendations, he may find that results differ substantially from those achieved on the research station. A number of experiments conducted at the National Dryland Farming Research Station at Katumani show results that promise increased yields and incomes if applied by farmers. However, before incorporating these findings into recommendations to farmers, they must be verified under existing farm conditions to determine if they can be applied within the constraints confronting farmers and to establish the relative benefits to be derived if they are applied.

A series of on-farm trials was initiated in 1981 in Machakos District, Kenya, to verify some of the more promising findings of the Dryland Cropping Systems Research Project. Twelve farmers—three in each of four clusters—cooperated. Researchers presented recommendations to the farmers, assisted in making the fertilizer applications, and collected information on labour inputs and yields. All other activities were carried out by the farmers in accordance with their normal schedules. Extremely dry weather during the first season and unforeseen events during the second restricted the usefulness of the data for evaluating the approach or establishing the relationship of experimental and farm-based findings. However, successful trials were completed in the third season. Findings indicated responses to fertilizer that were similar to, although lower than, those found in the experiments and clearly showed that such treatments were economically feasible if the operator has access to the required capital. Use of improved breeder seed increased yields and net returns. An alternative rate and pattern of planting a maize/bean intercrop was found to provide substantially higher yields and net returns than the method normally followed by farmers.

Verification trials on farms clearly appear to be a viable approach for testing the applicability of experimental results. In areas of highly variable climatic conditions, such as the semi-arid areas

of Kenya, the trials may have to be conducted for several seasons to obtain reasonably reliable results.

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TECHNICAL SESSION 2: REPORT ON DISCUSSION

Chairman (Mr D. M. Thairu): Papers presented in the second session related various crop-husbandry practices to insufficient rainfall and nutrients. The questions and issues raised relate to the management of crops such that the limiting factors are exploited with the utmost efficiency.

Mr B. M. Ikomba: What accounts for the reduction in terms of labour input in late planting (planting after the start of the rains), especially in situations where farmers do not use oxen as was done in the experimental plots?

Dr H. M. Nadar: Many things account for the reduction in labour input in planting after the start of the short rains. In particular, seed-bed preparation after the start of the rains controls the first flush of weeds, while for dry planting it does not, and this results in a large reduction in labour input for weed control after germination of the planted crop.

Mr A. M. Marimi: The rainfall distribution chart was based on Machakos town data, known to be different from the target area. Why did you not draw similar figures for Kampi ya Mawe and Kitui, which are more representative of the target area, at least to show whether both the hypotheses and results obtained from Machakos town data could be extrapolated to other areas?

Dr Nadar: Although the rainfall amount might be different, it was found that the rainfall pattern was the same for Machakos town, Katumani station, and Kampi ya Mawe station. We did not have a chance to do research in Kitui. The results obtained from research at Katumani and Kampi ya Mawe stations lead to the same conclusions.

Mr P. T. S. Whiteman: What do you consider the threshold rain to trigger a February relay sowing of maize?

Dr Nadar: Forty millimetres.

Dr R. K. Jones: Have you considered the use of herbicides as a method of weed control at the start of the growing season to reduce labour requirements for weeding and ploughing, and to prevent weed competition with the maize crop? (Ropewick applicators are a clever "new technology" for herbicide application which need to be tested.)

Dr Nadar: Chemical weed control is not at present practised in the area, and that is why it was not given first priority. It certainly has a value, and if it was found to be a feasible weed-control practice in the study area, the timing of planting for the short rains would have no relevancy to the efficiency of weed control.

Mr A. M. Kilewe: During the long rains the recommendation is to relay plant, while during the short rains it is to plant after ploughing down the weeds. How did the farmers respond to these two recommendations?

Dr Nadar: The weather situation of the last four seasons did not allow for testing these practices on farmers' fields. As a result, we were not able to get the farmers' responses to these practices.

Mr F. M. Ndambuki: The local maize variety used in your experiment at Muguga gave highest yield at a lower optimum density than either H512 or KAT C.B. Could this local variety be a derivative of Kitale hybrid local variety?

Dr Nadar: The local variety used in the population study at Muguga was obtained from one of the farmers in the area. Its origin is not known to me but in the field it was not similar to either H512 or Katumani Composite B.

Mr Marimi: In pure-stand studies of maize it has been shown that within certain limits row width (between 50 and 100 cm) and within-row spacing has no effect on yield. Did you use optimum populations in this study? Why are you emphasizing row width and not populations?

Dr Nadar: To answer your last question first, both row spacings and populations were equally emphasized. In response to your first question, I believe that the literature reported in some cases that row spacings had no significant effect on yield, while in other cases a significant effect was reported at a given population. Our results supported the latter observations.

Mr Marimi: In a situation where soil moisture is limiting, productivity of the optimum population reflects this limit. However, it is surprising that there was no indication that the overall population in the intercrop was adjusted to water limit. Is it not true that higher populations in the intercrop were responsible for the lower benefits from it?

Mr J. N. Chui: Under less-than-adequate rainfall conditions, increase in population was responsible for yield reduction as a whole, but the level of reduction was different from one cropping system to the other. If it was possible to predict the rainfall condition accurately early in the season,

then reducing the population would be beneficial. Otherwise, planting beans as sole crop and cowpeas and pigeonpeas as intercrops with maize would be the best possible practice under the unpredictable rainfall conditions of the area.

Mr Marimi: (1) There is increasing evidence that a double-row arrangement is superior to an alternate-row arrangement. Is there any reason why this treatment was not included? (2) There was no indication that maize population was reduced in the intercrop, implying that soybean/beans were growing under greater stress than in the sole crop of soybean/bean. The method to correct this would be to impose an equivalent soybean/bean crop population on intercrop. How come this treatment is not included?

Mr Chui: (i) Most of the "double-row" spacings of beans reported come from the high-rainfall areas and the spacings used are usually closer than the ones found suitable in the dryland areas, as they result in higher bean population. However, the reason why we did not include this treatment was to reduce the number of treatments. Nevertheless, it is planned to include this "double-row-pattern" treatment in the next season. (ii) In the case of the maize population, I did not want to introduce another variable of population differences that would have accounted for the lower yield. Legume intercrops always experience greater stress than their sole crops because they experience both intraspecific and interspecific competion for the environmental factors. Concerning the legume populations, I used also that equivalent to sole crops. Hence, this treatment was also included.

Mr Whiteman: Although only a little moisture is lost by preparing the soil after the rain, it is all in the surface, and commonly results in poor germination, especially with small-seeded crops that cannot be sown deep. You could use the foot to simulate planter-wheel effect.

Mr Chui: Maybe, but let's solve the weed problem first.

Mr. Ndambuki: In your intercropping experiment you have worked with the local pigeonpea. Recently a short-season (early) pigeonpea variety has been highly popularized in the area. How will this fit your recommendations?

Mr Chui: We did not have a chance to test the new pigeonpea varieties under intercropping conditions, because of the drought in the short rains of 1980/81 and 1981/82. They need to be tested to find out how they can fit the recommendations.

Mr H. L. Potter: (1) Was soil sterilized to remove contamination by "native" rhizobia before inoculation with selected rhizobia? (2) With the small significant differences and their somewhat haphazard pattern is it possible that differences noted were a reflection of soil-sample variation in rhizobia, fertility, etc., rather than simply a reflection of treatment effects?

Mr Chui: (1) Yes. Sterilization was done to part of the soil for observation purposes, but the data are not reported here. However, sterilization proved ineffective and plants nodulated without inoculation. Also, yellowing and dropping of leaves at vegetative stage was observed. Probably sterilization had some effect detrimental to the plants. (2) Although the variations observed were small due to inoculation, I still feel that they were due to treatment effects because we observed that inoculation had inhibitive effects on native rhizobia in some aspects and there were also two rhizobium strains which consistently showed better interactions with the two bean varieties than the native rhizobia.

Mr L. O. Sese: Could chemical fertilizer be substituted by farmyard manure as a source of nitrogen in the dryland farming areas?

Dr M. H. Nadar: Yes, if the quantities available were enough to provide the required amounts of nutrients.

Mr Marimi: There are claims that pasture legumes are more efficient in fixing N than grain legumes. It is further claimed that legumes grown for seed leave less N in the soil than those grown and harvested before seed filling and maturity. Were these considerations taken into account or are they going to be considered later?

Dr M. H. Nadar: Yes, you are right. But in our approach to research, we first study the feasibility of what the farmer is already doing, and then study the possibility of introducing new practices to him. We found that the farmers in the study area do not grow pasture legumes on the land reserved for crops, and they do not usually harvest their grain legumes at the vegetative stage. That is what prompted us to give priority to a maize/grain-legume rotation and intercropping study. It was planned to study the possibility of intercropping and/or rotating maize with forage legumes such as hairy vetch, but we ran out of time.

Mr K. Njoroge: How was the "local maize seed" obtained for use in the experiment?

Dr W. A. Faught: "Local maize seed" was that

used by farmers in planting their own fields. Generally the seed had been selected by the farmer from a preceding crop, but in some instances it had been obtained from neighbours.

Mr Marimi: A suggestion—could the 1:1 cost return line be added to improve the readability of figure?

Dr Faught: Yes, it will be added.

Dr R. K. Jones: Has there been any evidence of adoption of any of the "improved" practices by farmers who participated in the verification trial?

Dr Faught: No.

Mr M. Thiongo: Labour is usually a very critical factor in farming operations in semi-arid areas, especially because of the unreliability of the rainfall and the short growing seasons. When introducing new recommendations which require additional labour (intercropping, fertilizer application, extra weeding, etc.) it is important that you try to determine the additional labour requirements, and in the semi-arid areas of Kenya women, who perform most of the farm operations, also have to spend many hours daily fetching water and firewood. Therefore we cannot assume that family labour is unlimited, especially when you bear in mind that some operations like planting must be done within a few days.

Dr Faught: When you look at the approach followed for designing and implementing the research programme, you can see that all constraints facing the farmers were taken into consideration in the process of planning the experiments. The results which seem to be promising are tested under actual farm conditions to find out how they interact with the constraints facing the farmers. In other words, the experiments were originally designed to reduce the effect of these constraints.

Mr Marimi: During the first season farmers were unable to achieve recommended plant populations. In fact, achieved populations were only 50%. One obvious recommendation is to mount an investigation into a methodology for enabling farmers to achieve the recommended population levels. Did you consider this feasible, and if so, is anybody working on it?

Dr Faught: To the best of my knowledge, no one is working on this specific question. A plough developed by the FAO Mechanization Project might be suitable, but apparently has not been tested to date. Verification trials were limited to equipment farmers are currently using. Testing of the FAO-developed plough or development of new ploughs appear both feasible and desirable.

Mr Chui: The test-crop table shows that the cereal-bean intercrop had less extractable residual moisture than a cereal crop grown alone. However, the yield of the test crop was higher in the field previously under intercrops than in the cereal which had a higher level of extractable residual moisture. Did you attribute the yield of the test crop to the lower residual moisture in the intercrop, or did you hope there was a fertility contribution by the legume that had caused the test crop to have a higher water-use efficiency?

Mr Whiteman: The yields of the test crops after the cereal/bean and cereal treatments were not significant. Nitrogen was not limiting, as judged by the test-crop plots being split for nitrogen. The soils naturally mineralize considerable amounts of nitrogen each season.

Mr L. Ulsaker: Did you notice a difference in sorghum performance between the long and short rains that could have been attributed to temperature differences?

Mr Whiteman: Very definite differences occur. Lowland sorghums grown above 1200 m altitude in the long rains are seriously affected by diseases and protracted growth. Also there is a tendency to tiller more under the cooler conditions, and early growth is slower in the long rains due to cooler soil slowing down meristem activity.

Mr J. O. Mugah: What was the total yield (beans and sorghum) in your treatment involving beans followed by sorghum, and how do the benefits compare with those obtained from the plot that was first fallowed and then planted to sorghum?

Mr Whiteman: Yields of beans were recorded. Data are not at hand but it was about 500 kg/ha. Final assessment depends on the relative value of the grains. But the advantage of beans on bare fallow is that the farmer is more likely to weed the field if it has a crop than if it is completely bare. The advantage of stored moisture can be increased by keeping bean populations low.

TECHNICAL SESSION 3

PRESERVATION OF LAND FOR EFFECTIVE CROP PRODUCTION

SOIL EROSION: A THREAT TO LAND RESOURCES

A. M. Kilewe[1] *and L. G. Ulsaker*[2]

INTRODUCTION

The conservation of agricultural resources, including soil, water and nutrients, is essential for maintaining or increasing food production. However, the selection of a desirable conservation system is difficult because the system must satisfy several requirements, which include (a) providing an economic level of crop production, (b) controlling erosion, (c) controlling runoff, and (d) limiting movement of nutrients from agricultural land. Furthermore, a system that provides acceptable erosion control is not necessarily the best for controlling runoff, restricting movement of nutrients, or crop production, and specific management practices that comprise a system vary considerably within methods used for tillage, crop-residue management and fertilization.

In Kenya, soil erosion is a pressing agricultural problem. It presents a major threat to all facets of land productivity. Each year thousands of hectares undergo land-use changes. Forests and grasslands are continuously being converted to agricultural and pastoral uses, and rural lands are becoming urbanized. Each change in land use that alters the ground cover or grades the land is a potential catalyst for erosion. These changing lands are the sources of large quantities of sediment that pollute streams, fill reservoirs and contribute dust to the atmosphere.

Excessive soil erosion is a by-product of today's intensive agriculture. It results also from road and building construction and other intensive land uses. Continued excessive soil erosion has serious implications for the quality of life in Kenya. If left unchecked, it threatens the basic elements of life by decreasing the ability of Kenya land resources to produce the food supply that Kenyans expect and by degrading the quality of water and air. The economic and social costs of soil erosion are enormous and widespread. With the continuation of present management, these costs may be expected to be compounded progressively. Lower agricultural productivity resulting from soil misuse will lead to scarcity of low-cost food. This will lead in turn to further misuse of already cultivated land and the exploitation of other land that is even more vulnerable to erosion.

The problems of soil erosion and the related solutions are multifaceted and multidisciplinary. In addition, there are strong linkages between soil erosion and land-use management and practices. Hence a large number of government ministries, agencies, parastatals, and donor organizations are working actively to combat soil and water losses in Kenya. However, in spite of all these active organizations, the problem of soil erosion is still getting worse, particularly in the arid and semi-arid regions. This is probably due to the absence of analytical or systematic and coordinated studies to document the problem, its consequences, and its potential solutions. The arid and semi-arid regions are characterized by aggressive climatic conditions and increasing population, requiring intensification in subsistence modes of production and the abandonment of traditional forms of conservation. In the process of settling, clearing, tilling and grazing the land, the original vegetation cover has been completely removed or modified over vast areas. Because of the increased exposure of the soil, the forces of wind and water have greatly accelerated soil erosion to above the natural erosion rate. These arid and semi-arid lands, without adequate protective measures, are too fragile to be disturbed and are really only fit for permanent forest. Most of them are therefore continually threatened by accelerated and irreversible land degradation. Given the immediate severity of the problem, both short- and long-term actions are urgently required to insure optimal land use, to sustain productivity, and to maintain the quality of land resources. This action is not only required in those areas of Kenya where food supplies are marginal and soil erosion has a direct impact upon human life, but also in the high-potential areas where erosion and sediment may cause considerable economic damage to individuals and society in general. An appreciation and understanding of the basic erosion principles is essential in order to develop and implement a compre-

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hensive and cost-effective conservation programme. This paper will therefore attempt to discuss soil erosion by water from two standpoints: (a) quantitative prediction of soil erosion, and (b) impacts of soil erosion.

QUANTITATIVE PREDICTION OF SOIL LOSS

Soil erosion is related to the effective erosivity of raindrop impact and runoff acting on the soil, and the susceptibility of the soil to erosion (Foster and Meyer, 1977). Quantitative assessment of soil erosion requires full knowledge of many factors related to soil properties, land conditions, and rainfall characteristics. The universal soil loss equation, USLE (Wischmeier and Smith, 1965), expresses the relationship between these factors quantitatively as follows:

$$A = RKLSCP$$

where, A = average annual soil loss
R = rainfall erosivity factor
K = soil erodibility factor
L = slope-length factor
S = slope-gradient factor
C = cropping-management factor
P = supporting conservation practice factor.

The factors L, S, C and P serve to modify various topographic erodibility elements, and their values reflect various topographic conditions, cropping and management options.

The USLE was developed as a method of predicting average annual soil loss from interrill and rill erosion. With the factor values available, cropping and management alternatives can be determined to reduce the estimated soil loss to tolerable values for the soil type. As detailed by Wischmeier (1976), the USLE may properly be used to: (a) predict average annual soil loss from a field slope with specific land-use conditions, (b) guide the selection of cropping and management systems and conservation practices for specific soils and slopes, (c) predict the change in soil loss, cropping or conservation practices on a specific field, (d) determine how conservation practices may be applied or altered to allow more intensive cultivation, (e) estimate soil losses from land used for other than agricultural purposes, and (f) provide soil-loss estimates for conservationists to use in determining conservation needs. A generation of erosion research, data collection, equation development and field application of erosion equations preceeded the USLE. Some of the factors and techniques used in the USLE had evolved as early as 1940 (Zingg, 1940). Consequently, the USLE was both a refinement and a major advance in technology. Research for new applications of the USLE must consider the significance, meaning and derivation of each of its factors, particularly as they relate to those conditions of climate, soil, topography and land use that differ substantially from those which produced the original USLE data base.

Erosivity Factor, R

The erosivity factor R includes the erosivity of both rainfall and runoff. Effective rainfall erosivity at the soil surface depends on canopy and ground cover. Runoff erosivity depends on runoff volume and rate, which in turn depend on rainfall, infiltration, ground cover, surface roughness, and runoff flow pattern as influenced by soil, cover, management and supporting conservation practice. The selection of the erosivity factor R in the USLE was based on regression analysis of soil-loss data from cultivated continuous fallow plots for U.S. conditions. The erosivity factor R as used in the U.S. is expressed as the summation of the product of total storm kinetic energy, E, times its maximum 30-minute rainfall intensity, I_{30}, summed for all the storms in one year. The erosivity factor R for a specified year is stated as:

$$R = \sum_{i=1}^{n} (EI_{30})$$

This product is a measure of the manner in which energy and intensity are combined in a storm and defines the combined effect of raindrop impact and turbulence of runoff to transport soil particles from a field. Other erosivity indices have been used in other parts of the world. These include KE>25 (Hudson, 1971), $p^2/P = C$ (Fournier, 1956; Fournier and Henin, 1959), AI_m (Lal, 1976 a, b) and $V_r\ I_{30}$ (Lombardi, 1979). Where KE is the kinetic energy, p is the mean monthly rainfall in the wettest month of the year, P is the mean annual rainfall, C is the rainfall coefficient, A is the total rainfall amount, I_m is the peak storm intensity, V_r is the volume of rainfall and I_{30} is the maximum 30-minute rainfall intensity. EI_{15}, EI_5, $V_r\ I_{15}$ and $V_r\ I_5$ have also been used to express the R factor. In these expressions I_{15} and I_5 are the maximum 15- and 5-minute rainfall intensities. These expressions need to be related to actual soil-loss

data before a recommendation on the most appropriate index for Kenya can be made. The erosion research facility at Katumani National Dryland Research Station is capable of providing the required data, as discussed by Ulsaker and Kilewe (1983).

Soil Erodibility Factor, K

The soil erodibility factor K is a quantitative description of the inherent erodibility of a particular soil. It is defined as the rate of soil loss per unit erosion index from a unit plot. It reflects the fact that different soils erode at different rates when the other factors that affect erosion are the same. The approach used in the USLE development was to define a base reference, the unit plot (Wischmeier and Smith, 1978). A unit plot has been arbitrarily defined as 22.1 metres long with a uniform lengthwise slope of 9%, in continuous fallow, and tilled up and down the slope. Values of L, S, C and P in the USLE are defined as unity in the unit plot and therefore $K = AR^{-1}$. Continuous fallow was selected for the unit plot because no cropping system is common to all agricultural areas and soil loss from any other plot condition would be influenced by residual and current crop and management effects that vary between locations (Wischmeier, 1972). Soil loss from the unit plot is a reference for high erosion rates.

Since K is a measure of soil erodibility from both raindrop impact and surface runoff, plots used to determine K must be sufficiently long for runoff to accumulate at a rate typical of most field situations. A soil's susceptibility to interrill erosion by raindrop impact may not be related to its susceptibility to erosion by surface runoff (rill erosion). Two soils may be equally susceptible to interrill erosion, but have greatly differing susceptibilities to rill erosion (Meyer, Foster and Romkens, 1975). The relative erodibilities of two such soils therefore depend on the slope length used to evaluate them (Meyer, DeCoursey and Romkens, 1976).

Accurate K values have been determined for most soils in the U.S. soil erodibility nomograph produced by Wischmeier, Johnson and Cross (1971). However, El-Swaify and Dangler (1977) reported that K values estimated from the USLE nomograph were significantly in error for several Hawaiian soils. This is also expected for Kenyan soils, because the genesis of U.S. soils differs greatly from that of Kenyan soils. Furthermore, U.S. rainfall (temperate) patterns differ from Kenyan (tropical) patterns, which could give different K values for the same soil located in the two climates. There is, therefore, an urgent need to determine accurate K values for Kenyan soils before the USLE can be used for accurate prediction of soil loss in Kenya. Although a start has been made in this direction by establishing a soil erosion research facility at the Katumani National Dryland Research Station (Ulsaker and Kilewe, 1983), many more data remain to be collected. In order to determine K values for many important agricultural soils in Kenya, sufficient runoff plots need to be established soon. However, due to the high cost involved, the most cost-effective technique for accomplishing this would be through the use of a rainfall simulator which can be moved from place to place throughout the country. K values for all soils are then selected by comparing soil properties with those of the bench-mark soils having known K values.

The Slope-length Factor, L

The USLE slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough for deposition to begin or the runoff water enters a well defined channel (Wischmeier and Smith, 1978). The L factor is a measure of the effect of accumulated runoff with increased slope length on detachment by runoff and sediment transport capacity of runoff. It is given by:

$$L = \left(\frac{l}{l_u}\right)^m$$

Where L = slope-length factor
l = actual slope length
l_u = length of the unit plot
m = an exponent.

The recommended values for m range from 0.2 for low-steepness slopes to a constant 0.5 for slope steepness of 5% and steeper slopes (Wischmeier and Smith, 1978). The increase in m is the result of increase in rill erosion as the slope steepness increases. Errors in estimating field slope length, L, probably counter the need for precisely relating m to various other factors. Compared to other factors in the USLE, estimated soil loss is relatively insensitive to the L factor. However, consideration should be given to extremes like steep slopes and soils especially susceptible to rill erosion.

The Slope-steepness Factor, S

The slope-steepness factor of the USLE is a measure of the effect of slope steepness on hydraulic forces from raindrop impact and runoff, and their capacity to detach and transport sediment. It is given by the following expression:

$$S = 65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065$$

where S = slope-steepness factor
θ = angle of the slope.

The USLE slope-steepness factor should transfer well to Kenya for slope steepness up to 25%. However, research is needed to verify the relationship for steeper slopes.

The Cropping-management Factor, C

The cropping-management factor C represents the ratio of soil loss from a specific cover-management condition to the soil loss from a unit plot for the same soil, slope, and rainfall. It includes the interrelated effects of cover, crop sequence, cultural practices, residue management and rainfall distribution. This factor is difficult to determine because of the many cropping and cover-management systems. Either crops can be grown continuously or in rotation, residue removed or left on the field or incorporated into the soil, and the soil clean tilled, or one of the several conservation tillage systems may be used. Cropping and cover management have the greatest range of effect on soil erosion. They are also the most readily managed by the land user to control erosion. Therefore, accurate evaluations of the C factor for agronomically and culturally feasible cropping systems should be given great attention in transferring the USLE to Kenya. This is important because farming systems in Kenya are different from those in the U.S., where the factor was developed.

Supporting Conservation Practices, P

The supporting conservation factor P in USLE is the ratio of soil loss with a specific support practice to the corresponding soil loss with up- and down-slope culture. It reflects the influence of practices like contouring, strip cropping, terraces, and contour furrows used to support protection provided by crop rotation, canopy cover, and residue mulches. Standard USLE values should transfer with minimal problems to Kenyan situations.

Soil-loss Tolerance

A tolerable soil loss is the maximum long-term average annual erosion rate that a particular soil can tolerate without excessive degradation for continued crop production. This concept, used in conjunction with the USLE, is a valuable tool for identifying erosion problems and selecting an appropriate erosion-control practice. Tolerable losses in the U.S. range from 5 to 11 tonnes/ha/year (Wischmeier *et al.*, 1978). The data necessary to formulate soil loss tolerances and to quantify the causative parameters of erosional processes in Kenya are scarce. Efforts are therefore needed to acquire the necessary data and to evaluate the applicability of existing technological alternatives for erosion prediction and control in Kenya. In addition, there is a need to increase the cadre of technically trained personnel, to emphasize the socio-economic aspects of the problem, and to enhance the awareness of leaders and policy-makers to the importance of the problem.

IMPACTS OF SOIL EROSION

Quantitative determination of the extent and impact of soil erosion by water in Kenya are sketchy. However, the little and scattered information available indicates that accelerated erosion is a problem of serious magnitude with a multitude of detrimental impacts. Some of the major impacts of erosional processes include loss of soil productivity, loss of plant nutrients, and water pollution.

Loss of Soil Productivity

Soil erosion depletes soil productivity. However, the relationship between erosion and productivity is not well defined (Lengdale and Shrader, 1981; Pesek, 1980). When soil erosion is so severe and the soil is so shallow that complete denudation occurs, soil productivity is eliminated in that the soil itself is lost as a resource. In the more common case of partial erosion, topsoil removal has generally been associated with reduction in crop yield. Accurate estimates of present and future soil productivity are essential to make agricultural policy decisions and to plan land use from the field scale to the national level. A glossary of soil-science terms of the Soil Science Society of America (1975) defined soil productivity as the capacity of a soil, in its normal environment, to produce a particular plant or sequence of plants under a specified management system. A National Committee of the

USDA, Science and Education Administration, Agricultural Research (1981) listed the following ways through which erosion decreases soil productivity: (a) loss of plant-available soil-water capacity by changing the water-holding characteristics of the root zone or by reducing the depth of the root zone, (b) loss of plant nutrients, (c) degradation of the soil structure leading to increased soil erodibility, surface sealing and crusting, and (d) non-uniform removal of soil within a field. Loss of topsoil nearly always reduces the inherent productive potential of a soil. Characteristics of individual soils, however, can strongly affect the quantitative impact of soil erosion upon productivity. Until the relationship is adequately developed, selecting management strategies to maximize long-term crop production will be impossible. Wrong decisions can easily result in serious damage to soil resources and productivity may approach zero in the severely eroded areas. In view of this there is an urgent need for research to quantify the effect of erosion on soil productivity. Such a research programme should be geared to determining the effect of surface-soil thickness on productivity and whether the productivity of subsoil exposed by erosion could be efficiently and economically restored by the use of commercial fertilizer or farmyard manure.

Loss of Plant Nutrients

The use of commercial fertilizers in Kenya has increased substantially in the past few years because of the growing demand for food and depletion of native soil nutrients by erosion. Nitrogen (N) and phosphorus (P) are the major elements of commercial fertilizer essential to normal plant growth. However, much of what happens to them when a heavy storm occurs shortly after their application in sloping lands is not very well documented. Lush growth of vegetation along natural waterways and at the base of fertilized slopes is often attributed to washing of fertilizer into these areas.

Management practices greatly influence N and P losses from fertilized agricultural land. Timmons, Burwell and Holt (1973) found that losses of N and P were greater when fertilizer was applied to the soil surface than when mixed into the soil. Soil cover and seasonal periods have also been shown to influence N and P losses (Burwell, Timmons and Holt, 1975). The efficiency of applied fertilizer is highest when applied just before or during the period of greatest crop growth (Stanford, England and Taylor, 1970). Also, split application, timed to meet crop needs, reduces fertilizer loss from the rooting zone. The present fertilizer-application practices in Kenya do not conform to these "spoon-feeding" concepts. Usually the time, rate and method of fertilizer application depend more on fertilizer availability, seasonal fertilizer cost, and availability of transport and farm labour. As a result, fertilizer is often applied several weeks ahead or before the crop needs it and therefore much of it is lost in runoff or leaching. The energy crisis, which has increased fertilizer cost and reduced supplies, requires more efficient fertilizer-application practices. In view of this, there exists an urgent need for research to improve the efficiency of fertilizer use in crop production. Such research should be geared to a modification of the time, rate, and application practices of fertilizer so that more nutrients are available when needed by the crop. Research is also needed to establish the relationships of N and P concentrations in field soils to concentrations of these nutrients in runoff for different soil cover-cropping conditions in order to quantify nutrient losses in eroded soil. This information, used in conjunction with the universal soil loss equation, would provide a basis for predicting nutrient losses associated with runoff from agricultural land and aid in selecting appropriate cropping-management and supporting conservation practices to reduce these losses to acceptable levels. Again, the runoff research facility at the Katumani National Dryland Research Station is capable of providing all the required data.

Water Pollution

The major off-site impact of soil erosion is on water quality and on the condition of streams, reservoirs, and lakes. Sediment derived from soil erosion decreases the water-storage capacity and life expectancy of lakes and reservoirs, clogs streams and drainage channels, causes deterioration of aquatic habitats, muddies recreational water, increases water-treatment costs, damages water-distribution systems, and carries agricultural chemicals into water systems. By volume, sediment is the greatest pollutant of surface waters (Robinson, 1971; Burwell, Timmons and Holt, 1975).

The sediment and water components of runoff degrade the quality of surface waters with nutrients that could have been utilized by growing plants. When the concentration of these nutrient minerals in lakes, rivers and reservoirs becomes too high, growth of aquatic plants

usually becomes excessive. The water may then become undesirable for domestic and recreational uses. The chemicals in runoff from agricultural lands have been blamed as among the prime contributors to this nutrient enrichment of surface waters. However, few quantitative data are available for evaluating the amounts and sources of the contribution of agriculture to this eutrophication problem. It is true that fertilizers are being applied at higher rates to maximize food production or restore productivity on eroded lands. This results in increased concentrations of chemicals in agricultural runoff. The amounts of these chemicals in agricultural runoff need to be determined and their critical limits established so that methods can be developed and used to reduce them below critical levels in runoff waters.

SUMMARY

Soil erosion is related to the effective erosivity of raindrop impact and runoff acting on soil, and the susceptibility of the soil to erosion. The universal soil loss equation, USLE, developed in the U.S. as a method to predict average annual soil loss from rill and interrill erosion, expresses the relationship between these factors quantitatively as follows: A = RKLSCP, where A is the average annual soil loss, R is the rainfall erosivity, K is the soil erodibility, L is the slope length, S is the slope gradient, C is the cropping management and P is the supporting conservation practice. In order to accomplish a successfull transfer of the USLE to Kenya, concerted effort is required to derive the parameter values as they relate to the local conditions of climate, soil, topography, and land use. This will facilitate the formulation of soil loss tolerance values that a particular soil can tolerate without excessive degradation of the soil for continued crop production.

Soil erosion decreases soil productivity through loss of storage capacity for plant-available water, loss of plant nutrients, degradation of soil structure and decreased uniformity of soil conditions within a field.

Sediment derived from soil erosion is the greatest pollutant of surface waters. It decreases water-storage capacity and life expectancy of lakes and reservoirs, clogs streams and drainage channels, causes deterioration of aquatic habitats, increases water treatment costs and carries agricultural chemicals into water systems.

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RUNOFF AND SOIL EROSION FOR AN ALFISOL IN KENYA

L. G. Ulsaker[1] *and A. M. Kilewe*[2]

INTRODUCTION

Soil and water conservation problems are becoming increasingly serious in much of East Africa, especially in the arid and semi-arid areas where much of the resulting environmental degradation is irreversible. This situation is compounded by lack of research on erosion factors causing breakdown and transport of soil in these areas. Such research is required to quantify erosion rates accurately and to develop effective soil- and water-conservation programmes.

This report describes the results of soil and water-conservation work conducted by the USAID-funded Dryland Cropping Systems Research Project of the Kenya Agricultural Research Institute (KARI), Muguga. The field work was done on an alfisol. The results may be applicable to other similar soil and climatic conditions in East Africa.

The objectives of the work were:

1. to determine the magnitude of runoff and soil loss caused by natural erosive rainstorms under existing cultural practices associated with the small farmers of the area;
2. to gain insight into the erosive effects of rainfall, soil erodibility, land management, crop cover, and mulches on observed runoff and soil losses;
3. to evaluate the key parameters of the universal soil-loss equation (USLE) to extrapolate it to East African conditions.

RUNOFF PLOTS: LOCATION, DESIGN AND INSTALLATION

Runoff plot equipment was designed and installed at the National Dryland Farming Research Station (NDFRS), Katumani, Eastern Province, Kenya, during 1980. The installation will facilitate a long-term research programme involving measurement of soil erosion and water runoff, investigation of the causes and mechanics of each, and evaluation of preventive measures.

After several decades of specialized research on soil erosion and conservation problems, it has been found that there is no satisfactory substitute for runoff plots, as they supply basic data which may be secured only by actual measurement of the quantities of soil and water lost by erosion and runoff (Kirkby and Morgan, 1980).

Equipment-design criteria will vary with the location, soil type, land use, and climate of each site. Mutchler (1963) has developed the basic procedures to aid site selection and to determine equipment design. This account describes the factors considered for design, construction and installation of the Katumani runoff equipment.

Site selection

Geographic Area and Soil Type: The site was located on a prevailing slope of a major soil type. The shallow, reddish-brown, sandy clay soil of undulating uplands on which the site is located was developed on biotite and banded gneisses and occurs extensively in broadly scattered patterns throughout Machakos and Kitui Districts. It is classified as Ferral-chromic Luvisol, lithic phase, by Mbuvi and van de Weg (1975), using the FAO-UNESCO system. It corresponds to a fine, kaolinitic, isothermic Oxic Paleustalf, suborder Ustalfs, order Alfisols, in the USDA (1975) Soil Taxonomy System. This soil order covers the largest area of the semi-arid tropics (Virmani *et al.*, 1978). It has good internal drainage, but tends to seal at the surface. Selected soil characteristics of samples taken at the site prior to initiation of research are given in Table I. Details of the physical soil characteristics of the runoff plot site, identified as field N, are described by Kilewe and Ulsaker (1983b) in this volume. The climate at the Katumani station (1°35′s latitude, 37°14′E longitude, 1,575 m above sea level) is semi-arid tropical with a mean annual temperature of 19.5°C and mean annual rainfall of 709 mm occurring in a bimodal pattern.

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2. Soil Physicist, USDA/OICD Africa Bureau and KARI

TABLE 1—SOIL PROPERTIES OF THE RUNOFF PLOT SITE AT KATUMANI

Horizon	Depth (cm)	Texture: Sand 2-.1 (%)	V.F sand .1-.05 (%)	Silt .05-.002 (%)	Clay .002 (%)	Class (USDA)	B.D. (g/cm³)	pH (CaCl₂)	Org. C (%)	Total N (%)	P (ppm)	Exch. cations: K	Ca (meq/110 g)	Mg	Na	CEC	Base sat. (%)
AP	0–15	61	8	9	22	SCL	1.52	4.4	1.34	.10	14	0.8	3.6	2.4	0.1	22	22
Blt	15–35	58	6	10	26	SCL	1.44	4.7	0.77	.09	7	0.7	4.0	2.5	0.1	18	57.6
B2t	35–60	50	6	12	32	SC	1.43	5.1	0.72	.07	3	0.5	4.0	2.6	0.1	13.8	62
B31t	60–95	46	6	15	33	SC	1.40	5.5	0.54	—	—	0.5	4.0	3.9	0.1	14	73

The two seasons are referred to as the "long rains" (LR) and the "short rains" (SR) which respectively peak in April and November. The hydrological properties of each rainstorm that occurred during this study and the onset of each season are shown in Table XX.

Topographic Considerations: The plots must accommodate statistical comparison, which requires that all plots have comparable slopes, soils, history, etc., to minimize variables other than those being studied.

Careful inspection of over 240 hectares on the station failed to reveal a site with uniform slope, soil type, and history that was large enough to accommodate more than 12 plots. A 10% slope was selected because a considerable proportion of this soil type occurs on that gradient, as does much of the surrounding cultivated area. The plots are only 10 m long. The upper terrace would have to be removed to accommodate longer plots. This would cause extensive surface-soil disturbance, creating unnatural responses to erosive forces for several seasons. One of the fallow plots is being extended to 22 m in order to evaluate the effect of slope length on annual runoff and soil loss per unit area, but the data collected from this plot will not represent natural conditions before the 1985 long rains.

Plot width has little relation to soil loss per unit area on plots cultivated up and downhill, so a width of 3 m was selected, which will accommodate five 60-cm rows, and is considered adequate for most research purposes. In many of the earlier plots, rows were planted along the contour. It soon became recognized, however, that contour field management cannot be simulated in runoff plots because of complete balking within small plots and little concentration of row water (Mutchler, 1963). Most runoff plots are now planted up and downhill, and quantitative data are adjusted for effectiveness of contour farming.

The area was surveyed by the transit-tape method, from which a topographic map was made on a 3 m grid with a 0.5 m contour interval, as shown in Fig. 1. It would have been desirable to overlay a soil map on the topographic map, but Musuva (1969) reported that the soil map was lost before it could be reproduced.

The farm manager for the NDFRS, Katumani, provided the following history of the site. It was first cleared and ploughed in 1958. Although not recorded, it is assumed that the terraces were constructed at the same time.

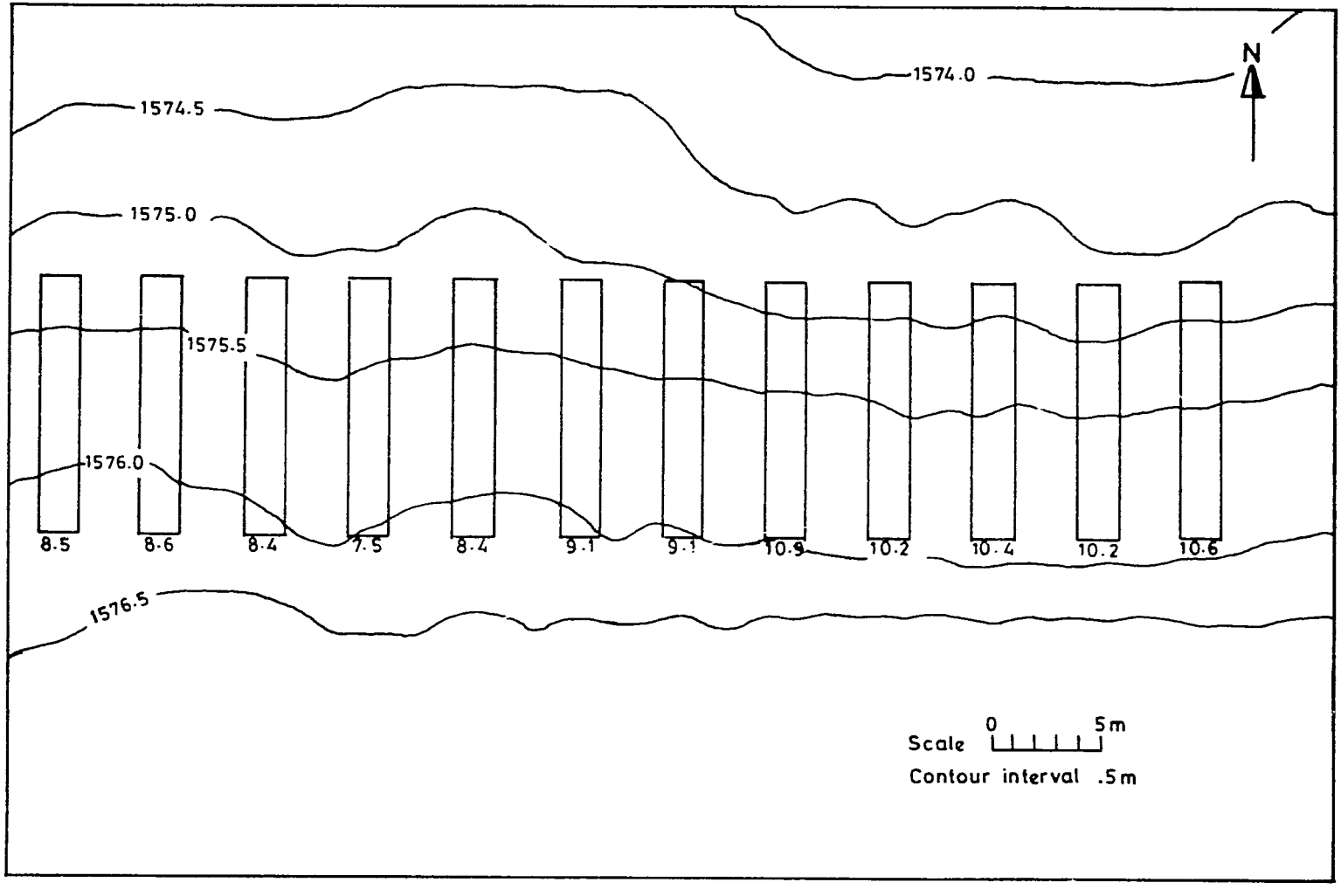

Fig. 1. Topography, plot alignment, and per-cent slope of runoff plot site

In some instances the specific crop was not recorded, nor were the fertilizer-application rates, yields, or other agronomic data.

1958 short rains through 1961 long rains	Grass
1961 short rains through 1964 long rains	Cropped
1964 short rains through 1974 long rains	Grass
1974 short rains	Beans
1975 long rains through 1975 short rains	Cropped
1976 long rains	Sorhum
1976 short rains through 1978 long rains	Pasture
1978 short rains	Maize
1979 long rains	Pasture
1979 short rains	Cropped
1980 long rains	Beans
1980 short rains	Runoff equipment installed
1981 long rains	Maize

Equipment design

The basic equipment consists of a plot boundary to prevent water and soil from entering or leaving the plot; a collector which serves as a weir at the end of the plot; a conveyance channel to handle the flow of soil and water; a sludge tank to contain the soil sediment and water; a multislot divisor with a precision plate to measure out a portion of the overflow from the sludge tank accurately; and one or more aliquot tanks to contain the measured overflow.

Small, removable intertanks are placed directly below the in-flow spout of the sludge and aliquot tanks to greatly reduce the time and labour required to sample and clean up after small storms and improve the accuracy of volume measurements.

This equipment collects the runoff and soil loss from the plot and holds it for measurement and analysis. Size and capacity of the equipment were determined by the anticipated maximum rate and amount of runoff and sediment to be sampled. The storage required for runoff and soil loss was estimated by using 100% of the 24-hour duration rainfall amount expected once in 100 years.

Mutchler (1963) acknowledges that runoff rarely equals 100% of the rainfall, but says that it is safest for figuring the storage capacity required. The maximum 24 hour rainfall amount recorded at Katumani between October 1956 and April 1983 was 102 mm. The soil loss estimate for an 8%, 60 m slope under continuous maize with residue removed was 114 t/ha/yr (Consortium for International Development, 1978).

Plot boundaries are 26 gauge galvanized sheet metal strips 2.5 m long × 22 cm wide. They are easily removed when cultivation of the plots is necessary. Two matched holes were drilled in the ends of each strip so that they can be bolted together, making them watertight. The downslope strip is overlapped on the outside of the upslope strip. They are placed on edge along the plot boundary and pounded in about 8 cm deep, enough to prevent piping and tunnelling by rodents.

The runoff collector was made of sheet metal rather than concrete so that its level can be adjusted to the level of the plot as erosion occurs. An end-plate of galvanized steel furnishes a stable attachment for the collector and blocks off the plot end. It extends 20 cm below the bottom of the collector trough. The collector and end-plate reach across the entire 3-m width of the plots. The collector and end-plate were made from 26 gauge galvanized sheet metal. The collector, as illustrated in Fig. 2, is 25 cm wide and forms an efficient channel and allows easy cleaning. The 35 cm depth is based on the size of the conveyance channel needed to carry the runoff load. The bottom slope is 5%. A 2.5-cm mesh screen covers the collector trough to help keep field trash out of the system. A galvanized sheet-metal cover fits over the top to prevent rain from entering.

The conveyance channel was designed to handle a minimum velocity of 0.61 m/s (2 fps) at about 20% of the largest flow expected, in order to insure non-silting velocities throughout most of the range of flows encountered when installed at a supercritical slope. The largest flow expected was estimated to be 0.0424 cusec. The channel size was calculated at 15 cm wide by 25 cm deep using procedures given by Mutchler (1963) and

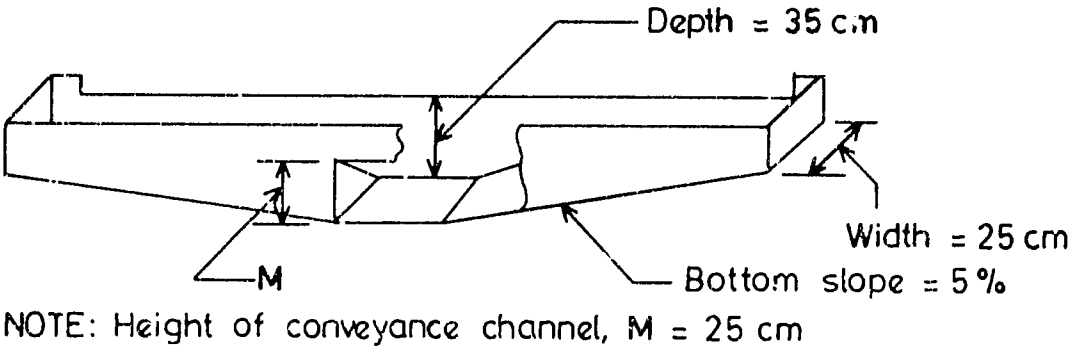

Fig. 2. Collector trough

allowing for a three-fold increase in plot size.

Sludge tank storage capacities vary greatly with location, soil type, land use, and climatic conditions. Brakensiek *et al.* (1979) report that sediment rates as high as 112 t/ha have been recorded from single runoff events and the bulk densities of the trapped sediment ranged from 641 to 1,602 kg/m^3. The bulk density of the surface soil at the Katumani runoff site is 1,520 kg/m^3. Assuming a maximum annual soil loss of 114 t/ha and that the sludge can be emptied after a storm causing half this loss, the required storage capacity was calculated at 0.14 m^3. To alllow for plot enlargement and storage space for water, a sludge tank with 0.24 m^3 capacity was designed to be made from 25 gauge metal, 1.82 × 0.76 × 0.60 m, with rounded ends and a cover. Two screens are placed across the flow through the sludge tank to reduce turbulence and increase deposition. The screens also keep trash, snakes, etc. from clogging the divisor. They do not extend to the tank bottom and freeboard is allowed at the top to insure flow even if the screens do become filled with trash. The screen near the entrance is of 2.5-cm mesh and the second is 1.3-cm mesh. Both screens are removable for easy cleaning of the tank and the tank bottom is fitted with a drain plug.

The multislot divisor is a device for taking an aliquot of runoff water. It is based on the premise of a uniform horizontal flow velocity throughout the head variations. The essential part is the slot plate, which contains 9 slots 2.54 cm wide × 20.32 cm high, with a capacity of 42.47 l/s. As the runoff flows through the slots, it is divided into equal parts. The portion discharged by the centre slot is retained in the aliquot tank. The heavier sediment settles out in the sludge tank, so that the divisor has to handle only the suspended sediment load. The entrance arrangement to the divisor, which insures suspended load mixing, is shown in Figs. 3 and 4. The multislot divisor is one of the best sampling units available for quantitative measurement of runoff, and with careful construction and installation the divisor ratio is accurate to about 1% for a runoff period.

The detailed specifications and plans for the multislot divisor that were followed by the contractor are included in Mutchler (1963).

The aliquot tank stores that portion of the runoff discharged by the centre slot of the multislot divisor and was made of 26 gauge galvanized metal, 1.5 m diameter and 1 m deep, with a storage capacity of 1.325 m^3. Like the sludge tank, it is coated with bitumen, fitted with a drain plug, and a 72-litre can is set under the inlet to catch small flows.

Covers prevent precipitation from falling directly into the system. The collector cover is 26 gauge galvanized sheet metal. Those for the sludge and aliquot tanks are 26 gauge sheet metal; for the conveyance channel, 22 gauge galvanized sheet metal; and for the multislot divisor, 20 gauge galvanized sheet metal.

Installation of equipment

The first step in installation was to establish permanent plot corner markers with the aid of the topographic map and the survey stakes. The primary tillage treatments will be performed by ox-drawn implements, so a 5-m strip was kept between each plot boundary to allow turn-around space for the oxen. Each half of this intermediate

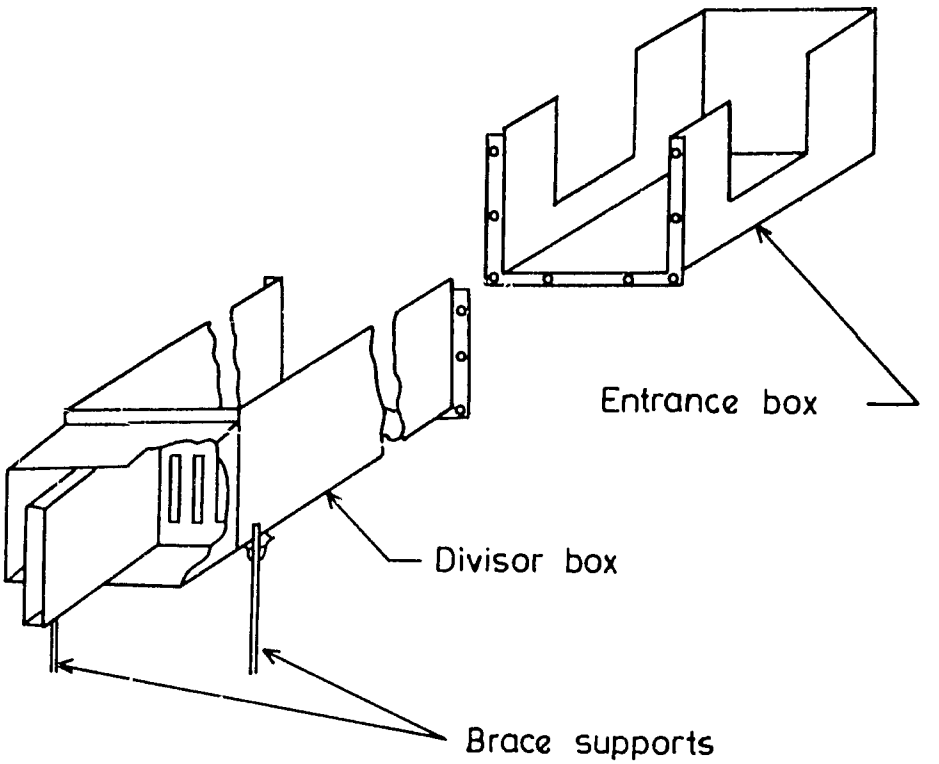

Fig. 3. Entrance box and multislot divisor alignment

strip is cropped and treated in the same manner as its adjacent plot. In the plot area no more than plus or minus 6 cm irregularity from the average plane surface was allowed. The few spots exceeding this irregularity were evened out by hand tools.

Next, the sites for installing the collectors, excavating the tank pits, digging the drainage ditches, and constructing the access road, with culverts and sump pits, were staked out. A service road along the line of equipment was constructed to provide access with vehicles. Not all the surplus runoff could be diposed of in the service road ditch; therefore, five 7-cm diameter culverts, equally spaced, convey runoff under the access road to five 2-m pits filled with rock. As in the conveyance-channel design, the culverts were installed so that the flow velocity would be above 0.61 m/s (2 fps). The down-slope topography dictated the pit excavation depth, which was calculated separately for each pit, based on the elevation of the collector unit and the conveyance-channel slope requirements. The elevation of the various pieces of equipment is recorded and checked annually to insure proper alignment and to maintain the runoff plot slope. A permanent bench-mark was established in a non-cultivated area of the runoff site.

The sheet metal boundaries are easily driven into the ground before each short rain. A jig is helpful in keeping the boundaries aligned during installation. At the lower end of the plot boundary, the strips are slipped into 1-cm slots cut 15 cm deep in the ends of the collector end plate.

Upon completion of the boundary installation, soil is packed around the boundary end plate joints and around the outside of the boundaries to increase their stability and prevent seepage.

The collector was welded to the end plate during fabrication to form one solid unit. A trench, wide enough to allow tamping from both sides of the end plate, was dug deep enough for the lip of the collector to be level with the soil surface. While digging the trench, the topsoil was stock-piled and then replaced last after tamping the end plate in solid with subsoil.

The conveyance channel was designed to slip

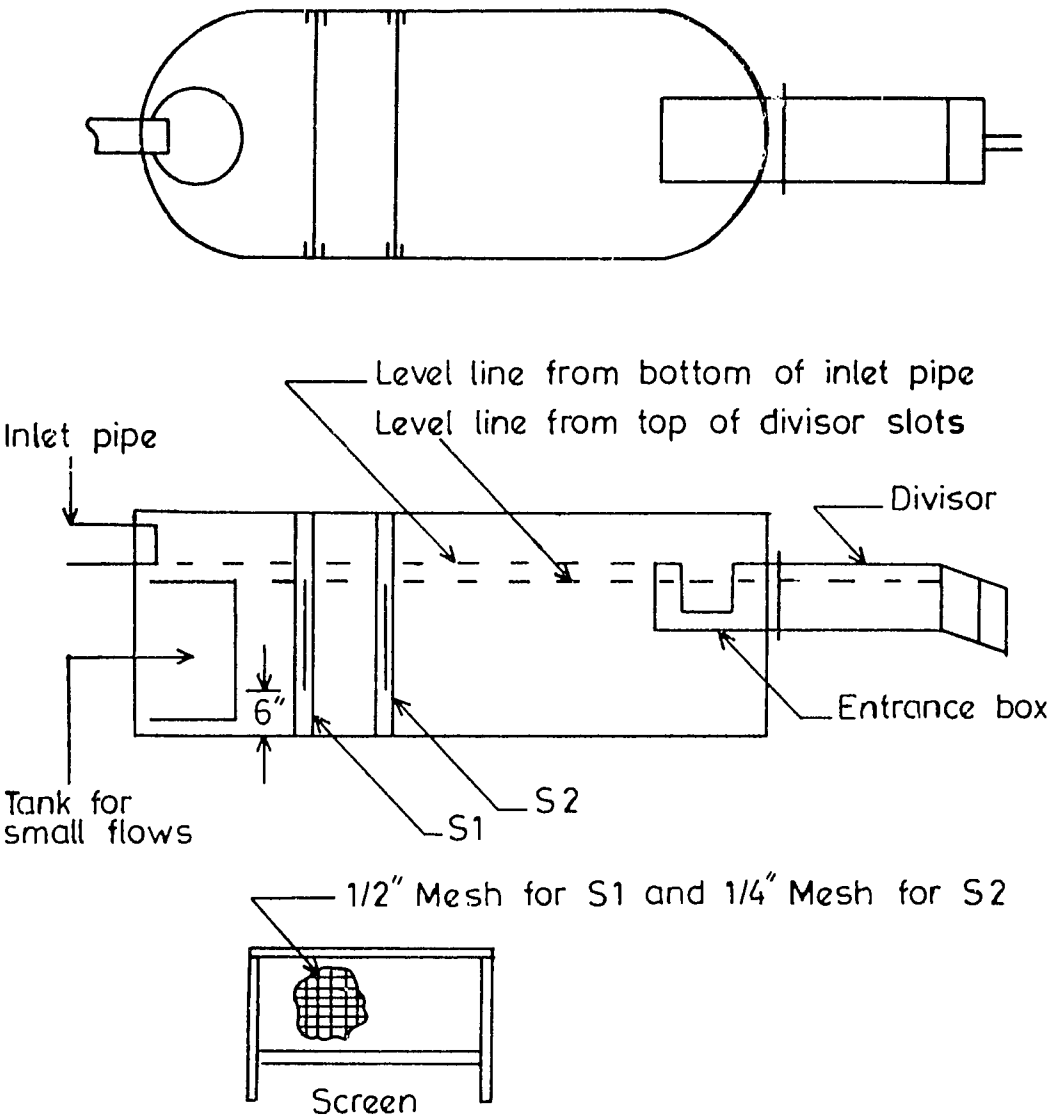

Fig. 4. Sludge tank, entrance box, and divisor

over the rectangular collector outlet and fit into the rectangular notch of the sludge tank. The seams of these two connections were sealed with roofing cement.

The space below the plots only allowed room for a 4-m conveyance channel, so the tanks had to be installed in excavated pits to maintain head. Here also the topsoil was stock-piled and spread over the subsoil after completing the excavation and forming the soil around the pit to keep out surface water.

The sludge tank was placed on a stable level platform to facilitate sampling the runoff and cleaning the tank. These platforms are of treated 5 × 15 cm boards nailed across 10 × 10 cm cedar planks. They are supported on concrete blocks and the bottoms of the pits are covered with a 10 cm layer of gravel.

The multislot divisor unit functions with the floor level and the precision strip level. It was bolted to the sludge tank in a semi-permanent manner and positioned so that the top of the entrance box was level with the bottom of the inlet pipe, as illustrated in Fig. 4.

Aluminium access tubes were installed in the centre of each plot to facilitate soil-moisture measurement. During the growing season soil-moisture content was measured weekly with a neutron probe at 30-cm intervals, starting from the 30 cm depth. A Troxler Model 1255 was used during 1981 and a Campbell Pacific Nuclear Model 503 during 1982 and 1983. Each was calibrated at KARI, Muguga.

TREATMENTS

Table V gives details of critical dates and classification of the seasons of the experiment.

This report describes the runoff plot treatments during 1981, 1982, and 1983 as given in Tables II, III, and IV respectively. Maize was the only crop and was always planted in 60-cm wide rows with 28 cm between seeds to produce a stand of about 51,000 plants/ha. Fertilizer was banded along the seed row at planting at the rate of 20–20–0 kg/ha of N and P_2O_5, respectively. The maize stand was maintained at about 51,000 plants/ha for a good season or thinned to 40,000 or 20,000 plants/ha for a fair or poor season respectively, following the recommendations of Stewart and Hash (1982), which include planting time and rate, fertilizer rates, and final plant

TABLE II—TILLAGE AND ROW DIRECTION TREATMENTS FOR 1981

	Long rains		Short rains
Plot No.	Ploughing treatment	Maize row direction	Treatment
1.	Chisel	Up-down	Maize on contour
2.	Chisel	Contour	Bare fallow
3.	Chisel	Up-down	Maize on contour
4.	Chisel	Contour	Bare fallow
5.	Chisel	Up-down	Bare fallow
6.	Chisel	Contour	Maize on contour
7.	Mouldboard	Contour	Maize on contour
8.	Mouldboard	Up-down	Bare fallow
9.	Mouldboard	Up-down	Bare fallow
10.	Mouldboard	Contour	Maize on contour
11.	Mouldboard	Contour	Bare fallow
12.	Mouldboard	Up-down	Maize on contour

TABLE III—TREATMENTS FOR 1982

Plot No.	Long-rains treatment	Short-rains treatment
1.	Maize on contour	Maize on contour
2.	Bare fallow	Bare fallow
3.	Maize on contour	Maize on contour + mulch
4.	Bare fallow	Maize on contour
5.	Bare fallow	Bare fallow
6.	Maize on contour	Bare fallow
7.	Maize on contour	Maize on contour + mulch
8.	Bare fallow	Maize on contour
9.	Bare fallow	Maize on contour + mulch
10.	Maize on contour	Maize on contour
11.	Bare fallow	Bare fallow
12.	Maize on contour	Maize on contour + mulch

TABLE IV—TREATMENTS FOR 1983

Plot No.	Long-rains treatment
1.	Maize up-down
2.	Bare fallow
3.	Maize up-down + mulch
4.	Maize up-down
5.	Bare fallow
6.	Bare fallow
7.	Maize up-down + mulch
8.	Maize up-down
9.	Maize up-down + mulch
10.	Maize up-down
11.	Bare fallow
12	Maize up-down + mulch

population. These recommendations are based on the date of onset of the rains and actual amounts received during the early part of the season. Accordingly, side-dressings of 40 and 20 kg/ha N were made for good and fair seasons respectively and within 50 and 35 days from onset of the short and long rains respectively. The mulch treatments were 3 t/ha of maize residue, uniformly spread on the surface immediately after planting. Then a point transit device was used to measure the percentage ground-cover to insure that it varied no more than ±2 from 56%. Seedbed preparation consisted of ploughing with oxen for the short rains and no-till (opening a seed furrow with a wheel-hoe) for the long rains. The 1981 long rains were an exception, as they were ploughed as shown in Table II. Weeds were controlled by cultivation with a wheel-hoe and hand hoe.

TABLE V—CRITICAL DATES AND CLASSIFICATION OF THE SEASONS

	1981		1982		1983
	L.R.*	S.R.	L.R.	S.R.	L.R.
Planting	10 Mar.	10 Oct.	9 Mar.	15 Oct.	21 Feb.
Onset of rains	17 Mar.	25 Oct.	28 Mar.	16 Oct.	14 Feb.
Season	Good	Poor	Fair	Good	Poor
Rain (mm)	424	179	266	530	298
Harvest	21 July	26 Feb. 1982	27 July	16 Feb. 1983	21 July

*L.R. = long rains. S.R. = short rains.

The 1983 treatments listed in Table IV will be continued until statistically valid results for determining the USLE's factor for sole maize and maize-with-residue and the K factor are obtained.

Sediment samples from each plot were collected after every soil-loss event and processed in the laboratory for physical analyses.

A wooden-framed mercury soil thermometer was used to record the 5-cm depth soil temperature of the maize and maize-plus-mulch plots at 1200 and 1600 hours daily.

Agronomic Results of Treatments

Agronomic and soil-management practices frequently have a more pronounced effect on soil and water losses than on crop yields in the short term. The non-significant effects of mouldboard versus chisel ploughing and of running the rows up and downhill rather than on the contour on maize yields during the 1981 long rains demonstrate this, as shown in Tables VI and VII. All yield values represent the 15.5% moisture grain weights.

The effects of mulching on maize yields during the 1982 short rains and 1983 long rains are shown in Table VIII.

TABLE VI—PLOUGHING EFFECT ON MAIZE YIELDS EXPRESSED AS THE MEAN OF 6 REPLICATIONS

Ploughing treatment	Yield (t/ha)
Chisel	3.81 NS
Mouldboard	3.80

TABLE VII—ROW-DIRECTION EFFECT ON MAIZE YIELDS EXPRESSED AS THE MEAN OF 6 REPLICATIONS

Row direction	Yield (t/ha)
Up-down	3.78 NS
Contour	3.83

TABLE VIII—MULCHING EFFECT ON MAIZE YIELDS EXPRESSED AS THE MEAN OF 4 REPLICATIONS

	Yield (t/ha)	
Treatment	1982 S.R.	1983 L.R.
Maize	4.81*	0.27 NS
Maize + mulch	3.75	0.35

*Significant at the 0.05% probability level.

Several factors may account for mulched-maize yields during the 1982 short rains being significantly lower. For one thing, they appeared to be more nitrogen-deficient than maize without mulch during the first three weeks of growth. Jack *et al.* (1955) report that carbonaceous residues tie up much of the soil nitrogen during the first seasons of surface mulching. Soil temperatures may also have been involved. The optimum root temperature for maize is 25 to 30°C. The daily mean and the seasonal minimum and maximum soil temperatures during the 1982 short rains growing season, as shown in Table IX, do not indicate that the mulch had much influence on them. Yet the soil-temperature record book showed that 20.6°C or less was recorded at 1200 hours on one occasion and at 1600 hours on two occasions for the maize-without-mulch plots. For the mulched maize plots, the same temperature was recorded at 1200 and 1600 hours on five and four occasions respectively. It is also known (Van Doren and Allmaras, 1978) that soil-temperature differences between mulched and adjacent bare plots often decrease as the surface residue ages. Where low temperatures under surface residues do more damage to the crop than water conservation benefits it, band application of the residue between the crop rows has proved desirable. Allmaras and Nelson (1971) showed that 4.5 t/ha residue between maize rows increased matrix suction by 40 to 20 mbar from 15 to 45 cm depths, reduced mean daily soil temperature by up to 2°C at the 5 cm depth, and increased yields over the uniform residue placement and no residue treatments in a moist season, but reduced all these parameters in a wetter season. In a review of the literature, Van Doren and Allmaras (1978) found that few of the research reports prior to 1960 showed gains in maize yield due to surface residues. Since then yield responses to residue treatments have improved, largely due to the development of herbicide technology for weed control. Low soil fertility may be another factor. Duley and Russel (1947) report that the highest efficiency of soil surface residues is found on fertile land.

TABLE IX—RUNOFF PLOT SOIL TEMPERATURES (1982 S.R.)

		Daily	Seasonal	
Treatment	Time	Mean (°C)	Min. (°C)	Max. (°C)
Maize	1200	24.6	20.6	28.3
	1600	25.1	17.2	31.1
Maize + Mulch	1200	24.7	20.0	30.0
	1600	24.9	18.3	31.1

The average change in per-cent ground cover of four replications and the 10 day rainfall increments after emergence for maize versus maize plus mulch, during the 1982 short rains and 1983 long rains, are respectively shown in Figures 5 and 6. The slower rate of ground-cover development in the mulched as compared with the unmulched maize may be partially due to the former's greater frequency of below-optimum soil temperatures and to greater nutrient deficiencies as discussed previously.

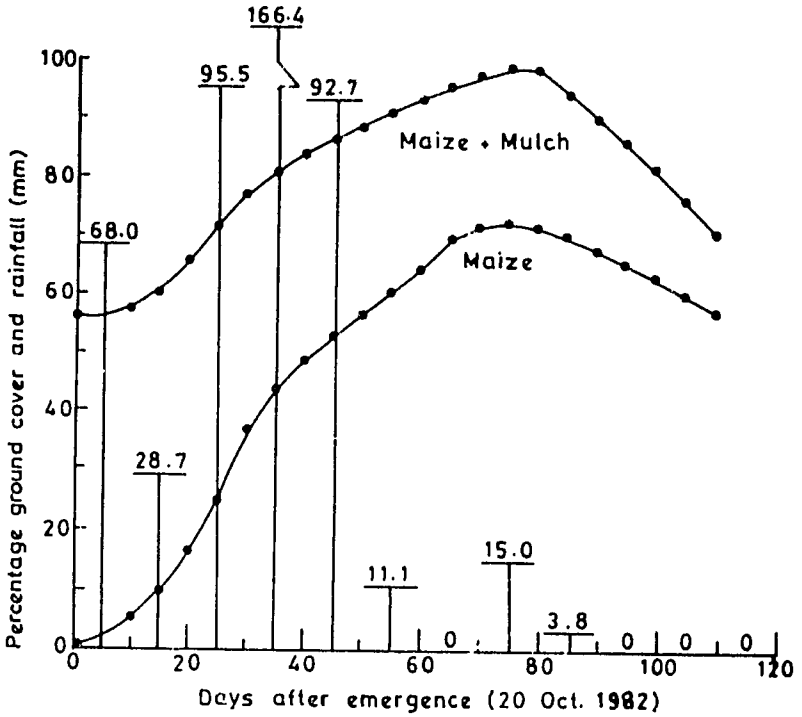

Fig. 5. Percentage ground cover and ten-day rainfall-increments, 1982 short rains

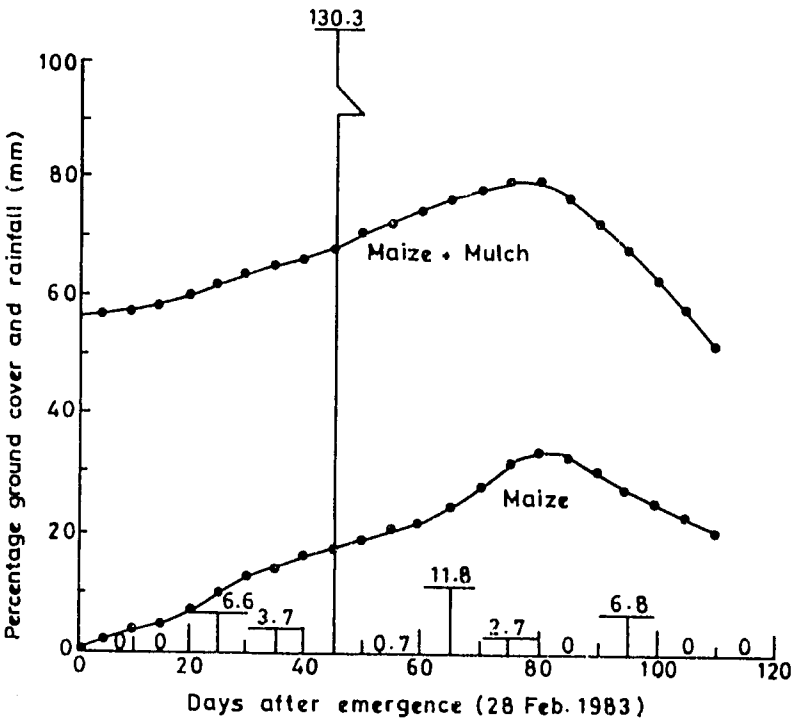

Fig. 6. Percentage ground cover and ten-day rainfall increments, 1983 long rains

Soil-water Content and Penetrometer Data

Water-holding capacity and soil-water release characteristics as influenced by clay content, organic matter content, bulk density, soil structure, per-cent total porosity, and pore size distribution at 30 cm depth increments for the runoff plot Alfisol, identified as field N, are discussed by Kilewe and Ulsaker (1983) elsewhere in this special issue.

The soil-water content of each runoff plot as affected by its particular treatment were measured by the neutron moderation method during the 1981 long rains, 1982 long and short rains, and 1983 long rains, as shown in Tables X, XI, XII, and XIII respectively. The probe was out of order during much of the 1981 short rains, so no data are available for that season. The average soil-water content data of three plots for each treatment during the 1982 short rains and the 1983 long rains were used to draw Figures 7 and 8 respectively. They illustrate the effect of season and treatment on soil-water content at 30, 60, and 90 cm depths. The soil-water content curves for the fallow, maize, and maize-plus-mulch treatments are respectively drawn from averages of plot numbers 2, 5, and 11; 1, 8, and 10; and 7, 9, and 12 in Tables XII and XIII.

The contrast between seasons reflects their extreme differences in rainfall amount and distribution. One week before planting for the 1982 short rains and 1983 long rains, 21 mm and 135 mm of rain fell respectively. After planting, the seasons' total was respectively 530 and 156 mm.

The amount and good distribution of the 1982 short rains resulted in small soil-water content differences due to treatments. The greater content at the 0–30 cm depth for maize over the maize-plus-mulch treatment indicates that the former plots on the average have a finer surface texture. The total season's soil-water contents at 0–90 cm depth for the three treatments were: fallow, 2,334 mm; maize plus mulch, 2,190 mm; and maize, 2,164 mm.

The first and last neutron-probe reading dates of the 1983 long rains were omitted when figuring the season's total soil-water contents by treatments to allow more uniform comparison between seasons. The last reading was therefore 93 days after planting. That for the 1982 short rains was 88 days after planting.

The low and poorly distributed 1983 long rains resulted in greater differences in soil-water content due to treatments. The difference between mulched and unmulched maize at 0–30 cm depth showed up during the latter part of the season, when the rate of decline was more gradual for the mulched maize. The total season's 0–90 cm depth soil-water contents for the treatments were: fallow, 2,026; maize plus mulch, 1,805; and maize, 1,720 mm.

Kemper (1965) outlined the basis for using aggregate stability as an index of soil structure in the field. Apparatus for measuring aggregate stability was not available, so a Soil Test Model CL-700 pocket penetrometer was used to measure the unconfined compressive strength of the surface soil at wilting point. Measurements were taken on a one-metre grid beginning one metre from the lower end of the plot for a total of 20 readings per plot. The average readings per plot and number of replications for treatments after the 1982 long and short rains and the 1983 long rains are given in Table XIV. More precise methods of field and laboratory testing and analysis of aggregate stability are necessary to verify such results in the future.

Rainfall Erosivity and Soil Erosion

Much effort has been devoted to the development of an erosivity index that best correlates with soil loss. Wischmeier's (1959) EI_{30} index is the most widely used and is the standard USLE erosivity index. Individual storm values can be added to give a weekly, monthly, or annual erosivity value, but it has not proved uniformly applicable world-wide.

In Zimbabwe, Hudson (1971) found the KE>25 index to be more appropriate. It is the total kinetic energy of the rain falling at intensities of more than 25 mm/hr, and is a function of drop-size distribution, velocity, and other parameters as discussed by Kinnel (1973), Rogers *et al.* (1967), and Elwell and Stocking (1975). Hudson (1971) found a correlation coefficient of 0.94 for KE>25 and soil erosion. Later, when data from other plots in the same study were analyzed by Elwell and Stocking (1973a, b and 1975; Stocking and Elwell, 1973a, b and 1976a, b) it was shown that for a wider range of plots, an energy-intensity parameter was the best predictor of soil erosion. The EI_{30} index was superseded by EI_5 and EI_{15} (energy times the maximum 5-min and 15-min intensity, respectively), on plots with high and medium crop cover respectively. Elwell (1977) used the seasonal kinetic energy, the total energy content of all rainfall events, as the erosivity index in developing his Soil Loss Estimator for Southern Africa

TABLE X—SOIL PROFILE WATER STORAGE (MM). 1981 LONG RAINS

Plot No.		1			2			3			4			5			6		
Treatment		Chisel up/down			Chisel contour			Chisel up/down			Chisel contour			Chisel up/down			Chisel contour		
Plt. pop./ha		53,000			72,000			55,000			60,000			54,000			60,000		
Soil depth (cm)		30	60	90	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
J. Day	*Date*																		
103	13 Apr	90	181	269	87	176	269	69	142	226	79	—	—	78	162	252	79	164	255
112	22	82	166	257	79	160	248	59	121	200	69	—	—	69	145	227	68	148	231
118	28	80	162	251	78	157	239	53	112	187	67	—	—	65	145	227	68	148	228
126	6 May	70	149	235	74	149	231	42	97	164	52	—	—	55	124	202	57	129	209
131	11	77	163	261	82	164	252	53	113	195	66	—	—	67	141	226	68	148	234
138	18	72	145	225	76	152	229	58	115	181	60	—	—	68	135	212	69	148	234
155	4 Jun	70	140	214	71	140	214	51	105	173	50	—	—	61	125	196	57	123	193
159	8	65	134	203	65	133	206	47	99	163	44	—	—	59	121	191	52	115	184
188	7 Jul.	58	115	177	57	110	165	43	89	142	36	—	—	47	100	163	42	89	143
195	14	53	109	169	55	106	157	40	82	132	35	—	—	43	92	152	36	81	132
202	21	53	109	169	52	102	153	40	82	132	35	—	—	43	92	152	36	82	131
	Total			2,430			2,363			1,895			593			2,194			2,156

Plot No.		7			8			9			10			11			12		
Treatment		Mouldbd. contour			Mouldbd. up/down			Mouldbd. up/down			Mouldbd. contour			Mouldbd. contour			Mouldbd. up/down		
Plt. pop./ha		49,000			69,000			57,000			63,000			71,000			58,000		
Soil depth (cm)		30	60	90	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
J. Day	*Date*																		
103	13 Apr.	76	164	254	84	173	267	85	177	273	89	180	273	83	173	271	85	178	283
112	22	73	150	232	78	159	250	77	163	259	80	168	266	78	161	258	78	166	269
118	28	68	142	223	74	152	241	72	158	288	67	153	247	72	161	258	78	166	269
126	6 May	63	136	213	68	143	229	62	143	233	63	145	236	59	134	224	64	145	233
131	11	71	148	229	75	156	249	71	157	253	75	161	257	69	153	250	73	161	261
138	18	72	139	212	78	148	225	68	140	220	72	145	227	72	141	224	74	149	233
155	4 Jun.	66	129	197	68	136	213	66	136	214	64	134	209	64	131	213	67	141	223
159	8	64	126	193	67	135	211	63	131	207	62	129	201	61	126	205	65	139	219
188	7 Jul.	53	102	152	53	106	166	52	109	172	52	111	174	50	104	171	59	122	187
195	14	47	96	146	48	98	156	49	105	168	52	110	171	50	103	168	56	115	179
202	21	47	94	143	48	98	156	49	105	166	51	109	170	50	103	166	50	110	174
	Total			2,194			2,364			2,453			2,431			2,399			2,521

TABLE XI—SOIL PROFILE WATER STORAGE (mm). 1982 LONG RAINS

Plot No.		1			3			6			7			10			12		
Treatment		Maize			Maize			Maize			Maize			Maize			Maize		
Plt. pop./ha		39,000			38,000			39,000			36,000			38,000			37,000		
Soil depth (cm)		30	60	90	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
J. Day	*Date*																		
96	6 Apr.	80	143	200	69	111	157	67	116	167	75	127	183	85	149	220	74	130	189
103	13	79	141	199	62	111	157	62	115	167	71	128	185	79	144	214	67	130	189
111	21	87	150	207	70	123	171	71	133	184	78	137	191	88	156	225	77	145	205
117	27	82	146	205	63	122	170	63	130	182	73	139	195	80	149	219	66	137	198
124	4 May	75	142	200	58	129	181	57	120	175	67	134	192	72	144	213	61	131	191
131	11	86	152	210	69	137	209	70	142	199	79	148	205	86	158	226	75	148	210
138	18	77	141	198	61	121	193	60	125	189	69	137	194	75	144	216	66	137	199
145	25	70	134	193	60	118	183	59	121	183	65	127	184	70	138	208	62	129	191
153	2 Jun.	64	129	186	51	112	183	49	106	165	55	112	169	62	126	196	52	112	174
167	16	59	122	179	44	87	138	40	90	142	48	100	156	56	116	184	43	99	158
180	29	59	121	179	41	83	131	39	87	139	46	98	153	54	115	181	43	98	158
194	13 Jul.	58	120	177	41	83	132	38	86	138	47	99	155	54	114	181	43	98	158
	Total			2,333			2,005			2,030			2,162			2,483			2,219

Plot No.		2			4			5			8			9			11		
Treatment		Unit plot			Unit plot			Unit plot			Unit plot			Unit plot			Unit plot		
Plt. pop./ha		—			—			—			—			—			—		
Soil depth (cm)		30	60	90	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
J. Day	*Date*																		
96	6 Apr.	84	152	217	70	—	—	78	152	223	82	148	214	80	155	220	80	155	230
103	13	77	148	214	65	—	—	72	147	221	77	147	215	73	147	212	77	154	233
111	21	83	154	222	72	—	—	79	154	230	84	155	222	82	158	226	83	162	243
117	27	77	148	217	67	—	—	74	150	230	79	151	223	74	150	220	78	158	240
124	4 May	78	149	218	65	—	—	72	149	228	77	148	221	72	146	219	77	157	242
131	11	86	164	237	73	—	—	80	162	247	85	164	174	81	163	239	84	172	263
138	18	82	156	232	67	—	—	74	156	244	78	154	154	76	154	234	79	162	252
145	25	82	158	231	67	—	—	74	155	242	79	154	238	76	151	232	78	161	252
153	2 Jun.	79	155	234	63	—	—	70	149	237	74	149	239	71	146	227	77	158	249
167	16	75	150	227	62	—	—	67	143	227	72	144	225	65	138	218	74	152	242
180	29	74	148	222	59	—	—	64	140	225	69	139	219	64	134	212	72	151	239
194	13 Jul.	73	146	220	59	—	—	64	139	221	68	140	218	62	123	202	71	148	238
	Total			2,691			789			2,777			2,562			2,661			2,923

TABLE XII—SOIL PROFILE WATER STORAGE (mm). 1982 SHORT RAINS

Plot No.		1			2			3			4			5			6		
Treatment		Maize			Unit plot			Maize + mulch			Maize			Unit plot			Unit plot		
Plt. pop./ha		75,000			—			57,000			60,000			—			—		
Soil depth (cm)		30	60	90	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
J. Day	*Date*																		
309	5 Nov.	75	138	189	71	139	206	54	109	157	60	—	—	66	138	218	56	117	168
313	9	74	139	189	71	140	209	54	108	158	58	—	—	64	137	218	53	113	166
320	16	89	162	212	81	156	227	67	134	198	69	—	—	75	154	238	68	140	202
327	23	86	168	222	80	155	233	66	129	197	68	—	—	75	152	240	67	137	210
336	2 Dec.	83	166	241	79	159	244	62	126	202	65	—	—	74	153	245	67	138	222
341	7	84	170	247	79	158	244	66	131	210	49	—	—	71	150	242	67	141	225
349	15	81	162	237	75	152	234	60	120	195	63	—	—	69	145	234	62	133	214
356	22	73	149	220	73	148	229	53	110	184	58	—	—	65	142	227	57	125	204
5	5 Jan.	63	128	184	71	146	224	46	96	162	47	—	—	62	142	234	62	135	219
11	11	60	123	176	71	144	221	45	93	156	44	—	—	62	135	219	52	117	192
	Total			2,117			2,271			1,819						2,315			2,022

Plot No.		7			8			9			10			11			12		
Treatment		Maize + mulch			Maize			Maize + mulch			Maize			Unit plot			Maize + mulch		
Plt. pop./ha.		60,000			60,000			54,000			59,000			—			57,000		
Soil depth (cm)		30	60	90	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
J. Day	*Date*																		
309	5 Nov.	64	130	182	68	135	208	66	135	207	72	135	195	69	143	225	58	126	184
313	9	62	127	182	66	134	208	61	128	199	68	133	193	68	141	223	56	122	181
320	16	75	152	219	80	153	230	77	157	233	84	152	212	78	160	244	74	153	220
327	23	76	152	235	79	151	234	77	154	237	82	158	222	76	156	245	75	151	230
336	2 Dec.	74	150	241	77	153	244	76	154	247	81	161	245	77	160	255	72	153	248
341	7	73	150	242	78	153	243	76	157	251	83	165	250	75	158	254	70	151	245
349	15	72	146	234	75	149	236	73	150	239	77	154	238	73	153	247	69	147	235
356	22	63	135	219	68	138	222	67	141	228	68	142	222	71	152	245	60	134	223
5	5 Jan.	62	135	204	61	124	202	64	138	223	62	132	205	72	152	244	57	127	204
11	11	54	119	193	57	116	183	52	118	195	55	117	183	67	144	234	53	120	194
	Total			2,151			2,210			2,259			2,165			2,416			2,164

TABLE XIII—SOIL PROFILE WATER STORAGE (mm), 1983 LONG RAINS

Plot No.		1			2			3			4			5			6		
Treatment		Maize			Unit plot			Maize + mulch			Maize			Unit plot			Unit plot		
Plt. pop./ha		20,000			—			20,000			20,000			—			—		
Soil depth (cm)		30	60	90	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
J. Day	*Date*																		
46	15 Feb.	92	160	217	217	77	148	221	69	112	167	56	—	—	79	152	232	72	142
61	2 May	63	137	194	71	143	219	57	113	179	57	—	—	64	137	220	58	126	204
82	23	76	148	207	70	141	216	55	110	176	55	—	—	62	135	216	53	119	197
90	31	73	145	208	70	140	215	55	110	176	54	—	—	62	135	217	53	118	194
96	6 Apr.	72	144	203	69	139	213	54	109	176	52	—	—	62	134	214	53	118	194
115	25	79	149	208	82	151	223	67	121	186	65	—	—	78	151	231	71	140	215
124	4 May	82	155	215	74	148	227	62	123	196	61	—	—	70	146	232	62	133	214
131	11	78	151	210	73	145	224	58	119	59	—	—	66	142	227	58	127	208	
138	18	76	147	207	72	144	221	56	116	189	57	—	—	64	138	224	56	122	199
145	25	76	147	207	72	144	221	56	116	189	57	—	—	64	138	224	56	124	203
145	25	74	145	206	70	142	218	56	115	187	55	—	—	64	138	221	56	122	199
158	7	65	131	190	69	139	214	55	112	182	52	—	—	63	135	217	55	121	198
	Total			2,261			2,411			1,831			623			2,451			2,245

Plot No.		7			8			9			10			11			12		
Treatment		Maize + mulch			Maize			Maize + mulch			Maize			Unit plot			Maize + mulch		
Plt. pop./ha		20,000			20,000			20,000			20,000			—			20,000		
Soil depth (cm)		30	60	90	30	60	90	30	60	90	30	60	90	30	60	90	30	60	90
J. Day	*Date*																		
46	15 Feb.	71	130	197	74	125	175	76	137	202	79	136	195	79	154	240	78	154	220
61	2 Mar.	67	137	216	68	128	182	66	136	209	73	134	193	70	146	234	62	135	216
82	23	61	130	209	62	122	181	55	120	192	67	130	191	66	142	228	57	129	208
90	31	61	127	206	60	119	178	54	116	188	64	127	187	67	142	231	56	127	206
96	6 Apr.	61	128	206	57	113	171	55	117	188	64	127	188	66	141	227	56	126	203
115	25	77	144	219	61	114	169	66	125	194	74	134	195	77	152	237	77	147	221
124	25	70	146	231	71	124	178	70	142	219	77	142	203	72	150	238	67	146	231
131	11	67	141	225	66	120	175	65	136	214	70	136	197	70	148	236	62	139	224
138	18	64	138	221	60	114	169	63	132	210	67	132	194	68	147	235	60	134	217
145	25	63	135	217	57	106	160	60	129	206	62	128	191	68	147	235	59	134	217
158	7 Jun.	55	124	203	55	103	156	57	122	197	57	117	179	67	145	232	54	125	205
	Total			2,350			1,894			2,219			2,113			2,573			2,368

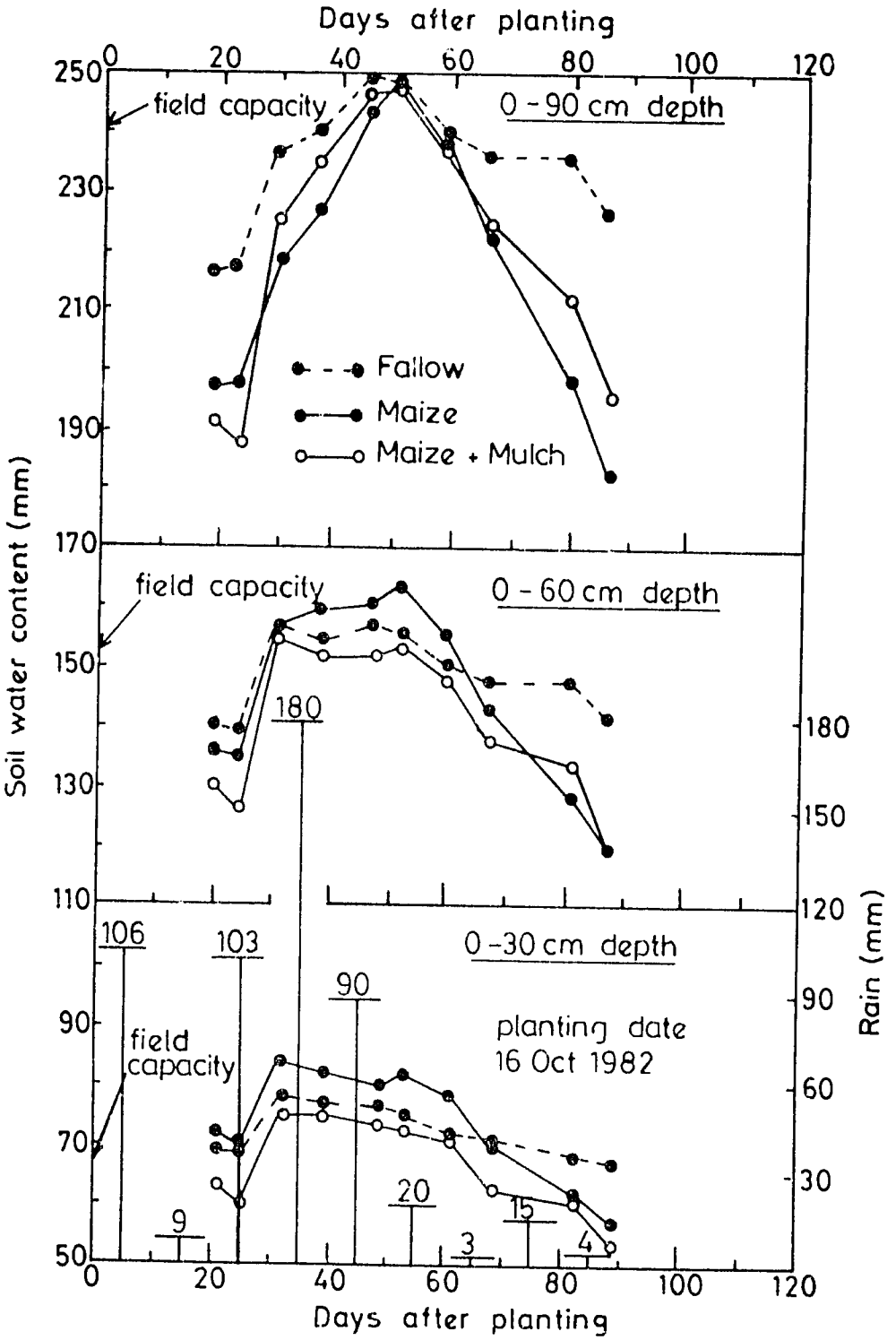

Fig. 7. Soil water content as affected by treatment, soil depth, and rain during the 1982 short rains

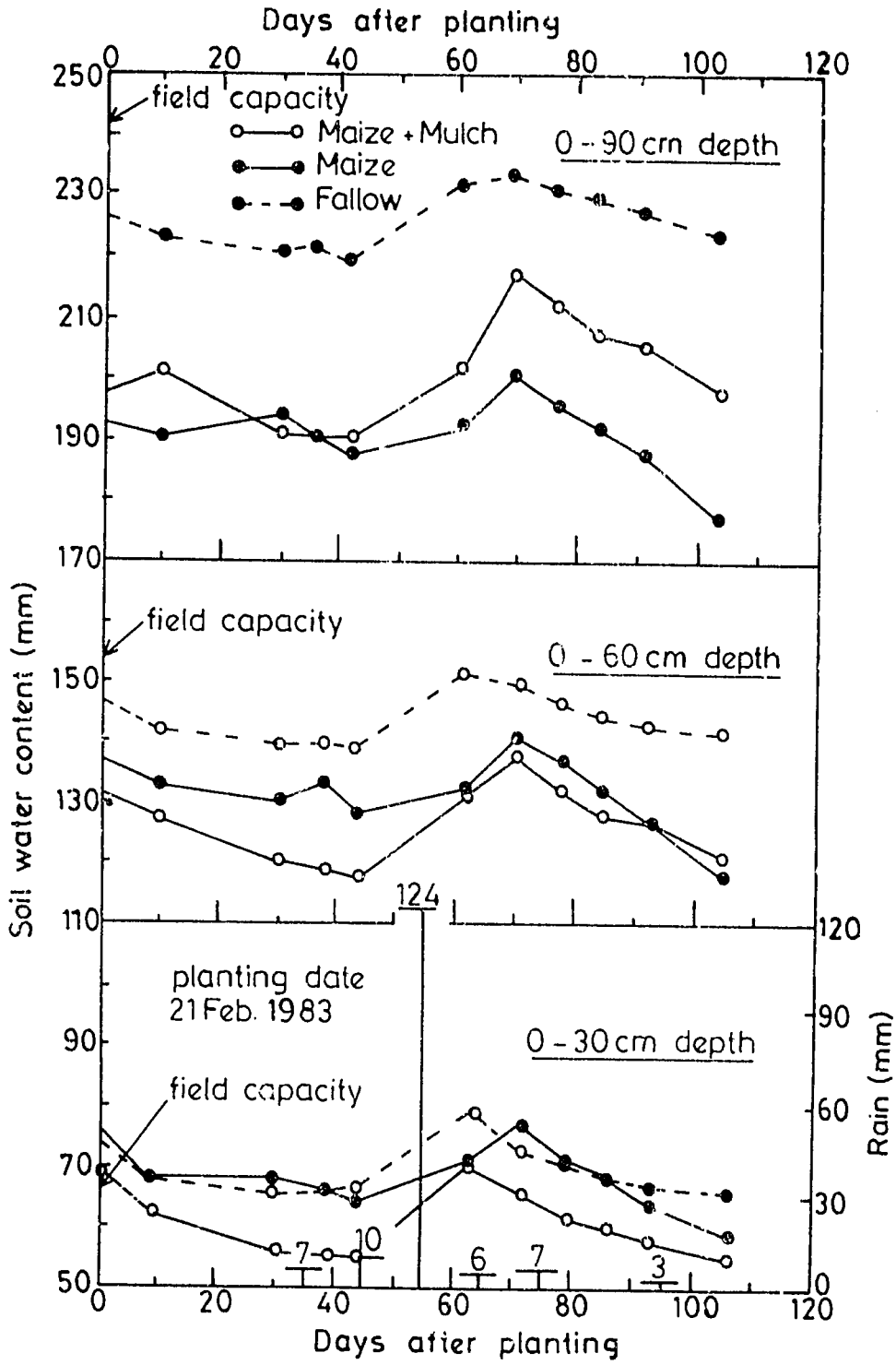

Fig. 8. Soil water content as affected by treatment, soil depth, and rain during the 1983 long rains

TABLE XIV—SOIL PENETROMETER READINGS (THE 1982 LONG RAINS VALUES ARE MEANS OF SIX REPLICATIONS. THE REST ARE MEANS OF FOUR REPLICATIONS.)

Treatments	1982				1983	
	L.R. (kg/cm²)	Sig. (kg/cm²)	S.R. (kg/cm²)	Sig. (kg/cm²)	L.R. (kg/cm²)	Sig. (kg/cm²)
Bare fallow	0.14	0.1	0.29	.05	0.13	NS
Maize	1.04		1.23		0.15	
Maize + mulch	—		0.99		0.16	

(SLEMSA) model to predict mean annual soil loss from sheet erosion. Lal (1976 a, b), working on Alfisols in western Nigeria, reported better correlation coefficient of runoff and soil loss with the AI_{30} index than with either EI_{30} or KE>25. The AI_{30} index is the product of total rainfall amount (A) and peak storm intensity (I_{30}). In the absence of reco raingauge data, Fournier (1960) related a rainfall distribution coefficient (C) to suspended sediment loads in African rivers. He defined C as p^2/P where p is mean rainfall for the wettest month of the year and P the mean annual rainfall. This index can only predict erosion when the suspended sediment load of a river is related to the soil loss for a whole watershed. Arnoldus (1980) proposed a modification of Fournier's p^2/P value. With $\sum_{1}^{12} pi^2/P$ in which pi is monthly precipitation and P is annual precipitation, he obtained a correlation coefficient of 0.83 between this index and EI_{30} for 14 West African raingauge stations.

In East Africa, Othieno (1975, 1977) at Kericho, Kenya, studied the influence of different tea-cultivation practices on runoff and soil erosion and found that rainfall intensity was significantly correlated with erosion losses, but it was included in a multiple regression with runoff and per-cent groundcover to predict soil loss. Rainfall intensity, runoff and per-cent ground cover were reported to account for as much as 86% of the variability in soil erosion. Significant amounts of erosion were recorded only when the rainfall intensity exceeded about 20 mm/hr. In Tanzania, Temple (1972) collected data on runoff and soil erosion while studying different cropping practices. In a coffee experiment at Lyamungu, runoff and erosion were produced when rainfall amounts exceeded about 45 mm and the average intensity exceeded 20 mm/hr.

Apart from the above two studies, Moore (1978) reported that no detailed analyses of rainfall erosivity and soil loss had been made in East Africa.

The objectives of our study were to evaluate and compare several individual storm erosivity factors that have been developed in tropical climates and elsewhere using soil-loss data from runoff plots in Kenya. A soil-erodibility factor value is also estimated using these data.

Experimental Data

The collection of runoff and soil loss data from three plots (Nos. 1, 5 and 11), which were established and maintained in continuous fallow as described by Wischmeier and Smith (1978), was conducted from 29 March 1982 through May 1983. During this time, 35 runoff events occurred from each of the plots.

Runoff was measured after each storm by measuring the depth of water in the can, tank or tanks, depending on the size of the runoff event, and converting to m³ with a calibration curve between depth and volume for the appropriate can or tank. Samples were taken for laboratory analysis of the sediment in suspension in mg/l following the procedures of Brakensiek, Osborn and Rawls (1979). For big runoff events, the water was decanted down to about 4 mm of the sludge level. Soil loss was determined by measuring the sludge depth, converting to m³ with the appropriate calibration curve, and sampling for laboratory analysis of the sediment concentration in mg/l according to the procedures of Brakensiek *et al.* (1979). The sludge volume was subtracted from the runoff volume in determining actual runoff.

The slopes of runoff plots 2, 5 and 11 are respectively 7.4, 8.0 and 9.5%. Consequently, the t/ha soil loss for plots 2, 5 and 11 was adjusted by using LS factors 0.51, 0.57 and 0.73 respectively, according to procedures developed by

TABLE XV—RAINFALL, RUNOFF, AND SOIL LOSS FOR FALLOW PLOTS

Julian day	Soil loss (t/ha)	Runoff (mm)	Rainfall (mm)	Kinetic energy (MJ/ha)	Max. rainfall intensity (mm/h) 15 min	30 min
1982						
88	1.31	4.2	31.0	—	—	—
92	0.08	0.5	7.3	0.91	6.8	3.4
93	0.23	1.5	14.7	2.99	26.0	14.8
126	1.92	4.6	27.5	5.67	32.0	27.0
128	17.17	7.3	31.0	5.72	22.0	15.0
290	0.004	0.1	23.3	3.86	20.0	15.8
294	0.004	0.4	12.5	2.22	20.0	15.0
295	2.03	11.0	34.0	7.66	44.0	22.0
296	0.001	0.1	14.2	1.43	5.6	4.0
313	0.77	1.3	22.7	4.22	19.2	15.6
315	0.52	0.9	17.1	3.94	24.0	14.6
317	0.09	0.8	9.5	1.74	17.2	10.6
318	1.01	12.2	33.7	6.01	28.0	18.6
320	0.01	0.3	6.0	0.68	6.8	4.0
322	0.03	1.0	10.2	2.28	9.6	4.8
325	0.43	5.6	13.3	2.84	24.0	15.8
326	0.52	3.8	11.5	3.00	28.0	18.0
328	0.81	6.5	20.0	5.47	36.0	26.0
329	7.72	14.0	39.7	7.20	40.0	33.0
330	1.76	13.1	32.2	4.84	44.0	22.0
331	0.13	1.7	12.3	2.19	12.0	6.0
332	14.36	13.2	34.5	6.70	20.4	13.2
335	0.05	0.7	11.8	1.62	6.0	6.0
336	2.47	6.4	19.5	3.40	16.0	14.0
337	4.84	11.3	29.8	6.37	20.4	18.6
338	0.39	1.7	9.9	1.19	12.0	8.0
341	0.01	0.6	11.0	2.07	9.2	6.4
1983						
5	0.07	0.4	9.3	1.68	24.0	12.0
45	39.41	53.1	102.68	20.68	64.0	44.0
48	0.05	0.6	4.8	0.40	8.0	4.0
49	0.11	4.7	17.3	0.87	18.0	16.0
50	0.05	0.8	7.3	1.27	9.6	4.8
51	0.001	0.1	3.7	0.70	12.0	6.0
113	6.43	16.1	57.7	12.75	52.0	42.0
116	0.51	2.9	20.0	3.31	15.2	8.0

Wischmeier and Smith (1978), where L = length of slope in metres and S = per-cent slope. This was done so that the amount of soil loss would correspond to that which would have occurred from a 22 m plot on a 9% slope (unit plot).

Total precipitation was recorded daily at 0830 hours by averaging the millimetres of rain collected by three non-recording raingauges mounted on cedar posts spaced 50 m apart along the line of runoff plots. These were 5-cm circular, plastic, self-reading raingauges. Each storm's kinetic energy, 15- and 30-min intensities, rainfall amount, and duration were obtained from a Dines Tropical Recording Raingauge at the station's meteorological centre, located 600 m from, and at the same elevation as, the runoff plots. The resolution of the recording-raingauge chart was not adequate for accurate determination of the 5-min rain intensities.

The non-recording raingauges were first checked with the recording gauge at the meteorological centre. A paired "t" test of the varia-

tion between gauges in amounts recorded was non-significant. A paired "t" test of the rainfall variations between the two locations for 46 storms was also not significant. Therefore, the data from the recording raingauge was considered representative of the rainfall characteristics for the runoff plot site.

Rainfall, runoff, and soil-loss data for each of the storms used in this study are shown in Table XV. The soil-loss and runoff values shown are averages of adjusted values for the three fallow plots.

Erosivity Factors

The 13 erosivity factors that were chosen for study included several of those outlined by Foster *et al.* (1982), some of which are undergoing study in the tropics (Lal, 1976a), and Hudson's (1971) factor.

The simplest factor was rainfall amount (A), which is a basic variable related to the two major erosive agents, raindrop impact and surface runoff. It was included even though Wischmeier and Smith (1958) report that it is generally a poor index. Runoff amount (RO) was included for the same reason as rainfall. Another single erosivity factor which Wischmeier *et al.* (1958) found to be most closely related to erosion is the kinetic energy of the rain (E), expressed in megajoules per hectare (MJ/ha). But even this has considerable unexplained variation and by itself is not considered a good indication of erosive potential. Maximum rainfall intensities (I_{15} and I_{30}) occurring respectively in any 15- and 30-min period during a storm were evaluated because raindrop erosion increases with intensity (Wischmeier and Smith, 1978). Therefore, each of these indexes indicates the prolonged peak rates of detachment and runoff. The squares of I_{15} and I_{30} were also evaluated, as Foster and Meyer (1975) report that they are strongly correlated with interrill sources of erosion.

A compound parameter formed by the product of two or more single erosivity factors is often the best estimator of soil loss. The products of the kinetic energy of a storm and its 15- and 30-min intensity (EI_{15} and EI_{30}) are two examples. Their disadvantage is that the computation of each is fairly involved and requires more detailed rainfall records than exist in several parts of the world. The compound parameters (AI_{15} and AI_{30}), the products of the amount of a storm and, respectively, its 15- and 30-min intensity, are indices that are easier to compute but ignore the influence of kinetic energy on erosion.

Hudson (1971) found the KE>25, mentioned earlier, to be more appropriate than EI_{30} for tropical and subtropical rainfall, so it is also included. The I_{30} value is not required for calculating KE>25, which is an advantage in areas with limited rainfall data.

The factor EIA (Foster *et al.*, 1982) is defined as the product of the I_{30} and the square root of the product of the rainfall and runoff volumes. This factor is similar to EI_{30}. The difference between them is the duration over which I_{30} is assumed to be effective. For EI_{30} the effective duration is the entire storm. For EIA it is the duration of runoff.

RESULTS AND DISCUSSION

Erosivity Factors

Erosivity-factors were evaluated for each runoff-producing storm for each runoff plot. Simple linear regression was used to fit the erosivity factors to the soil-loss data for each plot and storm. The results are shown in Table XVI.

The simplest factor, rainfall amount (A), proved to be one of the best erosivity factors, having a coefficient of determination (r^2) of 0.66. Foster *et al.* (1982), in a similar study for several U.S. stations, found that r^2 for rainfall amount alone ranged from 0.11 to 0.53. Wischmeier and Smith (1958) also found it to be a poor erosivity factor. Roose (1973), however, found soil loss in the Ivory Coast to be significantly related to rainfall amount. Total storm kinetic energy, E, also proved to be a relatively good erosivity factor, having an r^2 of 0.64. When total kinetic energy was related to rainfall amounts for the storms studied here, the resulting relation had an r^2 of 0.97, indicating that nearly all variations in total energy can be accounted for by rainfall amount. For this reason, rainfall amount and total storm kinetic energy, when used as an erosivity factor, produced similar results.

The best single variable erosivity factor was storm-runoff volume (RO), with an r^2 of 0.71. Even though RO is quite good, it is difficult to use because, for soil-loss prediction purposes, runoff volume would also have to be estimated. The poorest single variable erosivity factors are I_{15} and I_{30}, having r^2 of 0.35 and 0.36, respectively. When I_{15} and I_{30} were used, the r^2 values improved only slightly, to 0.51 and 0.49 respectively. These variables were chosen because Foster (1982) suggests that interrill erosion rates are highly dependent on the square of rainfall

TABLE XVI—REGRESSION COEFFICIENTS AND COEFFICIENTS OF DETERMINATION, AND STANDARD ERROR FOR VARIOUS EROSIVITY EXPRESSIONS

Erosivity factor	a	b	r^2	Std. error (t/ha)
1. aA* + b	0.33	−4.81	0.66	4.49
2. aRO + b	0.66	−1.40	0.71	4.13
3. aE + b	0.0015	−3.84	0.64	4.68
4. aI_{15} + b	0.33	−4.92	0.35	6.29
5. aI_{30} + b	0.45	−4.51	0.36	6.24
6. $a(I_{15})^2$ + b	0.0062	−1.93	0.51	5.45
7. $a(I_{30})^2$ + b	0.012	−1.55	0.49	5.55
8. a(KE>25) + b	0.020	−0.56	0.54	5.31
9. aEI_{15} + b	0.26	−1.18	0.71	4.19
10. aEI_{30} + b	0.35	−1.11	0.69	4.26
11. aAI_{15} + b	0.0054	−1.35	0.73	4.07
12. aAI_{30} + b	0.0075	−1.26	0.72	4.16
13. aEIA + b	0.011	−0.60	0.75	3.87

*Definition of symbols: RO = runoff amount; A = rainfall amount (depth); E = kinetic energy of the rain; I_{30} = maximum 30-min intensity; I_{15} = maximum 15-min intensity; EI_{30} = USLE rainfall erosivity index; EI_{15} = kinetic energy × maximum 15-min intensity; KE>25 = kinetic energy falling at intensities of more than 25 mm/hr.

intensity. The KE > 25 factor did not prove as efficient as Hudson (1971) found it to be in Zimbabwe.

The four compound erosivity factors involving rainfall variables only, EI_{15}, EI_{30}, AI_{15}, AI_{30}, all produced good results, having r^2 ranging from 0.62 to 0.73. Foster *et al.* (1982) in their analyses had r^2 ranging from 0.35 to 0.83 for EI_{30} and from 0.23 to 0.79 for AI_{30}. Lal (1976c) found that AI_{30} was a better erosivity factor for Nigeria than EI_{30}. He also showed that $EI_{30}/100$, in customary English units had the same values as AI_{30} in cm^2/hr. This enables soil erodibility values as defined by Wishmeier and Smith (1978) to be used with AI_{30} without magnitude adjustment as a result of different erosivity units. A similar analysis for the data in this study indicates that a one-to-one relation between the two factors does not exist.

Computation of EI_{30} is a fairly involved procedure, in which a rainstorm is subdivided into periods of constant intensity (Wishmeier and Smith, 1978). Foster and Meyer (1975) suggest that EI_{30} is linearly related to AI_{30}, which is much simpler to compute. When a regression was done here, the following relation resulted, having an r^2 of 0.992:

$$EI_{30} = 0.206\, AI_{30} - 3.9 \qquad [1]$$

where units of EI_{30} are MJ/mm/ha.h and AI_{30} are mm^2/h. Further analysis of the data revealed the following relationship, having an r^2 of 0.902:

$$EI_{30} = 9.00\, A - 97.4 \qquad [2]$$

where A is expressed in mm. Equation [2] indicates that an excellent estimate of EI_{30} can be made using rainfall volume. For rainfall amounts less than 10.8 mm, equation [2] indicates that EI_{30} is zero or negative, and therefore no erosion would be estimated. Inspection of Table XV reveals that 10 storms having a total EI_{30} of 82.4 MJ/ha.h produced soil loss and would be omitted. However, the total amount of soil involved is only 0.77 t/ha. During the 1.5 years of rainfall data, three storms, each over 10.8 mm and totalling 59.7 mm, did not produce any runoff. These would have been added to those storms producing soil loss using the criteria implied from equation [2].

Soil Erodibility

Using the data from Table XV, the average soil erodibility factor for the Alfisol at Katumani is 0.0314 t.ha.h/ha.MJ.mm. This corresponds to 0.24 in customary English units (CEU). El-Swaify *et al.* (1982) report soil erodibilities in CEU ranging from 0.69 in New York (Wischmeier and Smith, 1978) to 0.14 in Indonesia (Bols, 1978). Roose (1977) reports that the K values of three West Africa Alfisols are all 0.25.

Barber *et al.* (1979) evaluated soil erodibilites

for two Kenyan soils using a rainfall simulator on small plots having dimensions of 1.08 m by 1.40 m. One of the soils they investigated was an Alfisol located near Katumani in the vicinity of the present runoff-plot site. Five replications of three storms having intensities of 25, 50 and 100 mm/h were applied for various durations such that a total of 50 mm of rainfall were applied for each treatment. Each set of runs was applied to both a dry and a wet-soil state. Calculated soil erodibilities in CEU ranged from 0.03 for the lowest storm intensity on a dry soil to 0.60, which occurred with the middle storm intensity on wet soil. The erodibility in CEU for the soil, calculated from the average erodibility for all the storms, was 0.24, identical with the estimate obtained in this study.

CONCLUSIONS

Figure 9 shows the relation between the soil-erodibility factor and magnitude of storm soil loss. The figure indicates that the soil-erodibility factor values range from an average of 0.07 for storms producing soil losses of less than 1 t/ha to 0.55 for storms producing soil losses greater than 10 t/ha. Figure 9 also shows percentages of total soil loss in each category. These range from 5% for storms causing losses of less than 1 t/ha to 67% for storms causing soil losses of over 10 t/ha.

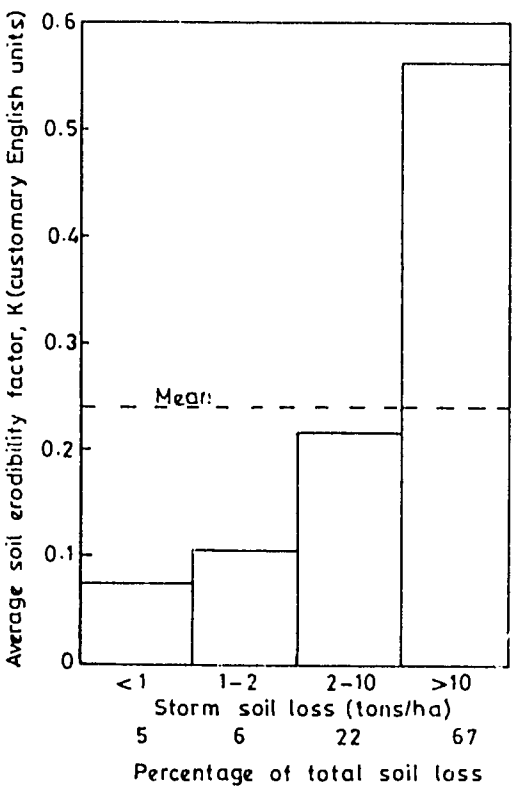

Fig. 9. Relation of average soil erodibility and amount of soil loss

For the Kenya conditions studied, the EI_{30} variable is a good erosivity factor. Other factors involving both rainfall and runoff were better but create the additional problem of estimating run-off volumes. A regression equation was developed relating EI_{30} to rainfall amount. For the rains studied, the relationship explained over 90% of the variance in the erosivity factor. The reasons that EI_{30} correlates well with storm rainfall amount in this part of Kenya are that total energy is directly related to storm rainfall volume (Foster *et al.*, 1982) and that I_{30} is relatively uniform for every storm, as shown in Table 20. The equation also indicates a rainfall amount threshold value of 10.8 mm, below which soil loss would not be estimated.

The soil-erodibility factor for the Alfisol located at Katumani was determined at 0.0314 t.ha.h/ha.MJ.mm. This corresponds to a value of 0.24 in customary English units. This value agrees well with previous work conducted using a rainfall simulator on small plots. The soil erodibility factor varied considerably, depending on the magnitude of the soil loss. The range was from 0.07 to 0.55 for storms producing soil loss under 1 t/ha and over 10 t/ha, respectively.

Contouring Effects on Soil Loss

It is well known that contour tillage reduces both runoff and erosion. The supporting-practices factor, P, in the USLE reflects the effects on soil loss of conservation practices such as contouring, strip cropping, terraces, and contoured irrigation furrows. P is the ratio of soil loss for a specific practice compared with the soil loss using up and downhill farming.

Contouring is most effective on slopes in the 3 to 8% range (Wischmeier and Smith, 1978). As land slope decreases, contour-row grades approach land slope, so that the P-factor ratio approaches the value of 1.0. As slope steepness increases, the water-holding capacity of the tillage marks, etc., on the contour decreases and again the P-factor ratio approaches 1.0.

Effectiveness of contouring is also influenced by slope length. As slope length increases the

chances of row breakover increase. When row breakover occurs on mechanical works such as contouring, large amounts of erosion can occur because runoff is concentrated at points of failure (Hudson, 1971). Information on slope-length limits and values for the P factor have been quantified and presented by Wischmeier and Smith (1978) and are shown in Table XVII.

TABLE XVII—P-FACTOR VALUES AND SLOPE-LENGTH LIMITS FOR CONTOURING (FROM WISCHMEIER AND SMITH, 1978)

Land slope (%)	P-factor value	Maximum length (m)
1–2	0.60	120
3–5	0.50	90
6–8	0.50	60
9–12	0.60	35
13–16	0.70	25
17–20	0.80	20
21–25	0.90	15

The data collected from the treatments established during the 1981 long rains permit calculation of the P factor for contouring. During this season, six replicates of maize planted on the contour and maize planted up and downhill were initiated. As can be seen from Table XX, five storms producing soil-loss were experienced during the season. Runoff on Julian Days 96, 127, 133, and 135 did not produce soil loss. The average soil loss for those plots planted up and downhill was 67.4 t/ha and that for plots on the contour was 44.4 t/ha after standard adjustments were made for slope length and steepness. Because the crop on each plot was maize and subjected to identical rainstorms, the only difference among the plots was row direction. The average P factor for the season was calculated as the ratio of the contour plot average to the up and downhill plot average or 0.66. Comparison of this value with Table XVII using the average slope steepnesses for the plots shown in an earlier table revealed that the derived P-factor value was close, but slightly higher than that recommended.

This is understandable because on the narrow plot (3 m) it is possible to place the rows nearly perfectly on the contour. In a field that has been contoured, it is not practical to ascertain that the rows are perfectly on the contour. As such, the efficiency of the contoured rows in retaining water and soil is less in the field than on a narrow contoured plot. The values shown in Table XVII reflect this loss of efficiency under field conditions. Because of these differences, it is felt that the P-factor values observed here from a small quantity of data are directly comparable to those used in the USLE for U.S. management conditions.

COVER-MANAGEMENT EFFECT ON SOIL LOSS

Estimates of the C factor at this stage are simple arithmetic means of the soil loss for a specified cover and management condition and that for bare fallow.

Table XVIII shows the C-factor values calculated over the four seasons shown for maize alone on mouldboard ploughing and no-till and maize with 3 t/ha maize residue on the soil surface after planting. Using the limited data available, the C factor for maize alone on ploughed ground is 0.82. Roose (1977) in West Africa indicates that maize had an annual average C factor ranging from 0.4 to 0.9.

TABLE XVIII—CROPPING-MANAGEMENT FACTOR EVALUATIONS THROUGH FOUR SEASONS (1981–83)

	Adjusted soil losses (t/ha)			
Season	Bare fallow	Plowed	Maize No-till	Maize w/residue
1981 LR	77.6	67.4		
1982 LR	15.7		4.2	
1982 SR	126.7	100.0	13.5	40.0
1983 LR	57.5		13.5	1.9
Mean C-factor	1.00	0.82	0.24	0.23

For no-till maize with the residue removed, the estimated C factor is 0.24, which is very close to that for maize with 3 t/ha residue added (0.23). These values are about 28% of that for maize alone with mouldboard ploughing. Mitchell and Bubenzer (1980) indicate that for U.S. conditions the C factor for continuous maize with the residue remaining and no tillage ranges from 20 to 29% of that for continous maize using mouldboard ploughing. The higher value is for a moderate productivity level and the lower for a high productivity level.

The C factor values obtained here, though not yet statistically valid, are within the ranges quoted by various sources throughout the world. More detailed analysis of C factors using soil-loss ratios and erosivity distribution needs to be conducted when the crop growth and climatic data become available.

Effects of Contouring and Tillage on Runoff

Runoff, in addition to soil erosion, is affected by contouring and tillage. If the soil surface is rough, more water is temporarily stored in depressions for infiltration. The same is true when tillage tool marks are on the contour.

When crop residues are left on the soil surface, they improve infiltration and decrease runoff by two methods. First, the presence of residue increases the hydraulic roughness of the soil surface, decreasing the runoff velocity. This creates more opportunity for infiltration to occur. Secondly, the residues absorb much of the forces created by raindrop impact. When raindrops strike the soil surface, impacting forces break soil aggregates into primary soil particles. When clay is present, these particles fill voids between aggregates at some small depth, creating a surface seal. The seal, ranging up to 1 cm in thickness, has a greatly reduced hydraulic conductivity, retarding infiltration and increasing runoff. During dry periods, such crusts are still plainly in evidence but often contain cracks due to the shrinking action of drying clay. However, upon rewetting the cracks shut quickly and the seal is re-formed.

Table XIX shows the average seasonal runoff quantities for four seasons beginning with the long rains of 1981. The short rains of 1981 are absent, as they were small and did not produce any runoff.

TABLE XIX—MEASURED MEAN SEASONAL RUNOFF FOR VARIOUS TREATMENTS FOR FOUR SEASONS

Season	Treatments			Significance
		Maize		
1981 LR	Chisel 67.3 mm		Mouldboard 68.7 mm	NS
1981 LR	Up and downhill 72.9 mm		Contoured 63.1 mm	.01
1982 LR	Fallow 16.8 mm		Maize No-till 14.5 mm	NS
1982 SR	Fallow 103.3 mm	W/O Residue 92.6 mm*	Maize W/Residue 49.9 mm	0.1
1983 LR	84.6 mm	56.7 mm	32.5 mm	.01

*Runoff means connected by the same line are not significantly different at the 5% level of probability by Duncan's Multiple Range Test.

During the 1981 long rains, the comparison of maize with chisel ploughing and mouldboard ploughing was made along with comparisons for up and downhill tillage versus contouring. Table XIX indicates that there was no significant difference between types of tillage. The degree of surface sealing and subsidence of the soil surface and tilled layer was apparently similar for both treatments and the net result was no runoff differences. However, the difference between the amounts of runoff for contouring versus up and downhill tillage was significant at the 1 per cent level, with the contouring giving less runoff.

The 1982 long rains provided a comparison between bare fallow and no-till maize. Both runoff values are small and not significantly different. During the 1982 short rains and the 1983 long rains, comparisons were made among fallow, maize without applied residue, and maize with 3 t/ha of maize residue applied. The results for the 1982 short rains indicate no difference

between the fallow and maize without residue at either the 5 or 1 per cent level. However, maize with residue was significantly lower, having a value of 49.9 mm or about half that of the other two treatments. Runoff differences among the treatments for the 1983 long rains were all significantly different at the 1 per cent level. Fallow was the highest, with maize without residue next, and maize with residue added the lowest.

TABLE XX—HYDROLOGICAL CHARACTERISTICS OF RECORDED STORMS DURING THE MONITORING PERIOD ([1]ONSET OF LONG RAINS; [2]ONSET OF SHORT RAINS)

Julian day	Storm length (hrs)	Rain (mm)	Run off (mm)	Run off (%)	Ant. moist. (mm)	Intensities (mm/hr) I_{15}	Intensities (mm/hr) I_{30}	Kinetic energy E (J/m²)
4	—	10.7	0	0	0	—	—	—
44	—	0.3	0	0	0	—	—	—
45	—	0.5	0	0	0.8	28.0	10.0	236
49	0.7	9.9	0	0	0.8	28.0	10.0	236
72	—	0.6	0	0	0	—	—	—
73	—	0.8	0	0	0.6	—	—	—
76[1]	2.6	5.2	0	0	1.4	10.0	6.4	79
77	0.2	2.0	0	0	6.6	4.0	2.0	43
77	4.5	22.4	0	0	8.6	14.4	14.6	434
78	—	0.1	0	0	30.4	—	—	—
79	3.3	11.1	0	0	29.7	6.0	6.0	196
81	6.0	39.0	6.43	17	30.8	56.0	41.2	828
82	—	1.4	0	0	74.6	—	—	—
83	—	1.1	0	0	51.6	—	—	—
84	—	8.2	0	0	52.6	—	—	—
85	2.5	17.0	0	0	49.7	22.0	14.6	339
86	5.2	9.0	0	0	66.7	6.0	5.0	142
87	4.7	31.8	8.43	27	36.7	34.0	23.0	637
88	6.8	12.6	0	0	67.1	20.0	11.6	230
89	1.3	3.3	0	0	78.6	4.0	1.6	60
90	2.0	3.2	0	0	73.7	2.0	2.6	44
91	7.8	14.0	0	0	59.9	7.2	4.0	228
92	4.3	6.9	0	0	64.9	4.0	2.4	100
93	0.8	2.8	0	0	40.0	6.0	5.6	50
94	0.9	3.3	0	0	30.2	8.0	4.2	76
95	1.0	2.2	0	0	30.2	4.0	3.0	33
96	3.0	13.0	0.23	2	29.2	8.0	3.5	234
90	—	0.5	0	0	18.5	—	—	—
100	2.3	4.8	0	0	15.7	8.0	4.2	76
101	5.6	11.1	0	0	18.3	16.8	10.0	192
102	6.0	95.3	34.81	37	16.4	70.0	69.8	2347
103	0.2	0.4	0	0	111.7	1.6	0.8	9
104	2.1	3.8	0	0	112.1	2.0	2.4	59
105	2.1	19.0	10.80	57	115.4	42.4	31.8	421
106	—	6.0	0	0	129.6	—	—	—
108	—	0.2	0	0	29.2	—	—	—
114	—	0.4	0	0	0	—	—	—
115	0.9	2.6	0	0	0.4	6.0	4.0	50
116	—	1.5	0	0	3.0	—	—	—
122	—	1.0	0	0	0	—	—	—
123	—	0.3	0	0	1.0	—	—	—
125	0.5	4.4	0	0	1.3	9.0	94	
126	—	0.2	0	0	5.7	—	—	—
127	0.8	13.0	0	0	5.9	50.0	26.0	342

Table 20 Cont.

Julian day	Storm length (hrs)	Rain (mm)	Run off (mm)	Run off (%)	Ant. moist. (mm)	Intensities (mm/hr) I_{15}	Intensities (mm/hr) I_{30}	Kinetic energy E (J/m²)
127	1.3	2.4	0.09	4	18.9	4.0	2.0	30
128	1.4	1.5	0	0	20.3	2.0	2.4	15
128	1.5	1.0	0	0	21.8	1.6	1.8	12
129	4.1	27.8	10.27	37	22.5	60.0	34.2	615
130	—	3.0	0	0	50.3	—	—	—
133	7.3	22.8	0.36	2	30.6	11.2	7.8	390
134	0.3	2.0	0	0	50.9	8.0	4.0	38
134	0.2	0.2	0	0	52.9	0.8	0.4	24
135	1.4	5.9	0.03	1	25.3	8.0	7.4	108
139	2.5	3.2	0	0	30.9	7.2	3.8	44
140	—	1.1	0	0	9.1	—	—	—
150	—	0.1	0	0	0	—	—	—
192	—	0.2	0	0	0	—	—	—
195	—	0.2	0	0	0.2	—	—	—
196	—	0.1	0	0	0.4	—	—	—
217	—	0.2	0	0	0	—	—	—
218	—	0.4	0	0	0.2	—	—	—
230	—	0.2	0	0	0	—	—	—
231	—	0.3	0	0	0.2	—	—	—
238	—	0.4	0	0	0	—	—	—
239	—	0.1	0	0	0.4	—	—	—
256	2.2	4.5	0	0	0	9.2	5.6	83
271	—	2.7	0	0	0	—	—	—
281	—	14.7	0	0	0	—	—	—
292	—	4.9	0	0	0	—	—	—
293	—	3.4	0	0	4.9	—	—	—
297	—	0.2	0	0	8.3	—	—	—
298[2]	—	31.5	0	0	3.6	—	—	—
299	—	2.8	0	0	31.7	—	—	—
312	—	0.7	0	0	0	—	—	—
314	3.3	22.3	0	0	0.7	34.0	32	438
315	—	0.2	0	0	23.0	—	—	—
316	0.2	2.1	0	0	23.2	7.2	4.2	47
317	1.9	10.9	0	0	25.3	16.0	10.0	207
318	—	1.8	0	0	35.5	—	—	—
320	2.1	5.9	0	0	15.0	7.2	4.2	104
320	2.8	7.6	0	0	20.9	10.8	5.8	137
321	—	0.2	0	0	28.3	—	—	—
323	0.5	2.8	0	0	15.5	8.0	6.0	55
323	0.1	0.2	0	0	18.3	0.8	0.4	3
324	—	0.4	0	0	16.7	—	—	—
329	—	0.2	0	0	0.4	—	—	—
339	6.1	28.9	0	0	0	20.0	15.0	558
340	—	1.3	0	0	28.9	—	—	—
341	—	1.6	0	0	30.2	—	—	—
349	—	0.6	0	0	[illegible]	—	—	—
350	—	0.4	0	0	0.6	—	—	—
351	—	2.8	0	0	1.0	—	—	—
352	—	1.4	0	0	3.8	—	—	—
353	0.7	7.1	0	0	5.2	16.8	8.4	151
355	—	0.6	0	0	11.7	—	—	—
356	—	1.8	0	0	11.9	—	—	—
357	1.2	11.6	0	0	10.9	16.0	12.0	246
363	—	0.2	0	0	0	—	—	—

Table 20 Cont.

Julian day	Storm length (hrs)	Rain (mm)	Run off (mm)	Run off (%)	Ant. moist. (mm)	Intensities (mm/hr) I_{15}	Intensities (mm/hr) I_{30}	Kinetic energy E (J/m²)
365	0.5	5.0	0	0	0.2	20.0	10.4	119
1982								
18	—	0.1	0	0	0	—	—	—
41	—	0.4	0	0	0	—	—	—
45	0.2	1.2	0	0	0.4	2.0	1.0	13
63	0.4	2.9	0	0	0	4.0	2.4	45
87[1]	0.8	6.7	0	0	0	8.4	5.6	135
88	—	31.0	4.22	13.6	6.7	—	—	—
90	6.8	25.0	0	0	37.7	20 0	13.8	466
91	2.0	6.7	0	0	62.7	4.0	3.0	99
92	1.2	5.0	0	0	69.4	6.8	3.4	61
92	.8	2.3	0.50	6.8	74.4	3.6	1.8	30
93	7.8	14.7	1.53	10.4	39.0	26.0	14.8	299
94	0.5	2.0	0	0	41.0	3.2	1.6	14
98	0.3	9.0	0	0	16.7	28.0	14.0	175
99	—	0.5	0	0	11.0	—	—	—
106	2.6	7.4	0	0	0	7.2	7.8	111
107	0.3	3.0	0	0	7.4	11.6	5.8	60
108	5.9	23.2	0	0	10.4	7.2	7.8	355
109	3.4	8.3	0	0	33.6	8.0	5.4	174
113	0.3	2.7	0	0	31.5	14.4	7.2	84
114	0.4	4.2	0	0	11.0	5.6	5.0	45
1982								
115	0.1	0.4	0	0	6.9	0.2	0.1	9
116	1.0	5.0	0	0	7.3	0 4	0.3	58
117	2.3	10.8	0	0	12.3	36.0	22.0	289
118	—	0.6	0	0	23.1	—	—	—
124	—	1.0	0	0	0	—	—	—
125	0.5	4.3	0	0	1.0	6.0	3.0	62
126	1.3	27.5	4.56	16.6	5.3	32.0	27.0	567
127	0.4	3.3	0	0	32.8	6.0	3.0	28
128	1.0	9.0	0	0	36.1	21.2	15.0	174
128	2.3	22.0	7.33	23.6	45.1	22.0	14.4	399
129	0.2	1.2	0	0	67.1	2.0	1.0	19
133	1.3	5.2	0	0	32.2	17.6	8.4	245
134	0.7	6.7	0	0	6.4	14.0	9.6	101
135	—	0.6	0	0	11.9	—	—	—
139	3.5	17.2	0.001	0.01	7.3	12.8	9.8	238
141	—	0.3	0	0	17.2	—	—	—
144	1.8	4.6	0	0	17.5	6.0	6.0	100
145	0.1	0.5	0	0	4.9	0.4	0.2	17
147	0.7	6.3	0	0	5.1	12.8	6.4	128
172	0.2	1.4	0	0	0	4.0	2.0	15
174	0.2	1.1	0	0	1.4	0.9	0.4	13
176	0.1	0.4	0	0	1.1	0.2	0.1	9
181	0.9	4.4	0	0	0	5.0	3.0	60
192	0.1	0.5	0	0	0	2.0	3.0	10
275	0.7	1.9	0	0	0	3.6	3.6	31
279	0.3	1.2	0	0	1.9	2.8	1.4	20
283	0.7	1.5	0	0	1.2	2.0	1.0	25
284	1.1	5.3	0	0	2.7	6.0	4.0	96

Table 20 Cont.

Julian day	Storm length (hrs)	Rain (mm)	Run off (mm)	Run off (%)	Ant. moist. (mm)	Intensities (mm/hr) I_{15}	Intensities (mm/hr) I_{30}	Kinetic energy E (J/m²)
286	0.5	2.3	0	0	6.8	11.2	5.6	70
287	1.7	11.8	0.01	0.1	9.1	11.6	7.0	108
288	0.3	0.1	0	0	20.9	0	0	0
289[2]	1.6	8.7	0	0	19.5	6.0	4.0	126
290	1.7	20.3	0	0	22.9	20.0	15.8	326
290	0.4	3.0	0.12	0.5	43.2	6.0	3.0	60
291	2.0	9.3	0.11	1.2	46.2	12.0	6.2	135
293	1.3	4.3	0	0	41.4	5.6	2.8	60
294	1.7	12.5	0.37	3.0	45.6	20.0	15.0	222
295	2.2	34.0	10.97	32.3	49.4	44.0	22.0	766
296	2.6	14.2	0.10	1.0	60.1	5.6	4.0	143
301	0.6	2.5	0	0	14.2	2.8	2.0	16
303	0.1	0.5	0	0	2.5	1.2	0.6	4
304	0.5	2.8	0	0	3.0	2.0	2.0	31
305	0.3	2.5	0	0	5.8	2.0	1.8	15
306	0.2	0.7	0	0	8.3	1.0	0.5	6
313	2.6	22.7	1.29	6.0	0	19.2	15.6	422
314	0.7	4.0	0	0	0	22.7	6.0	3.4
315	1.0	11.5	0	0	26.7	24.0	14.6	277
315	1.4	5.6	0.92	5.4	38.2	10.0	7.0	117
316	0.1	0.9	0	0	43.6	2.8	1.4	11
317	1.9	9.5	0.81	8.5	44.5	17.2	10.6	174
318	4.0	33.7	12.23	36.3	54.0	28.0	18.6	601
319	0.7	1.2	0	0	65.2	1.6	2.0	10
319	0.3	0.9	0	0	66.4	1.6	1.8	12
320	0.8	6.0	0.33	5.5	63.3	6.8	4.0	67
321	0.2	1.5	0	0	52.2	0.4	0.2	19
321	1.7	5.2	0.02	0.3	53.7	4.0	2.2	60
322	1.7	8.7	0	0	58.0	9.6	4.8	185
322	0.3	1.5	0.97	9.5	66.7	4.0	2.0	43
323	1.7	5.3	0	0	58.7	6.0	3.0	57
325	1.2	13.3	5.60	42.1	28.2	24.0	15.8	284
326	0.8	3.7	0	0	35.5	8.0	6.4	82
326	0.4	7.8	3.78	32.9	32.2	28.0	18.0	218
327	0.7	2.1	0	0	40.3	3.2	1.6	15
328	2.3	20.0	6.45	32.3	32.3	36.0	26.0	547
329	6.6	39.7	14.01	35.3	46.9	40.0	33.0	720
330	5.7	32.2	13.05	40.5	86.6	44.0	22.0	484
331	0.2	3.0	0	0	105.5	12.0	6.0	70
331	3.5	9.3	1.71	13.9	114.8	11.2	5.6	149
332	8.0	34.5	13.20	38.3	106.3	20.4	12.2	670
333	0.1	0.8	0	0	138.7	4.0	2.0	22
335	1.8	11.8	0.67	6.0	79.8	6.0	6.0	162
336	3.5	19.5	6.39	33.0	59.4	16.0	14.0	340
337	6.7	29.8	11.32	38.0	66.6	20.4	18.6	637
338	1.5	9.9	1.70	17.2	61.9	12.0	8.0	119
339	—	0.8	0	0	71.0	—	—	—
340	0.2	4.0	0	0	71.8	4.0	2.4	48
341	3.1	11.0	0.62	5.6	60.8	9.2	6.4	207
343	0.2	1.0	0	0	25.7	2.0	1.0	11
343	0.2	1.1	0	0	26.7	1.6	0.8	6
344	1.0	3.8	0	0	17.9	10.0	5.0	78
345	0.7	6.0	0	0	20.9	7.2	3.2	84
346	0.1	0.5	0	0	26.1	2.0	1.0	9

Table 20 Cont.

Julian day	Storm length (hrs)	Rain (mm)	Run off (mm)	Run off (%)	Ant. moist. (mm)	Intensities (mm/hr) I_{15}	Intensities (mm/hr) I_{30}	Kinetic energy E (J/m²)
347	0.7	5.1	0	0	12.4	8.0	5.0	74
349	0.1	0.9	0	0	15.4	—	—	—
351	0.1	0.5	0	0	6.5	—	—	—
352	0.9	3.1	0	0	6.5	10.0	5.0	80
355	0.2	2.1	0	0	3.6	—	—	—
356	0.1	0.4	0	0	5.7	—	—	—
1983								
5	0.5	9.3	0.44	5.9	0	24.0	12.0	168
6	0.7	5.7	0	0	7.4	8.0	2.0	41
11	0.1	0.5	0	0	2.4	2.0	1.0	—
15	0.5	3.8	0	0	0.5	8.0	3.8	39
35	0.2	0.8	0	0	0	2.0	1.0	—
43	0.1	0.3	0	0	0	2.0	1.8	—
44[1]	4.4	8.3	0	0	0.3	4.0	2.0	74
44	0.3	2.0	0.01	0.1	8.6	8.0	4.0	38
45	7.7	102.0	53.08	52.0	10.6	64.0	44.4	2068
48	0.3	4.8	0.59	12.3	112.6	8.0	4.0	40
49	2.2	17.3	4.68	27.1	117.1	18.0	16.0	87
50	0.9	7.3	0.81	11.1	124.1	9.6	4.8	127
51	0.2	3.7	0.08	2.2	29.4	12.0	6.0	70
85	0.1	0.2	0	0	0	0	0	0
86	0.6	5.2	0	0	0.2	4.8	4.4	67
87	0.3	1.2	0	0	3.9	2.0	1.0	7
105	0.2	3.7	0	0	0	5.2	2.6	26
112	2.6	6.6	0	0	0	11.2	8.0	172
113	2.2	10.8	0	0	6.6	16.0	11.0	191
113	1.7	46.9	16.10	28	17.4	52.0	42.0	1084
114	1.0	4.3	0	0	64.3	10.0	8.4	98
114	3.2	10.7	0.004	0.03	68.6	20.0	11.0	236
115	0.5	14.7	7.83	53.3	79.3	24.0	15.0	188
116	4.7	20.0	2.92	14.6	94.0	15.2	8.0	331
117	0.5	1.3	0	0	114.0	2.0	2.0	21
118	3.5	8.3	0.014	0.17	108.7	4.0	3.0	94
119	0.7	6.7	0.005	0.07	59.3	16.8	8.4	142
123	—	0.7	0	0	15.0	—	—	—
131	0.6	2.2	0	0	0	3.2	1.6	30
132	0.8	2.8	0	0	2.2	2.4	1.2	31
136	1.0	6.8	0	0	5.0	6.0	4.0	57
156	0.4	2.7	0	0	0	6.4	3.2	39
174	1.2	1.5	0	0	0	0.8	0.4	10
175	0.7	5.3	0	0	1.5	12.0	11.0	155

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PHYSICAL PROPERTIES OF SOILS IN RELATION TO EROSION

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INTRODUCTION

The physical properties of soil affect its infiltration capacity and the extent to which it can be dispersed and transported. Those properties that influence erosion include soil structure, texture, organic-matter and moisture content, and density or compactness, as well as chemical and biological characteristics of the soil.

Soil structure refers to the arrangement of the soil particles and pore spaces between them (Marshall, 1962). It includes the size, shape, and arrangement of the aggregates formed when primary particles are clustered together into large separable units. Aggregation has a pronounced effect on such soil properties as erodibility, porosity, permeability, infiltration, and water-holding capacity. The structure of surface soil is usually given more attention in relation to soil erosion than the subsoil structure, since it is most subject to deterioration under raindrop impact and poor agricultural practices.

For many years soil scientists have attempted to relate the amount of soil erosion as measured in the field to various physical characteristics of the soil which can be measured in the laboratory. Work on these lines has included, either singly or in combination, almost every soil property capable of quantitative measurement (Middleton, 1930; Bouyoucos, 1935; Yoder, 1936; Lutz, 1934; Ballal, 1954). Some of these studies have been partly successful in that they have given some indication of the relative resistance to erosion inherent in different soil types, or have allowed a comparative assessment of the effects of alternative management practices on a particular soil. The objective of the present study was to assess the influence of the physical properties of soil on its erodibility.

MATERIALS AND METHODS

The soil samples used in this study were collected from soil profiles developed on two different parent materials at the Katumani National Dryland Research Station (KNDRS), Machakos and the Kenya Agricultural Research Institute (KARI), Muguga. The soils at KNDRS are classified as Ferro-chromic Luvisols (FAO/UNESCO system). They are shallow, well drained, dark reddish-brown, hard when dry, very friable when wet, sandy clay loam tending to sandy clay at lower horizons (Mbuvi and Van de Weg, 1975; Barber and Thomas, 1979; Kilewe and Ulsaker, 1983). The KARI soils on the other hand fall within the Nitosol unit in the FAO/UNESCO classification. These soils are referred to as Kikuyu friable clay derived from Tertiary trachytic lava. This is deep, well drained, dark reddish-brown clay overlying dark red clay. They exhibit a deep clay bulge and deep argillic horizon at the lower depths.

At KARI, soil samples were collected on the farm near the lysimeter, while at KNDRS samples were collected from field N. At each location samples were taken at depths of 10, 30, 60, and 100 cm from four representative sampling areas.

In the laboratory, the soil samples were air dried and split into four portions for the determination of particle-size distribution, dispersion ratio, water-stable aggregates (wet sieving), and degree of aggregation (dry sieving). The portion for water-stable aggregate analysis was passed without forcing through 5 mm and 2 mm sieves. The portion remaining on the 5 mm and that passing through the 2 mm sieve were discarded. A 25 g sample for analysis was taken from the fraction retained on the 2 mm sieve and added to the top of a set of sieves of 2, 1, 0.5, 0.25 and 0.15 mm, fixed on Endecotts test sieve-shaker model EFL 2 with wet sieving attachment. The sample was then wetted with a little water and allowed to stand for ten minutes. The water was turned on to give a fine spray on the sample and then the shaker was switched on for 10 minutes. The fraction of the sample retained on each sieve at the end of the shaking time was quantitatively transferred into weighed evaporating dishes and oven dried at 105°C to constant mass. The oven-

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dried material was weighed to 0.01 g and expressed as a percentage of the total sample on an oven-dry basis.

The degree of aggregation was determined by dry sieving with a set of sieves with openings similar to those used in water-stable aggregate analysis and using 25 g of air-dry sample taken from the soil fraction passing through the 5 mm sieve.

The particle-size distribution was determined by the hydrometer method outlined by Day (1965). A second determination of particle-size distribution was made using non-chemically-dispersed samples. The two particle-size distributions were used for the determination of clay ratio (Cr), dispersion ratio (Dr), erosion ratio (Er), colloid-moisture equivalent ratio (CMr), and erosion index (EI) as follows:

$$Cr = \frac{\%\ \text{Sand}}{(\%\ \text{Silt} + \text{Clay})}$$

$$Dr = \frac{(\%\ \text{Silt} + \text{Clay})\ (\text{dispersed sample})}{(\%\ \text{Silt} + \text{Clay})\ (\text{undispersed sample})}$$

$$CMr = \frac{\text{Colloidal content}}{\text{Moisture equivalent}}$$

$$Er = \frac{\text{Dispersion ratio}}{\text{Colloidal content moisture equivalent ratio}}$$

$$EI = \frac{\text{Dispersion ratio}}{\text{Clay/half water-holding capacity}}$$

where colloidal content is the percentage sum of clay and organic-matter content, while the moisture equivalent is the moisture content held at field capacity.

RESULTS AND DISCUSSION

Table I shows some of the important physical characteristics for KARI and KNDRS soils. The quantity of organic matter contained in soils is important from many points of view. With respect to erodibility, its greatest effect is on structure. The organic fraction of the soil has a greater capacity, proportionately, for absorbing and storing water than the mineral fraction, but its most important effect is in forming water-stable aggregates that increase the porosity and permeability of the soil. Soils of low organic-matter content, like those found at KNDRS, are subject to comparatively rapid erosion and are less retentive of moisture and less able to deliver to plants that which is retained. The percentage size distribution of aggregates after wet sieving is shown in Table II. Soils that break down into many very small aggregates or primary particles are considered more erodible than soils that break down into intermediate-size aggregates or remain stable. The soil structure is therefore a very important factor in soil erosion because it largely determines the rate at which water can enter the soil, as well as the resistance of soil particles to detachment by rainfall impact and subsequent removal in surface runoff. The stability of any given structural organization is important in relation to soil erodibility. This arises firstly in relation to the ease of detachment of particles from aggregates and secondly in relation to the detached smaller particles of clay and silt, which are likely to be washed into the coarser pores of the existing structure and cause a decrease in its hydraulic conductivity. The proportion of soil in water-stable aggregates less

TABLE I—SOME OF THE IMPORTANT PHYSICAL CHARACTERISTICS FOR KARI AND KNDRS SOILS

Location and site	Depth (cm)	Bulk density (g/cm³)	Water-capacity (%)	Moisture equivalent (%)	Percentage particle-size distribution: Sand (2.0–0.6 mm)	Silt (0.06–0.02 mm)	Clay (0.02 mm)	Silt + clay undispersed	Organic-matter content (%)	Classification
KARI Farm	0–10	1.11	64.2	48.7	28.8	31.9	35.9	25.8	4.2	Clay loam
	10–30	1.12	63.7	41.3	24.9	28.0	43.5	20.2	3.6	Clay
	30–60	1.19	61.4	43.0	13.7	23.7	61.1	17.1	1.4	Clay
	60–100	1.22	58.2	45.9	10.3	16.5	72.4	14.5	0.8	Clay
KNDRS Field N	0–10	1.52	40.2	25.8	67.1	8.5	22.2	24.2	2.2	Sandy clay loam
	10–30	1.44	43.3	21.3	63.9	9.6	25.1	25.9	1.4	Sandy clay loam
	30–60	1.43	44.8	27.9	55.2	12.4	31.5	27.5	0.9	Sandy clay
	60–100	1.40	46.6	23.3	51.7	15.0	33.3	28.7	0.0	Clay

TABLE II—PERCENTAGE SIZE DISTRIBUTION OF AGGREGATES AFTER WET SIEVING

Location and site	Depth (cm)	Percentage particle size finer than the upper limit					
		5–2 mm	2–1 mm	1–0.5 mm	0.5–0.25 mm	0.25–0.16 mm	0.15 mm
KARI Farm	0–10	100	95.8	88.4	68.3	56.7	46.5
	10–30	100	96.7	81.1	69.5	47.2	44.0
	30–60	100	95.8	89.9	67.4	40.3	34.9
	60–100	100	89.4	65.0	47.0	36.1	24.8
KNDRS Field N	0–10	100	92.9	89.4	75.7	50.3	31.9
	10–30	100	91.7	88.1	75.8	49.4	29.7
	30–60	100	98.3	95.7	78.6	46.3	26.3
	60–100	100	96.0	91.7	78.3	52.3	26.7

than 0.5 mm was therefore taken as an index of soil erodibility. The percentage of aggregates less than 0.5 mm for KARI soil decreased from 68.3% at the surface to 47.0% at 100 cm depth, while for KNDRS soil it increased from 75.7% at the surface to 78.3% at 100 cm depth. The greater the proportion of aggregate less than 0.5 mm, the greater the erodibility. The erodibility for KARI soil therefore decreased with depth. This could be attributed to a sharp increase in clay content, from 31.1% at the surface to 72.4% at 100 cm depth. The erodibility of KNDRS soil, however, showed a slight increase with depth, probably due to the total absence of organic matter at the lower horizons. The sand and clay content for this soil varied between 67.1% and 22.2% respectively at the surface to 51.7% and 33.3% at 100 cm depth. The sandy clay loam soils of KNDRS, characterized by dispersed particles, are therefore more erodible than the KARI clay soil because the aggregates of this sandy soil slake more readily and seal the surface. This reduces the rate of infiltration of water and causes runoff.

The degree of soil aggregation after dry sieving is shown in Table III. This is an indication of a soil's susceptibility to wind erosion. The percentage aggregates less than 0.5 mm after dry sieving varied between 7.0% and 57.9% at the surface to 4.3% and 43.7% at 100 cm depth for KARI and KNDRS soils respectively. Soils vary considerably in their resistance to wind erosion, depending on their structure, the size of particles, and the organic-matter content. The finer-textured soils, especially those of granular structure like the KARI soils, show the greatest resistance. These remain undisturbed through

TABLE III—PERCENTAGE SIZE DISTRIBUTION OF AGGREGATES AFTER DRY SIEVING

Location and site	Depth (cm)	Percentage particle size finer than the upper limit					
		5–2 mm	2–1 mm	1–0.5 mm	0.5–0.25 mm	0.25–0.16 mm	0.15 mm
KARI Farm	0–10	100	20.1	9.1	7.0	5.2	3.5
	10–30	100	29.2	11.1	8.4	4.9	1.8
	30–60	100	22.1	7.5	5.9	3.6	1.8
	60–100	100	14.7	5.9	4.3	2.3	0.5
KNDRS Field N	0–10	100	86.0	74.2	57.9	32.7	15.7
	10–30	100	77.2	65.2	52.4	28.3	13.0
	30–60	100	85.6	70.1	50.6	27.3	12.6
	60–100	100	76.1	59.4	43.7	25.8	14.1

years of cultivation, although when subjected continuously to diminution of organic matter under cultivation the granules break down eventually, and the deflocculated particles are then susceptible to removal by wind. The KARI clay soil is well structured and therefore the number of soil particles small enough to be moved is very low and abrasion is minimal, due both to a limited supply of abrasives and to the mechanical strength of the structural units. On the other hand, the KNDRS soil has a weak structure and ample initial supplies of erodible material which are rapidly abraded. The state and stability of the structural units are principally determined by water, soil texture, organic cements, and disaggregating processes, and therefore wind erosion is more pronounced in arid and semi-arid regions.

The coarse texture associated with KNDRS soil suggests high infiltration rates and the necessity of comparatively high velocities of runoff water to move the individual soil particles. However, coarse-textured soils are generally associated with single-grain structure and less resistant to concentrated flow of runoff water, and are therefore more susceptible to erosion than fine-textured soils.

The ease and degree of dispersion of the soil particles, together with the degree of aggregation, provide the most useful information on the structural stability of soil. The measurements of dispersion and aggregation are complementary, in that particles of soil not dispersed by water remain aggregated or clustered in granules which are favourable to infiltration of rainwater. The dispersion ratio for both KARI and KNDRS soils shown in Table IV decreased with depth and varied between 38.5 at the surface and 16.3 at 100 cm depth for KARI soil, and between 78.8 at the surface and 59.4 at 100 cm depth for KNDRS soil. The dispersion ratio is an index of the ease with which soil particles can be brought into suspension by the action of raindrops or runoff water, and therefore the greater the ratio the more easily the soil can be dispersed and eroded.

The colloid-moisture equivalent ratio shown in Table IV expresses the relative permeability of the soil water. This ratio increased with depth from 0.8 and 0.9 at the surface to 1.6 and 1.4 at 100 cm depth for KARI and KNDRS soils respectively. Consequently the percolation rates for these soil profiles were considered to increase with depth.

TABLE IV—SOIL ERODIBILITY INDICES

Location and site	Depth (cm)	Colloidal content/ME	Clay ratio	Dispersion ratio	Erosion ratio	Erosion index
KARI Farm	0–10	0.8	1.7	38.5	48.1	35.0
	10–30	1.1	1.2	28.3	25.7	20.2
	30–60	1.5	0.6	20.2	13.5	10.1
	60–100	1.6	0.4	16.3	10.2	6.5
KNDRS Field N	0–10	0.9	3.4	78.8	87.6	71.6
	10–30	1.2	2.9	74.6	62.2	62.2
	30–60	1.2	2.1	62.6	52.2	44.7
	60–100	1.4	2.0	59.4	42.4	42.4

Since the erosion increases directly with dispersion ratio and inversely with colloid-moisture equivalent ratio, the erosion ration was obtained as shown on table IV. The erosion ratio decreased with depth in the two profiles and varied between 48.1 and 87.6 at the surface and 10.2 and 42.4 at 100 cm depth for kari and KNDRS soils respectively. The clay content for both soils increased with depth and therefore the erosion ratio decreased with the increase in clay content. The erosion index values followed the same trend as the erosion ratio values. However, the corresponding erosion ratio values were always higher than the erosion index values. Since the erosion ratio is a measure of degree of erosion and not how much soil is lost due to erosion, it may be substituted for by the erosion index, whose determination is simple and less time consuming.

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SOIL PHYSICAL CHARACTERISTICS AND THEIR APPLICATION TO AGRICULTURE

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INTRODUCTION

Knowledge of how the physical characteristics of the soil profile are altered by different land-use practices is basic to land-use planning for soil and water conservation. The physical characteristics of the profile essential to water movement and water storage may be defined largely in terms of pore space.

Pore sizes can be arbitrarily divided into macroporosity and capillary porosity. Macroporosity is the percentage of pore space filled with air after the soil has drained to field capacity. These pores are sufficiently large to allow water to drain by gravity alone and are largely responsible for soil aeration and for infiltration and percolation rates of the water at the surface and through the different horizons of the soil profile. Capillary porosity, on the other hand, is the percentage of pore space that may be occupied by capillary water. These pores retain water against gravity and are responsible for plant moisture supply. The moisture held in the large pores is termed detention storage.

Soils differ widely in their total water-storage capacity. This capacity is closely related to soil texture. Fine-textured clay soils contain a large number of capillary pores which contribute to a high water-holding capacity and low permeability, while sandy soils have more large pores, which are responsible for rapid drainage and low water-holding capacity (Baver, 1956). Fine-textured clay soils hold water so tenaciously that less than half is available to plants. In sandy soils, however, a higher percentage of total water at field capacity is available to plants. Therefore, in soils of different textures, the amount of water available to plants does not differ so much as the total amount of water at field capacity. In general, medium-textured soils, such as loams, silt loams, and silty clay loams have better moisture relations than either coarse-textured sandy soils or fine-textured clay soils.

The purpose of this study was, therefore, to determine and interpret the soil physical characteristics and their application to agriculture.

METHODS

The field work was conducted at the Kenya Agricultural Research Institute (KARI), Muguga, and the Katumani National Dryland Research Station (KNDRS). At KARI soil samples were taken at the farm near the lysimeter, while at the KNDRS samples were collected from fields N, O and Q. At each location, disturbed and undisturbed samples were taken at depths of 10, 30, 60 and 100 cm from four representative sampling areas. The undisturbed cores were taken in aluminium cylinders of 5.0 cm outside diameter and 4.5 cm long.

In the laboratory, the bottom of the undisturbed soil cores was covered with a cloth membrane held in position by a strong elastic band. The samples were then saturated by capillary action for three days. The samples were then placed on a lightly flooded pressure cooker after the initial weighing and subjected to suctions of 20, 100 and 330 cm of water. The samples were weighed after a minimum equilibration period of 4, 8 and 16 hours at each suction, respectively. After the final weighing the soil was transferred to preweighed containers, oven dried at 105°C to constant mass, and weighed. The volumetric water content at any given suction was then calculated for the oven-dry soil by:

$$\theta_I = \left(\frac{m_I - m_c - m_s}{m_s} \right) \gamma_d$$

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where

= volumetric water content at T cm of water suction

m_T = mass of core at T cm of water suction

m_e = mass of empty core with saturated cloth membrane elastic band

m_s = mass of total oven-dry soil

γ_d = dry bulk density of the soil.

Loose but otherwise undisturbed samples collected at the same depth as the pressure-cooker samples were used for pressure-plated measurements at 1, 5 and 15 bars pressure. For each depth five replicated samples were placed in circular plastic retaining rings of 3.0 cm diameter and 1.0 cm depth, resting on a saturated pressure plate. The samples were saturated on the plate by maintaining excess water on the plate surface prior to applying pressure. Equilibrium was considered to have been attained when no further outflow greater than 0.5 ml was measured over a period of twelve hours. The samples were quickly transferred into preweighed containers, weighed, oven dried at 105°C to constant mass, and reweighed. Volumetric water content was then calculated in the usual manner.

The particle size distribution of soil samples for each site was determined by the hydrometer method as described by Day (1956, 1965). The organic-carbon, and hence the organic-matter, content was determined by the loss-on-ignition method outlined by Ball (1964) as follows:

$$C = 0.467L - 1.87$$
$$OM = 1.72C$$

where

C = the organic carbon

L = the loss-on-ignition, and

OM = The organic matter content.

RESULTS AND DISCUSSION

The bulk density, particle size distribution, and organic-matter content for four layers in the 0–100 cm soil profiles for KARI and KNDRS soils are shown in Table I.

The bulk density for KARI soil increased with depth from 1.11 gcm^{-3} at the surface to 1.22 gcm^{-3} at 100 cm depth. However, the bulk density for KNDRS soils decreased with depth and varied between 1.52 and 1.61 gcm^{-3} at the surface and 1.29 and 1.40 gcm^{-3} at 100 cm depth.

The sand and clay content for KARI soil varied between 28.8 and 35.1% at the surface and 10.3 and 72.4% at 100 cm depth respectively. The organic-matter content ranged from 4.2% at the surface to 0.8% at 100 cm depth. This soil was classified as clay loam at the surface and clay at the lower horizons. The sand content for KNDRS

TABLE I—BULK DENSITY, PARTICLE-SIZE DISTRIBUTION, AND ORGANIC-MATTER CONTENT

Location and site	Depth (cm)	Bulk density (gcm^{-3})	Percentage size fraction: Sand (2.0–0.06 mm)	Silt (0.06–0.002 mm)	Clay (<0.002 mm)	Organic matter content	Textural classification
KARI farm	0–10	1.11	28.8	31.9	35.1	4.2	Clay loam
	10–30	1.12	24.9	28.0	47.5	3.6	Clay
	30–60	1.19	13.7	23.7	61.1	1.4	Clay
	60–100	1.22	10.3	16.5	72.4	0.8	Clay
KNDRS field N	0–10	1.52	67.1	8.5	22.2	2.2	Sandy clay loam
	10–30	1.44	63.9	9.6	25.1	1.4	Sandy clay loam
	30–60	1.43	55.2	12.4	31.5	0.9	Sandy clay
	60–100	1.40	51.7	15.0	33.3	0.0	Sandy clay
KNDRS field O	0–10	1.61	64.8	7.6	25.7	1.9	Sandy clay loam
	10–30	1.53	57.6	11.8	29.6	1.0	Sandy clay loam
	30–60	1.47	50.3	16.5	32.4	0.8	Sandy clay
	60–100	1.35	42.1	20.1	37.8	0.0	Clay
KNDRS field Q	0–10	1.59	59.9	9.3	28.2	2.6	Sandy clay loam
	10–30	1.48	48.9	10.4	38.9	1.8	Sandy clay
	30–60	1.35	41.2	14.5	43.3	1.0	Clay
	60–100	1.29	30.5	19.3	50.0	0.2	Clay

soils varied between 59.9 and 67.1% at the surface and 30.5 and 51.7% at 100 cm depth. The clay content increased gradually with depth, ranging from 22.2 to 28.2% at the surface to 33.3 to 50.0% at 100 cm depth. These soils were very low in organic-matter content and exhibited a sandy clay loam texture at the surface, changing with depth to sandy clay and clay at the lower horizons.

Average moisture-release characteristics for all sites are shown in Figs. 1 to 4 and Table II. The moisture-release characteristics reflect the pore-size distribution in a non-swelling soil and therefore any point on the curves represents a moisture content at which pores of larger than the corresponding equivalent diameter will be air filled and those smaller will be water filled.

TABLE II—SOIL MOISTURE RELEASE CHARACTERISTICS DATA

Location and site	Depth (cm)	Percentage volumetric moisture content						
		Suction (bars)						
		0	0.02	0.10	0.33	1	5	15
KARI farm	10	64.2	60.3	55.8	48.7	33.7	29.8	28.1
	30	63.7	61.7	49.8	41.3	34.8	30.8	29.0
	60	61.4	59.7	50.9	43.0	35.8	32.7	31.5
	100	58.2	56.9	52.5	45.9	39.9	36.8	34.6
KNDRS field N	10	40.2	37.9	31.5	25.8	15.1	11.6	9.6
	30	43.3	38.5	28.1	21.3	15.8	12.2	10.7
	60	44.8	39.6	34.1	27.9	17.6	15.6	13.4
	100	46.6	42.2	37.9	23.3	20.0	16.5	15.3
KNDRS field O	10	36.3	34.2	30.5	28.7	21.1	17.5	14.7
	30	40.6	37.5	33.3	27.3	24.7	21.1	18.9
	60	43.1	38.6	35.5	29.9	25.0	21.7	19.6
	100	51.5	44.3	39.1	31.6	22.3	19.4	17.8
KNDRS Field Q	10	36.0	32.8	30.7	26.6	21.2	16.2	13.5
	30	41.4	36.9	33.8	30.3	25.8	20.5	16.9
	60	44.9	40.6	35.2	31.7	24.6	21.7	18.7
	100	49.4	44.5	38.3	32.5	26.5	22.9	19.9

Differences between moisture-release characteristics for different depths at each site were consistent with the observed variation in texture, structure, organic-matter content and bulk density with depth. For all KNDRS soils, the bulk density decreased with depth and therefore total porosity, and hence moisture content at 0 suction, increased with depth. The KARI soils, however, showed a gradual increase in bulk density with depth and therefore total porosity and moisture content at 0 suction decreased gradually with depth.

The variation in measured water content within each set of replicates for each depth at each site was appreciable in the lower suction range. However, in the higher suction range the variations were small. The observed variation in the measured water content in the lower suction range is partly due to structural differences between replicate samples and partly to small differences in particle size distribution and organic-matter content. Water-content retention in the higher suction range is mainly related to texture. This explains the smaller variability observed between replicate samples in the higher suction range, since the texture at each sampling depth on each site was fairly uniform.

The KARI clay soil has a more uniform pore size distribution, and therefore more of the water is adsorbed, so that increase in the suction caused a more gradual decrease in water content. In the KNDRS sandy clay and sandy loam soils, however, most of the pores are relatively large and once they are emptied at a given suction only a small amount of water remains and therefore the suction increases rapidly. In general, it was observed that with increased clay content at each site and depth there was a greater water content at any particular suction and a more gradual slope of the moisture-release-characteristic curve.

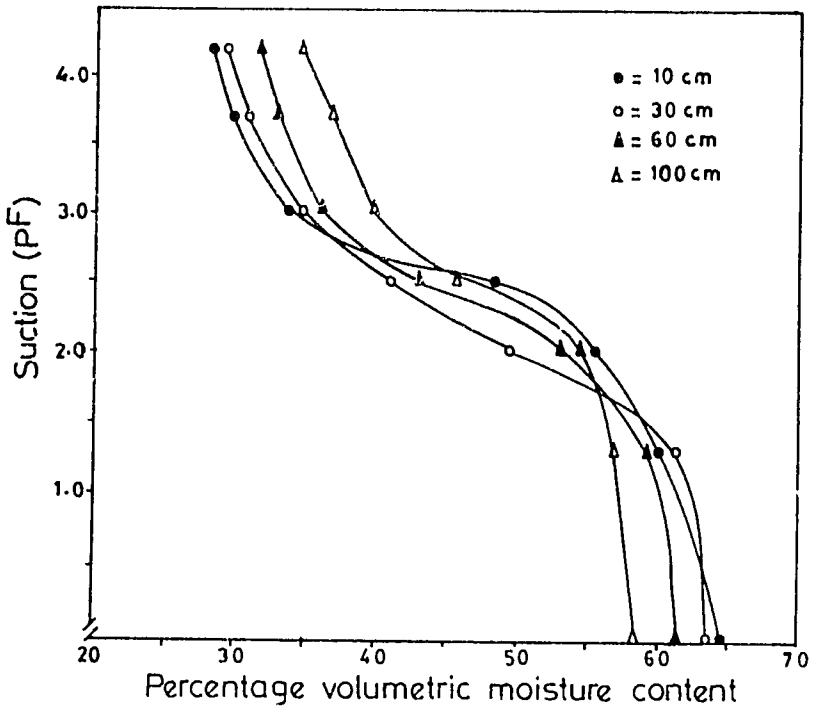


Fig. 1. Average moisture release characteristics for KARI farm.

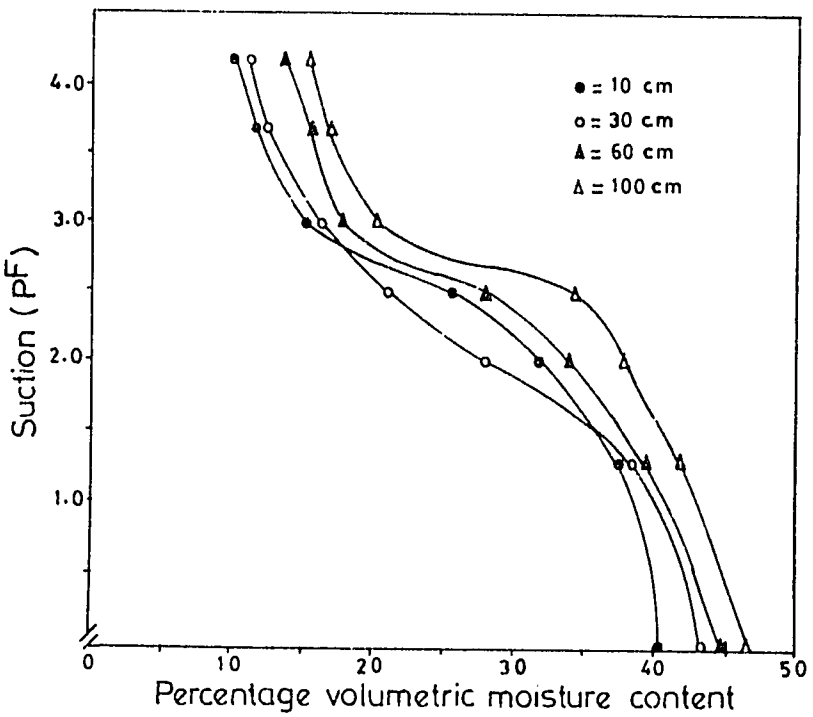


Fig. 2. Average moisture release characteristics for field N at KNDRS.

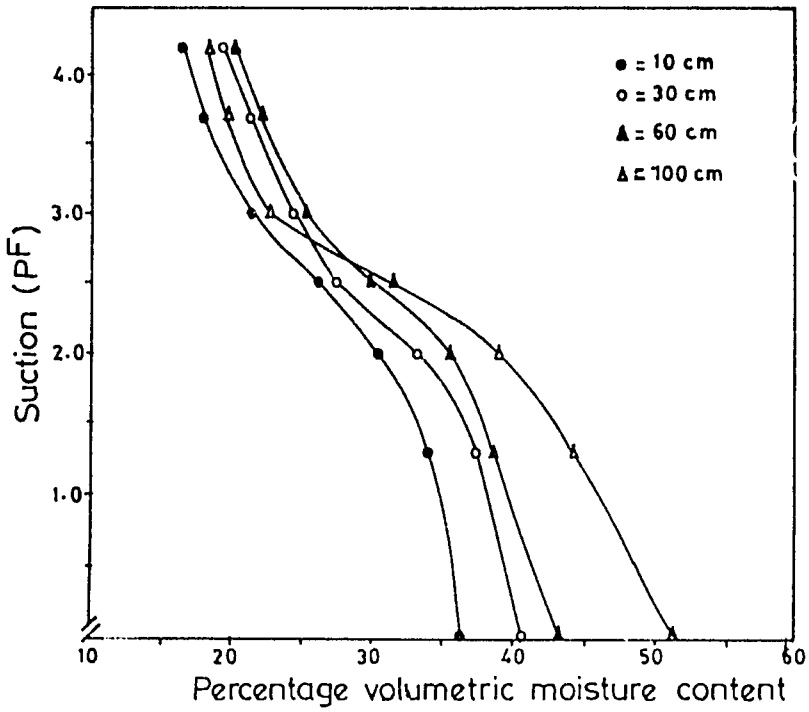


Fig. 3. Average moisture release characteristics for field O at KNDRS.

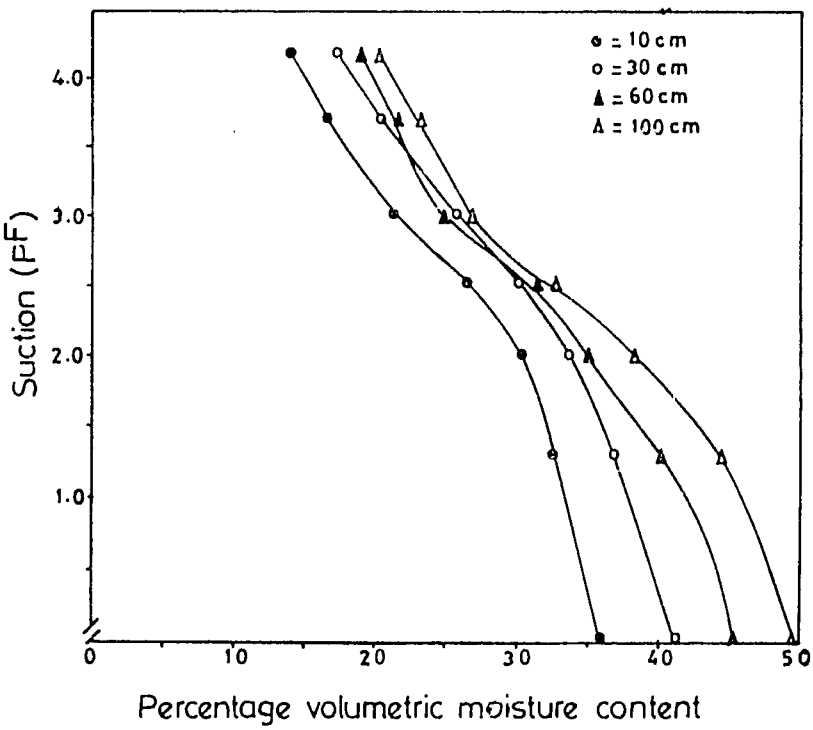


Fig. 4. Average moisture release characteristics for field Q at KNDRS.

The type and arrangement of soil particles determines the amount and nature of the pores. Figs. 5 to 8 and Table III show the variation in pore size distribution with depth for KARI and KNDRS soils. The KARI clay soil has 64.2% pore volume at the surface, decreasing with depth to 58.2% at 100 cm depth. The KNDRS soils, however, showed lower total pore volume, ranging between 36.0 and 40.2% at the surface and 46.6 to 51.5% at 100 cm depth. This implies that the total pore volume for KNDRS increased appreciably with depth.

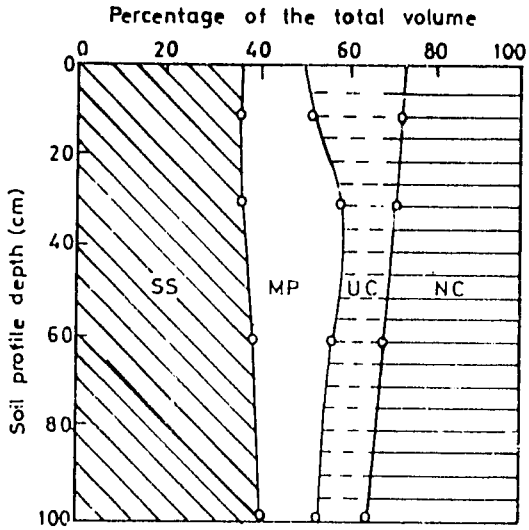
TABLE III—STRUCTURAL AND HYDROLOGICAL CHARACTERISTICS

		Percentage pore-size distribution				
			Macropores		Capillary pores	
Location and site	Depth (cm)	Total pore space	Very freely drained	Freely drained	Retaining available water	Retaining unavailable water
KARI farm	0–10	64.2	3.9	11.6	20.6	28.1
	10–30	63.7	2.0	20.4	12.2	29.0
	30–60	61.4	1.7	16.7	11.5	31.5
	60–100	58.2	1.2	11.0	11.4	34.6
KNDRS field N	0–10	40.2	2.3	12.2	16.2	9.6
	10–30	43.3	4.8	17.2	10.6	10.7
	30–60	44.8	5.2	11.6	14.6	13.4
	60–100	46.6	4.4	18.9	8.0	15.3
KNDRS field O	0–10	36.3	2.1	5.5	13.9	14.7
	10–30	40.6	3.1	10.2	8.3	18.9
	30–60	43.1	4.5	8.7	10.4	19.6
	60–100	51.5	7.2	12.7	13.7	17.8
KNDRS field Q	0–10	36.0	3.2	6.1	13.1	13.5
	10–30	41.4	4.4	6.7	13.4	16.9
	30–60	44.9	4.4	8.9	13.0	18.7
	60–100	49.4	4.9	12.0	12.06	19.9

Except for fields O and Q at KNDRS, all profiles showed an appreciable increase in macroporosity between the 20 and 50 cm depths at the expense of "useful" capillary pores, and then decreased gradually with depth.

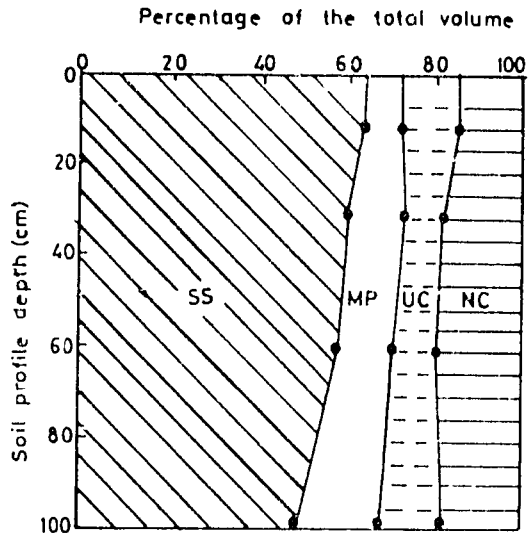
Fields O and Q (Figs. 7 and 8) showed a gradual decrease in soil solid volume with depth. As a result the macroporosity and capillary porosity increased gradually with depth. The "useful" capillary pores for KARI soil (Fig. 5) decreased with depth up to 30 cm and remained uniform for the rest of the profile, while the "non-useful" capillary pores showed a gradual increase with depth. This behaviour is in agreement with particle size distribution, which showed a gradual increase in clay content with depth. In field N (Fig. 6) both "useful" and "non-useful" capillary pores increased with depth. The low macroporosity observed at the surface at all the sites can be attributed to structural degradation due to cultivation. The high soil solid, sand content and macroporosity observed in all KNDRS soils makes them susceptible to drought, for they contain insufficient water-retaining capillary pores. Conversely, heavy clay soils, as in the KARI samples, often lack enough macropores and are likely to suffer as a result from poor drainage and inadequate aeration. Between these two extremes lies the ideal soil, which should have the pore space about equally divided between macro- and capillary pores.

Soil moisture content alone is of limited value, since not all the moisture present in the soil at any given moment is available to plants. That present above field capacity (pF 2.51) or below permanent wilting point (pF 4.2) is not utilized by plants. It is therefore appropriate to speak of the available water capacity of a soil. This is the amount of water between the upper and lower limits of available water expressed as per cent by



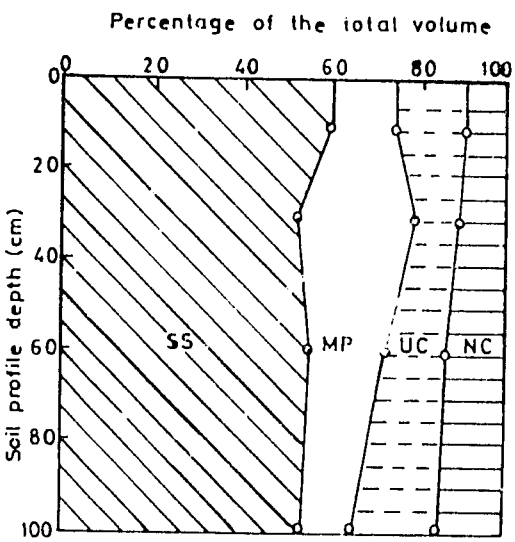
SS = soil solids
MP = macropores (aeration porosity)
UC = useful capillary pores
NC = non-useful capillary pores

Fig. 5. Variation of pore size distribution with depth for KARI farm.



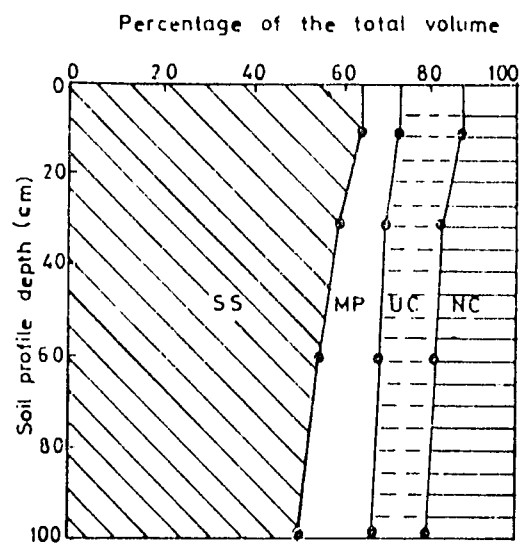
SS = soil solids
MP = macropores (aeration porosity)
UC = useful capillary pores
NC = non-useful capillary pores

Fig. 7. Variation of pore size distribution with depth for field O at KNDRS.



SS = soil solids
MP = macropores (aeration porosity)
UC = useful capillary pores
NC = non-useful capillary pores

Fig. 6. Variation of pore size distribution with depth for field N at KNDRS.



SS = soil solids
MP = macropores (aeration porosity)
UC = useful capillary pores
NC = non-useful capillary pores

Fig. 8. Variation of pore size distribution with depth for field Q at KNDRS.

volume or, more usefully, as available water content in millimetres of water for a given depth of soil. The available water capacity of a soil can therefore be regarded as an index of the ability of a soil to store water and thus allow plants to maintain normal growth during dry periods.

TABLE IV—PROFILE WATER HOLDING CAPACITY IN MM OF WATER

Location and site	Profile depth (cm)	Water holding capacity (mm)			
		At saturation	At optimum growth condition	At field capacity	At wilting point
KARI farm	10	64.2	60.3	48.7	28.0
	30	191.6	183.6	131.2	86.1
	60	375.7	362.7	260.2	180.7
	100	608.3	590.6	444.1	319.0
KNDRS field N	10	40.2	38.0	25.8	9.6
	30	126.9	115.0	68.4	31.1
	60	261.3	233.8	152.3	71.2
	100	447.5	402.3	245.3	132.4
KNDRS field O	10	36.3	34.2	28.7	14.7
	30	117.5	109.2	83.3	52.7
	60	246.8	224.9	175.1	111.4
	100	452.6	402.0	299.3	182.7
KNDRS field Q	10	36.0	32.8	26.6	13.5
	30	118.7	106.7	87.1	47.3
	60	253.6	228.4	182.3	103.4
	100	451.0	406.4	312.3	182.8

Table IV shows the running totals for the maximum profile water-storage capacity at saturation, optimum growth condition, field capacity, and permanent wilting point for KARI and KNDRS soils. When the soil samples are saturated in the laboratory the total storage space is occupied by water. However, this is not the case in the field situation, since a downward rather than upward wetting of the soil profile is liable to trap air in the form of isolated bubbles and irregular pockets, because fastest flow occurs in the large continuously connected pores (Kilewe, 1981). The trapped air has the effect of reducing the maximum possible water-storage capacity and therefore these soils are expected to store slightly less water in the actual field situation than is shown in Table IV. Water held in the large pores, which drains to lower depths, is termed detention storage. In time, some of this water may percolate to the zone of saturation and thereby recharge the groundwater. The moisture held in the capillary pores is mostly available for plant growth or for evaporation and is often referred to as retention storage. It can be seen from Table IV that the KARI soils hold nearly twice as much total water at field capacity and permanent wilting point as KNDRS soils.

Totals for the available water capacity for four layers in the 0–100 cm soil profiles for KARI and KNDRS are shown in Table V. The KARI soil profile holds up to 444.1 mm of water at field capacity and 319.0 mm at wilting point for the 100 cm profile depth. This implies that only 125.1 mm of water is available for plant use and that plants will wilt on this soil while there is still more than 319.0 mm of water in the soil profile. On the other hand, the total water-storage capacity for the 100 cm profile depth for KNDRS soils ranged from 245.3 to 312.3 mm of water at field capacity and from 132.4 to 182.8 mm at wilting point. The plant-available water capacity, therefore, ranged from 112.9 to 129.5 mm. It therefore follows that the KARI soil has a much higher water content at field capacity than KNDRS soils. Due to higher sand content and insufficient water-retaining capillary pores in KNDRS soils, as well as to the higher soil and surface temperatures prevalent in this region, much of the water held by KNDRS soils is lost to downward drainage and evaporation at a faster rate than in KARI soil. This makes the KNDRS soils more susceptible to drought than KARI soil, and they therefore need replenishing more often by regularly distributed rainfall.

TABLE V—AVAILABLE WATER STORAGE CAPACITY IN MM OF WATER

Location and site	Profile depth (cm)	Available water capacity (mm)		
		At saturation	At optimum growth condition	At field capacity
KARI farm	10	36.2	32.3	20.7
	30	105.5	97.5	45.1
	60	195.0	182.0	79.5
	100	289.3	271.6	125.1
KNDRS field N	10	30.6	28.4	16.2
	30	95.8	83.9	37.3
	60	190.1	162.6	81.1
	100	315.1	269.6	112.9
KNDRS field O	10	21.6	19.5	14.0
	30	64.8	56.5	30.6
	60	135.4	113.5	61.7
	100	269.9	219.3	116.6
KNDRS field Q	10	22.5	19.3	13.1
	30	71.4	59.4	39.8
	60	150.2	125.0	78.9
	100	268.2	223.6	129.5

Plant roots can only extract water from a soil if they can apply sufficient suction to move it out of the pore space. As the soil dries, the suction needed to extract water increases and the rate of movement of water into a given length of root decreases. If the crop is growing under conditions conducive to high rates of transpiration, as at KNDRS, the actual maximum rate it can reach decreases as the soil dries. Recently germinated crops and those that are very shallow rooted will only be able to draw moisture in the surface layers. These will therefore be more susceptible to periods of drought and have a quicker cut-off at the end of the rainy season than those crops with deeper rooting characteristics, which have a larger reserve of moisture content. From Table V, the difference in soil-moisture reserves available to crops can be appreciated. A crop rooting to a depth of 30 cm in KARI and KNDRS (fields N, O and Q) will have a reserve of 45.1, 37.3, 30.6 and 39.8 mm of available moisture respectively. However, a crop rooting to 100 cm depth will have a reserve of 125.1, 112.9 116.6 and 129.5 mm respectively. It can therefore be seen that the amount of water actually available to plants depends on the soil's available-water capacity and the plant rooting depth. A high available-water capacity will not be of much use if the soil is shallow, as at KNDRS due to the presence of petroplinthite (murram) horizons (Marimi, 1977), which restrict the rooting depth of plants. On the other hand, very deep friable soils can supply large amounts of water to deep-rooting plants, which continue to grow for a considerable time after rains have ceased.

CONCLUSION

It is becoming increasingly apparent that most of the good agricultural land in high-potential regions is already utilized. However, several crop species are now being produced which mature quickly and possess a low water requirement. These are suitable for areas that have hitherto been regarded as of low potential. In areas of erratic rainfall which often occurs in brief intense storms, the physical condition of the soil can be a major factor in deciding whether a crop is a success or failure, for it determines how much water from an intense storm is absorbed by the soil, and how much of the stored water is then available to the plants to enable them to survive until the next rainfall. In conjunction with climatic data, soil physical characteristics can provide a good indication of which drier areas may be suitable for agricultural development.

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TOPOGRAPHIC MODIFICATION OF LAND TO CONCENTRATE AND REDISTRIBUTE RUNOFF FOR CROP PRODUCTION

A. M. Kilewe[1] *and L. G. Ulsaker*[2]

INTRODUCTION

Water is the limiting natural factor in crop production in arid and semi-arid regions, and therefore improving the management and conservation of soil and water for increased crop production becomes the primary aim of agricultural research. Rainfall, the only source of moisture available in these regions, is unpredictable and may not occur when needed by the crops. When it does occur, however, it is usually of short duration and high intensity, and much is lost as runoff. Rains often stop before crops have had sufficient moisture to take them to maturity. A reserve of moisture in the soil profile at this stage is highly desirable and therefore appropriate conservation measures are necessary to concentrate and redistribute runoff. Land- and crop-management practices that have been developed to conserve rainfall and provide additional moisture for crop production include fallowing, terracing, mulching, land levelling, and contour tillage (Jones and Hauser, 1975; Musick and Dusek, 1971; Jones and Shipley, 1975; Zingg, 1940).

The total amount, the intensity, and the distribution of rainfall are of great importance in considering the effectiveness of rainfall in crop production. However, the actual proportion of rainfall available for plant growth depends on the infiltration rate of the surface soil, the moisture storage capacity of the soil profile, and the rooting characteristics of the crop. The infiltration rate depends on the soil type and the soil surface treatment. The Alfasols (USDA classification) common in the arid and semi-arid regions of Kenya have a high initial infiltration rate. However, this is often greatly reduced during the early part of the rainy season by surface sealing caused by the impact of rain drops on the bare soil. The most effective water-management systems in this region would therefore be those that retain rain where it falls so that infiltration can take place slowly and continue long after the rain has ceased. The total rainfall will then be available to wet the soil down through the profile and build up an adequate moisture reserve. The objectives of this study were therefore (i) to develop low-cost land-management systems to concentrate and redistribute runoff for crop production, and (ii) to determine their water-storage and crop-production efficiency and effectiveness in preventing runoff and controlling erosion.

MATERIALS AND METHODS

The research work was conducted at the Katumani National Dryland Research Station (KNDRS), Machakos. The soil at this research station is classified as Ferral-Chromic Luvisols (FAO/UNESCO system; Alfasols in the USDA taxonomy). These soils are shallow, well drained, dark reddish-brown, sandy clay loam, tending to sandy clay at the lower horizons (Mbuvi and Van de Weg, 1975; Barbar and Thomas, 1979; Kilewe and Ulsaker, 1983).

They tend to harden when dry but are very friable when wet. They are shallow, due to the presence of a petroplinthite (murram) horizon (Marimi, 1977). The region receives a bimodal rainfall ranging between 500 and 800 mm annually and split almost equally between the long rains (March-June) and the short rains (October-January).

Treatments were: (a) contour furrows, comprising conventional beds and furrows formed on 0.75 m centres with maize planted in each furrow, (b) wide furrows, consisting of 1 m furrows and 0.5 m beds with two rows of maize planted in each furrow, (c) a mini-bench, consisting of a narrow, level conservation bench terrace with five 0.75 m wide maize rows, and (d) flat beds (no furrows) with five 0.75 m maize rows. In all cases the beds were about 0.20 m high. All treatments were planted at a 1.05 m module using 0.75 m

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row spacing and 0.30 m crop spacing to give a population of about 44,000 plants/ha. Each treatment was replicated three times. The experimental plots were 9 × 4 m. Equal quantities of farmyard manure were used to restore soil fertility associated with areas cut during levelling. No commercial fertilizer was used throughout the study period. Soil water content was measured weekly at 30, 60, and 100 cm depths in the middle of each plot and using a neutron probe. Minimum tillage was carried out in the furrows only before planting.

RESULTS AND DISCUSSION

Some of the important soil physical properties of the experimental plots have been reported by Kilewe and Ulsaker (1983b). Tables I and II and Figs. 1 to 6 show the total water storage and available water content (in brackets) in mm for 30, 60, and 100 cm soil-profile depths for each treatment and rainfall received between measurement dates. During the short rains, Katumani Composite B maize was dry-planted on 1[illegible] October 1982, when the water content in the soil profile was at permanent wilting point. However, at the planting date in the long rains, 22 February 1983, there were 79.9, 126.2, 124.0 and 107.0 mm of available water stored in the 100 cm depth on the flat, conventional furrows, wide furrows, and mini-bench treatments respectively. The conventional furrows, wide furrows, and mini-bench treatments retained all the runoff within the furrows and allowed infiltration to continue long after the rainfall had ceased. Thus the whole rainfall was available to wet the soil down through the profile and build up adequate soil moisture reserve.

All the treatments that retained runoff resulted in significantly higher water-storage capacity than the flat treatment during both the short and long rains. There were no significant differences in water-storage capacity between the runoff-retaining treatments. However, the wide furrows consistently resulted in higher water-storage capacity, followed by the conventional furrows during both seasons. This could be attributed to the fact that the maximum potential surface-water storage capacity for the wide furrows was double that of the conventional furrows and had a better surface distribution of runoff than the mini-bench. The mini-bench, although it had a higher maximum potential surface-water storage capacity than all the other treatments, showed poor soil moisture distribution, due to high water accumulation in the lower parts.

A build-up of a reserve store of moisture in the soil profile was achieved on all the treatments that retained runoff. During the short rains of 1982 the 100 cm soil profile on the conventional furrows, wide furrows, and mini-bench was at field capacity for 24, 28, and 16% of the total growing period respectively. The moisture stored in the conventional furrows and wide furrows during the long rains of 1983 reached field capacity for 23 and 51% of the total growing period respectively. The moisture stored in the 100 cm soil profile depth on the flat treatment failed to reach field capacity throughout the short or long rains. The short rains of 1982 were well distributed and all the treatments had attained their highest moisture conservation by the middle of the season. The highest moisture conservation achieved on all the treatments during the long rains of 1983, however, occurred too early in the season, when the maize crop had a low water requirement, and too late in the season, after the maize had already suffered severe moisture stress.

If a soil is wetted only down to half a metre it may be considered sterile below that depth as far as plant growth is concerned. There may be untapped sources of plant nutrients below, but if there is no moisture they are out of reach. By utilizing the total moisture-storage capacity of the soil, a much larger volume of soil becomes available to root growth and therefore roots go deeper to tap the otherwise unavailable nutrients. Crop production in semi-arid regions is limited by inadequate moisture supply, and therefore any attempt to increase crop yields by the application of fertilizer is doomed to be only partly effective if the crop suffers from lack of water. Maximum conservation of rainfall and its most efficient use in semi-arid areas lead to direct and indirect improvement of soil fertility.

Table III shows the seasonal marketable maize yield. There were significant differences in the annual marketable yield between all the treatments. The maize yields achieved on all the treatments during the long rains were very much lower than those achieved during the short rains. This could be attributed to the dry period that occurred in the early part of the season. During this period the available water content in the surface layers approached permanent wilting point 30 days after germination. At this early stage of growth the plants did not have a well established root system and were therefore more susceptible to periods of drought than those crops with deeper rooting systems, which would have a larger moisture reserve to exploit.

TABLE I—TOTAL WATER STORAGE AND AVAILABLE WATER CAPACITY (IN BRACKETS) IN MM OF WATER FOR 30, 60, AND 100 CM SOIL PROFILE DEPTHS DURING SHORT RAINS 1982

	Flat			Conventional furrows			Wide furrows			Mini-bench		
Measurement dates	30 cm	60 cm	100 cm	30 cm	60 cm	100 cm	30 cm	60 cm	100 cm	30 cm	60 cm	100 cm
25.10.82	60.2	121.5	186.9	79.6	138.0	220.6	79.2	146.0	231.0	75.5	138.7	218.9
	(29.1)	(50.3)	(54.5)	(48.5)	(66.8)	(88.2)	(48.1)	(74.8)	(98.6)	(44.4)	(67.5)	(86.5)
5.11.82	47.8	105.6	173.6	70.8	135.9	201.3	68.0	139.2	214.9	64.2	132.1	194.2
	(16.7)	(34.4)	(41.5)	(39.7)	(64.7)	(68.9)	(36.9)	(68.0)	(82.5)	(33.1)	(60.9)	(61.8)
9.11.82	42.4	97.5	162.1	64.6	123.7	191.4	62.6	127.0	205.2	61.5	120.6	182.8
	(11.3)	(26.3)	(29.7)	(33.5)	(52.5)	(59.0)	(31.5)	(55.8)	(72.8)	(30.4)	(49.4)	(50.4)
16.11.82	65.4	130.1	193.0	81.0	156.4	235.8	80.3	157.1	242.3	76.1	149.5	222.2
	(34.3)	(58.9)	(61.4)	(49.9)	(85.2)	(103.4)	(49.2)	(85.9)	(109.9)	(45.0)	(78.3)	(89.8)
23.11.82	63.7	126.8	203.2	83.7	164.8	247.6	82.7	161.7	252.6	78.1	158.8	236.0
	(32.6)	(55.6)	(70.8)	(52.6)	(93.6)	(115.2)	(51.6)	(90.5)	(120.2)	(47.0)	(87.6)	(103.6)
2.12.82	66.1	135.5	220.2	81.7	160.7	261.9	80.1	162.2	265.1	75.2	153.3	256.6
	(35.0)	(64.3)	(87.8)	(50.6)	(89.5)	(129.5)	(49.0)	(91.0)	(132.7)	(44.1)	(82.1)	(124.2)
7.12.82	61.4	122.8	242.8	85.0	165.5	280.1	83.6	168.6	278.9	79.5	161.6	271.3
	(30.3)	(51.6)	(110.4)	(53.9)	(94.3)	(147.7)	(52.5)	(97.4)	(146.5)	(48.4)	(90.4)	(138.9)
15.12.82	50.4	112.3	213.3	75.9	155.1	261.9	78.3	159.1	263.5	68.8	90.4	138.9
	(19.3)	(41.1)	(81.4)	(44.8)	(83.9)	(129.5)	(47.2)	(87.9)	(131.1)	(37.7)	(73.7)	(114.9)
22.12.82	45.1	100.8	196.8	61.4	136.2	238.9	67.5	142.9	243.2	63.1	126.1	219.5
	(14.0)	(29.6)	(64.4)	(30.3)	(65.0)	(106.5)	(36.4)	(71.7)	(110.8)	(32.0)	(54.9)	(87.1)
11. 1.83	37.8	85.4	162.4	49.7	112.6	202.7	55.7	115.9	204.9	47.2	104.1	183.8
	(6.7)	(14.2)	(30.0)	(18.6)	(41.4)	(70.3)	(24.6)	(44.7)	(72.5)	(16.1)	(32.9)	(51.4)
8. 2.83	33.4	72.9	124.2	47.3	100.3	172.9	50.5	104.0	179.6	42.9	91.3	153.2
	(2.3)	(1.7)	(0.0)	(16.2)	(29.1)	(40.5)	(19.4)	(32.8)	(47.2)	(11.8)	(20.1)	(20.8)
Total	573.7	1,211.2	2,080.1	780.7	1,549.2	2,515.1	788.5	1,583.7	2,581.2	732.1	1,481.0	2,385.2
	(231.6)	(428.0)	(631.9)	(438.6)	(766.0)	(1,058.7)	(446.4)	(800.5)	(1,124.8)	(390.0)	(697.8)	(928.8)

TABLE II—TOTAL WATER STORAGE AND AVAILABLE WATER CAPACITY (IN BRACKETS) IN MM OF WATER FOR 30, 60 AND 100 CM SOIL PROFILE DEPTHS DURING LONG RAINS 1983

Measurement dates	Flat			Conventional furrows			Wide furrows			Mini-bench		
	30 cm	60 cm	100 cm	30 cm	60 cm	100 cm	30 cm	60 cm	100 cm	30 cm	60 cm	100 cm
22.2.83	66.5	144.2	212.3	79.6	158.9	258.6	84.3	162.6	256.4	69.7	150.0	239.4
	(35.4)	(73.0)	(79.9)	(48.5)	(87.7)	(126.2)	(53.2)	(91.4)	(124.0)	(38.6)	(78.8)	(107.0)
2.3.83	58.4	118.1	195.0	73.7	154.0	249.6	81.0	160.0	264.4	64.4	140.7	228.3
	(27.3)	(46.9)	(62.6)	(42.6)	(82.8)	(117.2)	(49.9)	(88.8)	(132.0)	(33.3)	(69.5)	(95.9)
18.3.83	38.7	104.2	180.3	59.1	130.8	222.8	65.7	146.1	252.3	52.4	117.8	204.2
	(7.6)	(33.0)	(47.9)	(28.0)	(59.6)	(90.4)	(34.6)	(74.9)	(119.9)	(21.3)	(46.6)	(71.8)
31.4.83	25.5	81.9	165.4	40.7	117.4	210.8	49.7	112.1	235.6	36.8	100.2	196.5
	(0.0)	(10.7)	(33.0)	(9.6)	(46.2)	(78.4)	(18.6)	(40.9)	(103.2)	(5.7)	(29.0)	(64.1)
12.4.83	42.8	90.9	160.8	65.7	134.7	203.2	62.4	126.1	228.7	54.4	116.1	191.1
	(11.7)	(19.7)	(28.4)	(34.6)	(63.5)	(70.8)	(31.2)	(54.9)	(96.3)	(23.3)	(44.9)	(58.7)
25.4.83	57.1	108.2	192.5	78.6	152.3	233.6	85.0	161.3	257.3	68.0	138.7	224.0
	(26.0)	(37.0)	(60.1)	(47.5)	(81.1)	(101.2)	(53.9)	(90.1)	(124.9)	(36.9)	(67.5)	(91.6)
11.5.83	50.1	116.2	197.6	75.3	159.0	265.8	83.6	154.8	271.1	66.4	140.6	240.7
	(19.0)	(45.0)	(65.2)	(44.2)	(87.8)	(133.4)	(52.5)	(83.6)	(138.7)	(35.3)	(69.4)	(108.3)
25.5.83	41.8	98.9	192.1	65.0	135.3	231.3	71.3	140.1	246.9	53.1	112.8	213.1
	(10.7)	(27.7)	(59.7)	(33.9)	(64.1)	(98.9)	(40.2)	(68.9)	(114.5)	(22.0)	(41.6)	(80.7)
7.6.83	30.1	84.5	84.5	173.1	50.4	122.7	217.4	62.0	133.3	232.5	43.1	99.8
	(0.0)	(13.3)	(40.7)	(19.3)	(51.5)	(85.0)	(30.9)	(62.1)	(100.1)	(12.0)	(28.6)	(63.3)
1.7.83	18.2	72.3	151.5	36.4	36.4	93.5	188.7	45.7	107.6	203.9	28.5	81.4
	(0.0)	(1.1)	(19.1)	(5.3)	(22.3)	(56.3)	(14.6)	(36.4)	(71.5)	(0.0)	(10.2)	(35.8)
Total	429.2	1,019.4	1,820.6	624.5	1,358.6	2,281.8	690.7	1,404.0	2,449.1	536.8	1,198.1	2,101.2
	(137.1)	(307.4)	(496.6)	(313.5)	(646.6)	(957.8)	(379.7)	(692.0)	(1,125.1)	(228.4)	(486.1)	(777.2)

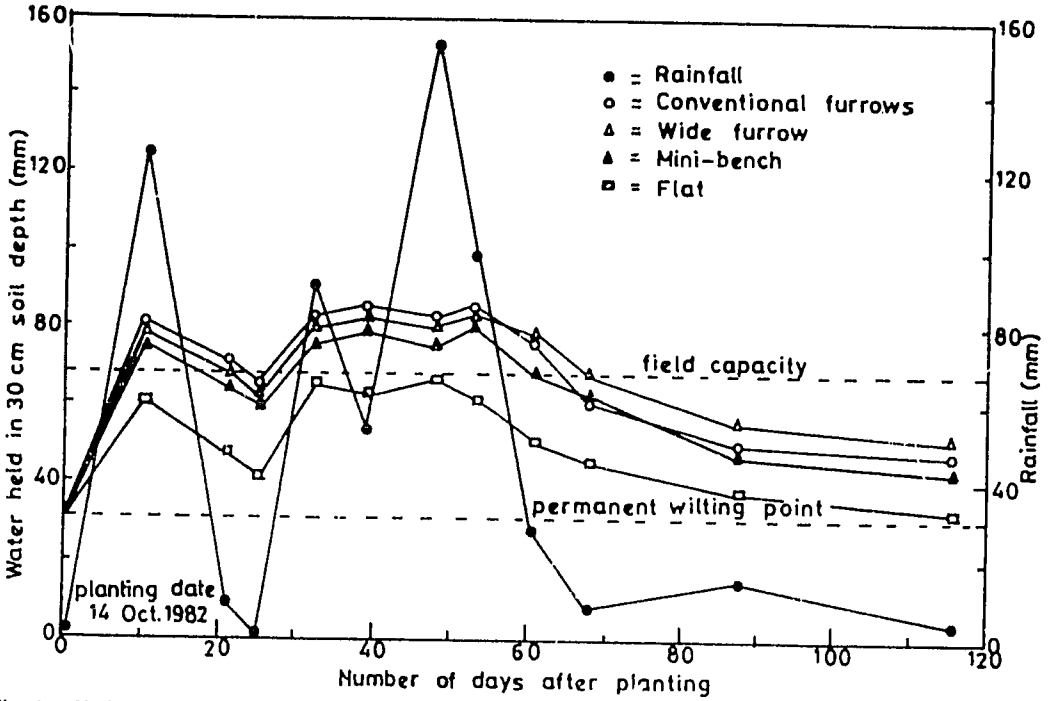

Fig. 1. Variation of water content for each treatment at 30 cm soil depth and rainfall distribution during short rains, 1982

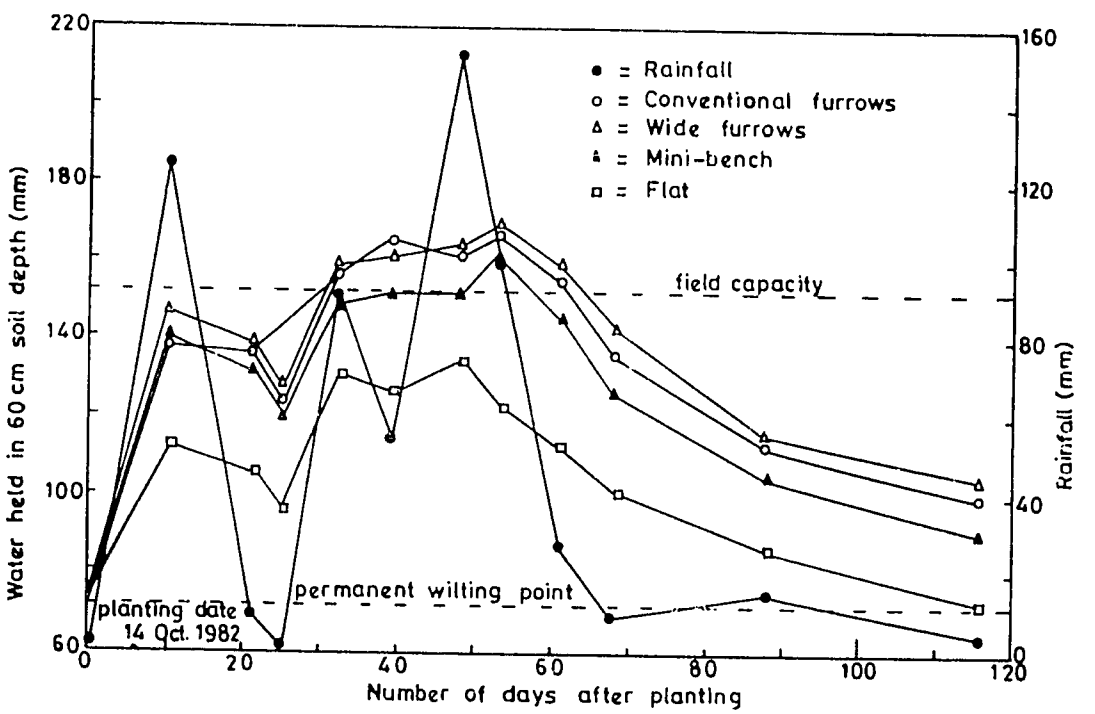

Fig. 2. Variation of water content for each treatment at 60 cm soil depth and rainfall distribution during short rains, 1982

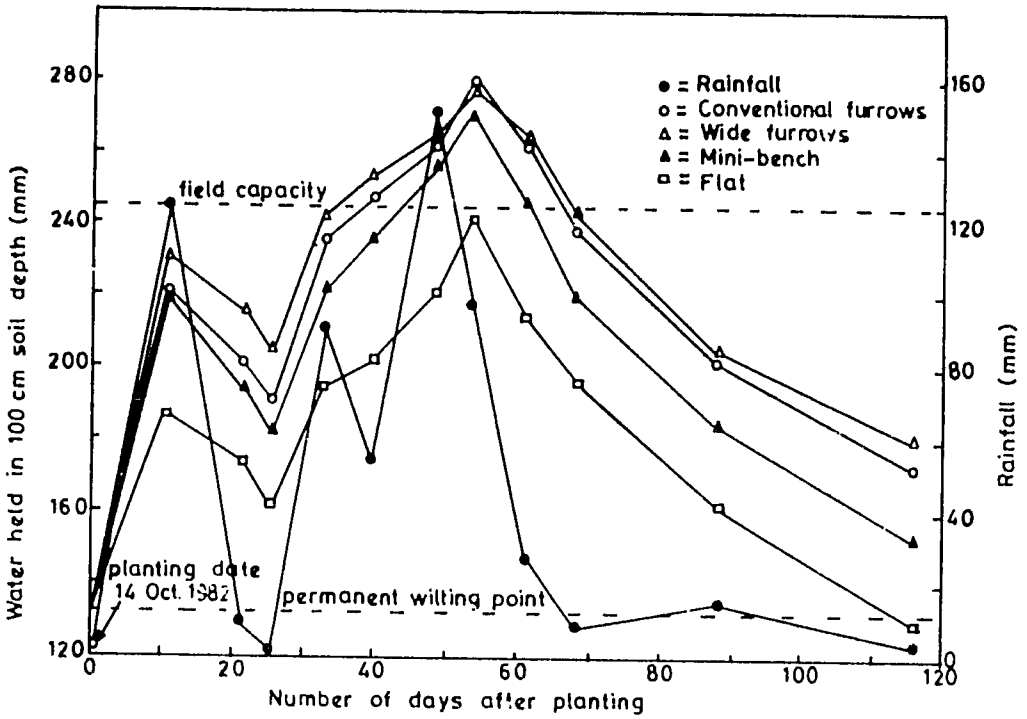

Fig. 3. Variation of water content for each treatment at 100 cm soil depth and rainfall distribution during short rains, 1982.

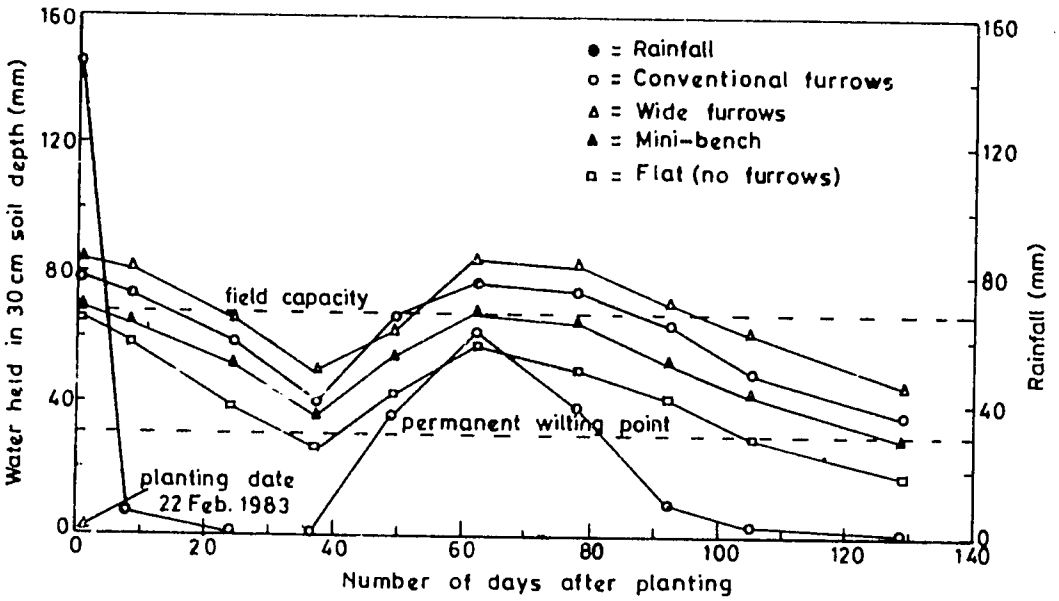

Fig. 4. Variation of water content for each treatment at 30 cm soil depth and rainfall distribution during long rains, 1983.

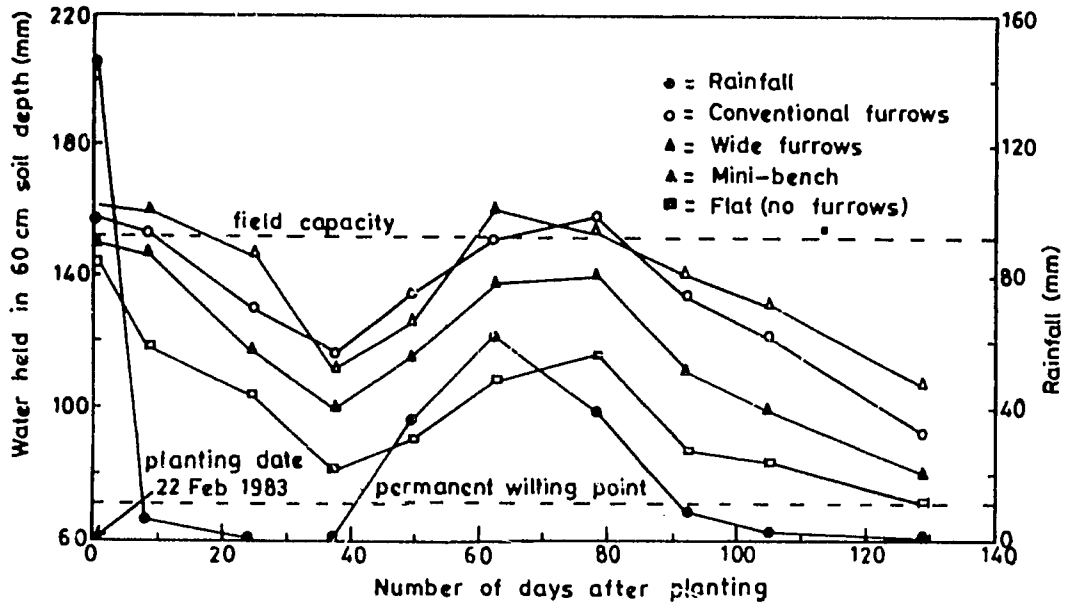

Fig. 5. Variation of water content for each treatment at 60 cm soil depth and rainfall distribution during long rains, 1983.

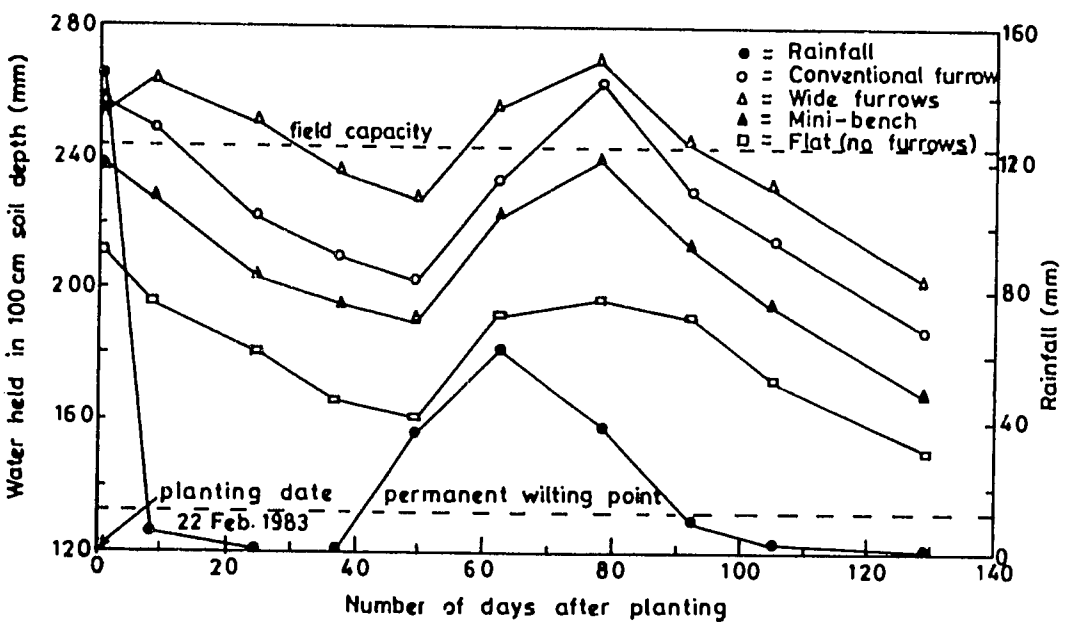

Fig. 6. Variation of water content for each treatment at 100 cm soil depth and rainfall distribution during long rains, 1983.

TABLE III—TOTAL SEASONAL WATER USE, MARKETABLE MAIZE YIELD, AND WATER-USE EFFICIENCY FOR ALL TREATMENTS

	Total water use (mm)		Maize yield (kg/ha)		WUE (kg/ha)		% Annual increase over flat treatment	
Treatments	Short rains	Long rains	Short rains	Long rains	Short rains	Long rains	Maize yield	WUE
Flat	521.2	359.3	3,722	256	7.1	0.7	0.0	0.0
Conventional furrows	506.2	368.8	5,242	725	10.4	2.0	50.0	59.0
Wide furrows	509.9	351.4	5,458	844	10.7	2.4	58.4	67.9
Mini-bench	524.2	370.1	4,680	643	8.9	1.7	33.8	35.9

The wide-furrow treatment was superior to all others, with an annual yield 335 kg/ha greater than the next-highest treatment (conventional furrows), and 2,324 kg/ha greater than the lowest treatment (flat). The percentage increase in marketable maize yield on the runoff-retaining treatments over the flat treatment ranged from 33.8% for the mini-bench treatment to 58.4% for the wide furrows. The higher yield realized on the wide-furrow treatment could be attributed to its efficient conservation and utilization of potential runoff.

Since water is the first limiting natural factor in crop production in the arid and semi-arid regions, the selection of any land-management system to conserve soil and water should depend on the efficiency with which the water content of the soil can be used for increased crop production. Seasonal water-use efficiency, defined as the marketable crop yield in kg/ha per mm of water used, for each treatment during the 1982 short rains and 1983 long rains is shown in Table III. The water-use efficiency achieved during the long rains was lower than that during the short rains for all treatments. In each season, it was lowest on the flat treatment, which lost runoff, followed by the mini-bench treatment. The wide-furrow and conventional-furrow treatments retained all the runoff and therefore achieved the highest water-use efficiency. The differences in water-use efficiency were not statistically significant at the 5% level, according to the Duncan multiple range test. Since the benefits of runoff conservation are not often realized until the subsequent season, more emphasis was placed on annual rather than seasonal water-use efficiency. The percentage increase in annual efficiencies of the treatments that retained runoff over the flat treatment ranged from 35.9% on the mini-bench to 67.9% on the wide furrows. Water-use efficiency is dependent on total yield, and therefore factors effecting the latter will affect the former.

The effectiveness of all the treatments for runoff control and erosion prevention was severely tested during a 10-year frequency storm of 102 mm of rainfall in less than 24 hours that occurred at the beginning of the 1983 long rains, at a time when the soil surface was bare. The conventional furrows had lower surface-water storage capacity than all the runoff-retaining treatments and could easily overtop during high-intensity rainstorms. The mini-bench had a much higher surface storage capacity than all the other treatments. However, it was found difficult to construct level mini-benches so as to achieve an even water distribution on the surface. If a completely level mini-bench is not attained, higher accumulation of water at the lower parts may occur and cause overtopping. The wide furrows, however, had about twice the maximum surface-water storage capacity of the conventional furrows, and therefore had less chance of overtopping. The wide furrows were also found easier to construct, for they require only minor soil movement and the problems of reduced soil fertility associated with areas cut during the levelling of mini-benches are avoided.

Since the wide-furrow system can be easily maintained as a permanent land feature, it would provide water conservation and considerable protection against soil erosion on a year-round basis, even when high-intensity rains occur after the prolonged hot and dry non-crop periods. Conventional furrows were found to have limited flexibility for accommodating the wide range of intercropping practised in the semi-arid areas. With the wide furrows, however, it is possible to plant two, three, or four rows per furrow at 0.75,

0.45, and 0.30 m row spacing respectively, as shown in Fig. 7.

SUMMARY

Low cost land management systems aimed at improving moisture entrapment and conservation while creating an environmental zone adapted to seedling germination and effective plant growth were developed. The system included conventional contour-furrow, wide-furrow, mini-bench, and flat (no furrow) treatments. The conventional contour furrows, wide furrows, and mini-bench retained all the runoff and resulted in significantly higher water-storage capacity than the flat treatment. The wide-furrow treatment produced significantly greater yields and had a higher water-use efficiency than all other treatments.

The wide-furrow system was found to be easy to maintain as a permanent land feature.

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EFFECTS OF FARMYARD MANURE AND FERTILIZERS ON MAIZE IN SEMI-ARID AREAS OF EASTERN KENYA

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INTRODUCTION

Sessional paper No. 4 of 1981 on National Food Policy in Kenya has underscored the importance of developing efficient crop-production systems for semi-arid lands. However, food production in these areas is limited by inadequate rainfall and low soil fertility. Recently, for example, analysis of soil collected by the author has revealed that most of the soils in semi-arid areas of Eastern Province are deficient in N, P, Cu, and Zn, and are also quite low in organic-matter content. Under these conditions, the maintenance and improvement of soil fertility becomes funda mental in all agronomic studies.

Several methods have been suggested for maintaining soil fertility. In parts of East Africa that experience pronounced dry seasons, it has been observed that many grasses growing under fallow explore the soil to considerable depths and it would appear that they can effect a substantial transfer of nutrients from the subsoil (Webster and Wilson, 1973). Fallowing as a system, however, has been replaced by continuous cropping, due to population pressure on the limited land resources.

Another effective method could be the use of mineral fertilizer. However, the current prices of imported mineral fertilizers are beyond the economic capability of the subsistence farmer in the semi-arid areas. Furthermore, when th yields of the crop obtained can no longer pay fc the fertilizer, the best option would then be t look for other cheaper sources of plant nutrient in the form of farmyard manure.

It is considered that in an area like easter Kenya, where the tradition of keeping livestoc still persists, the availability of farmyard manur poses little problem. Table I shows the distri bution of livestock in three districts of Easter Province.

According to Rukandema and Muhammec (1982), in Mwala Location of Machakos Distric 80% of the farmers own cattle and 68% of then use farmyard manure, while only 8% use minera fertilizers.

This paper contains the results of farmyard manure experiments carried out at the Katuman Research Station and the Kampi ya Mawe substation, both in Machakos District, and the Ithookwe substation in Kitui District between the years 1981 and 1983.

MATERIALS AND METHODS

The experimental sites and chemical characteristics of the soil are shown in Tables II and III. Katumani and Kampi ya Mawe, being in ecological zone IV, are representative of much of the

TABLE I—DISTRIBUTION OF LIVESTOCK PER FAMILY IN EASTERN PROVINCE OF KENYA (RUKANDEMA AND MUHAMMED, 1982)

	District		
	Machakos	Kitui	(Lower) Embu
Cattle/family	7	8	8
Goats/family	10	12	10
Sheep/family	3	6	5

1. National Dryland Farming Research Station, Katumani

semi-arid area of eastern Kenya. Ithookwe is in ecological zone III, and is therefore generally wetter than Katumani and Kampi ya Mawe. The expected rainfall shown is an average for 27 years at Kampi ya Mawe, 19 years for Katumani, and 7 years for Ithookwe.

TABLE II—EXPERIMENTAL SITES, ALTITUDE AND RAINFALL

		Seasonal rainfall (mm)					
		1981	1982	1983		Expected rainfall	
Site	Altitude (m)	Short rains	Long rains	Short rains	Long rains	Long rains	Short rains
Kampi ya Mawe	1,250	182	287	517	138	263	328
Ithookwe	1,233	431	275	803	116	479	515
Katumani	1,600	176	261	463	128	294	253

The long rains start in March and end in May, while the short rains start in October and end in December. Each season corresponds to one harvest.

TABLE III—SOIL CHEMICAL CHARATERISTICS OF THE EXPERIMENTAL SITES

Site	Depth (cm)	pH H_2O (1:1)	N (%)	P (ppm)	K (m.e.%)	C (%)	Mg (m.e.%)	Mn (m.e.%)	C/N ratio
Katumani	0–20	5.8	0.08	126	0.96	0.77	2.3	0.83	9.6
	21–40	5.8	—	92	0.93	—	2.8	0.74	—
Ithookwe	0–20	5.5	0.08	9	0.41	0.72	1.2	0.72	9.0
	21–40	5.5	—	7	0.38	—	1.2	0.49	—
Kampi ya Mawe	0–20	5.1	0.16	16	0.70	0.71	1.8	0.60	4.4
	21–40	5.4	—	5	0.60	—	2.0	0.39	—

Soil containing 0–16 ppm phosphorus according to the extraction methods proposed by Mehlich is rated as low, 17–37 ppm as medium, and >38 ppm as high. Soils from all the sites except Katumani are therefore deficient in P, and are also quite low in carbon and total nitrogen.

The farmyard manure was analysed before application and found to contain 1.62% nitrogen, 1.15% phosphates, 1.62% potash, 0.36% calcium (CaO); 1.49% magnesium oxide, 500 ppm manganese, 200 ppm zinc, 30 ppm copper, and 15,000 ppm iron on a dry-matter basis.

The trial started in the short rains (October) of 1981 to verify the effects of farmyard manure and fertilizers on yield of maize and the properties of the soil and also to determine whether FYM should be applied at high rates at long intervals of time or at low rates at short intervals. The manuring patterns were:

1. M0: control plot where no manure or fertilizer was applied;
2. M1: 8 tons/ha of manure applied only once in three years (first year);
3. M2: 16 tons/ha of manure applied as M1;

4. M3: 4 tons/ha of manure applied twice, in the first and third years;
5. M4: 8 tons/ha of manure applied as M3;
6. M5: 2 tons/ha of manure applied every year during the short rains;
7. M6: 4 tons/ha of manure applied as M5;
8. F: fertilizer, 40 kg/ha N + 40 kg/ha P_2O_5, applied every planting season; compound fertilizer N, P, K, 20:20:0, was used and the rate is considered to be the standard for the area.

The design was a randomized block replicated four times at each site. During the first season the fields were ploughed by tractor, but in the subsequent seasons plots were prepared by hand to avoid mixing soils from different plots.

Katumani maize (Composite B) was planted at a spacing of 90 cm between the rows and 30 cm between the plants, giving a population of 37,037 plants per hectare. The plots were 7 m long and 5.4 m wide. Two seeds were planted per hill and thinned to one plant two weeks after germination. The plots were maintained weed free and the plants dusted with DDT for control of stalk-borers. The four middle rows were harvested, leaving out one metre at each end.

The manure was applied during the short rains every year according to treatments. The manure for each plot was weighed separately, spread evenly in each plot, and then mixed with the soil. The fertilizer was banded about 6 cm from the seed to avoid injury and then covered with soil. The data were statistically analysed by established procedures.

RESULTS AND DISCUSSION

The results of the first season of the trial are given in Table IV. The grain yield of the short rains of 1981 at both sites, Ithookwe and Kampi ya Mawe, showed that the application of farmyard manure significantly (P=0.05) increased grain yield compared to the control, indicating that soil fertility was an important limiting factor. At Ithookwe, the application of 16 t/ha of farmyard manure gave the highest grain yield, 4,318 ha, outyielding the control by more than 96%, while the application of fertilizer gave 80% higher yield than the control.

At Kampi ya Mawe the yields were generally low, with an overall mean of 520 kg/ha. The highest grain yields, 677 kg/ha, came from the plots receiving 16 t/ha FYM. Nearly all the plots where FYM was applied showed increased grain yield, but, on the other hand, application of

TABLE IV—YIELD OF MAIZE, SHORT RAINS 1981

	Sites			
	Kampi ya Mawe		Ithookwe	
Treatments	Grain (kg/ha)	Grain/cob (g)	Grain (kg/ha)	Grain/cob (g)
M0	438	24.8	2,201	40.0
M1	568	37.3	3,060	48.0
M2	677	36.7	4,318	62.8
M3	567	30.1	2,867	49.8
M4	611	33.8	3,711	50.4
M5	624	39.9	2,361	44.0
M6	428	26.7	2,239	45.8
F	243	20.6	3,982	69.1
Overall means	520	31.3	3,092	51.2
F-Test	*	NS	*	NS

Note: The trial at Katumani during the short rains of 1981 was destroyed by wild animals and therefore no yields were obtained.
* = Significant at P = 0.05
NS = Non-significant

fertilizer significantly decreased the yield, by 44%. The observation confirms the findings of Holliday *et al.* (1965) that there are occasions when the manure appears to give a yield response over and above that given by fertilizer, as for example in dry and hot summers. Stewart (1980) has also cautioned on the use of nitrogen fertilizer in what appears to be a dry season, and suggested that if the risk of crop failure is fairly high it would be most economic to forgo nitrogen application at planting time and wait for the rainfall pattern to clarify itself.

It was noticed in the course of field observation that maize plants in the plots that received mineral fertilizer were taller and healthier during the early stages of growth; however, during their reproductive stage, when moisture became limited, they appeared to wilt and suffer more than those that were unfertilized or received farmyard manure.

The reduction of maize yields by mineral fertilization may therefore be associated with moisture availability during the vegetative period. Since only 182 mm of rain was received at Kampi ya Mawe during the season, the readily soluble fertilizers may have created a region of high osmotic pressure, the consequent withdrawal of water from the rooting zone creating moisture stress. Alternatively, the more readily available nutrients from the fertilizers could have encouraged an early vegetative growth to the detriment of reproductive growth, which occurred mainly under conditions of limited moisture supply.

There were no significant differences between grain weight per cob at Kitui and Kampi ya Mawe, indicating that the increased grain yield in different treatments could not be attributed to this parameter.

Tables V and VI show the yield obtained in the two seasons. During the long rains (March-May) of 1982, the highest yield, of 6,558 kg/ha, was recorded at Katumani under the M5 treatment, and the lowest, of 860 kg/ha, at Ithookwe in

TABLE V—YIELD OF MAIZE, LONG RAINS 1982

	Sites					
	Kampi ya Mawe		Ithookwe		Katumani	
Treatments	Grain (kg/ha)	Grain/cob (g)	Grain (kg/ha)	Grain/cob (g)	Grain (kg/ha)	Grain/cob (g)
M0	1,167	55.0	860	37.1	4,705	111.3
M1	2,083	91.6	1,289	40.0	4,705	112.9
M2	2,763	109.2	1,220	57.1	4,777	117.5
M3	1,885	81.8	1,136	48.9	4,702	110.5
M4	2,333	91.7	1,313	53.3	4,576	119.1
M5	2,013	81.5	1,053	36.8	6,558	111.8
M6	1,680	89.5	893	33.2	4,569	112.9
F	2,056	89.2	1,308	54.1	4,699	101.8
Overall means	1,998	86.2	1,134	45.1	4,876	
F-Test	NS	*	NS	NS	NS	NS

* = Significant at P = 0.05
NS = Non-significant

M0 plots. However, these differences were not statistically significant at all the sites. In the 1982 short rains, significant grain-yield increases were obtained at both Kampi ya Mawe and Ithookwe (P=0.05), with 16 t/ha FYM giving the highest yield, of 4,605 kg/ha at the former station and fertilizer giving the highest yield, of 3,322 kg/ha, at Ithookwe (Table VI). The highest yields for the two consecutive seasons, 4,876 kg/ha for the long rains and 4,129 kg/ha for the short rains of 1982, were recorded at Katumani. This can hardly be attributed to the effect of rainfall, as Katumani

TABLE VI—YIELD OF MAIZE, SHORT RAINS 1982

	Sites					
	Kampi ya Mawe		Ithookwe		Katumani	
Treatments	Grain (kg/ha)	Grain/cob (g)	Grain (kg/ha)	Grain/cob (g)	Grain (kg/ha)	Grain/cob (g)
M0	1,819	27.0	762	24.2	3,351	33.8
M1	3,186	29.3	1,034	24.7	4,115	33.4
M2	4,606	27.3	2,576	27.9	4,403	34.7
M3	3,315	27.5	910	24.4	4,101	36.3
M4	2,961	28.0	1,198	25.8	4,337	35.7
M5	2,105	29.3	746	24.3	3,864	34.2
M6	2,991	26.8	1,140	24.7	4,271	36.3
F	3,418	30.0	3,322	29.0	4,589	36.2
Overall means	3,050	28.2	1,349	25.6	4,129	35.1
F-Test	*	NS	*	NS	NS	NS

* = Significant at P = 0.05
NS = Not significant

had the least rain during the study period of the three sites (Table II). The increased yields may probably be associated with the initial relatively higher soil fertility, especially available P (Table III), and the relatively higher altitude with cooler temperature.

Figs. 1, 2, and 3 show the yields of treatments M0, M1, M2, M5, and F, giving a clear indication of the general yield trends. The locational performance over different seasons indicates that there was a reasonable response to FYM through the ranges zero to 16 t/ha, except at Katumani, where the fertilizer performed marginally better than the farmyard manure. The application of 16 t/ha FYM gave the highest yield when the rainfall was high; however, it would appear that in the event of limited rainfall, as at Ithookwe in the long rains of 1982 (Fig. 2), the decrease in yield might be more than that of lower rates of FYM. Wigg *et al.* (1972), working in Tanzania, also obtained similar results. They found that the response of the sown pasture to the heaviest rates of farmyard manure was very good in years of high rainfall, when the yields were more than doubled, but became much less in dry years. The application of FYM at the rate of 8 t/ha appeared to give high and consistent yields, close to that obtained by applying the standard rate of mineral fertilizers, indicating that this could supply maize plants with enough nutrients.

From these results it would appear that the use of farmyard manure by subsistence farmers in semi-arid areas should be encouraged, since it can maintain soil fertility and provide a cheap source of plant nutrients. However, since these results are from only a few seasons and the trials are still in progress, no final conclusions have been drawn.

SUMMARY

A long-term manurial experiment was initiated in the short rains of 1981 at three sites, two in Machakos and one in Kitui, to study the effects of farmyard manure and fertilizers on maize grain yields. The responses to both farmyard manure and fertilizers were very large in years of high rainfall. Compared with the control, the residual effect of the FYM was still apparent in the third season after application. Manurial and fertilizer responses varied with the season and locality, but the trends on the average were fairly constant over the three seasons. Application of 16 t/ha farmyard manure gave the highest yield in years of high rainfall, but decline in yields was highest in this treatment during the dry seasons. A rate of 8 t/ha farmyard manure gave relatively high and consistent yields in all the seasons, while the application of fertilizers lowered grain yield in very dry seasons.

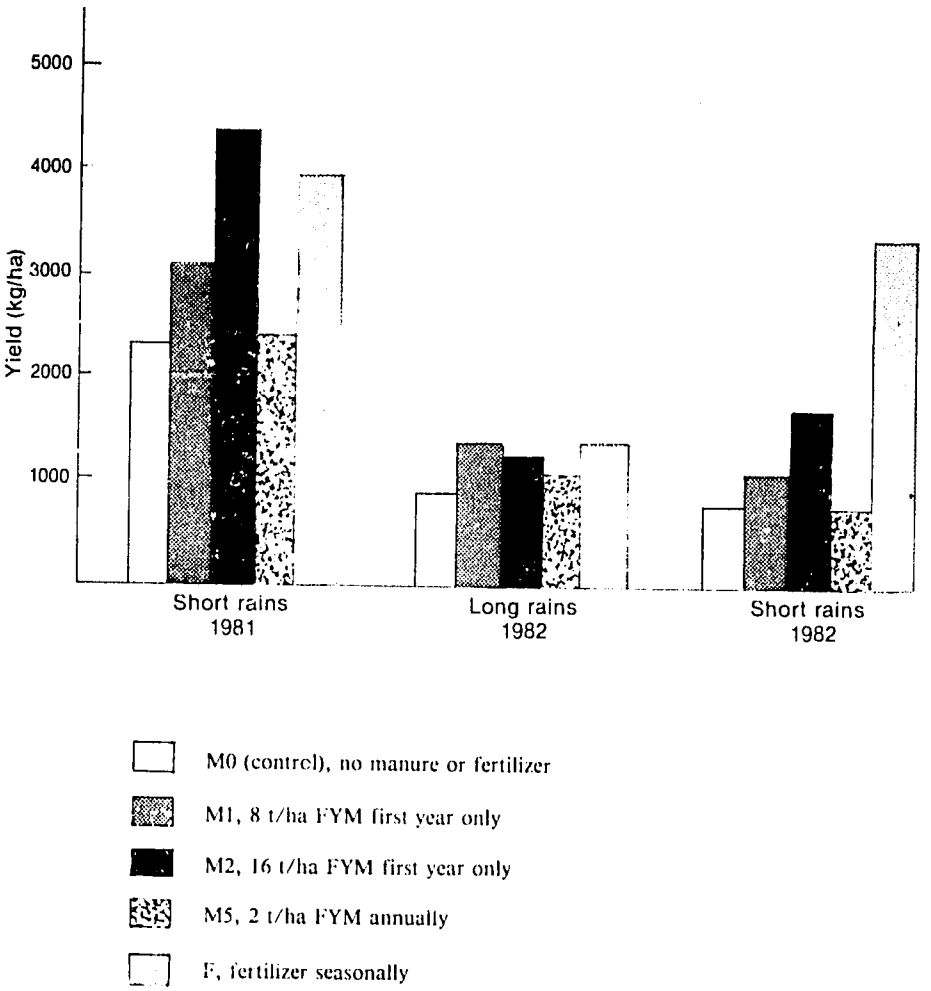

Fig. 1. Effects of farmyard manure and fertilizer on grain yield of maize at Ithookwe (Kitui)

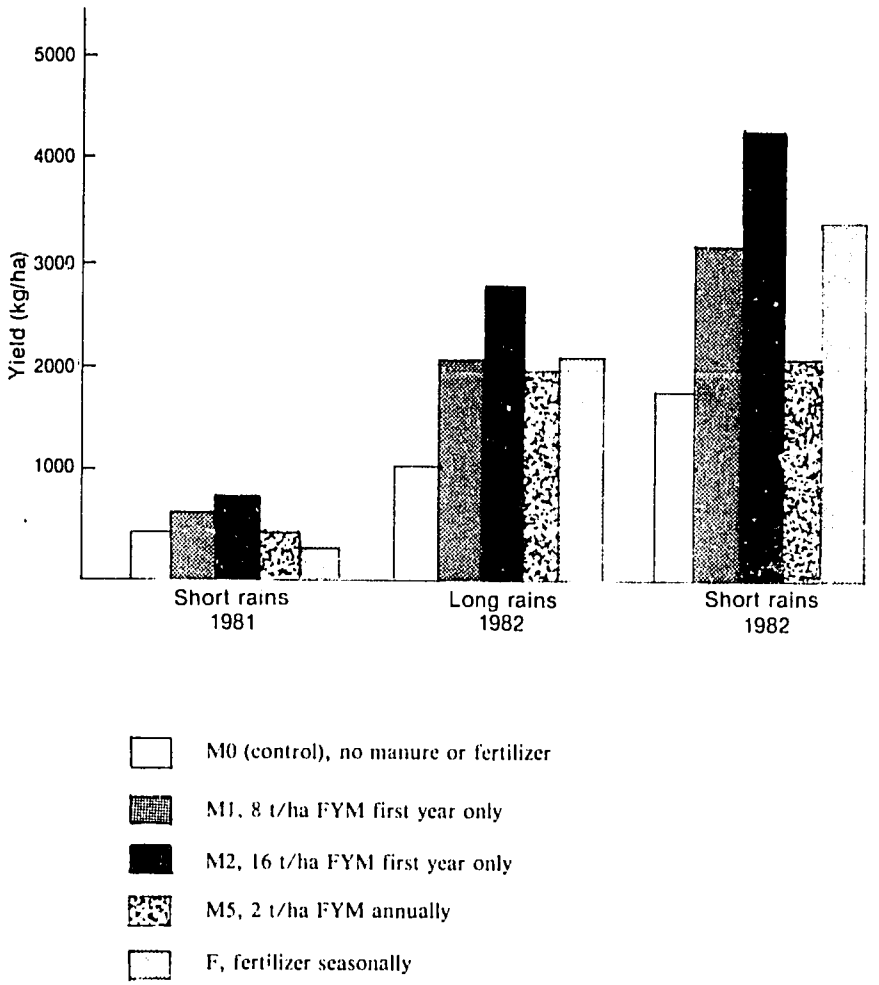

Fig. 2. Effects of farmyard manure and fertilizer on grain yield of maize at Kampi ya Mawe (Machakos)

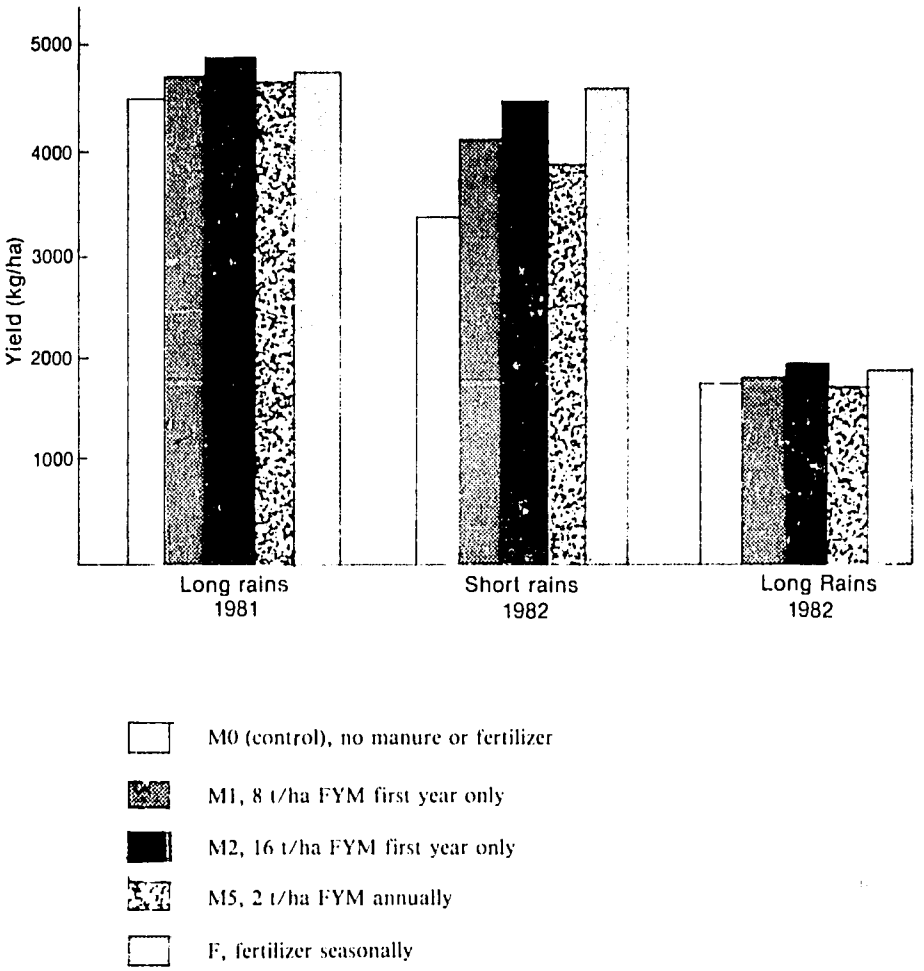

Fig. 3. Effects of farmyard manure and fertilizer on grain yield of maize at Katumani (Machakos)

ACKNOWLEDEMENTS

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DEVELOPMENT OF THE BUKURA MARK II PLOUGH: A MULTIPURPOSE OX-DRAWN TOOLFRAME FOR SMALL FARMERS

R. E. Figueroa[1] *and J. K. Mburu*[2]

INTRODUCTION

Kenya is basically an agricultural country and her economy depends on agricultural production. But only about 15% of Kenya's land has enough rainfall to allow arable cropping; the rest of the country consists of arid and semi-arid regions with low agricultural potential. Ninety per cent of its people live in rural areas and derive their livelihood from smallholdings. The average holding for high-potential areas is 3.5 ha and about 7.5 ha for low-potential regions. The population growth rate in the country is high and is contributing substantially to the fragmentation and subdivision of arable land.

More and more people are moving to marginal areas, whose potential has not been fully realized, due to limitations of energy supply. The contribution of the smallholder agriculturalist to the country's economy being quite significant, the Government's policy is to encourage and promote the mechanization of small farms. There has been a growing awareness that tractors and tractor-drawn equipment can meet the needs of only a small fraction of the rural population because of the limited cash income of the average farm household. Moreover, the enormous increases in the price of petrol and a substantial rise in the import cost of tractors and spares have accentuated the difficulty of such heavy investment for the small farmer. This situation has underscored the need to give serious attention to farm equipment innovations which are less capital-intensive and which will also entail smaller demands on the limited cash resources of small farmers.

The Government has in the past made considerable research efforts to find equipment and implements better suited to these farming conditions, and is still doing so. Hand in hand with the Government and FAO, this task is being carried out by the GK/FAO/UNDP Agricultural Equipment Improvement Project launched some 5 years ago.

This paper deals with one of the by-products of the project.

PRINCIPLES OF DESIGN AND DEVELOPMENT FOR ANIMAL-TRACTION EQUIPMENT

The design and development of animal-traction equipment involves three important and closely interrelated factors. They are draught animals, local field conditions, and construction materials. When these factors are taken properly into account, the risk of failure through inappropriate design can be reduced to a minimum.

Draught Animals

The tractive power available from draught animals is one of the deciding factors in determing the weight, size, and complexity of design of animal-traction equipment. The limits on the power that an animal can produce impose limits on the whole design. The tractive effort obtainable from a draught animal depends on its breed, sex, age, weight, and size, the quality of its feed, its training for work, its health, and other factors. The variability of these factors makes it difficult to give a precise figure that will be applicable everywhere. A report by Goe and McDowell (1980) stated that a well-trained, healthy, mature animal can usually exert a force equivalent to 10–14% of its body weight while travelling at a speed of 2.4 to 4 km/hr. According to the FAO Manual (FAO, 1972), a pair of animals can develop a maximum instantaneous effort from 215 to 1,000 kg, depending on their body weight. This instantaneous force plays a very important role in the design of an implement, and the safety factor can be based upon it.

What spoils an implement is not so much

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constant normal use as the accidents that can happen during field operation, especially in breaking new ground. The sudden impact of hidden obstructions such as tree stumps or stones can easily bend, twist, or cut an implement if account is not taken of such sudden stresses during the design of the equipment.

The use of several animals together, even if they are well driven, results in loss of tractive effort. The relationship between the number of animals used together and the resulting loss of efficiency, as reported in the FAO Manual (1972), compared to the tractive effort of a single animal, is 7.5% for two animals, 15% for three, 22% for four, 30% for five, and 37% for six. Thus it is clearly not practical to keep and use more than one good pair of draught animals.

Local Field Conditions

Much of the criticism of unsuitable animal-traction equipment in developing countries arises from improper selection and poor adaptation to local field conditions. Soil and climate are crucial factors, since they determine the relative importance of different cropping operations, which in turn affects the type of equipment applicable.

In areas of low rainfall, where a growing season is short, timely planting is crucial, as late planting may cause a large reduction in yield or even crop failure. This means that land preparation has often to be carried out before the onset of rain, when the soil is still dry and hard. Mouldboard ploughs, for example, were designed for moist soil, and they are unsuitable and ineffective for use before the rain. Where the growing season is prolonged by higher rainfall and early sowing is less urgent, its employment is possible and advantageous, especially on flat land.

When there are great differences of ecological conditions within a country, it is most important that the development of equipment should be based on the local condition.

Construction Materials

This factor is crucial when the equipment is to be produced with locally available materials. More often than not, suitable materials are not locally available, and even if they are the chances are that they will be of substandard quality.

During the first phase of the project, when attention was concentrated on the testing and evaluating of equipment, some imported implements were found to work well and to be technically suitable, but when the manufacturing aspect was considered, there were constraints due to the non-availability of suitable materials in the local market. A case in point that resulted in some frustration was the attempt to use the design of a multipurpose plough made in France. The prototype toolframe, a T-shape chassis that accepts various implements for cultivation, was ideal for multipurpose operations. It was light, weighing only 16 kg. The prototype was copied and duplicated using the same specification and local steel, but the locally manufactured version was weak, due to the poor quality of the local steel. To overcome this, the cross-sectional size of the beam was increased, which resulted in an implement double the weight of the original plough. The decision was nevertheless made to manufacture them in large numbers, and the ploughs were made available to farmers. The increase in weight tremendously increased the draught requirement for pulling the equipment. With only the same animal power available, working the implement in the field became difficult for both operator and animals. Farmers refused to buy, even at the very low subsidized price of KSh. 350/= for a complete set of plough and cultivator. This hasty decision not only caused a loss of confidence among farmers but also huge financial losses. This project has encountered several cases where imported implements performed satisfactorily under local conditions, but had to be abandoned because they could not be manufactured using local material without prejudicing quality.

TESTING PROCEDURES

International testing standards and procedures exist only for tractors, and these are oriented towards providing the manufacturers with data. With animal-traction equipment, there has been little effort to standardize data collections. Many testing stations have developed their own systems, and the interchangeability of results is thus limited.

Testing equipment can involve many variables. There is little point in spending time collecting data that will not contribute to the final decision. In Kenya, the FAO Agricultural Equipment Improvement Project decided to include only the minimum details of technical specification, and instead to concentrate on performance and suitability data that can be more readily understood by the layman. A typical Test Report is

attached as Appendix I. It is essential, however, that all the factors considered should be expressed as far as possible in a quantitative manner. The factors will vary according to the type of equipment, but some of the commonest, taking the plough as an example, are draught requirement, handling characteristics, labour requirement, quality of work, rate of work, and construction quality.

Draught Requirement

Draught requirement is one of the most critical factors in animal-traction equipment. One easy way of measuring this is to use a spring-type dynamometer placed between the implement and the animal. Several readings are taken at various speeds, depths, and widths of ploughing, taking note of the prevailing soil conditions, classified as wet, moist, or dry, light for volcanic soils, medium for loam, and heavy for clay.

Handling Characteristics

The point to assess here is the drudgery involved during the field operation. The operator's opinion is noted regarding the steerability of the implement, whether it is heavy or light, or difficult or easy to operate. If it is an adjustable implement, the period it takes before an operator can get used to operating it is noted.

Labour Requirement

This is given in number of operators required to operate the implement effectively.

Quality of Work

This is measured as poor, good, or excellent, based on the particular field operation an implement is being tested for under typical conditions. As for a ploughing test of a mouldboard plough, assessment is linked to penetration, inversion and scouring of soil, and also to maintenance of furrow depth.

Rate of Work

This is reported in hours/hectare and measured in relation to the draught requirement and the time spent working on a certain unit area during the test, including a short operational break. The type of animal used and its weight is noted.

Construction Quality

This aspect is assessed on the quality of materials used, any manufacturing defects, durability and rigidity of the implement, and whether it can withstand difficult conditions and accidental abuse. One simple test for this is to sink a heavy post in the field and drive the implement over it. This tests the resistance of the beam to shock and reveals any weakness in construction and material.

EVALUATION OF EQUIPMENT

The test results can generally indicate which implements are technically unsuitable. But for those found suitable, it may be difficult to quantify their degree of suitability without making an overall evaluation, which should consider, along with the technical aspect, relevant economic and sociological factors. The wide variability of bioclimatic, economic, and social conditions in Kenya makes these factors a matter of serious concern, especially when a new piece of equipment is under consideration.

Technical Suitability

Good technical performance can increase and hasten the farmers' acceptance of an implement. Indeed, the main value of testing an implement is to obtain enough data to permit a reasonably accurate final evaluation of the implement on the basis of the factors quantified under the testing procedure. Most of these values pertain to the animals being used at the time of testing. Bearing in mind that an animal normally produces 10–14% of its body mass as sustained draught force, this limit must be observed strictly in the performance evaluation to ensure that the implement does not require more draught force than what is available in terms of the mass of the common draught animals in the locality.

ECONOMIC CRITERIA

Financial constraints are the main reason why so few small farmers invest in farm equipment. As reported in the Nzaui/Machakos Farming System Study (Ministry of Agriculture, 1981), the average total household cash income and household cash expenditure of a Nzaui farmer for 1980 were KSh. 4,845 and KSh. 4,062 respectively. The greater part of the income was derived from regular off-farm employment. Virtually all the income is committed, first to food and non-farm expenditures like school expenses for children, clothing, etc., and there is little left over for farm investment, of which equipment is only one of many possible items. Most farmers have priorities they consider much more important than just owning a piece of farm equipment,

but such an outlook can be changed if we look at and study their way of life.

One must consider all the factors that may influence a farmer's demand for mechanization and place this demand in perspective; this is the only way one can evaluate his likely demand for farm equipment. One such important factor is the existing farm power bottlenecks and the extent to which these constrain the farmer's objectives. Nzaui farmers are very much concerned with risk avoidance, and obtaining an assured, adequate yield is the cropping goal. The probability of a poor yield or even a crop failure is a constant worry. The farmer, then, seeks more guarantee for his crop yield, and in this area improved equipment can play a vital role, mostly in promoting the timeliness that is so important in semi-arid areas. The Nzaui farmer is likely to pursue mechanization first and foremost to ensure timely planting and then to ensure that all other practices can be properly carried out.

With extremely limited cash in hand, the cost of an implement will greatly influence the farmer's decision to invest in it. An essential question when evaluating the economics of implements is whether the implement is within the financial means of the individual farmer who is to purchase it. Also whether it will increase the timeliness of operations that affect crop yield, reduce manual drudgery, and give other benefits.

Sociological Aspects

The introduction of new equipment often meets serious difficulties because its equipment does not fit the social life and farming system in the locality and would involve changes in the traditional ways of doing things. Most farmers accept less efficient equipment more easily than more efficient implements, simply because it can be better assimilated into their traditions with only minor changes in the basic values held by the people. A typical example of this is reported in the same Farming System Survey at Nzaui/Machakos. Mixed cropping is a traditional practice at Nzaui. The reasons offered for the practice are varied. The new ox-cultivation tools being introduced by M.I.D.P. have been mainly developed for the cultivation of a pure-crop stand. The Nzaui farmer may make minor changes in his mixed cropping practices, such as row planting or regular intercropping, but he is unlikely to change to pure cropping without proof of striking advantages related to his objectives. The question must then be asked: Should we go on trying to change the traditional Nzaui system of cropping to match the new ox-tool, or should the ox-tool be developed to match the system of mixed cropping?

In the final evaluation of equipment, factors that may appear less influencial can form major constraints during the test marketing exercise. This risk can be minimized by comprehensive evaluation of all factors that could affect the farmers' acceptance of new equipment and innovations.

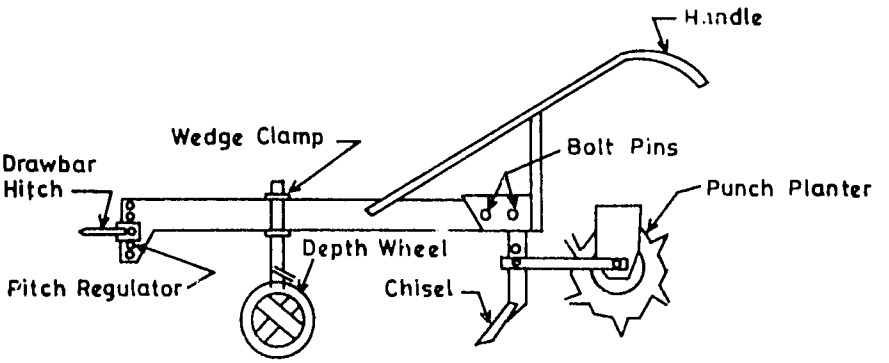
DESIGN FEATURES OF THE BUKURA MARK II PLOUGH

The development of the Bukura Mark II Plough, a multipurpose ox-drawn toolframe, was started in western Kenya at Bukura, where one of the substations of the FAO Agricultural Equipment Improvement Project is sited. During the early stage of the project, it has made an intensive effort to develop farm equipment which is less capital-intensive and will entail smaller demands on the limited cash resources of the small farmers. Local equipment available was identified and tested and evaluations made. The project also imported a wide range of small farm equipment and implements that are used in other countries with similar ecological conditions to that of Kenya. All these have been subjected to a course of testing, modification, and evaluation.

Almost all the single-purpose animal-traction implements that were tested have impediments, either technical or economic. Those found technically suitable cost too much to make them acceptable equipment for a single job. Nevertheless, a study of the relative merits of all the systems tested resulted in the development of a prototype technically suited for multipurpose operations.

Technical Features

The Bukura Mark II Plough uses the same working principle as any ordinary plough. It is hitched to the draught animal by a trek chain and operated by one or two operators. The major development breakthrough was its lightness, durability, simplicity, versatility, and suitability for local manufacture. It can work with minimum adjustment, and such adjustment as is required can be made without the need for special tools. The demanding work of hitching on or disengaging different attachments has been totally eliminated by devising a hole and simple pin-clip system.



RANGE OF ATTACHMENTS:

Mouldboard plough
Cultivator frame
Desi plough
Coil stirrer
Chisel plough
Rolling punch planter
Furrow opener-cum-ridger
Lifters for groundnut and potato

Fig. 1. Bukura mark II plough

Main Toolframe

The basic toolframe chassis has a straight rectangular hollow beam, 60 × 40 × 3.5 mm in cross section. It has two handles, welded almost at the middle section of the beam at a 45-degree angle, with a vertical support that serves to reinforce the beam. The rear end of the beam has a hole, also reinforced, to which various implements may be attached and secured by two 14 mm diameter pins. The hake is welded at the front end with a series of vertical holes. These accept the drawbar hitch, secured to the hake by a 14 mm diameter pin. Adjustment of the drawbar hitch can be made in five positions for vertical setting of the plough. The toolframe weighs only 14 kg, which accounts for the reduction in the draught required to pull the implement. The drawbar hitch has three positions for lateral plough adjustment to reduce or increase ploughing width.

Plough Body

The assembly consists of mouldboard, share, frog, landside, and heel, all attached to a plough leg with a right-angled headstock for fitting to the toolframe. All parts are standard, except for the share, which was provided with a bar point made out of spring steel. This bar point has strengthened the plough share and increased soil penetration.

Cultivator Frame

Made of hollow section bar of the same cross-sectional size with that of the toolframe beam. A right-angled headstock similar to that of the plough leg is welded at the middle for fitting to the toolframe. The length of the cultivator frame is 600 mm. Cultivator components can be attached to the frame at desired spacings by a special wedge-type clamp. This wedge clamp can be loosened or tightened using a stone.

Depth Wheel

The depth wheel is fixed to a single leg with a scraper, an innovation that minimizes the accumulation of soil in a muddy field and the collection of trash in a dry and weedy field. The depth wheel is attached to the beam of the tool-

frame using a wedge clamp to facilitate the making of adjustments.

ADAPTATION FOR DRYLAND FARMING

The Bukura Mark II Plough, with an improved mouldboard, was originally developed for the wet areas of Western Province, but provision was made for the toolframe chassis, which was the major innovation in the system, to be used in semi-arid areas by developing appropriate tillage components as attachments. When a substation of the project was established at the Katumani Dryland Farming Research Station, Machakos, the development effort was aimed towards the employment of the toolframe for dryland farming cultivation.

The objectives of tillage in semi-arid areas are to improve soil structure, reduce bulk density, control weeds, reduce runoff, increase infiltration and reduce moisture loss by evaporation (Johnston and Muchiri, 1975). The mouldboard was found ill-adapted for most of these objectives. The problems created by low and unreliable rainfall, plus the obvious lack of farm-power available to small farmers, have imposed a major constraint in achieving appropriate tillage practices for dryland farming. Low rainfall and erratic distribution dictate the necessity of planting early to get the maximum available moisture. A study by Stewart (1982) shows that not only has timeliness of planting a major effect on crop yield but that the probability of crop failure is increased by late planting. During dry periods and before the onset of the rains, soil conditions make early land preparation difficult. Ironically, the draught animals are also in their poorest physical condition for heavy work at this time, due to poor grazing at the end of the drought.

Before the coming of the FAO Agricultural Equipment Improvement Project to Katumani, the University of Nairobi had developed a tillage system at Katumani Station using a combination of the Sine Hoe (T-shape toolframe) and the Desi plough. The Desi plough is an improved version of an Indian Desi, and was also developed by the University of Nairobi. This attachment was intended to replace the mouldboard plough. With its extended wings, the Desi when used as a plough is working like a furrow opener. A report on the field trials conducted at Katumani by Muchiri (1981), on comparative tillage equipment using the Sine Hoe system, gives the following performance under dry soil conditions:

	Desi	Chisel
Average draught (kg)	183.0	98.0
Depth of cultivation (cm)	9.3	7.1
Rate of work (hr/ha)	8.1	8.3

The same tillage components were adapted to the Bukura Mark II toolframe. The field test obtained a much lower draught. For the Desi plough, an average draught force of 95 kg at a working depth of 11 cm was taken. Chiselling has taken 100 kg at a working depth of 15 cm. The difference in draught requirement between Sine Hoe and Bukura Mark II, using the same tillage component, must be attributed to their difference in weight. The Sine Hoe T-toolframe weighs 27 kg, while the Bukura Mark II toolframe is only 14 kg.

The use of the Desi for dryland farming has shown some success in achieving the majority of the objectives of tillage for semi-arid areas. Cost-wise, however, its acceptance by small farmers may be doubtful. The present price quoted by Kenya Industrial Estates at Machakos for one Desi attachment is KSh. 500, much higher than other attachments that can do a similar job.

Tillage Accessories for Dryland Cultivation

Apart from the Desi plough, several other attachments were developed by the project for possible employment in dryland farming cultivation. These are currently under comparative field trial to establish an attachment package that can eventually be recommended to small farmers in the semi-arid regions of Kenya.

Mouldboard Plough (with only an improved share)

The mouldboard of the plough bottom was removed, using only the plough share with a bar point made from leaf spring. Without the mouldboard, the share breaks the soil without inverting. This leaves the trash on the surface, which can help reduce surface runoff and moisture evaporation. The landside of the plough bottom helps to stabilize the implement during operation, thus making it easy to maintain a straight furrow. The absence of the mouldboard also reduces soil resistance, giving a significant reduction in the draught requirement of the implement.

Soil Stirrer

This is an improvement on the Ards generally used in Libya and Egypt. The working parts are

essentially a share and rudimentary mouldboard symmetrically in the vertical plane through the draught axis. It does not have lateral forces, which makes control simpler. During field operations, the soil is not turned over, resulting in furrows with slightly raised edges.

Chisel Plough

The chisel point is a triangular share. The working width is 8.5 cm. It breaks the soil but causes no inversion. The ground is penetrated at a 60-degree entry angle. Deep soil penetration is easily achieved, but implement stability is difficult to attain where ground surface varies in hardness. The chisel tends to deviate to either side whenever it hits some obstruction or difficult soil condition, and thus maintaining a straight furrow often becomes difficult.

Chisel/Rolling Punch Planter

The rolling punch planter developed by the Project was adapted to work behind the chisel. The idea was to chisel and plant in one operation. The fingered rolling punch planter was designed to plant directly in moderately loose soil, but with compacted and dry soil the fingers of the planter failed to penetrate. The chisel point serves to loosen the soil and facilitate drilling. With the punch planter attached to the chisel leg, the implement is stabilized for lateral movement during chiselling-planting operation.

Furrow Opener-cum-Ridger

A simple furrow opener, convertible into a ridger, was also developed for the toolframe. The share point made from leaf spring, the furrow opener wing, and the ridger wing are easily detachable and secured to the main body by bolt pins. It has a landside which provides stability for the implement during field operation. Making straight furrow and ridge can easily be achieved.

Weeders

Various weeding blades and soil-contacting parts that could be attached to the cultivator frame have been developed for the Bukura Mark II toolframe. They are currently under field trial at Katumani to compare and assess their effectiveness in eradicating weeds. Those under consideration are A-blades of various sizes, duckfoots, sweeps, and reversible cultivator shares.

The Farming System Specialist of the FAO Dryland Farming Research Project, with the collaboration of the AEIP/FAO Project, established a field trial at Katoloni Farm for Maize, employing direct tillage-planting for dryland conditions. Before the onset of rain, the field was chiselled and simultaneously planted with maize using the rolling punch planter. This was followed by passing A-blade cultivators between the plant rows to eradicate weeds. This operation was done at pre-emergence stage. There was no regrowth of weeds as the field was completely dry. At the onset of rain, maize germinated in a weed-free field. The trash that had been slashed by the A-blades remained on top of the ground, minimizing soil erosion. Subsequent weeding cultivation was also carried out with the A-blade cultivator. The blades penetrate the soil horizontally and parallel to the ground at a depth of about 4 to 8 cm. They do not disturb the soil surface but slash the weeds in their root zone. It is most effective for annual grass, but difficulty was encountered in the eradication of couch grass.

The employment of such a farming system for crop establishment in dryland areas must be pursued, as it achieves the requirements of early land preparation and planting, soil and water conservation, and weed control. Further trial, however, is recommended to ascertain its successful applicability. Research must also include other tillage equipment and farm practices employing the Bukura Mark II toolframe chassis.

APPENDIX

AGRICULTURAL EQUIPMENT IMPROVEMENT PROJECT—KEN 74/019
SUBCENTRE BUKURA
TEST REPORT NO.4

Description:

1. Type of equipment	Ox-drawn multipurpose toolframe, T-shape made of solid steel bar.
2. Weight of toolframe	23 kg
3. Manufacturer	S'MECMA Co. Ltd., Mali, W. Africa.
4. Local distributor	None
5. Cost	N.A.

Performance Characteristics

6. Ploughing (Attachment: Mouldboard Plough)

Weight of attachment	22.4 kg
Average width of cut	26 cm
Average depth of cut	22 cm
Average plough speed	2.32 km/hr
Dynamometer reading range	150 to 180 kg
Average draft	165 kg
Rate of work	27.8 hr/ha

7. Weeding (Attachment: 3 tine-tooth and 2 springtine cultivator)

Weight of attachment	16.5 kg
Weeding width	54 cm
Average depth	14 cm
Average draft	100
Rate of work per pass	14 hr/ha
No. of passes required	2

8. Score (Out of 10 points)

Ploughing Operation

Draft requirement	5
Rate of work	7
Trash burial	8
Furrow-depth maintenance	8
Scouring ability	7
Ease of handling	6
Construction quality	8
Suitability for local manufacture	8
Total score	71%

Weeding Operation

Draft requirement	6
Rate of work	8
Weed removal	7
Ease of handling	7
Soil penetration	8
Construction quality	8
Suitability for local manufacture	8
Total score	74%

Observations

9. Field condition suitable with moist sandy loam soil and very light trash.
10. Vertical regulator of plough is high for local animals.
11. Bolts for clamps are very soft, refused to loosen after tightening.
12. Cultivator effective only for weeds not more than 10 cm high.
13. Operator needs to push cultivator down during operation to penetrate.
14. Weeds blocked tines at close position; wider space leaves uncultivated areas.

Test Status of Implement: Needs modification of vertical regulator and further field testing required.

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TECHNICAL SESSION 3: REPORT ON DISCUSSION

Chairman (Dr D. B. Thomas): One of the major problems of land management in semi-arid areas is soil erosion and runoff. Various studies on soil physical and chemical characteristics to examine possible modification measures to conserve, preserve, and improve the land resource were conducted so as to increase and/or maintain crop yield.

Dr F. H. C. Scott: On the control plot the furrows are made down, not across the slope. Does this simulate the real situation?

Mr L. G. Ulsaker: Soil loss from the unit plot is used as a reference for the highest erosion rate. It is therefore ploughed up and down the slope instead of across it so as to stimulate the highest possible erosion rate for that particular soil.

Mr A. M. Marimi: Permanent wilting points for different crops vary from c. 10 atmospheres to c. 20 atmospheres, the lower being for vegetable crops and the higher for xerophytic plants. Would you be able to include 20 atmospheres (20 bars) in your table and calculate available water from soils in the target area?

Mr A. M. Kilewe: Yes, it is possible to include the 20 bars moisture content without any problem.

Mr F. M. Ndambuki: In one of the tables on water-holding capacity you showed available moisture as the difference between field capacity and wilting point. What reference-crop species did you refer to for wilting point? Different crops have different wilting points.

Mr Kilewe: The field capacity was determined using a tension table, while the permanent wilting point was determined using a pressure plate—in the laboratory. No crop species were used for these measurements.

Mr J. K. Kimemia: With the knowledge that most farmers in Machakos and other dry parts of Eastern Province use ox-drawn implements, how do the wide furrows fit into such a system?

Mr Kilewe: It is quite possible for the agricultural engineers to design ploughing, weeding, and construction implements to fit the wide-furrow systems by minimal modification of the existing implements.

Mr L. F. Scherer: What rainfall range are furrows applicable to?

Mr Kilewe: This system is applicable to areas with annual rainfall of up to 899 mm. However, the internal drainage of the soil in question should be looked into first to avoid running into water-logging problems.

Mr Marimi: Ridging increases the surface area from which evaporation takes place. One can predict that doubling the number of ridges in unit length may double the surface area. Did you witness faster wilting with more ridges than with few ridges, especially when light showers—about 10 mm—were received?

Mr Kilewe: This observation was not recorded. However, the wide furrows stored more water than the conventional furrows, which had more ridges. This difference could be a result of the increased surface area on the conventional furrows, from which evaporation took place.

Mr S. C. Ondieki: With the erratic nature of rainfall, will manure production be constant?—since pasture will also disappear with rain and animals sold. So will the study be adaptive effectively? Also has a survey been done on flow of animals throughout the year per family?

Mr Kilewe: The production of manure will apparently vary according to availability of the feeds. The study was meant to evaluate the available manure. However, if the animals are sold, the study would be of great use because the farmer will know the best way to utilize the manure already produced, and this probably may help him in managing his crops until he gets other animals after drought.

Mr J. O. Mugah: Farmyard manure has a high content of carbon compounds, which immobilize soil nitrogen in competition with the crop. Do you see this as a factor?

Mr Ondieki: This is a factor—especially so in the case of fresh manure. A good storage system is therefore necessary to enable farm manure to decompose and release nutrients without loss of nitrogen in the form of ammonia.

Mr Mugah: How do you explain the drastic yield decrease observed when you increased the farmyard-manure application rate to 16 tonnes/ha under conditions of low rainfall?

Mr Ondieki: The high rates of farmyard manure apparently release great amounts of nutrients. The high nitrogen content encourages vegetative growth at the early stages of plant development. Under conditions of low rainfall at the reproduc-

tive stage, the demand for water becomes more for these plants because of the increased mass and evapotranspiration, and therefore they suffer more, with a resultant decrease in yield.

Mr L. O. Sese: Please elaborate more on the following: (1) rate of adoption of the multipurpose plough by farmers in Kitui and Machakos District; (2) cost of the plough; (3) where the plough is available.

Mr J. K. Mburu: (1) It is not possible now to give an account of the rate of adoption because this equipment has not been made available to the farmers. The initial plan of the Ministry of Agriculture and Livestock Development to have the equipment manufactured, bought by the ministry, and then sold to the farmers at a reasonably low price has not been realized. On points 2 and 3, since the equipment has not been mass produced commercially the market price has not been determined. However, the expected selling price will be within the limited income of the small-scale farmers. The cost will also depend on the number and types of implements the farmer selects to go with the multipurpose tool frame. After manufacturing, the plough was to be sold from Farmers Training Centres and Agricultural Machinery Testing Unit substations.

TECHNICAL SESSION 4

CROP IMPROVEMENT

MAIZE BREEDING AT KATUMANI: THE FIRST 25 YEARS (ABSTRACT)

K. Njoroge[1]

The semi-arid areas of eastern Kenya constitute an important portion of the country's agricultural land. The numerous problems found in this zone include poor soils and an insufficient rainfall erratically distributed over the seasons.

Maize is one of the most important food crops of the area and a breeding programme established at Katumani in 1956 has produced several improved early-maturing maize varieties. These include eight synthetic varieties and three composites. One of these varieties, Katumani Composite B, is the most widely grown type of maize in these semi-arid areas. There is, however, evidence available that indicates that, though widely adapted, this variety does not flower early enough to escape drought in certain drier areas of Eastern Province. A recently composed early-maturing variety named Makueni seems to hold good promise. Data presented show that this variety flowers significantly earlier than the well established Katumani Composite B. Experimental evidence presented also shows that Makueni has a wide adaptation, similar to that of Katumani, and that reasonable yields have not been sacrificed for earliness.

1. National Dryland Farming Research Station, Katumani

SCREENING XEROPHYTIC PLANT SPECIES FOR ADAPTABILITY TO MACHAKOS AND KITUI DISTRICTS (ABSTRACT)

L. Ulsaker[1]

The objective of this study was to evaluate the adaptability and potential for improving efficient water use and/or conservation of soil by the introduction of xerophytic plant species with economic value as food, forage, or fuel to the predominantly subsistence-level farmers in the Machakos and Kitui Districts of Kenya. Plant screening began in October 1980 on the National Range Research Station, Kiboko, and subsequent studies were made at the National Dryland Farming Research Station, Katumani, and on test plots on farmers' fields. The results indicate that the plant species most suitable for introduction for food production in the hottest, driest areas of the region appear to be: tepary bean (*Phaseolus acutifolius*), winged bean (*Psophocarpus tetragonolobus*), bambara groundnut (*Voandzeia subterranea*), moth bean (*Vigna aconitifolia*), and grain amaranth (*Amaranthus hypochondriacus*). Marama bean (*Tylosema esculentum*) deserves another trial. Mung bean (*Vigna radiata*), hyacinth bean (*Dolichos lablab*), and, in very limited areas, guar or cluster bean (*Cyamopsis tetragonoloba*) are already being grown but warrant considerably more attention to varietal selection, planting patterns, intercropping, rotational sequences, *Rhizobium* requirements, pest control, and other cultural practices. Such efforts would be desirable for most or all of the species that were screened, but priorities, in most instances, would logically be assigned to those already being produced.

Better adapted fodder production species may be of equal or even more interest to many farmers. Apple-ring acacia (*Acacia albida*), blue-leafed wattle (*A. saligna*), salt bush (*Atriplex nummularia*), carob (*Ceratonia siliqua*), mesquite (*Prosopsis nigra*), leucaena (*Leucaena leucocephala*), and moth bean (*Vigna aconitifolia*) appear suitable for introduction on a trial basis in the drier areas if proper attention is given to the recommended establishment procedures and management practices. These are, except for moth bean obtainable from the International Centre for Research in Agroforestry (ICRAF) Station, Machakos for the tree species. In areas receiving at least 700 mm annual rainfall, perennial peanut (*Arachis glabrata*), perennial soybean (*Glycine wightii*), and leucaena are more suitable.

Wood for fuel and other uses is expensive and in short supply in most of both districts. Species suitable for such uses are blue-leafed wattle (*Acacia saligna*), leucaena (*L. leucocephala*), mesquite (*Prosopsis nigra*), tamarind (*Tamarindus indica*), and in the better rainfall areas, August flower (*Sesbania grandiflora*). These represent only the species that were tested in this study. Information on many others that are equally adapted is available at the ICRAF Station, Machakos.

Isle cropping with leucaena has been tested for four seasons at Katumani, and is a practice that appears ready for introduction via on-farm verification trials. Additional research on establishment and cultural practices of food production in living mulches is required before judgement of their suitablity and recommendations can be made.

1. USAID/Kenya Agricultural Research Institute, Muguga

BREEDING SORGHUMS FOR THE SEMI-ARID AREAS OF KENYA (ABSTRACT)

I. R. Kermali,[1] *A. Shakoor,*[2] *J. W. Kamau*[3]

Sorghum is an important cereal for the arid and semi-arid areas of Kenya. The Sorghum Improvement Programme for these areas, based at the National Dryland Farming Research Station, Katumani, has the objective of developing drought-resistant, good-quality, short-to-medium statured, early-maturing genotypes with insect and disease resistance, with particular emphasis on charcoal-rot. Good grain-quality sorghums, 76T—23, 954063 and NES 7360, have been identified for the medium altitudes, while Dryland Bulk 822 and IS 8595 perform well in the dry lowlands below 1000 m. Serena and 80/32 are suitable for the medium and low altitudes respectively, where efficient bird scaring is not possible. Due to their persistent testa, they are not attractive to birds. Information on breeding for resistance to birds, droughts, pests, and charcoal-rot and for grain quality is given and various aspects of their implications for sorghum production are discussed.

1. National Dryland Farming Research Station, Katumani
2. FAO/National Dryland Farming Research Station, Katumani
3. Embu Institute of Agriculture

PHYSIOLOGICAL MEASUREMENT FOR RANKING BEAN CULTIVARS WITH RESPECT TO RELATIVE DROUGHT AND HEAT RESISTANCE

B. A. N. Masumba[1]

INTRODUCTION

Agriculture is the backbone of Kenya's economy, with more than 90% of the population living in the rural areas and wholly dependent on agriculture for a living (Mukunya *et al.*, 1982). National agricultural production largely depends on about 19% of the total agricultural land classified as having high-to-medium rainfall, and to a lesser extent on small-holder farming. The latter is carried on at subsistence level on the vast expanse of land falling in the category of semi-arid to arid, comprising about 81% of the total agricultural land of Kenya (Central Bureau of Statistics, 1980).

In 1980, the population of Kenya stood at 16.3 million. From recent research findings of the Population Studies and Research Institute of the University of Nairobi, the current rate of growth is approximately 4% per annum. By the end of the decade the population will have reached an estimated 23.1 million or 42% above the 1980 level (Government of Kenya, 1981).

The rapid expansion of the population and a shortage of unexploited arable land in the better rainfall areas are beginning to expose a potentially dangerous imbalance in the relationship between food supply and demand at the national level (Government of Kenya, 1981). One of the major objectives of the national policy on food will be to meet an ever-increasing demand for food arising from a rapidly expanding population.

The required food-supply increase must come primarily from semi-arid land with an annual rainfall of 500–800 mm and of marginal agricultural potential. The development of crop varieties more tolerance of adverse environmental conditions offers considerable promise for increasing food production in the semi-arid areas of Kenya.

Beans are one of the most important crops grown in these areas (Mukunya *et al.*, 1982). The bean-growing areas are situated in Eastern, Central, Western, and Nyanza Provinces at altitudes varying from 1,500 to 2,500 m. In Eastern Province, where the bulk of the bean production takes place, there are two rainy seasons with mean annual rainfall ranging between 500 and 800 mm and the early season often lasting less than 60 days. Therefore short-maturing varieties which flower before the rain ceases are to be preferred in order to avoid the crop failures that occur all to often in these areas.

Bean development in Kenya is at present mainly co-ordinated by the Thika National Horticultural Research Station and implemented at the Katumani, Embu, Nyanza, and Western Agricultural Stations. In addition, the UNDP/FAO Dryland Farming Research Development Programme based at the Katumani Research Station and the USAID Dryland Cropping Systems Research Programme based at the Kenya Agricultural Research Institute (KARI) at Muguga are the two major programmes recognize beans as a major crop for the semi-arid areas.

The research station at Katumani has identified and developed maize cultivars capable of yielding acceptably in semi-arid areas, and work has been going on to develop sorghums, pigeonpeas, cowpeas, and millets for these areas. Research at the Thika Agricultural Station in collaboration with the Faculty of Agriculture, University of Nairobi, has resulted in the release of three bean varieties for the main growing areas. They are GLP-24, GLP-2 (Roko), and GLP-1004, for high, medium, and marginal rainfall areas respectively. These varieties have been well accepted by farmers in the higher-rainfall areas. Unfortunately, the variety selected for the marginal rainfall areas, Mwezi Moja, is not sufficiently drought-tolerant to stabilize yields in those areas (Mukunya *et el.*, 1982). There is therefore need to identify drought and heat resistance in bean cultivars capable of stabilizing yields in the semi-arid areas of Kenya.

Drought resistance is a complex of many physiological characteristics and it is doubtful whether any one criterion will be adequate for selection for drought resistance in crops. A combination of desirable factors must be selected (Sullivan and Ross, 1979; Anayaba *et al.*, 1979). Various attempts have been made to define

specific physiological characteristics that are indicative of drought and heat resistance. Among these are low stomatal conductance (Sullivan, 1971), low leaf transpiration per unit area (Wilson, 1975), and low leaf-water potential (Turner, 1974). Other researchers (Idso *et al.*, 1977; Idso, 1982) have shown that the differential in leaf-air temperature can be used to assess the water status of plants and hence serve as a practical operational guide to irrigation scheduling.

Two bean cultivars, Pinto and Mwezi Moja (*Phaseolus vulgaris L.*), with potential for producing relatively high yields in the semi-arid areas of Kenya, and one imported heat-tolerant bean type, Tepary (*Phaseolus acutifolius Gray*) were chosen for the present study.

The main objectives of this study were (a) to determine at low, medium, and high irrigation levels the comparative levels of stomatal conductance, leaf transpiration rate, leaf-water potential, and the differential in leaf-air temperature from the three bean cultivars during the reproductive growth period from early flowering to pod filling, and (b) to determine the feasibility of ranking the bean cultivars for drought and heat resistance as indicated by the above parameters and to verify the ranking by comparison with yield performances.

MATERIALS AND METHODS

The experiment was conducted at Kiboko, Kenya (latitude 2° 20'S, longitude 17° 45'E, altitude 980 m), about 150 km south-east of Nairobi. It was carried out in the dry season between December 1981 and February 1982.

Three early-maturing bean cultivars with high yield potential, Tepary (*Phaseolus acutifolius Gray*), Pinto and Mwezi Moja (*Phaseolus Vulgaris L.*), were planted on 5 December 1981.

The experimental design was the "line source" design described by Hanks *et al.* (1974) and adopted for co-ordinated 4-university studies of maize responses to water in the USA in 1974 and 1975 (Stewart *et al.*, 1977).

Fig. 1 shows a schematic representation of the experimental layout. The circles represent the location of catch-cans installed to measure the applied irrigation water. The numbers above the circles represent the irrigation levels. Each

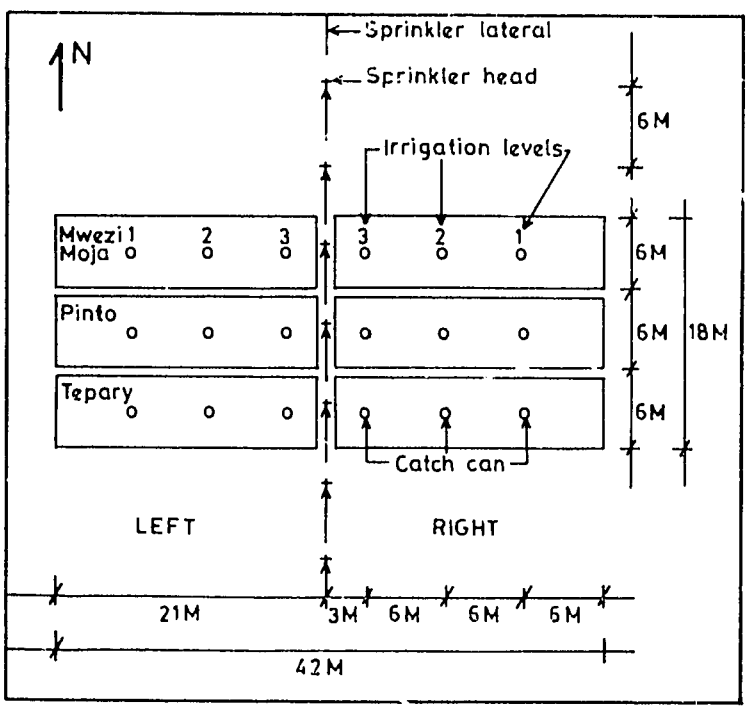

Fig. 1. Experimental layout

irrigation level consisted of 5 rows of beans. Tepary bean was spaced 5 cm within rows and 37.5 cm between rows, while Pinto and Mwezi Moja were spaced 10 cm within rows and 75 cm between rows.

No irrigation was applied from planting to flowering stage; the rainfall in that period was 138 mm. Variable irrigation was applied from flowering through the yield formation (pod development and bean filling) stages, during which no rain fell. The total amount of water (actual rainfall plus applied irrigation) on irrigation levels 1, 2, and 3 totalled 169, 266, and 348 mm respectively. The 169, 266, and 348 mm represent a very highly stressed level, considerably stressed level, and fully adequate water supply for Tepary bean, and a slightly stressed level for Mwezi Moja and Pinto beans.

Measurements from each irrigation level were taken at intervals of seven days, 1 day preceding each irrigation, and the measurements covered a period of five weeks. Due to lack of instruments, no measurements were made prior to the second irrigation, which occurred on the 14th day from flowering. Measurements were taken between 11.00 and 14.00 hours, when photosynthetically active radiation was nearly uniform.

Leaf-water potential was measured on four leaves in each irrigation level, using a pressure chamber. Each leaf was taken from a different plant adjacent to the catch-can. Only the most recently developed, fully expanded, sun-exposed leaves at the top of the canopy were measured.

A LI-COR Model LI-1600 steady-state porometer was used to measure the following parameters simultaneously: stomatal diffusive resistance, transpiration rate, temperature (at the surface and in the ambient air), and quantum (photosynthetically active) radiation. Measurements were made on five leaves in each irrigation level. Each leaf measured was from a different plant adjacent to the catch-can. Stomatal conductance was calculated as the reciprocal of stomatal diffusive resistance (Watts, 1975).

RESULTS AND DISCUSSION

At all irrigation levels Tepary bean produced the highest grain yield. Mwezi Moja yielded lower and Pinto lowest (Fig. 2). The measurements of stomatal conductance, transpiration rate, leaf-water potential, and leaf-air temperature differential, through comparison with actual yields, were used as indicators of the relative drought and heat resistance of the three cultivars.

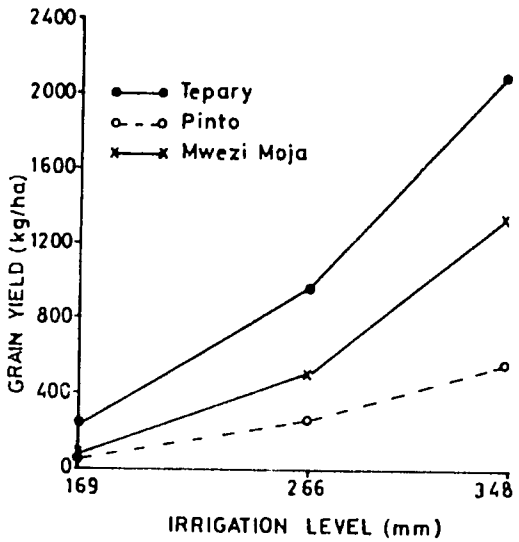

Fig. 2. Effect of the Bean Cultivars and Irrigation Levels on Grain Yield

At all irrigation levels, Tepary bean consistently had the lowest values for stomatal conductance and transpiration rate, with Pinto next and Mwezi Moja highest (Tables I and II, Figs. 3 and 4).

At the highly stressed level, the relatively high grain yield in Tepary bean appears to verify the suggestion that lower values of stomatal conductance and transpiration rate indicate drought resistance. However, for Mwezi Moja and Pinto beans, which had closer stomatal conductance and transpiration rate values, the order was reversed. Therefore stomatal conductance and transpiration rate values close together cannot be used for ranking the bean cultivars for drought resistance.

Similarly, at the high irrigation level, the lower values for stomatal conductance and transpiration rate found in Tepary bean appear to indicate heat resistance, whereas the values for Pinto and Mwezi Moja are again reversed

These results indicate that stomatal con-

TABLE I—EFFECT OF BEAN TYPES (B), IRRIGATION LEVELS (IRR) AND TIME IN DAYS AFTER FLOWERING (T) ON STOMATAL CONDUCTANCE (cm/s)

Bean types \ Time after flowering (days)	Irrigation levels (mm) 169				266				348				B Means
	7	21	28	35	7	21	28	35	7	21	28	35	
Mwezi Moja (46x)	0.19*d-i		0.11f-i	0.03f-i	0.9f-i	0.44b-g	0.72b	0.24c-i	0.16e-i	0.76b	1.39a	0.83b	0.57b-e
Pinto	0.19d-i	0.08f-i	0.01h-i	0.03f-i	0.45b-f	0.29c-i	0.14f-i	0.13f-i	0.74b	0.61bcd	0.62bc	0.41b-h	0.31y
Tepary	0.02ghi	0.01hi	0.00i	0.00i	0.28c-i	0.05f-i	0.09f-i	0.09f-i	0.64bc	0.58b-e	0.22c-i	0.05f-i	0.17z
T means	0.13n	0.07n	0.02n	0.04n	0.39n	0.35n	0.16n	0.13n	0.7in	0.86	0.55n	0.58n	
IRR means			0.06u				0.26t				0.68s		

*If the letter series following any two values overlap, the values are not significantly different at the 5% level according to Duncan's Multiple-Range Test. ("d-i" = "d to i inclusive")

TABLE II—EFFECT OF BEAN TYPES (B), IRRIGATION LEVELS (IRR) AND TIME IN DAYS AFTER FLOWERING ON LEAF TRANSPIRATION RATE ($\mu g/c^2/S$)

Beans types \ Time after flowering (days)	Irrgation level (mm) 169				266				348				B Mean
	7	21	28	35	7	21	28	35	7	21	28	35	
Mwezi Moja	8.9*d-j	5.5f-j	1.3ij	4.6g-j	12.9b-j	20.2b-e	8.5d-j	5.0g-j	19.8b-e	32.0a	23.3abc	13.3b-i	12.9w
Pinto	7.9c-j	3.4hij	0.7j	1.2ij	16.9b-g	10.3d-j	5.1f-j	4.7g-j	23.3abc	15.2b-h	17.6b-f	11.0d-j	9.8x
Tepary	1.7ij	0.5j	1.3ij	0.6j	11.1c-j	3.2hij	4.1hij	3.1hij	20.7a-d	18.6b-e	7.7e-j	4.1hij	6.4y
T means	6.7n	3.1n	1.1n	2.1n	13.6n	11.2n	5.9n	4.3n	21.3n	21.9n	16.2n	16.1n	
IRR means			3.1s				8.7r				18.9q		

*If the letter series following any two values overlap, the values are not significantly different at the 5% level according to Duncan's Multiple-Range Test ("d-i" = "d to i inclusive")

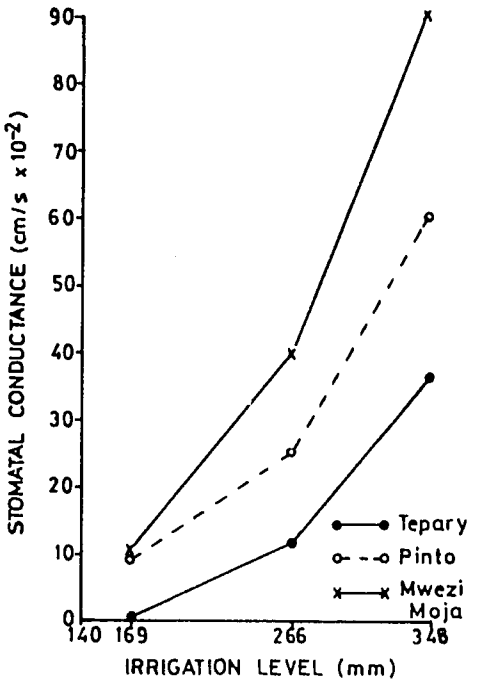

Fig. 3. Effect of the Bean Cultivars and Irrigation Levels on Stomatal Conductance

ductance and transpiration rate can be used as an indicator of relative drought and heat resistance only when the measurements from different cultivars differ, as was the case for Tepary but not for Pinto and Mwezi Moja Beans.

At all irrigation levels, high leaf-water potential values were observed at 7 days after flowering, tending to fall until 35 days after flowering (Figs. 5, 6, 7). At the low and high irrigation levels there was no clear separation in leaf-water potential among the cultivars, except that Mwezi Moja consistently had the highest values at the low level. These results indicate that leaf-water potential is not a very useful indicator of relative drought and heat resistance.

At all irrigation levels, Tepary had, fairly consistently, the highest temperature differential (Fig. 8). There was also a tendency for Mwezi Moja to have greater temperature differentials than Pinto. However, at all irrigation levels, differences were very small between the temperature differentials of the three cultivars.

These results indicate that although the comparative temperature differentials did occur in the same order as grain yields, the differences between cultivars were too small in magnitude to serve as an index of drought and heat resistance.

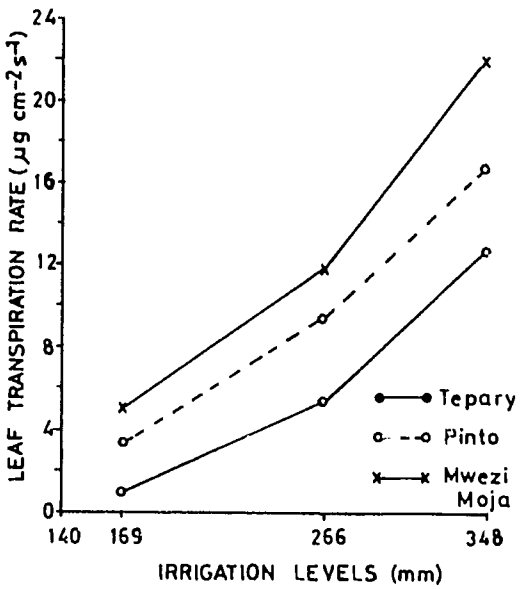

Fig. 4. Effect of the Bean Cultivars and Irrigation Levels on Leaf Transpiration Rate

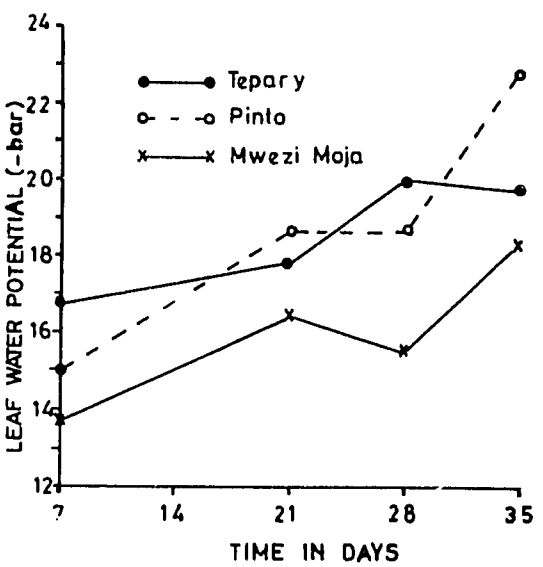

Fig. 5. Effect of Bean Cultivars and Days from Flowering on Leaf Water Potential at the Low Irrigation Level (169 mm)

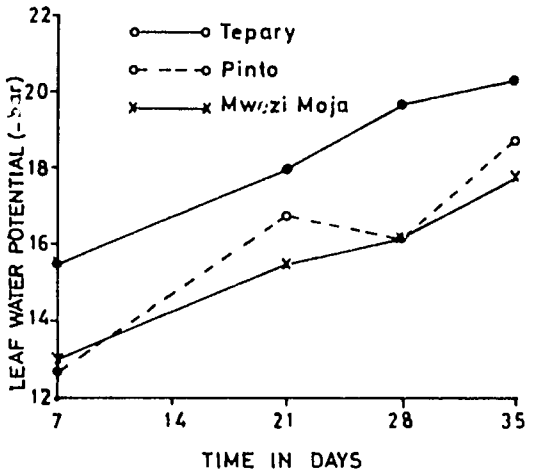

Fig. 6. Effect of Bean Cultivars and Days from Flowering on Leaf Water Potential at the Medium Irrigation Level (266 mm)

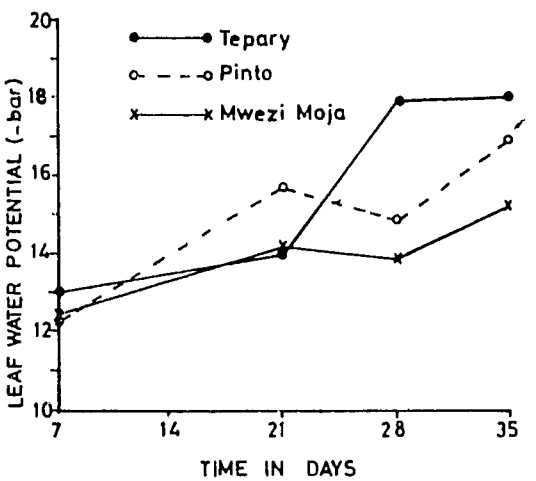

Fig. 7. Effect of Bean Cultivars and Days from Flowering on Leaf Water Potential at the High Irrigation Level (348 mm)

Fig. 8 shows that a leaf-air temperature differential in a bean plot exceeding 1.8°C signals that the plants are experiencing water stress. This is in close agreement with the findings of Ehrler (1973) that a 2°C temperature differential signals the need for irrigation. However, other findings indicate that the leaf-air temperature alone is not sufficient as a basis for scheduling irrigation (Gardner, 1979; Walker, 1980). Idso and his colleagues (1981) have developed a new water-stress index which depends upon the relationship that exists between foliage-air temperature differentials and the air vapour pressure deficit.

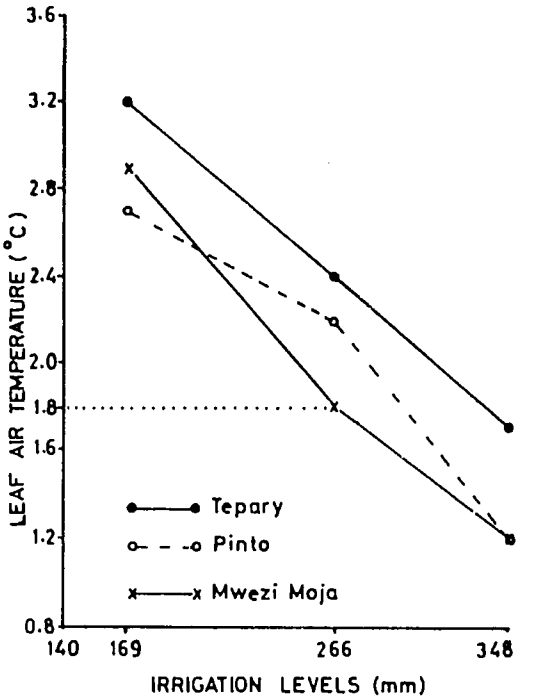

Fig. 8. Effect of the Bean Cultivars and Irrigation Levels on the Leaf-air Temperature Differential

SUMMARY AND CONCLUSION

The conclusions from this study are:

a. At all irrigation levels Tepary bean had the highest grain yield, Mwezi Moja lower, and Pinto lowest. Despite its high yield, Tepary required only 70 days to mature, while Mwezi Moja and Pinto required 80 days. The short maturity period of Tepary resulted in a lower water requirement than that of the other two cultivars.

b. At all irrigation levels Tepary consistently showed the lowest values of stomatal conductance and transpiration rate. Pinto was next and Mwezi Moja highest. Tepary also showed fairly consistently the greatest differentials between leaf and air temperature, with Mwezi Moja next and Pinto least

The cultivars could not be differentiated on the basis of leaf-water potential.

c. Stomatal conductance and transpiration rate can be used as indicators of relative drought and heat resistance only when the measurements from different cultivars differ considerably, as was the case for Tepary bean but not for Pinto and Mwezi Moja. Leaf-water potential is not a very useful indicator of relative drought and heat resistance for the cultivars studied.

d. Although the comparative differentials between leaf and air temperature occurred in the same order as grain yields, the differences between cultivars were too small to serve as an index of drought and heat resistance. However, the results show that a leaf-air temperature differential in a bean plot exceeding 1.8°C signals that the plants are experiencing water stress.

The demonstrated superior drought and heat resistance of Tepary bean and its short maturity, with consequent lower water requirement, lead to the recommendation that it be considered for planting in the lower-altitude zones of the marginal rainfall areas of Kiboko. It may also be considered during the warm short-rains season in the higher-altitude zones of Machakos and Kitui Districts. Other data indicate that Mwezi Moja yields better in cooler environments, such as those of Muguga or Machakos District during the long-rains season.

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IMPROVEMENT OF CASSAVA FOR DRY AREAS OF KENYA AND CONTROL OF CMD THROUGH RESISTANT VARIETIES (ABSTRACT)

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In Kenya cassava is mainly grown in Western, Nyanza, and Coast Provinces. The area of cultivation under this crop in Eastern Province is at present very low. As it is a drought-resistant crop suitable for semi-arid areas, improvement work was undertaken during 1981 at the National Dryland Farming Research Station, Katumani. Lack of suitable varieties and heavy losses due to cassava mosaic disease (CMD) appear to be the major constraints on its cultivation.

The exotic introductions have in general shown poor adaptability under local conditions. KME2, a local selection from a farmer's field in Makueni Location, Machakos District, has so far shown resistance against CMD. Further tests of its resistance are in progress. The tuber character of the resistant line KME2 is good in taste and has no fibre.

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THE PROSPECTS OF GROWING PROSO MILLETT IN ARID AND SEMI-ARID AREAS OF KENYA

Petra Penninkhoff[1]

INTRODUCTION

Proso millet (*Panicum miliaceum L.*) has had little attention from agronomists and plant breeders in the East African Region. The programme of the East African Agriculture and Forestry Organization at Serere (Uganda) carried out a few variety trials in the early 1970s, but results have not been recorded in their annual reports (Thairu, personal communication). In Kenya, proso-millet breeding started only in 1980 with the evaluation of 191 introduced and 2 locally collected varieties (M'Ragwa, 1981). The crop is one of the least water-requiring of the cereals with 200—300 mm of rainfall supporting a crop. Its short duration also makes it possible for proso millet to escape drought (Netherlands Ministry of Agriculture and Fisheries, 1981).

Pintilli (1972), comparing oats and proso, reported that the latter appears to have no permanent wilting point. Even when the suction pressure in the leaves had gone up to 30—60 atm the crop yielded when watering recommenced.

In general, proso millet can be grown in places that are too hot and too dry and have too poor a soil for other cereals and at altitudes ranging from sea level to 2,000 m and more (Purseglove, 1972).

Mbogoh (1982), in his study of the feasibility of a national sorghum and millets expansion programme in Kenya, states that people living in the marginal areas should become more independent of the higher-potential areas. They must therefore be encouraged to grow their own food requirements. Considering the fact that more than 80% of Kenya receives less than 800 mm of rain yearly (mostly in two rainy seasons), proso millet appears to be one of the crops, next to bulrush millet and sorghum, that have an enormous potential. However, it cannot be denied that certain aspects of proso cultivation make the small farmer reluctant to accept the crop as a replacement for maize. Major constraints are low returns because of high labour inputs and low yields, limited alternative uses, eating habits, and not least lack of information (Hulse *et al.*, 1980; Mbogoh, 1982).

This paper discusses the problems mentioned and seeks to find answers using field observations and trial results collected over four rainy seasons and using information obtained from the cited literature.

BACKGROUND

History

The origin of proso millet is said to be in Central Asia, where it was domesticated around 4800B.C. Nomads used to grow it because of its short duration and low water requirements, which make it an easy catch crop. During the Middle Ages, proso was grown in Europe as a food crop for the poorer people. Due to the increasing popularity of raised bread it was gradually replaced by other cereals. At present the crop is grown in China where it is the second most important millet, in Southern India, Japan, Central Asia, the Middle East, Soviet Russia, and Eastern Europe. It is being used for porridge, flat bread, as rice, and for wine making and beer brewing. In some Western European countries as well as in the United States it is grown for animal and poultry feed, using the grain or the stover (Purseglove, 1972; Rachie, 1975).

In Africa the more important millets are bulrush and finger, most of it grown under primitive conditions. Until about 30 years ago, however, proso millet was grown in Kenya from the Ngong Hills down to lower Embu and lower Meru (Thairu, personal communication). With the introduction of maize, proso millet disappeared. D. Wood during his germ-plasm collection trip in 1980, found only two local varieties growing "much like a clump of a perennial grass" (pers. comm). According to Dowker (1963), the hand-

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threshing methods, causing dirt to mix with the grain, and the bird problem contribute largely to the disappearance of sorghum and millets.

Nutritive value and processing

In the arid and semi-arid areas of the developing world, cereals are of much greater nutritive importance than in the so-called First World countries. A diet showing little variation requires a proper nutrient balance in its component foods (Hulse *et al.*, 1980). Therefore, before introducing a crop in a certain area it is important to obtain information on its nutritive value and processing possibilities and problems.

Table I shows that proso compares well with other cereals in protein and fat content. The high percentage of indigestible fibre is due to the presence of a husk that encloses the grain. The nutrient percentage of a dehusked sample (obtained from another source) is given for comparison in Table II. The proteins of proso are nutritionally superior to those of sorghum. Lysine is limiting, as in most cereals, but ranges from 89 to 266 mg/100 g N, compared with 71–212 mg/100 g N for sorghum. Among the millets only bulrush scores higher, with 109–297 mg/100 g N (Hulse *et al.*, 1980). Methionin content is high and the threonin level is maximum. Proso millet is a good source of thianin and the other B vitamins, which levels out the high leucine/isoleucine balance, which ranges from 2.4–4.3. The information on mineral content shows considerable variation (Table III), but amounts appear adequate. Kies and Fox (1975) report that N digestibility is rather low compared with triticale. However, the rate of N digestibility of

TABLE I—REPRESENTATIVE VALUES OF NUTRIENTS IN VARIOUS CEREALS (MATZ, 1969) IN PERCENTAGES OF EDIBLE PORTION

	Protein	Fat	Fibre	CBH	Ash
Proso	11.7	3.3	8.[illegible]	64.2	1.9
Sorghum	11.3	2.9	2.2	71.3	1.7
Maize	9.7	4.0	2.3	71.7	1.4
Wheat	13.2	1.9	2.6	69.9	1.9

TABLE II—NUTRIENT PERCENTAGES OF A DEHUSKED SAMPLE OF PROSO (AYKROYD *ET AL.*, 1963) IN PERCENTAGES OF EDIBLE PORTION

Protein	Fat	Fibre	CBH	Minerals
12.5	1.1	2.3	70.4	1.9

TABLE III—CALCIUM AND IRON IN VARIOUS CEREALS (mg PER 100 g EDIBLE PORTION) (PLATT, 1962; AYKROYD, 1969)

	Calcium		Iron	
	Platt	Aykroyd *et al.*	Platt	Aykroyd *et al.*
Proso	20	14	5.0	11.5
Sorghum	32	25	4.5	5.3
Maize	12	10	2.5	2.0
Wheat	30	41	3.5	4.9

proso is comparable with those of sorghum and the other millets (Hulse *et al.*, 1980).

To obtain a more palatable end product for human consumption, the grain of proso can be dehusked. Observations in Machakos indicate that the traditional method of pounding can be satisfactory, although a lighter pestle than that used for maize is required to reduce the percentage of broken grains. Soaking and wet pounding resulted in higher losses, as the grain becomes soft and breaks easily. Apart from this, wet processing reduces the protein content (Hulse *et al.*, 1980). James (1982) reports that mechanical dehulling, using a PRL/RHC dehuller with a running time of 4 minutes, leaves 10% of the grain unpolished, while the husks have to be removed by hand winnowing. A longer dehulling time will cause a high percentage of brokens and dust. Hammer-milling of the dehusked grain gives a coarse flour. Removing the husk after milling can be difficult (Matz, 1969). The flour of proso millet can be used in combination with wheat flour for bread making. According to Lorenz and Disaver (1980), a 15% proso/85% wheat mixture is acceptable. Crabtree and Dendy (1977), on the other hand, are of the opinion that the optimum mixture is 10% proso and 90% wheat, co-milled at an RH of 16%. This mixture gives an optimum bread volume and has no negative effect on flavour; only crust and crumb colour get darker while the crust is slightly harder and thicker.

In general, however, proso is consumed in the form of porridge, flat bread (chapatis), and as a rice substitute.

Studies on proso grain for animal and poultry feed are many, and proso compares well with other cereals. More important for proso cultivation in the dryland areas, where crop and livestock production exist next to each other, is the feeding value of the crop residue. Two proso millet varieties (Serere 1 and N-40101) have therefore been tested for neutral detergent fibre content. The high fibre percentage of proso stover compared with that of maize (Table IV) gives the impression that the palatability of the former will be considerably lower. On the other hand, unpublished data of Johnson *et al.* (1981) indicate that the feed value of proso millet stover is good. Heifers in calf, fed on 100% proso stover, had a daily weight gain of 0.5 kg. A diet of 50% proso and 50% maize and a control diet consisting of 50% maize, 25% alfalfa and 25% oats showed daily weight gains of 0.36 and 0.44 kg respectively.

TABLE IV—NEUTRAL DETERGENT FIBRE PERCENTAGE IN STOVER OF PROSO AND MAIZE

	% Fibre
Proso (Serere-1)	74.94
Proso (N-40101)	80.60
Maize	56.96

MATERIALS AND METHODS

Varieties and cultural practices and their feasibility

In the course of the proso-millet breeding programme at Katumani, two promising varieties have been identified. The yields presented in Table V were achieved under low to medium rainfall conditions and without the use of fertilizer. The very low yields in Murinduko during the 1982 long rains (March-June) were caused by a very high weed infestation, the first weeding only taking place at flowering. The low yields obtained in Ithookwe and Kampi ya Mawe during the 1982 short rains (November-January), with a total precipitation of about 850 and 517 mm respectively, may indicate that high rainfall has a negative influence on proso millet performance.

Attempts to introduce the crop to farmers have met with varying degrees of success. Farmers give as a main reason for rejecting sorghum and millets in general the high labour requirements, mainly for bird scaring. Planting and weeding are also mentioned as being too labour-intensive compared with maize cultivation. Indeed, labour input in man days for bird scaring, as outlined by Chiodo-Juve (1980) and Rukandema *et al.* (1983a, b) is high.

It is assumed, however, that inadequate planting techniques and cultural practices are to a large extent the cause of these high labour inputs. Proper planting techniques contribute to uniform plant populations and restricted maturity range, with the result that the labour required for weeding and bird scaring is reduced. Sixty to seventy man days per hectare are mentioned (Netherlands Ministry of Agriculture and Fisheries, 1981). Dry-matter production of proso can be increased when the soil is chiselled before planting. By breaking the A2 horizon deeper rooting is stimulated, the upward movement of water into the root zone is improved, and the effects of drought are minimized (Doty and

Reicosky, 1978). A firm seedbed (Matz, 1969; Arnon, 1972) has to be prepared and seeds planted in warm, wet soil at 1—2 cm depth will show optimal germination.

The second important factor in determination of final yield is the population density. Purseglove (1972) recommended a seed rate of 8—11 kg/ha. The seed rate suggested by Arnon (1972) of 25 kg/ha appears to be too high for the rainfall conditions in arid and semi-arid areas. In trials where seed rate was kept constant and row spacing varied (Nelson, 1977), the wider spacings yielded less, due to the higher competition between plants in the row, which caused the plants to grow taller and to mature later.

Whiteman (1981) carried out population-density trials at Kampi ya Mawe using fertilizer at the rate of 20 kg N and 20 kg P per hectare. The season was very wet (598 mm) and did not demonstrate the crop's potential (see also Table V). The highest yields were achieved at a density of 800,000 plants per hectare (i.e. 25 cm interrow and 4 cm intrarow) and amounted to 1,325 kg/ha. In the 1982 long rains an unreplicated trial was conducted at Katumani (rainfall during crop life 166 mm) without fertilizer application. In general the 10 cm row spacing appeared to be superior to the 20 cm and 30 cm spacings (Table VI). The broadcast plot yielded only 1,862 kg/ha, the lowest yield obtained in this exercise. Population density at time of harvest was not estimated but appeared rather low. It is assumed that during the first weeding, proso millet seedlings were mistaken for grass weeds and were consequently removed. As could be expected, tillering at the narrow row spacing was low. The number of effective tillers ranged from 1.0 for the 10 cm interrow, no-thinning treatment to 3.9 for the 30 cm interrow, 10 cm intrarow spacing.

TABLE V—YIELD DATA OF TWO PROSO MILLET VARIETIES (SERERE-1, N-40101) FOR SEVERAL SITES AND SEASONS

Site and season		Rainfall during crop life (mm)	Yield (kg/ha)	
			S-1	N-40101
Ithookwe	81SR	—	550	404
Kampi ya Mawe	81SR	172	710	1,329
Ithookwe	82LR	—	350	619
Kampi ya Mawe	82LR	231	549	1,441
Katumani	82LR	166	993	1,045
Murinduko	82LR	—	23	67
Ithookwe	82LR	427	149	367
Kampi ya Mawe	82SR	370	152	289
Kithangaini	82SR	—	349	828
Kampi ya Mawe	83LR	220	281	296

LR = Long rains
SR = Short rains
— = No information

A trial comparing population densities and weeding frequencies was grown in the 1982 short rains at Kampi ya Mawe (rainfall during croplife 370 mm). Included were 3 interrow spacings (20, 30 and 40 cm), 3 intrarow spacings (10 cm, 5 cm, and no thinning resulting in 2—4 cm between plants), and 3 weeding frequencies (1 early weeding, 2 weedings, no weeding). The trial was planted in a randomized complete block design in three replications. Statistical analysis of the results, presented in Table VII, revealed that only interrow spacing has a significant influence on yields. Thinning and weeding frequencies seem to have no effect. This would imply an enormous reduction in labour requirements. The results of the Murinduko trial in the long rains of 1982 (see Table V), however, suggest that one weeding at least is needed. Whiteman (1981)

TABLE VI—RESULTS OF UNREPLICATED PROSO MILLET POPULATION-DENSITY TRIAL, KATUMANI 1982 LONG RAIN (VARIETY: SERERE-1, RAINFALL 166 mm; YIELDS IN kg/ha)

	Spacing between plants			
Spacing between rows	No thinning	5 cm	10 cm	Mean
10 cm	1,994	4,017	4,386	3,466
20 cm	3,366	2,919	2,634	2,973
30 cm	2,113	2,141	2,199	2,151
Mean	2,941	3,026	3,073	2,863

TABLE VII—YIELDS OF PROSO MILLET AT SEVERAL INTERROW AND INTRAROW SPACINGS AND UNDER DIFFERENT PRACTICES: AVERAGES OVER 3 REPLICATIONS (RAINFALL DURING CROP LIFE 370 mm; KAMPI YA MAWE, 1982 SR)

Treatment			Yield	Treatment			Yield	Treatment			Yield
B	W	F	(kg/ha)	B	W	F	(kg/ha)	B	W	F	(kg/ha)
20	0	0	993	30	0	0	845	40	0	0	795
20	0	1	812	30	0	1	843	40	0	1	875
20	0	2	1,066	30	0	2	654	40	0	2	833
20	5	0	840	30	5	0	725	40	5	0	528
20	5	1	1,299	30	5	1	636	40	5	1	771
20	5	2	1,028	30	5	2*	772	40	5	2	611
20	10	0	993	30	10	0	778	40	10	0	479
20	10	1	1,097	30	10	1	580	40	10	1	615
20	10	2	941	30	10	2	722	40	10	2	569

B = Interrow spacing (20, 30, 40 cm)
W = Intrarow spacing (no thinning (0), 5 cm (5), 10 cm (10))
F = Weeding frequencies (no weeding (0), first weeding only (1), two weedings (2))
* = Standard practice.

reports that panicle formation occurs approximately 3 weeks after germination. As this is a critical stage in determining the panicle size and number of flowers, stress should be minimal and weeds should be absent. Drought at panicle emergence (approximately 6 weeks after germination) can reduce grain yields up to 65% (Pintillie *et al.*, 1972), and therefore weed infestation at that time should also be low. One early weeding within the first 3–4 weeks after germination is usually sufficient to protect both critical stages. Narrow rows will have an effect on weed growth by suppressing them. The drawback, however, is that during the (first) weeding extreme care has to be taken in order not to cover the young millet plants with turned-over soil.

A second possibility for controlling weeds is to interplant proso with pulses (Netherlands Ministry of Agriculture and Fisheries, 1981). Yield data from intercropping trials carried out during the 1982 long and short rains and the 1983 long rains are not complete because of sheep damage, among other reasons. The figures for land equivalent ratio (LER) presented in Tables IX and X have been derived by using the limited information available. Field observations suggest that an arrangement of alternating single rows is su-

TABLE VIII—CALCULATED AND TABULATED F-VALUES (5% LEVEL) FOR THE DIFFERENT MAIN EFFECTS AND INTERACTIONS IN A PROSO MILLET POPULATION-DENSITY TRIAL (KAMPI YA MAWE, 1982 SR)

Effect/ interaction	F-values	
	Calculated	Tabulated
B	13.78	3.18
W	1.27	3.18
F	0.33	3.18
B × W	1.22	2.56
B × F	0.68	2.56
W × F	0.50	2.56
B × W × F	0.72	2.13

(For key see Table VII.)

perior to alternating double rows. Intercropping studies planted in the 1983 short rains (at the time of writing this paper) include the arrangements mentioned as well as a 2-proso-rows, 1-pulse-row arrangement.

Lastly, yields are strongly influenced by bird damage and time of harvest. Proso shatters easily and birds have ready access to the seeds. Shattering is also increased by the movement of the birds just above or in the crop. Timely harvest will therefore reduce these yield losses. Farmers tend to delay harvesting until all the heads are golden yellow and leaves and stalks have dried off. This increases the period for which bird scaring is needed. The grain is mature when the lower part of the panicle as well as the leaves and stalk are still green (Arnon, 1972), and harvesting by uprooting the plant should take place at the earliest opportunity after this. The

TABLE IX—YIELDS AND LAND EQUIVALENT RATIOS (LERs) OF PROSO MILLET INTERCROPPING TRAIL, KATUMANI, 1982 LR (RAINFALL DURING CROP LIFE 166 mm; PLANTING ARRANGEMENT 2 ROWS PROSO : 1 ROW PULSE)

	Yield (kg/ha)	LER
Proso/Green gram	1,274/230	0.81
Proso/Cowpea	1,183/338	1.09
Proso/Bean (Mexican 142)	1,409/336	0.86
Proso	2,141	
Green gram	1,054	
Cowpea*	630	
Mexican 142	1,660	

*Computed data; original yield 315.9 kg/ha; about 50% sheep damage occurred shortly before harvest.

TABLE X—YIELDS AND LAND EQUIVALENT RATIOS (LERs) OF A PROSO MILLET INTERCROPPING TRIAL, KAMPI YA MAWE, 1983 LR (RAINFALL DURING CROP LIFE 220 mm; AVERAGES OVER FEW DATA)

	Yield (kg/ha)	LER
Proso : Green gram 1 : 1	250/333	1.25
Proso : Cowpea 1 : 1	375/388	0.89
Proso : Green gram 2 : 2	333/333	1.33
Proso : Cowpea 2 : 2	438/229	0.74
Proso	500	
Green gram	167	
Cowpea	379	

slightly higher yields that could be gained by waiting till all panicles have matured are nullified or worse by delaying harvest.

Summarizing, it can be concluded that narrow rows giving less tillers and therefore a more uniform maturity can reduce labour requirements for weeding as well as bird scaring.

CONCLUSION AND RECOMMENDATIONS

Farm extension workers and even agricultural scientists are often of the opinion that proso millet is an inferior crop that cannot by any means compete with maize. This paper has tried to challenge this view. It is stressed, however, that it is not intended to introduce proso in those areas that are suitable for maize cultivation. The literature cited and trial data presented demonstrate the prospects for proso millet. In agreement with Vose (1981), it is thought that it is better to produce a reasonable crop at minimum cost than to increase the costs for a maximum positive yield; a crop should suit the environment it is grown in. More agronomic studies will have to be undertaken to develop cultural practices that will result in an optimal crop performance under low labour-input requirements. Breeding should focus on higher, more stable yields, higher 1,000-grain weights, and reduced shattering. On the other hand, labour requirements as for maize or higher should not influence the adoption of proso millet by the farmers in those areas where this crop, possibly next to bulrush millet, is the only cereal that can be grown and give reasonable yields. Whiteman (1981) calculated that the grain production per unit time is up to 40 kg/ha/day. A 100-day crop such as maize or sorghum would have to produce 4 tons per hectare, requiring much more rainfall and with a higher risk.

It is appreciated that a change in attitude towards proso millet, especially regarding eating habits, is needed. An organized extension effort backed up by recommendations developed by a well organized research programme could, however, result in the incorporation of proso millet in the farming systems of arid and semi-arid Kenya.

SUMMARY

Proso millet is a short-duration, low-water-requiring cereal that has received little attention in East African agricultural research. But with over 80% of the area of Kenya in arid and semi-arid regions, the crop can have enormous potential. Constraints on acceptance are discussed. Results of yield trials conducted over several seasons show considerable fluctuation, ranging from 67 kg/ha (very poor management) to 1,441 kg/ha (proper management, no fertilizers, 231 mm of rainfall).

Preliminary agronomic studies on population density and intercropping indicate that proper management contributes largely to increased production and reduced labour inputs.

The literature cited shows that the nutritive value of proso is good compared with other cereals. The amount of indigestible fibre of the non-dehusked grain, on the other hand, is quite high. Traditional and mechanical processing have been observed in connection with food palatability.

It is concluded that there are possibilities of proso millet finding its place in the farming systems of those marginal areas where livestock is the main production factor and where food production needs a hardier cereal such as bulrush and proso millet. Agronomy and breeding research need more attention, however, while the identified optimal cultural practices need to be critically examined on the score of their economic viability. Last but not least, extension efforts will play a big role in re-introducing the crop.

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IMPROVEMENT OF COWPEA VARIETIES FOR DRY AREAS IN KENYA

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INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is an important grain-legume crop of arid and semi-arid regions in the tropics. In East Africa it is grown on an area of about 1 million hectares (Singh and van Emden, 1979). In Kenya it is the third most important grain legume after beans (*Phaseolus vulgaris*) and pigeon peas (*Cajanus cajan*) and is grown on 106,000 hectares annually (Ministry of Agriculture, 1981). About 85% of the total area under cowpea lies in the marginal-rainfall areas of Eastern Province and the remaining 15% is in Coast, Western, and Central Provinces (Muruli *et al.*, 1980). Cowpea is mainly grown in mixtures together with maize, sorghum, or pigeonpea, and rarely grown as a pure stand.

Cowpea grains contain 20–22% protein and the green leaves are a rich source of protein and vitamins. Dry grains are eaten together with maize, while the tender green leaves are boiled or fried and eaten with *ugali* or other cereal preparations (Acland, 1980). In Western and Central Provinces cowpea is mainly grown for its leaves, while in Eastern Province the crop is grown for both grain and leaves.

It has a well developed deep root system and can thrive well under drought conditions. In Eastern Province both indeterminate and semi-erect types are grown, while indeterminate land races are predominant in Western and Central Provinces. Cowpea nodulates freely with the wild *Rhizobium* strains present in these soils and can fix atmospheric nitrogen through symbiosis with *Rhizobium* for its own use as well as leaving some nitrogen in the soil for the succeeding crop. In some countries cowpea is grown as a forage crop, and in some places it is used to check soil erosion because of its rapid growth and creeping habit.

Yield potential in cowpea, as with most of the other grain legumes, is lower than some cereals due to the marginal conditions of moisture stress and soil fertility under which these crops have been grown for many years. The low yield in grain legumes is largely a matter of poor harvest index (Jain, 1975), rather than of total biological yield. There are indications that determinate types have a better harvest index than indeterminate types. However, it still remains to be determined whether determinate types are likely to perform better than indeterminate types in the dryland areas of Kenya. There are suggestions that indeterminate types, where vegetative development and pod formation occur simultaneously, perform better under drought conditions than determinate types (Chaturverdi *et al.*, 1980).

One of the major limiting factors in selection for increased crop yields is the genotype-environmental interaction. Stability of performance is a good technique for measuring the adaptability of different cultivars to variable environments (Eberhart and Russel, 1966).

The cowpea improvement programme at the National Dryland Farming Research Station (NDFRS) at Katumani aims at developing indeterminate, semi-spreading, dual-purpose, widely adapted, disease- and insect-resistant lines of cowpea suitable for dryland areas in Kenya. The results obtained from various experiments are outlined in this paper.

MATERIALS AND METHODS

In the course of 1980, 174 accessions of cowpea land races grown by farmers in Eastern and Coast Provinces were collected. Later, 146 lines were obtained through Plant Quarantine, Muguga, and another 91 lines from IITA, Nigeria. The local and exotic germ-plasm was evaluated during the subsequent crop season at both Katumani and Kampi ya Mawe for plant type, maturity, yield, and resistance to diseases and insect pests.

Pure lines developed from the local material

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and promising lines selected from exotic germ-plasm were advanced for preliminary yield evaluation during 1981–82. The preliminary yield trials were laid out in a randomized block design with 3 replications, at both Katumani and Kampi ya Mawe. Individual plots consisted of four rows each 4 m long with spacings 60 cm between the rows and 20 cm between the plants. Data on days to 50% flowering, plant height, number of grains/pod, and 100-seed weight were recorded. The central two rows from each plot were harvested for recording data on grain yield.

In a separate trial, 9 lines were evaluated for leaf yield at Katumani. The design of the experiment and spacings was the same as for the variety trial. The fresh leaves were weighed and then dried at 60°C in the oven for recording data on leaf dry-weight.

RESULTS AND DISCUSSION

Early cowpea-improvement work carried out at the NDFRS and the substation of Kampi ya Mawe revealed that most of the cultivars introduced from IITA, Nigeria, were relatively more susceptible to various diseases, septoria leaf spot, cercospora yellow mottle, ascochyta, powdery mildew, and rust than local material (Pathak, 1979; Muruli *et al.*, 1980). In the marginal areas of Kenya diseases pose a more serious problem in cowpea production than insect pests (Allen, 1979). Selections arising from the local germ-plasm proved to be higher yielding than most of the cultivars introduced from IITA (Pathak, 1979). In the later cowpea-breeding programme attention was focused on full exploitation of the local germ-plasm. 174 accessions collected from the Eastern and Coast Provinces were evaluated for plant type, maturity, disease resistance, etc. A wide range of genetic variation was observed for various plant characters of economic importance. Yield evaluation and a description of other characteristics of some promising selections made from this germ-plasm are given in this paper. In addition to the agronomic evaluation, the germ-plasm was also screened and studied against important cowpea diseases and the results appear in a separate paper in these proceedings (Waite *et al.*, 1983).

Grain Yield

Yield trials consisting of 7 local and 3 IITA entries were conducted during the short rains of 1980–81 and long rains of 1981. The results obtained are presented in Table I. Combined analysis was run on the data from Katumani and Kampi ya Mawe for the long rains of 1981. Highly significant varietal differences were observed for each location. Katumani 80 (353), a dual-purpose, semi-spreading indeterminate line, showed superiority in grain yield at the two locations, followed by Machakos 66 (012) and VITA 3. Variety × location linear interactions were found to be highly significant (Table II), showing that the yields are not consistent over the locations. Katumani 80 has the highest mean yield for the two locations (1,535.9 kg/ha), followed by Machakos 66 (1,335.9 kg/ha).

TABLE I—RESULTS OF THE COWPEA VARIETY YIELD TRIALS CONDUCTED AT KATUMANI AND KAMPI YA MAWE DURING DIFFERENT RAINY SEASONS (MEAN YIELD, kg/ha)

Genotype	1980/81 SR Kampi ya Mawe	1981 LR Katumani	1981 LR Kampi ya Mawe	1981 LR Katumani/ Kampi ya Mawe
TVX 337–3F	527.6	406.3	1,015.6	710.9
Emma-60	263.5	1,072.9	1,023.4	1,048.2
Katumani 80 (353)	710.9	1,833.3	1,238.5	1,535.9
Kang'au I	424.5	937.0	1,000.0	968.8
Kathoka	620.3	1,447.9	992.2	1,220.1
VITA 3	522.9	1,596.4	570.0	1,083.2
TVX 33–1J	699.7	1,171.9	1,046.9	1,109.4
Machakos 66 (012)	1,562.5	1,109.4	1,335.9	
TVX 1999–02E	613.5	494.8	843.6	669.3
Kang'au II	599.6	1,515.6	765.6	1,140.3
LSD 5%	107.3	148.6	134.3	
LSD 1%	146.9	203.5	184.0	

TABLE II—ANALYSIS OF VARIANCE FOR KATUMANI AND KAMPI YA MAWE DURING LONG RAINS 1981

Source	df	MS	Fcal
Total	59		
Locations	1	363793.1	53.43***
Blocks	4	2306.6	0.34
Varieties	9	168152.2	24.70***
Locations × varieties	9	157356.6	23.11***
Error	36	680.8	

C.V. = 11.9%

S.E. (Locations) = 15.1
S.E. (Varieties) = 33.7
LSD 5% = 137.5
LSD 1% = 185.3

Stability of yield is an important aspect of crop production, particularly for dry areas of Kenya where the rainfall is erratic and unpredictable, resulting in frequent crop failure. Stability of performance as a measure of determining the adaptability of different cultivars to different environments, as given by Finley and Wilkinson (1963) and Eberhart and Russel (1966), has been extensively used in various crops, but very little has been reported on grain legumes (Malhotra *et al.*, 1971). Katumani 80 has shown superior performance across the localities and is likely to perform better in variable environments.

The number of days taken to 50% flowering by various entries in the trial varied from 45 to 66 days (Table III). Emma 60 took 45 days to flower, while VITA 3 was the last to flower (66 days). 100-seed weight varied from 12.4 g/100 to 20.5 g/100 in TVX 337—3F and VITA 3 respectively. The high-yielding lines Katumani 80 and Machakos 66 do not differ much in number of days taken to 50% flowering, but 100-seed weight is higher in Machakos 66 (16.6 g/100) as compared to Katumani 80 (13.6 g/100). The number of seeds per pod varied from 10 to 18; however, the high-yielding lines Katumani 80 and Machakos 66 had 16 and 15 seeds/pod respectively.

Leaf Vegetable

Cowpea leaves are extensively used as a leaf vegetable in various parts of Kenya. During the dry months following each rainy season, cowpea leaves are perhaps the only green leaf vegetable available to the majority of the farmers in the dry areas. One of the major objects of the cowpea-improvement programme at Katumani is to develop dual-purpose varieties.

TABLE III—MORPHOLOGICAL CHARACTERISTICS OF COWPEA LINES EVALUATED IN THE YIELD TRIALS DURING 1981 LONG RAINS

Genotype	100-seed weight (g)	Days to 50% flowering	Mean no. of seeds/pod
TVX 331—3F	12.4	59	11
Emma-60	16.0	45	10
Katumani-80 (353)	13.6	55	16
Kang'au I	12.4	56	13
Kathoka	14.0	57	16
VITA 3	205.0	66	18
TVX 33 1J	12.4	54	12
Machakos 66 (012)	16.6	52	15
TVX 1999-2E	14.1	54	14
Kang'au II	18.4	57	14

Nine promising lines were tested for their fresh- and dry-matter leaf yield and the results obtained are presented in Table IV. Significant varietal differences existed among the genotypes. In green leaf yield, line 353 out-performed other entries (2,792 kg/ha), followed by No. 12 (2,475 kg/ha). On the basis of dry-matter yield, 353 maintained superiority in yield (469 kg/ha), followed by No. 11 (467 kg/ha). The fresh-leaf yield of No. 12 is second highest, but its dry-matter weight is low. Large differences in percentage dry-matter weight existed among various cultivars. Some of the low-yielding lines produced a high percentage of dry matter. Katumani 80 has 16.8% dry matter and its yield of fresh and dry weight is highest. In cowpeas, loss in grain yield due to defoliation before the flowering stage is negligible (Ezedinma, 1973). In a dual-purpose variety leaf picking during early stages of growth may not have adverse effect on grain yield. The indeterminate type can tolerate defoliation up to 50% without any appreciable loss in grain yield (Ezedinma, 1973). The flowering and immediate post-flowering period is the most critical period, and reduction in leaf area due to defoliation at this time is likely to affect yield (Sinha and Savithri, 1978). It is advisable to reduce leaf picking after the flowering stage when the crop is being grown for grain production. The determinate cultivars are more prone to loss in yield due to defoliation, since such cultivars produce little vegetative growth after flowering (Vien and Tayo, 1978). In Eastern Province the importance of leaves cannot be ignored in the future cowpea varietal improvement programme.

TABLE IV—COWPEA LEAF VEGETABLE VARIETAL YIELD TRIAL CONDUCTED AT KATUMANI DURING 1980/81 SHORT RAINS

Strain	Fresh-wt. yield/ha (kg)	Dry-wt. yield/ha (kg)	Percentage of dry weight
Kang'au II			
(009)	2,308	421	18.24
011	1,708	467	27.34
012			
(Machakos 66)	2,475	313	12.65
025	1,300	256	19.69
024	933	150	16.08
010	2,050	321	15.66
026	2,142	390	18.21
353	2,142	469	16.80
(Katumani 60)			
028	1,608	192	11.94
LSD 5%	26.5	15.52	
LSD 1%	36.5	22.29	

Insect Pests

Cowpea suffers heavily from insect pests, and losses in grain yield may sometimes be very high. Farmers in Africa generally consider monoculture cowpea as a high-risk crop (Singh, 1980). By adopting appropriate plant-protection measures, spectacular increases in yield, sometimes as much as ten-fold, have been reported (Booker, 1965; Kayumbo, 1975; Koehler and Mehta, 1972). This shows that insect pests are one of the biggest constraints on cowpea production.

In Kenya a number of insect pests can damage the crop, the major ones being thrips (*Megalurothrips rjostedti* Tryhom), leaf hoppers (*Empoasca* spp.), legume pod-borers (*Maruca testulalis* and *Heliothis armigera*), aphids (*Aphis craccivora* Koch), pod-sucking bugs (*Clavigralla gibbosa*), and apion beetle (*Apion solenortum*). Bruchid is a very serious stored-grain pest of cowpea. Of the pod-borers, *Maruca testulalis* is more serious at the coast, while *Heliothis armigera* causes more damage at Katumani (Muruli *et al.*, 1980). Considerable progress has been made in recent years in developing insect-resistant varieties of cowpea at IITA (Singh, 1980).

Advanced breeding lines showing resistance against thrips, aphid, and bruchid have been secured from IITA. Tests on their adaptability

and reaction to these insects under Kenya conditions are in progress. The aphid-resistant lines were inoculated with aphid introduced from a cowpea field. The local check lines 349 and 355 showed a high aphid population, while lines TVU 3000 and TVU 801 were found free of any aphid infestation. The population of thrips during the long rains of 1983 was too low to show appreciable differences between resistant material and the susceptible check. Field screening of the IITA insect-resistant material will be continued during the coming crop season.

It is planned to screen the local cowpea germplasm against various insect pests in collaboration with the Senior Entomologist, National Agricultural Laboratories, Nairobi during 1983–84.

CONCLUSION

Cowpea, being a drought-resistant crop, can thrive well under moisture-stress conditions. The grains are a rich source of protein and the leaves contain 20–40% protein on a dry-matter basis, depending on the stage of plant growth. Cowpea crops are prone to a number of diseases and insect pests.

Indeterminate semi-spreading plant types appear to be more suitable for the dry areas than determinate types. Such plants have the potential to recover better after stress and can tolerate insect damage to a greater extent because of a compensatory mechanism—if the first flowers/pods are destroyed by insects the indeterminate types continue producing more flowers and set pods (Singh, 1980). Katumani 80, a selection from local germ-plasm, is a semi-spreading indeterminate cultivar widely adapted to low altitudes (below 1,300 m) in the dry areas of Eastern Province. Machakos 66 is an indeterminate dual-purpose type likely to perform better at higher altitudes (above 1,300 m). It is susceptible to rust in the Makueni and Kiboko areas (Waite *et al.*, 1983).

Insect pests are a major problem in cowpea production. Most of the small farmers in the area cannot afford to spray this crop and the possibility of extending or even maintaining the area under cowpea is remote. There is an urgent need to develop insect-resistant/tolerant varieties and also to work out appropriate technologies for integrated pest management to reduce yield losses.

SUMMARY

Cowpea is one of the most important grain legumes in Kenya, where 85% of the area under this crop lies in the semi-arid areas. Both dry grains and green leaves are eaten along with cereals. Cowpea yields are low due to lack of appropriate varieties and susceptibility to insect pests and diseases. The cowpea improvement programme at the NDFRS aims at developing semi-spreading, indeterminate, early-maturing, widely adapted, insect- and disease-resistant varieties. Katumani 80, a local selection, is a dual-purpose, semi-spreading, high-yielding, widely adapted line which has shown field tolerance to various diseases. Its grain yield in the trial reported was 1,535.9 kg/ha and green leaf yield 2,792 kg/ha.

Insect pests are a major constraint. Seeds of advanced breeding lines showing resistance against thrips, aphid, and bruchid were secured from IITA, Nigeria. Preliminary investigations have shown that their response to pests under local conditions appears to be encouraging.

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DEVELOPMENT OF DROUGHT-RESISTANT, HIGH-YIELDING PIGEONPEA LINES SUITABLE FOR SEMI-ARID AREAS

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INTRODUCTION

Pigeonpea (*Cajanus cajan* (L). Millsp.), commonly known as *mbaazi*, is one of the most important grain legumes in marginal-rainfall areas of Kenya. With an approximated area of 164,000 ha and an average production of 635 kg/ha (Ministry of Agriculture, 1981), Kenya ranks second only to India in pigeonpea production. Kenyan farmers grow tall, late-maturing land races with large seeds which take up to 10 months to mature and are adapted to the local farming systems. Traditionally, the crop is generally intercropped with maize, sorghum, beans, and cowpea (Shakoor *et al.*, 1983). It is rarely grown as a sole crop. However, in Coast Province it is largely grown as a perennial border crop.

Pigeonpea is a deep-rooted legume capable of withstanding very dry conditions. The plant can be used as an animal feed, green manure, and a cover crop (Khan, 1973). The late-maturing varieties are used as temporary shade for coffee, tea, and cocoa, as a source of fuel, and for thatching and making baskets and grain stores (El Baridi, 1978). Pigeonpea nodulates freely under normal conditions and rhizobia, through a symbiotic relation, can fix nitrogen sufficient for the plant's own use and leave residual nitrogen of about 40 kg/ha in the soil, which can be used by the subsequent crop (Sheldrake and Narayana, 1979; Rao *et al.*, 1981). Pigeonpea plays an important role in providing an amino-acid-balanced diet in the developing tropical countries, where large sections of the population cannot afford animal protein in their daily diets. In Kenya, both green and dry peas are boiled together with maize, and at times potatoes can be added to this preparation.

Although pigeonpea is widely grown in marginal-rainfall areas of Kenya, its improvement through breeding has received very little attention and the yields are still rather low.

The long-maturing character of the indigenous pigeonpea makes it vulnerable to the drought conditions prevalent after the long rains, when the crop reaches the reproductive phase. Moreover, due to its tall stature and long duration, valuable soil nutrients and limited soil moisture are largely utilized for vegetative growth rather than grain development. Therefore, early-maturing, short-statured varieties with a large number of fruit-bearing branches are expected to perform better in areas with low rainfall, without affecting the existing farming system.

Previous attempts to introduce high-yielding, early-maturing, small-grained pigeonpeas from India did not succeed in Eastern Province because of consumers' preference for large grains as well as of adaptation to local conditions. However, Indian types are grown along with local pigeonpea in Coast Province. The development of short-statured early-maturing varieties with medium to large grains adapted to the low rainfall is necessary for the marginal areas. The first early-maturing variety in Kenya was released recently (Onim, 1983).

Realizing the importance of pigeonpea, the Government of Kenya, with funds from UNDP/FAO, gave the National Dryland Farming Research Station (NDFRS) at Katumani, Machakos, the mandate to improve pigeonpea production. Eastern, Coast, and Central Provinces are the major pigeonpea-growing areas of Kenya. According to the basic report on the Integrated Rural Survey 1974—75, Eastern Province leads in hectarage and 90% of the total area under pigeonpea lies in this province. Compared to other pulses in Kenya, pigeonpea ranks second to beans in both area under cultivation and production. Late pigeonpea is planted in the October-November period (short rains). It comes to flower in June-July, after the long rains, and matures in the month of September. Because of bimodal rainfall patterns in most of the dryland areas of

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Kenya, two crops of early pigeonpea varieties (up to 120 days) can be grown.

MATERIAL AND METHODS

The germ-plasm collected from Eastern and Coast Provinces was grown at both Katumani and Kampi ya Mawe during 1980–82 for evaluation. Single plant selections made on the basis of maturity, plant type, raceme length, grain characters, and grain yield were grown in plant progeny rows.

Nineteen promising and nearly uniform lines were bulked for a preliminary yield test along with a late local line as a check. The trial was conducted in a randomized block design with three replications at Kampi ya Mawe during the 1982–83 season. Each plot consisted of 5 rows, with 75 cm between rows and with plants spaced 40 cm apart. No fertilizer was applied. Two sprays with Rogor E were given at the flowering and grain-formation stages. Yield data were taken on a plot basis. After the first harvest in March, the plants were allowed to grow on to give a second harvest after the long rains.

A number of single-plant selections from segregating populations 20 and 85 were evaluated for their resistance to pod-sucking bug (*Clavigralla gibbosa*), using entry 109 as a susceptible check. The plants were covered by wire-mesh cages measuring one square metre at flowering. Fifteen pairs of pod-bugs (at mating time) were collected from separate pigeonpea fields and released in the cages. Data were recorded on number of eggs per cluster, days to hatching, and mortality of nymphs.

The procedure for screening against wilt (*Fusarium udum*) is outlined in Waite *et al.*, (1983).

RESULTS AND DISCUSSION

Germ-plasm

In the recent past efforts have been focused on exploiting the indigenous pigeonpea, which has been grown by farmers for a long time. The pigeonpea improvement programme at the NDFRS collected over 200 accessions from the districts of Kitui, Machakos, Embu, and Meru in Eastern Province in 1979–80. The ICRISAT Genetic Resource Unit, in collaboration with the NDFRS also collected 250 accessions from various parts of Kenya (Ramanandan *et al.*, 1982). Observations on this germ-plasm at Kampi ya Mawe and Katumani revealed enormous genetic variability for maturity, plant height, number of grains per pod, grain characters, and other traits.

Materials collected from the coastal areas were early in maturity and of short stature when grown at Katumani and Kampi ya Mawe.

Most of the tall accessions had apical bearing, while the raceme length varied considerably in the semi-dwarf and short accessions. Accessions KCC 610 and KCC 810, of coastal origin, had 8 grains per pod. The grain colour varied from black to purple, brown, cream, and white, with various degrees of mottling and speckling.

In Kenya land races, the flower petals are predominantly long and tightly overlapping. This character ensures self-pollination unless climatic and insect conditions interfere. A similar floral biology has been reported by Wallis *et al.*, (1981). This character is being exploited in our breeding programme for maintaining purity of the lines.

Early maturity

A number of early-maturing lines were selected from a heterogeneous population of accession numbers KCC 423 and KCC 422, collected from Mwingi location in Kitui, on the basis of maturity, plant type, raceme length, grain characters, and grain yield during 1980–81. In 1981–82, plant row progenies were grown and uniform-looking lines were bulked for preliminary yield trials.

Nineteen promising early lines were included in the preliminary yield trial, with late and medium local checks. The yield was taken on a plot basis for the first crop. The experiment was ratooned during the long rains of 1983. The final harvest was completed in July-August 1983. The yields of the two harvests were combined in the case of the early-maturing lines. Due to unequal stands, yields were adjusted using covariance analysis.

Yield comparisons (Table I) revealed that fourteen entries gave significantly higher yield than the late local check, while only seven entries performed significantly better than the early-maturing check (NPP 670). Entry KCS 74–1 had the highest yield (2,268 kg/ha), followed by KCS 22–4 (2,241 kg/ha) and KCS 13–11 (2,042 kg/ha). Generally, the highest-yielding lines had an average of 10 g/100 seeds.

The early-maturing lines had higher yields than the medium- or late-maturing checks. In

TABLE I—RESULTS OF THE PRELIMINARY YIELD TRIAL CONDUCTED AT KAMPI YA MAWE DURING 1982–83

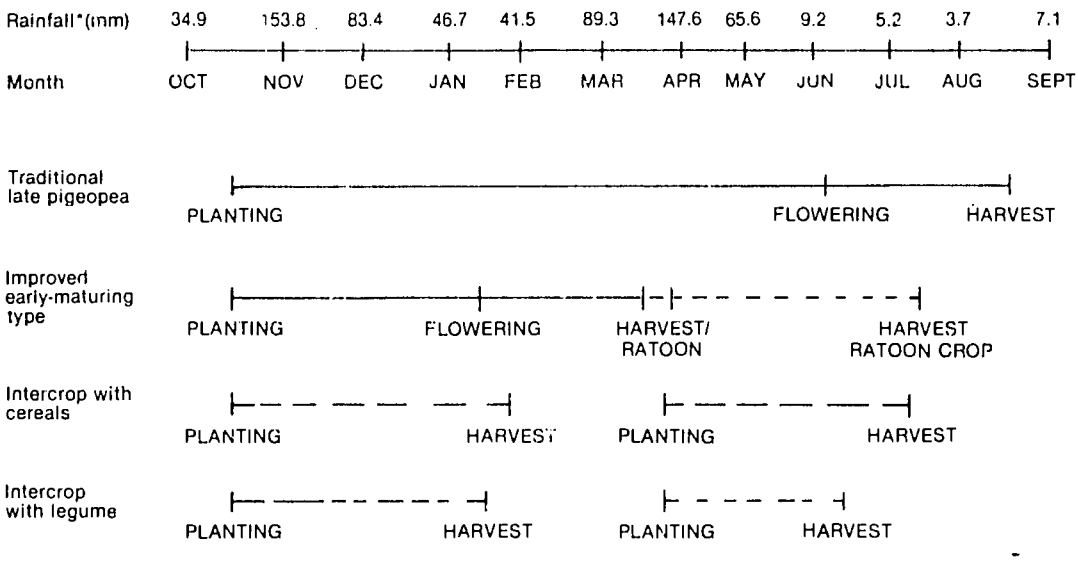
Entry	Ajusted yield* g/plot	Ajusted yield* kg/ha	Maturity	100 seed weight (g)
KCS 7401	5,103	2,268	Early	10.0
Local	2,049	911	Late	13.0
KCS 25–2	3,939	1,751	Early	14.0
KCS 43–8	3,329	1,480	Early	11.1
KCS 37–10	4,077	1,812	Early	9.5
KCS 95–4	4,165	1,851	Early	14.3
KCS 78–4	3,783	1,681	Early	10.4
KCS 80–RAI	4,463	1,984	Early	11.1
KCC 422–22–4	5,043	2,241	Early	9.8
KCS 50–3	4,031	1,791	Early	11.3
KCS 5–12	3,827	1,701	Early	11.0
KCS 21–12	4,561	2,027	Early	10.7
KCC 576–3	2,258	1,004	Medium	16.8
KCS 96–7	3,044	1,353	Early	10.0
KCS 13–11	4,595	2,042	Early	13.0
KCS 11 RAI	2,712	1,205	Early	9.9
NPP 670	2,800	1,244	Early	17.2
KCS 40–10	3,295	1,466	Early	12.9
KCS 21–6	4,258	1,892	Early	10.7
KCS 60–8	3,453	1,534	Early	13.0
SED	631			
LSD 5%	1,279			
C.V.	19.8			

*Yield adjusted using eovariance analysis

fact, this was expected because of the two harvests for the early entries. A similarly higher grain yield in early-maturing pigeonpea was reported in Coast Province by Nangju *et al.* (1976). The yield increase of the best-yielding line (KCS 74–1) over the late local and early (NPP-670) checks was 149% and 82% respectively.

The ratoon yield was 36.3% more than the first harvest yield. This may be attributed to the fact that pigeonpea is inherently a slow-growing crop in the early stages (Wallis *et al.*, 1975). Most of the soil moisture during the short rainy season is lost by the time the early lines come to flower. During the subsequent regrowth, the already established plants utilize the moisture from the long rains more efficiently for both vegetative and reproductive growth.

The general problem with early-maturing pigeonpea is its vulnerability to insect pests (Green *et al.*, 1979). In Eastern Province, early-maturing pigeonpea flowers when the weather is warm and there is no other alternate crop in the field, and hence the insect pressure is high (Fig. 1). At present, plant-protection measures seem to be necessary to realize the high yield potential of the early-maturing lines until appropriate pest management methods have been developed. However, during the ensuing long rainy season, if the crop is ratooned by cutting the plant at a height of approximately 25 cm from the ground, fresh regrowth occurs and flowering is delayed to coincide with other alternate-host legume crops. This is likely to reduce the insect pressure on the early-maturing pigeonpea. Appropriate pest-management techniques and agronomic practices need to be worked out under the prevalent farming systems for the early-maturing pigeonpea varieties.



*Average for 24 years (1957–80) recorded at Katumani Research Station

Fig. 1. Production system of pigeonpea in Eastern Province of Kenya

Medium and late maturity

Green *et al.* (1979) observed that the maturity period of pigeonpea lines ranges from 120–270 days and that each specific maturity group is adapted to a specific environment. They found that early-, medium-, and late-maturity groups are suitable for areas of low, medium and high rainfall respectively. Therefore, our breeding programme on medium- and late-maturing pigeonpeas is receiving equal attention for their areas of adaptation. A number of promising lines have been identified which will be evaluated for yield and yield components during the short rains of 1983. The progress on the late-maturing varieties of pigeonpea is relatively slow due to their long duration in the field.

Breeding for disease resistance

Wilt caused by *Fusarium udum* is the commonest disease of pigeonpea in Kenya. Apart from 3–4 year rotation, genetic control through wilt-resistant varieties is considered to be the most effective method (Nene *et al.*, 1981). A wilt sick plot, as described by Nene *et al.* (1980), has been developed at Katumani for screening against wilt disease. A number of local and exotic lines have been screened. Out of 100 lines received from ICRISAT, only two lines showed consistent resistance to the local wilt strains (Waite *et al.*, 1983). Eleven local lines have been identified as wilt-resistant during the two years of testing. Some of these lines are being evaluated for yield and other agronomic characters and are also being used in the breeding programme.

Insect pests

Among the insect pests, thrips, *Heliothis*, podfly, and pod-sucking bug are the most serious pests of pigeonpea in Kenya. In the long rainy season of 1983, pod-sucking bugs caused maximum damage in pigeonpea germ-plasm at Katumani (Kabir and Kibata, 1983). The breeding programme on insect pests is still in the initial stages. However, potentially resistant population lines have been identified for further studies. These include two selections from accession KCC 423 (Nos 20, 85) and accession KCC 610 for pod-sucking bug.

On these selections, appreciable differences were noted in the number of eggs per cluster. Hatching was delayed by two days and the nymphs started dying after feeding on the resistant plants. Pod-sucking bug is usually gregarious, but in the case of resistant plants, the adults were found to be scattered. The basis of resistance appeared to be antibiosis. A similar type of

resistance was reported by Ferry and Guthbert (1975) and by Singh (1977). The lines tested are early maturing, with desirable plant type and acceptable grain characters. Efforts are under way to develop true-breeding lines with good yield potential.

CONCLUSIONS

Pigeonpea is traditionally grown as a mixed crop and rarely grown as a sole crop. The early-maturing short-statured types fit in the bimodal rainfall pattern prevalent in the Eastern Province of Kenya, where the larger proportion of the pigeonpea crop is grown. Early-maturing pigeonpeas provide green peas during the months of February and March, when the farmers have nearly exhausted their previous harvest of other grain legumes. Preliminary investigations carried out at NDFRS, Katumani, on the cropping pattern showed that the early-maturing types are equally suitable both as a pure stand and when grown in mixture with maize or other legumes (Dr. John Ashley, personal communication).

The already established ratoon plants have the potential to utilize the residual moisture more efficiently, during the ensuing long rains, which are relatively unreliable. Therefore, the ratoon crop is likely to succeed, even if the rains are not adequate for long-duration types or for a freshly planted crop. More information on appropriate crop combination, plant population, ratooning, and other agronomic aspects needs to be gained for fully exploiting the high yield potential of early-maturing types.

The early types are likely to be a target for various insect pests, because pigeonpea comes to flowering at a time when there is no other legume crop in the field. In cases of high incidence of insect pests the crop will need one or two sprays, particularly during the short rainy season. However, during the long rains in the case of the ratoon crop (cut back) flowering usually synchronizes with other crops having common insect pests. The traditional long-duration pigeonpea usually flowers late, during the comparatively cool dry months of June and July, when the insect activity slows down.

This warrants a careful study to monitor the behaviour of major insect pests of pigeonpea in Eastern Province. Such information will have important implications for the pigeonpea breeding programme.

SUMMARY

Pigeonpea is an important crop in the Eastern Province of Kenya for its grain. Tall, late varieties are grown, intercropped with either cereals or other legumes or both. Early-maturing lines which fit into the bimodal rainfall pattern of the area have been identified from the local germ-plasm. A preliminary yield trial at Kampi ya Mawe revealed that KCS 74–1, KCS 22–4 KCS 13–11, and KCS 21–12 among the early lines yielded over 2,000 kg/ha. The average for ratoon crop was 36.3% higher than the first harvest. Generally, the highest-yielding lines had an average of 10 g/100 seeds. Promising material of medium- and long-maturity groups possessing large grains has been identified. Various aspects of the possible implications of early-, medium-, and late-maturity types in the existing farming system have been discussed.

Other aspects of pigeonpea breeding include insect pests and disease resistance. Material showing resistance to pod-sucking bug has been identified. The mechanism of resistance appears to be antibiosis.

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BREEDING FOR EARLY MATURITY, DROUGHT, DISEASE AND INSECT RESISTANCE IN SWEET POTATO

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INTRODUCTION

In Kenya, sweet potato (*Ipomoea batatas L.*) is grown on 40,000 ha annually (Ministry of Agriculture, Annual Report 1981) and is the third most important tuber crop after Irish potato and cassava. Most of the acreage lies in the densely populated areas of Central (13,000 ha) and Nyanza Provinces (14,200 ha) (Central Bureau of Statistics, 1977). In the semi-arid areas of Eastern Province the crop is grown in a limited area (1,900 ha). The total production of sweet potato is 340,000 tonnes at an average yield of 8,947 kg/ha (FAO, 1974). The farmers grow local land races depending on taste, skin, and flesh-colour preferences. White flesh-colour types are predominant in Central and Eastern Provinces, while both white and orange flesh types are grown in Western and Nyanza Provinces. Up to the late 1960s the use of sweet potato as a food was common. There is, however, a declining trend in the consumption of sweet potatoes, particularly in Central Province. The per capita consumption during the 1964–1966 period was 29.5 kg, which dropped to 26.3 kg during 1972–74 (FAO Food Balance Sheets). This may be partly due to an increasing trend to grow more maize and cash crops. Sweet potato, being a long duration and less remunerative crop, is receiving less attention from the farmers in these areas.

In addition to being a rich source of carbohydrate, the sweet potato also provides 4.5–7% protein (Purcell, 1972) depending on the cultivar. The vines are a good source of animal feed and can provide green forage during the dry months of February, March, August, and September, when there is a scarcity of green grass. The plant parts above ground contain 21.7–31.3% protein on a dry-weight basis (AVRDC, 1974). Tender vine tops about 10 cm long are used as a green vegetable in various countries. They are a rich source of vitamins A, B, and C, iron, calcium, and fibre (Villareal *et al.*, 1982). In countries like the Philippines and Taiwan, the vines and tubers are frequently used as animal feed (Yang, 1982). Sweet potato is considered a fairly drought-resistant crop and can be grown from sea level to 2,100 m (Acland, 1980). The present land races grown by the farmers generally take 5–7 months to mature. Although foliar diseases, with the exception of virus, are not very serious, crop loss due to sweet potato weevil can be very severe, especially in dry areas (Kibata, 1973). The weevil can damage both vines and tubers. The damaged tuber has a bitter taste due to ipomeamarone which is released by the sweet potato (Akazawa *et al.*, 1960). Generally there is no antagonistic feeling against sweet potato as compared to cassava. Most of the people in this country have a preference for it. As it is a drought-resistant crop, the prospects of extending its cultivation on a large scale in Eastern Province are reasonably encouraging. In view of its importance, systematic work on the development of early-maturing, drought-resistant, weevil- and virus-resistant varieties was undertaken during 1982 at the National Dryland Farming Research Station (NDFRS), Katumani. The results obtained are discussed in this paper.

MATERIALS AND METHODS

Hybrid seed of USA origin involving drought-resistant parents was obtained through the plant quarantine at Muguga and grown at Katumani. Several clones were selected from it. In the meantime two drought-resistant, early-maturing varieties, KSP_2 (Vardaman) and KSP_3 (Travis), were obtained from the USA and another nine improved varieties were secured from the IITA, Nigeria. Simultaneously, efforts were made to assemble local germ-plasm, and at present 93 accessions are available. As a result of prelimi-

1. FAO/National Dryland Farming Research Station, Katumani
2, 4. National Dryland Farming Research Station, Katumani
3. Kenya Agricultural Research Institute, Muguga

nary screening, seven lines were selected for preliminary yield evaluation and planted at the NDFRS during the long rains of 1983. The rains came late and therefore the trial was planted on 23 March. The variety trial was laid out in a randomized block design with three replicates.

In another trial, variety KSP_{19} (TIS 3017) was used to investigate the effect of root initiation on plant establishment and tuber yield. The end portions, measuring 30 cm and containing about five nodes, were cut and the lower two nodes were immersed in water, about two weeks before the expected onset of rains. The material was planted after the first effective rain, which was 8.5 mm followed by 49.3 mm after planting. The experimental plot in both trials consisted of 5 rows 70 cm apart, with 8 plants/row at 50 cm spacing between plants. No fertilizer was applied and the experiment received two weedings. Proper ridging was done during the second week after planting. The crop was sprayed with carbaryl at the rate of 1.5 kg/ha to control leaf-eating insects. The crop was harvested after 18 weeks and roots with a diameter of 30 mm and above were weighed. The vines were measured from the base to the tip of the longest vine for recording of the height of the plant on 5 randomly selected plants.

At harvesting time, the main stem of the plant was scored for weevil incidence by using a scale 0—2, where 0 indicates no visible sign of damage, 1 indicates swelling at the base of the stem and 2 indicates severe damage. A scale of 0—3 was used to measure weevil damage to tubers, 0 indicating no sign of weevil incidence, 1 holes at the neck of the tuber, 2 holes on the root neck extending to 5 cm down the storage root, and 3 indicating damage throughout the root.

A disease with typical virus symptoms was noticed in the yield trial plots at Katumani on the variety KSP_3. The plants were dwarfed, and the leaves mottled with vein clearing. Several plants from the field were potted and taken to KARI, Muguga, for virus indexing. Attempts were made to isolate and characterize the causal agent in the glasshouse by host-range and insect-vector studies. Sap inoculations were made by grinding sweet potato leaves in water, as described by Sheffield (1957). The inoculum was then rubbed on the leaves of young indicator plants which had been pre-darkened for 24 hours and dusted with 600 mesh carborundum. The following species of plants were inoculated: *Ipomoea setosa, Chenopodium quinoa, Chenopodium amaranticolor, Nicotiana clevelandii* and *Nicotiana tabacum*. Insect transmission was carried out using the aphid *Myzus persicae* and the whitefly *Bemisia tabaci*. Aphids reared on healthy Chinese cabbage were starved for one hour, and then fed for 10—15 minutes on diseased sweet potato leaves to acquire the virus. Five aphids were then transferred to each *Ipomoea setosa* plant and allowed to feed for one week, after which the plants were sprayed with a nicotine-based insecticide to kill the aphids. Whiteflies reared on healthy cassava were transferred on to diseased sweet potato and allowed an acquisition feeding of 48 hours before being moved on to *Ipomoea setosa*. Graft transmission was carried out by top cleft graft using infected sweet potato scions on healthy plants of *Ipomoea setosa*.

RESULTS

The results obtained from the varietal trial are presented in Table I. Although the yield differences among the varieties are quite high, the results are non-significant. This may be attributed to unusual dry weather conditions influencing the tuber formation in various treatments. The high C.V. of 107.95% indicates the magnitude of variation in the experiment. However, line KSP_{20} (TIS 2534) outyielded (8.21 t/ha) all the other entries, and the lowest yield was recorded from KSP_{10}—the local check (1.43 t/ha). KSP_2 was the second-highest yielding line (4.46 t/ha) followed by KSP_{19} (3.34 t/ha).

The total rainfall received during the growing period was 144.4 mm. The inadequate moisture affected the development of vines in all the entries and the vine length varied from 35.00 cm to 81.60 cm (KSP_2 is an erect and compact bunch type, KSP_3 is semi-erect, while the other entries are the spreading type). The entries did not show any disease symptoms, except for KSP_3, which showed virus symptoms two weeks after planting and continued throughout the growing period.

The quality characteristics of these lines are given in Table II. The highest yielding line, KSP_{20}, has an attractive creamy-white flesh and sweet taste, free of fibre and of moist texture. The panel taste test was based on 21 participants, representing different classes of people. Most of the tasters did not like the orange flesh colour of KSP_2 and KSP_3.

The experiment on root initiation before planting was carried out using KSP_{19}. Data on tuber yield, vine length, and plant establishment are presented in Table III. The treated vines gave significantly higher yield (14.10 t/ha) as com-

TABLE I—RESULTS OF SWEET POTATO YIELD TRIAL CONDUCTED AT NDFRS KATUMANI DURING LONG RAINS 1983

Entry	Yield (t/ha)	Number of tubers/plant	Weight/tuber (g)	Vine length (cm)	Virus incidence	Weevil incidence on tuber
KSP_1	1.91	2.40	44.58	57.30	None	0.00
KSP_2 (Vardaman)	4.46	3.5	71.58	35.00	None	1.30
KSP_3 (Travis)	2.98	2.20	75.91	36.20	Present	0.16
KSP_{10} (local check)	1.43	2.20	36.36	72.30	None	0.30
KSP_{15} (TIB 9)	2.98	3.80	43.95	41.70	None	0.10
KSP_{19} (TIS 3017)	3.34	2.30	81.30	44.70	None	0.07
KSP_{20} (TIS 2534)	8.21	2.80	64.29	81.60	None	0.07
LSD 0.05	NS*	NS	—	17.18	—	4.83

*NS = non-significant

TABLE II—TUBER CHARACTERISTICS OF THE ELITE LINES OF SWEET POTATO

Line	Skin colour	Flesh colour	Texture	Fibre	Taste	Remarks
KSP_1	Light brown	Yellow with an orange tinge	Moist	None	Sweet	Flesh colour not attractive
KSP_2	Copper brown	Orange	Moist	None	Sweet	Flesh colour not attractive
KSP_3	Brown	Orange	Moist	None	Not sweet	Flesh colour not attractive
KSP_{10}	Purple	White	Dry	None	Sweet	Flesh colour attractive
KSP_{15}	White	Ligh yellow	Moist	None	Sweet	Flesh colour acceptable
KSP_{19}	White	Yellow	Moist	None	Not sweet	Flesh colour acceptable but texture too soft
KSP_{20}	Purple	Creamy white	Moist	None	Sweet	Flesh colour attractive

TABLE III—RESULTS OF THE EXPERIMENT ON EFFECT OF ROOT INITIATION ON TUBER YIELD, VINE LENGTH, AND STAND IN SWEET POTATO AT KATUMANI, LONG RAINS 1983

Treatment	Yield (t/ha)	Vine length (cm)	Stand (%)
Rooted cuttings	14.10	104.20	92.19
Direct planting (control)	10.00	83.20	84.38

pared to the control (10.00 t/ha). In the treated plots the plant stand was also better (92.19%) compared to the control (84.38%).

KSP_3 is an early-maturing good yielding line but is susceptible to the virus complex. During the 1983 long rains, KSP_3 was severely affected by virus and investigations were carried out at KARI, Muguga. The results obtained are discussed here. The virus was easily sap-transmitted to *Ipomoea setosa*; five plants of the seven inoculated became infected. The virus induced severe systemic vein chlorosis and vein netting in *Ipomoea setosa* 14 days after inoculation. No symptoms were observed on the non-inoculated controls. Local chlorotic lesions were observed on the leaves of the five sap-inoculated *Chenopodium quinoa* plants after ten days. There were only a few local lesions, indicating low virus concentration in the sweet potato. No symptoms were observed on the other index plants. Two of three *Ipomoea setosa* plants grafted became infected. Electron micrographs showed flexuous rods 850 nm in the four infected leaf samples.

So far, 93 accessions have been added to the sweet potato germ-plasm, consisting of both exotic and local land races (Table IV). Preliminary observations on this germ-plasm show that a wide genetic variability exists for maturity period, plant type, tuber character, disease reaction, and insect incidence. KSP_2 and KSP_3 (exotic) are extra-early in maturity. Both take 100 days to mature. Systematic evaluation of this material will be continued in the ensuing seasons.

TABLE IV—SWEET POTATO GERM-PLASM MAINTAINED AT NDFRS, KATUMANI, DURING 1983

Country of origin	Place	Number of accessions (seed samples)	Type of material
Puerto Rico	—	1	Seed
USA	Mississippi	1	Variety
USA	Louisiana	2	Varieties
Nigeria	IITA Ibadan	9	Varieties
Nigeria	IITA Ibadan	10	Seed
Kenya	Eastern Province	19	Land races
Kenya	Western Province	24	Land races
Kenya	Nyanza Province	28	Land races
Kenya	Central Province	8	Land races
Kenya	Nairobi Province	1	Land races

DISCUSSION

In the semi-arid areas of Eastern Province the early-maturing drought-resistant varieties of sweet potato fit in very well with the bimodal rainfall pattern. The sweet potato is likely to fit into the existing farming system based on crop and animal production. Both tubers and vines are a good source of animal feed (Ruiz, 1982). The green vines and tubers are available during the scarcity period at the end of each rainy season, when most of the other fodders usually dry up. KSP_{20} takes about 130 days to mature at Katumani and showed a high degree of resistance against the sweet-potato weevil. The skin colour of the tubers is purple and they have an attractive creamy-white flesh with no fibre. The texture of the tubers remains moist after cooking and tastes sweet. The yield increase over the local check is 474.13%. This large difference in yield over the local variety may be attributed to its earliness and drought tolerance in a bad season like the long rains of 1983. The vine development was also better than the other entries, showing that KSP_{20} may also yield more forage during a dry season. The tubers are oblong in shape and the average weight is 164 g. Although KSP_2 and KSP_3 are drought resistant, take about 100 days to mature, and give a reasonable yield, they are likely not to be accepted by the farmers because of their deep orange flesh. KSP_2 is susceptible to sweet-potato weevil, while KSP_3 is susceptible to the virus complex. The drought resistance, earliness, and plant-type attributes of KSP_2 and KSP_3 are being incorporated into good-quality, well-adapted local lines.

The flowering behaviour of the germ-plasm is being studied, because some of the lines intended to be used in crosses (KSP_{20}, KSP_8) did not flower during the long rains of 1983. Grafting and other techniques will be exploited to induce flowering in the lines which do not flower under Katumani conditions. Thrips and insect larvae feeding on sweet potato flowers were a hindrance in obtaining hybrid seed at one stage in the crossing programme. Under these circumstances, suitable plant-protection measures should be employed to ensure a good seed set in a crossing programme. KSP_1 and KSP_{23} freely set seed under natural conditions, which shows that these lines may be self-compatible. Wang (1964) also reported self-compatibility in sweet potato, which could be used in a breeding programme.

Availability of vines at the time of planting is a general problem elsewhere (Bartolini, 1982) as well as in the dryland areas in Kenya, due to the dry spell before the onset of the rains. To get a quick establishment and good stand of the crop is of great importance where the effective rains come only for a short period. The root initiation by standing the vines in water improved the stand of the crop by 9.26%, tuber yield by 41%, and vine length by 25.24%. In cassava root, initiation before planting has resulted in increased yield (Vichukit and Toro, 1975).

Virus-affected sweet potato plants generally show stunted growth and tuber yield can be greatly reduced, depending on the severity of the disease (Meynhardt and Joubert, 1982). A 78% reduction in fresh root yield in virus-affected plants has been reported in Nigeria (Hahn, 1979), while Mukibi (1977) reported that sweet-potato virus caused a reduction of 57% in yield, both in weight and number of tubers in Uganda. The only effective method of controlling sweet-potato virus lies in the breeding of resistant varieties (Sheffield, 1957). In the present study this sap-transmitted virus was also aphid-transmitted, which is contrary to the observation made by Hollings *et al.* (1976). Five of the seven *Ipomoea setosa* plants inoculated by aphids became infected. No infection was observed on *Ipomoea setosa* inoculated with whiteflies. Based on symptoms and alternate hosts, it appears that Katumani virus is related to the one described by Hollings *et al.* (1976) as sweet potato mild mottle, and by Sheffield as sweet potato virus B. However, the Katumani virus differs from the above in being both sap-transmitted and aphid-transmitted. More studies need to be carried out to establish the relationships of this virus to the one described by the above authors.

CONCLUSIONS

The introduction of early-maturing, drought-resistant, insect- and virus-resistant varieties of sweet potato in the dry areas of Kenya is not likely to compete with the existing cropping system and may go a long way to improving the food and feed supply in these areas. In these dry areas, cowpea is perhaps the only green-leaf vegetable at present, and there is a need to exploit the other potential crops as well. Sweet-potato vines and leaves, being a rich source of vitamins, protein, and minerals, are being used as a vegetable in some countries (Bartolini, 1982). In Nyanza Province, sweet-potato leaves are used as vegetable, particularly during the period when other green-leaf vegetables are in short supply. The use of tender leaves as a vegetable in the local food preparations needs to be exploited. Wheat flour can be replaced by sweet-potato flour up to 15% without affecting the quality of bread (Sammy, 1970). Sweet-potato protein is high in lysine and is good supplemental protein to cereals. Replacing 30% of rice and wheat diets with sweet potato enhances the biological value of dietary protein (Yang, 1982). The addition of sweet-potato flour to bread would ease the ever-increasing demand for wheat. Sweet potato has many industrial uses—as a source of starch, as animal feed, as dried chips for human consumption, and as sweet-potato flour. In Nyanza Province and western Tanzania, sweet potatoes are peeled, sliced, dried, and then ground into flour with sorghum or maize for making *ugali* or *uji* (Acland, 1975).

Sweet potato in Kenya is at present being consumed as a staple, supplemental food and leaf vegetable to various extents in different parts of the country. There is need to develop appropriate recipes for dishes to popularize it.

SUMMARY

In Kenya most of the area under sweet potato lies in the densely populated areas of Central and Nyanza Provinces and it is grown only in a limited area in Eastern Province. Since it is a drought-resistant crop, prospects for extending its cultivation in the dry areas of Kenya are quite encouraging.

Considering its usefulness as a food and feed crop and its ability to grow in the dry areas, various aspects of sweet potato production and varietal improvement in Eastern Province have been investigated.

The major constraints on sweet-potato produc-

tion are lack of suitable varieties and susceptibility to weevil and virus. Seven early/medium-maturing lines were yield tested at the National Dryland Farming Research Station, Katumani, during the long rains of 1983. KSP_{20} (TIS 2534), a medium-maturing line (130 days), outyielded all the other varieties (8.21 t/ha). KSP_{20} has a purple skin, white flesh, and an acceptable taste. It has good vegetative growth, showing its ability to produce forage even under dry conditions.

Large varietal differences in weevil incidence were observed and lines KSP_{20}, KSP_1, and KSP_{19} (TIS 3017) showed a fair degree of resistance.

Line KSP_3 (Travis) is highly susceptible to virus complex. It was found that the virus in this case is only aphid-transmitted and not both aphid- and whitefly-transmitted like other viruses reported previously. In the dry areas the availability of propagation materials and establishment are among the constraints on production. End portions of sweet potato vines, placed in water for two weeks to initiate roots, improved the stand of the crop as well as the tuber and vine yield.

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PERFORMANCE OF EARLY-MATURING DETERMINATE VARIETIES OF GREEN GRAM IN SEMI-ARID AREAS

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INTRODUCTION

Green gram (*Vigna radiata* Wilczek), also known as mung bean, is an important grain-legume crop in the warm dry parts of Eastern Province, Kenya. No reliable statistics on area or production are at present available. It is conventionally shown as gram in various Government publications, but this includes chickpeas and black gram as well. The mung bean is grown as both a subsistence and a cash crop.

In local preparations, the whole grains are boiled together with cereal grains, while the Asian community, the largest consumer of mung bean in this country, use it mainly as dhal (split grains). Its use as bean sprouts is increasing as a health food in Western countries (Chandel *et al.*, 1980). The seed protein varies from 21–29%, depending on the variety and the environment in which the crop was grown. Mung bean is generally considered free from the flatulence-inducing factors that are common in many grain legumes. Sulphur, amino acid, methionine, and cystine content are low, as with most other legumes, and lysine is high (8 g/100 g protein dry weight).

Mung bean is pan-tropical in distribution and its ability to grow under adverse conditions makes it a remarkable crop for warm dry areas. It is considered to be more drought-resistant than cowpea. The crop can escape the effects of drought because of its ability to mature in a short period (Rowe, 1980). The local cultivars/land races grown by the farmers are low yielding and indeterminate in growth habit. The indeterminate types do not respond to improved management and make excessive vegetative growth in favourable environments. Unnecessary vegetative growth in grain legumes generally results in low yield, and an improved harvest index has been suggested as one way of raising yield potential in these crops (Jain, 1975). The mung bean improvement programme at the National Dryland Farming Research Station (NDFRS), Katumani, has mainly involved the development of high-yielding, disease-resistant, determinate types with good grain character.

MATERIALS AND METHODS

Local germ-plasm was collected from Eastern and Coast Provinces, and seed of some high-yielding lines was obtained from other mung-bean-growing countries of the world. As a result of preliminary screening of the germ-plasm, nine promising lines were selected for yield evaluation. The yield trials were laid out in a randomized block design with four replications at both NDFRS and the substation Kampi ya Mawe during the long rains of 1982. Each plot consisted of 4 rows 4 m long with spacings of 40 cm between the rows and 20 cm within rows.

Data on days to 50% flowering and maturity were recorded at appropriate stages of growth. Five plants were selected at random from each plot to record data on number of pods/peduncle and number of grains/pod. The central 2 rows from each plot were harvested at maturity to record dry weight of grain. Damaged seeds from each sample were discarded in recording 1,000-grain weight.

RESULTS AND DISCUSSION

Highly significant differences were observed among varieties for each location as well as in the case of the combined analysis (Table I). The location and location × treatment effects were highly significant (Table II). The mean yield level of all lines at Kampi ya Mawe is invariably higher than at Katumani. This may be attributed to the relatively higher mean temperature at Kampi ya Mawe (April 24°C, May 21.5°C, June 21°C) than Katumani (April 20°C, May 18.7°C, June 17.9°C) during the growing season. Mung bean requires comparatively warmer temperatures for adequate growth (Rowe, 1980). Significant locality effects observed indicate the need to include more sites in the warmer areas for future evaluation.

The line KVR 26 outyielded other entries in each locality as well as over the mean value of the two localities (1,412.9 kg/ha), followed by KVR 11 (1,331.1 kg/ha). KVR 26, with a determinate growth habit, took 44 days to flower and matured in 74 days, as compared to the indeterminate line

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TABLE I—RESULTS OF GREEN GRAM YIELD TRIALS CONDUCTED AT KATUMANI AND KAMPI YA MAWE DURING LONG RAINS 1982 (MEAN YIELD, kg/ha)

Genotype	Katumani	Kampi ya Mawe	Mean of two localities
KVR 11	1,271.3	1,331.1	1,301.2
KVR 13	895.0	1,316.4	1,105.7
KVR 8	807.2	1,282.8	1,045.0
KVR 9	735.0	1,199.4	967.2
KVR 14	865.0	1,414.7	1,139.9
KVR 26	1,295.0	1,530.9	1,412.9
KVR 10	740.6	1,261.6	1,001.1
KVR 12	1,093.4	1,304.4	1,198.9
KVR 22	698.8	1,208.1	953.5
LSD 5%	93.7	190.8	103.3
LSD 1%	127.1	258.7	137.9

TABLE II—GREEN-GRAM YIELD TRIAL 1982—KATUMANI AND KAMPI YA MAWE—ANALYSIS OF VARIANCE FOR GRAIN YIELD OF THE GREEN GRAM VARIETY TRIALS CONDUCTED AT KATUMANI AND KAMPI YA MAWE DURING LONG RAINS 1982

Source	df	MS	F
Total	71		
Location	1	263,828.5	431.52***
Blocks	6	441.13	0.7215 NS
Treatments	8	20,160.41	32.9748***
Location × treatments	8	5,888.39	9.6312***
Error	48	611.39	

C.V. = 6.9%

S.E. (Treatments) = 8.7
S.E. (Localities) = 4.1
LSD (Treatments) 5% = 24.8 1% = 33.1
LSD (Treatments) 5% = 24.8 1% = 15.6

TABLE III—MORPHOLOGICAL CHARACTER OF VARIETIES INCLUDED IN THE YIELD TRAILS DURING LONG RAINS 1982

Genotype	Days to 50% flowering	Days to maturity	Number of pods/peduncle	Weight of 1,000 seeds (g)	Mean yield (kg/ha)	No. of grains per pod
KVR 11	58	98	13	44.9	1,301.2	12
KVR 13	48	79	14	41.7	1,105.7	10
KVR 8	50	79	17	43.7	1,045.0	11
KVR 9	55	82	20	34.7	967.2	10
KVR 14	54	91	11	43.7	1,139.9	7
KVR 26	44	74	14	60.3	1,412.9	11
KVR 10	54	86	20	36.9	1,001.1	11
KVR 12	49	85	19	43.0	1,198.9	10
KVR 22	55	92	10	48.2	953.5	10

KVR 11, which matured 24 days later under Katumani conditions. In Eastern Province the effective rains extend for a period of 6–8 weeks and any short-duration type capable of maturing within 10–11 weeks is more likely to escape drought than the long-duration cultivars. KVR 26 yielded 8.5% higher than the best indeterminate improved line, KVR 11, under normal spacings. However, the compact genotypes can be planted more closely in order to realize their high yield potential (Chandel *et al.*, 1980).

The high-yielding line KVR 26 has bright light-green, bold grains (60.3 g/1,000 grains) with a prolific bearing habit, producing 14 pods/peduncle. The plant is short statured with a stout stem. The upright plant type exposes the leaves well to sunlight for better photosynthesis. Although pod maturity is not completely synchronous, more than 85% of pods mature at the same time, which makes harvesting much easier. The plants at maturity can be uprooted and transported to the threshing floor to separate the grains by beating. Losses in yield due to shattering, if any, can be reduced by avoiding harvest during the noon hours, when the dry pods are more liable to shatter while handling.

The seed of KVR 26 was first distributed during the short rains of 1982–83 to the farmers taking part in the pre-extension trials. Their reaction in general is quite encouraging. They liked it for its better yield, earliness, and large grain size (Bakhtri *et al.*, 1983). The Ministry of Agriculture, in collaboration with the Machakos Integrated Development Programme, plans to distribute seed to a large number of farmers in Machakos District for further trials during the short rains of 1983–84.

CONCLUSIONS

The major drawbacks to the present-day mung bean cultivars grown in Eastern Province are late maturity, irregular ripening of the pods, and small grain size (Bakhtri *et al.*, 1983). In the semi-arid areas of Eastern Province, the effective rains are confined to the first few weeks of the growth period; therefore long-duration indeterminate types are likely to suffer more from drought when the crop is simultaneously blooming and growing. The indeterminate types are irregular in maturity and require 2 to 3 pickings to reduce losses in yield due to shattering.

The new improved type KVR 26 is determinate, early maturing, relatively synchronous in maturity, and has attractive large grains. It is convenient to harvest, can cope with drought better, and is suitable for closer planting to obtain higher yields per unit area. In Kenya, consumer preference, particularly in pulses, is generally for large grain size; therefore the use of small-grain pulses has remained limited in the past. With the development of large-seeded varieties of mung bean, this grain legume is likely to gain popularity in local preparations and is expected to go a long way in diversifying food habits.

SUMMARY

Local and exotic germ-plasm of mung bean (*Vigna radiata* Wilczek) was evaluated during 1980–82 at the National Dryland Farming Research Station for plant type and other agronomic characters. Nine promising lines were yield-tested at Katumani and Kampi ya Mawe during the long rains of 1982. The line KVR 26 yielded on average 1,412.9 kg/ha, followed by KVR 11 (1,301.9 kg/ha).

The high-yielding line KVR 26 is determinate, takes 74 days to mature under Katumani conditions, possesses attractive large light-green grains (60.3 g/1,000 grains), and is prolific (14 pods/peduncle). The pods are to a great extent synchronous in maturity, and this permits the harvesting of plants at maturity, when they can be pulled and threshed. It performed very well in the pre-extension trials and has been readily accepted and adopted by farmers in the area.

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THE USE OF MALE STERILE LINES TO MEASURE THE NATURE AND MAGNITUDE OF HYBRID VIGOUR IN PIGEONPEA (ABSTRACT)

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Pigeonpea (*Cajanus cajan* (L.) Millsp.) improvement by breeding has been limited to the testing of existing varieties and practising selection from available landraces. If a major breakthrough in yield is to be achieved, the future improvement in pigeonpea must be based on planned hybridization to identify parental combinations likely to produce superior segregates or to obtain F1s with high heterosis.

The biological requirement for successful commercial hybrid seed production, which includes the presence of hybrid vigour, elimination of fertile pollen in the female parent, adequate pollination by the male parent and synchronization of flowering, has limited its use in a number of crops. Hybrid vigour has been reported in pigeonpea. With the existence of male sterility and a considerable degree of natural outcrossing by bees, it is possible to easily test a large number of germ-plasms and exploit commercially the hybrid vigour which may be present in the crop.

The present investigation, involving three male-sterile and seven fertile lines, was designed to collect information on the nature and magnitude of heterosis in pigeonpea hybrids derived from geographically and genetically diversified parents.

Three male sterile lines, MS-3A, MS-4A and MS-Prabhat and seven fertile lines were crossed in a line × tester fashion to determine the nature and magnitude of hybrid vigour in pigeonpea. The hybrids bloomed earlier, were taller and had more grain yield than their parents.

Heterosis for grain yield and other characters were much larger for crosses involving MS-Prabhat than for MS-4A crosses. C-11 among the male parents had the best general combining ability effects from grain yield. ICP-7035 and ICP-9150 showed the highest GCA for 100-seed weight. For short plant height and earliness, BNN-1, C-322 and Royes were the best while ICP-9150 and ICP-9180 were best combiners for tallness and lateness.

1. National Dryland Farming Research Station, Katumani

TECHNICAL SESSION 4: REPORT ON DISCUSSION

Chairman (Mr B. N. Majisu): Selection for suitable crop varieties in the dry areas is a notable contribution to overall crop production. The selection objectives in the crops reported include the yield, early maturity, and tolerance to drought, insect pests and diseases. There are, however, economic limitations on research investment in some of the popular food crops because low yield ceilings are already set by the biological potential of dryland farming areas.

Mr J. G. M. Muasya: Farmers in the hill masses in the marginal areas, for example, Iveti, Kilungu, etc., have found the present Katumani Composite B and hybrid varieties not suitable to their areas. What action is being taken to breed an appropriate variety?

Mr K. Njoroge: This is true, and this problem has been brought to the attention of breeders both at Embu Station and at Katumani and, with the recommendation of the National Maize Reseach Specialist Committee, a serious and vigorous hybrid programme has now been started at Katumani. These areas are, however, not rated high in priority at Katumani as they neither constitute a very expansive area nor are they really semi-arid. The hybrid programme just mentioned is a joint venture between Embu and Katumani. To repeat, the problem is being handled seriously but results will take some time before they are available in a form useful to the farmers.

Mr B. M. Ikombo: (1) It appears that since 1968, when Katumani Composite B was produced, the programme has slowed down. What is the cause of this? (2) How has the present Katumani Composite B been improved as compared to the original one produced in 1968?

Mr D. K Muthoka: The maize-breeding programme slowed down at Katumani basically because of staff changes. However, it was realized that for this programme to develop new varieties of maize, there was a need to have staff stability in the programme. Since the adoption of this policy, the Katumani maize breeding programme is making steady progress towards the development of new varieties to replace Katumani Composite B.

Mr Njoroge: Mainly, improvement has been in yield while still maintaining the original range of maturity. In fact, testing to compare the original cycle of Katumani Composite B with the most recent cycle has been initiated. If it is proved that the latest cycles are indeed superior (significantly different within the acceptable limits of usual distinctiveness, uniformity, and stability) then consideration will be given to the possibility of releasing the latest cycle under a different name.

Mr L. F. Scherer: What specifically do the districts need to do to determine the proper varieties for the different areas within them?

Mr I. R. Kermali: Help the Katumani sorghum breeder to maintain observation trials in selected fields. This will involve getting the seeds from Katumani, planting, weeding, thinning, bird scaring, harvesting, threshing, and taking the necessary data. The Director, Katumani, should be contacted for the latest information.

Mr L. O. Sese: In view of the importance bulrush millet has as a major food crop in the dryland areas, with particular reference to lower Meru District, what breeding programme is going on to improve the varieties of high yield and resistance to pests and diseases?

Mr Kermali: Improved pearl millet composite is in the pipeline. It gives higher yields than local cultivars. We hope to clean it up further for four seasons and release it to the farming community. Another composite (lines derived from local cultivars) has been formed and will also be released if it performs better than the parents.

Mr S. C. Ondieki: Is there anybody working on bulrush millet, which is widely grown in the dry areas, rather than working on proso millet, which is probably unknown and unpalatable?

Mr Kermali: Yes, Mr M'Ragwa is working on millets and has obtained substantial results. Ms Penninkhoff has also worked on millets and more information should be available at Katumani.

Dr F. H. C. Scott: The 1982 short rains were very good, and the local pigeonpea developed strongly. Nevertheless, most of the pigeonpea did not yield after the poor long rains. Did the early-maturing variety yield satisfactorily under this situation and thus has it drought-escaping properties that may be more important than its two yields per year characteristic?

Dr A. Shakoor: The early-maturing, short-statured pigeonpea varieties are likely to perform better under low-rainfall conditions as compared to the tall, long-duration types. The root system in the early-maturing types is equally extensive

and deep and can exploit the limited moisture more efficiently.

Dr H. A. van Rheenen: (1) Is there a breeding programme and what methodologies are used? (2) How many local and introduced accessions have been screened? (3) What steps are being taken to maintain the germ-plasm?

Dr Shakoor: There is enormous genetic variability in the local germ-plasm for most of the economic characters and selection as a breeding method appears to be quite effective. We have about 450 accessions in our pigeonpea germ-plasm which will be documented in the near future, and the station has one full-time scientist to maintain the germ-plasm.

Mr P. T. S. Whiteman: I recall that the local pigeonpea is valued as a late dry-season fodder. What is the reaction to the new short-season pigeonpea in respect of fodder?

Dr Shakoor: Tall pigeonpea cultivars are generally woody at harvest time and the farmers usually browse the animals after the harvest. However, the early-maturing pigeonpeas have a relatively thin stem, convenient for chop. Preliminary experiments carried out at Katumani by the animal-production section have found the early maturing pigeonpea residue a good forage.

Dr van Rheenen: (1) One of the tables shown gives yields ranging from 1.43 to 8.21 tonnes per hectare and the differences were not significant. Could identification of "best" varieties, therefore, be on the basis of *cylus* resistance? (2) On rooted and non-rooted planting vines: were the yield differences significant?

Dr Shakoor: The non-significant results could be attributed to a high coefficient of variation and the soil in that field. For any conclusive results we need at least three seasons' results. The differences in the root-initiation experiment were significant.

Mr Ondieki: What work has been done on the storage of this crop, since traditionally the farmers harvest the tubers when they want to eat them immediately? Also, in breeding for early maturity, how will the tubers be used during the dry periods when there is an acute food shortage?

Dr Shakoor: We have not so far looked at storage of tubers and this we plan to investigate in future. However, the early maturity is combined with weevil resistance and so the farmer can prolong harvest according to his requirement.

Mr F. M. Ndambuki: Apart from drought escape through selection for earliness, which is the most important drought-tolerance mechanism in the sweet-potato plant, and how is this manifested?

Dr Shakoor: In our breeding programme we are at present concentrating on developing for earliness and appropriate plant type as a measure of drought tolerance.

Mr Muasya: Bearing in mind the shortage of fodder crops in arid areas, is the programme contemplating breeding for high quality and quantity of vines for livestock feed?

Dr Shakoor: The sweet-potato breeding programme at Katumani is primarily focused on tuber yield, but does not ignore the possible use of vines as animal feed.

Dr B. H. Waite: Do all the sweet-potato lines you are working with flower under Katumani conditions?

Dr Shakoor: Some of the exotic as well as the local lines did not flower during the long rains of 1983. The material will be studied during the short rains as well. The lines intended for crossing, in case they do not flower under normal field conditions, will be grafted on to the stalk of the profusely flowering lines for flower induction.

Dr C. L. Coulson: Do you know anything of the tuberization—soil temperature relationship and leaf area—tuberization relationship in sweet potato?

Dr Shakoor: The total leaf area in sweet potato has little effect on tuber yield; it is the sink rather than source which is the more important. There appears to be a linear relationship between soil temperature and tuberization, starting from 20° to 40°C.

Mr Sese: Comparing the two green-gram crops at the Meru farmer's field and at Kampi ya Mawe in Machakos in the trial, the Meru crop looked vigorous in comparison with the crop at Kampi ya Mawe. In your opinion what was the reason for this difference?

Mr E. C. K. Ngugi: Green gram normally grows well under warm conditions. The differences in the growth of the crop at Kampi ya Mawe and Meru are more due to differences in plant types; in Meru the crop was indeterminate while in Kampi ya Mawe it was determinate.

Mr I. R. M'Ragwa: I would like to know why in your programme you prefer short-internode green-gram ideotypes to long ones or increased

number rather than short ones.

Mr Ngugi: Any reduction in plant height should not be associated with reduction in number of nodes, which ultimately would affect the number of fruit-bearing branches.

Dr Coulson: Have you noticed any relationship between pod number and the amount of rain and differences between the varieties?

Mr Ngugi: The crop can grow well with a minimum of 200 mm of rain. However, severe drought stress may induce abscission of flowers.

Dr van Rheenen: Do farmers grow undeterminate varieties? And if so, is there not a reason for them to do so? Is the underterminate type possibly preferable?

Mr Ngugi: The farmers' traditional varieties are undeterminate, grown under low fertility and minimum management and consequently realizing a low harvest index. The high-yielding varieties suitable for improved cultural practices should be determinate and should possess a high harvest index.

Dr Waite: What is the resistance of green gram KVR26 to yellow virus?

Dr Shakoor: KVR26 has shown resistance to yellow virus across the locations listed so far.

Dr L. V. Peters: What factor (environmental or chemical action) within the plant makes the plants flower early and all at once?

Mr Ngugi: The flower induction under Katumani conditions is not environmental but genotypic. The chemical action within the plant, however, remains to be studied.

Mr Sese: While I appreciate the tremendous effort made by research workers to improve suitable crops for the drylands, very little of these materials are reaching the majority of farmers in these areas. In your opinion, by what means or ways should these materials be multiplied and bulked and made available to farmers, to avoid resource wastage in the research work if these materials never reach the farmers as required?

Dr Shakoor: Efforts are under way to strengthen seed multiplication of the dryland crops on existing farms. Another way of hastening this process is to identify progressive farms through agricultural extension, where the seed of new varieties can be multiplied and distributed in that particular location.

TECHNICAL SESSION 5

CROP PROTECTION

EVALUATION OF BEAN DISEASES IN THE GRAIN LEGUME PROJECT TRIALS, KATUMANI RESEARCH STATION

H. A. I. Stoetzer[1] *and B. H. Waite*[2]

INTRODUCTION

Eastern Province has the largest hectarage under grain legumes in Kenya (Table I). The bulk of bean (*Phaseolus vulgaris*) production in this province is from Embu, Meru, Machakos, and Kitui Districts (Njugunah *et al.*, 1981), although the percentage of the total production of Kenya which is produced in the semi-arid zones is not known. The semi-arid zone (zone IV in the *National Atlas of Kenya* (1970) and zone V in the *Agro-Climatic Zone Map of Kenya* by Sombroek *et al.* (1982)) constitutes the major area of production in Eastern Province, but semi-humid to humid areas also occur, the latter around Mount Kenya. Relatively good growing conditions exist in Machakos and Kitui Districts, especially in hilly areas (Braun, 1977). Other bean-growing zones in Kenya are shown in Fig. 1.

In general, a semi-arid tropical agroclimate is unfavourable for pathogens of all crops, although smuts, some of the rusts, and soil fungi such as *Macrophomina phaseolina* and *Sclerotinia rolfsii* are fairly common. However, little research has been carried out on the survival of pathogens in semi-arid areas between growing seasons in the absence of the hosts and when prolonged drought reduces the inoculum of the pathogen (Palti, 1981).

World-wide, about 150 fungal, bacterial, mycoplasmal, and viral diseases have been reported on beans (Schwartz and Galvez, 1980). Most of them are of minor economic importance. In Kenya, 19 fungal, 4 bacterial, and 2 viral diseases of beans have been reported (Stoetzer, 1983), as summarized in Table II. Diseases in the semi-arid areas of Kenya have also been listed by Gathuru and Mukunya (1983), Gerlagh (1982), Grain Legume Project reports (1977–1981), Hubbeling (1973), Mukunya and Keya (1975), Mukunya *et al.* (1982), Muthangya (1980), Mutitu and Mukunya (1979), Mutitu and Musyimi (1980), Roosje and Hubbeling (1977), Schönherr and Mbugua (1976), and Waite *et al.* (1982).

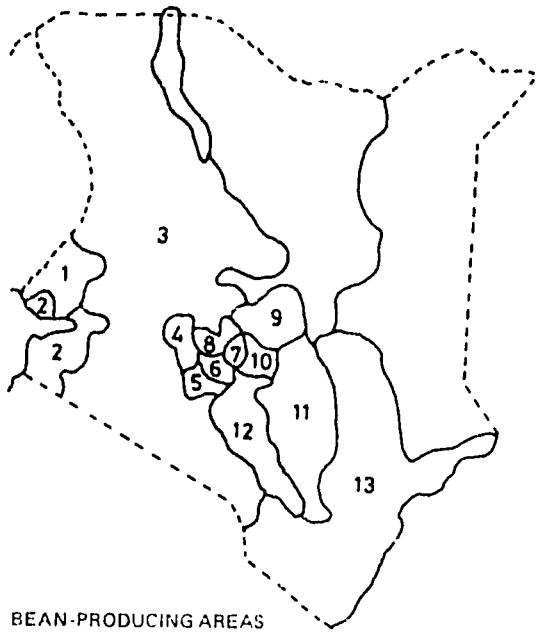
This paper discusses and summarizes the

TABLE I—ESTIMATED AREAS UNDER GRAIN LEGUMES BY PROVINCE IN THE 1974–1975 CROP YEAR

	Area (000 ha)					
Province	Beans	Pigeonpeas	Cowpeas	Field peas	Other	Total
Eastern	284.6	104.5	208.4	2.8	30.2	630.5
Central	232.4	4.2	7.8	13.6	0.0	258.0
Nyanza	73.6	0.0	0.0	1.7	78.2	
Western	148.4	0.0	13.2	0.4	1.4	163.4
Rift Valley	7.0	0.0	0.0	0.0	0.0	7.0
Coast	17.5	6.5	38.9	9.1	4.1	67.1
Total	763.5	115.2	271.2	25.9	37.4	1204.2

Source: Thairu, 1979.

1. Grain Legume Project, National Horticultural Research Station, Thika, Kenya
2. Dryland Cropping System Research Project, Kenya Agricultural Research Institute, Muguga, Kenya



BEAN-PRODUCING AREAS

1. Western Province
2. Nyanza Province
3. Rift Valley Province
4. Nyandarua District
5. Kiambu District
6. Murang'a District
7. Kirinyaga District
8. Nyeri District
9. Meru District
10. Embu District
11. Kitui District
12. Machakos District
13. Coast Province

Fig. 1. Bean-producing areas of Kenya (*Source:* Njugunah *et al.*, 1981)

incidence of seven important bean diseases in various trials carried out from the period of the short rains of 1976/1977 to the long rains of 1983 by the Grain Legume Project (GLP) at the National Dryland Farming Research Station, Katumani. Attempts were made to relate disease incidence to total rainfall for the growing period as well as to 10-day periods within the season. In addition, there was an effort to relate incidence to origin and seed type for halo blight, scab, and angular leaf spot.

MATERIALS AND METHODS

Most of the observations on diseases were recorded in breeding trials from the GLP. These were basically cultivar trials or evaluations of the germ-plasm collection (Table III). The beans were grown as recommended by the Kenya Ministry of Agriculture (1976–1979), as a monocrop at row spacing of 50 cm and with 10 cm between plants in the rows. In the germ-plasm collection row spacings were increased to 75 cm. Fertilizers were applied at the rate of 40 kg P_2O_5 and 40 kg N per hectare as superphosphate and calcium-ammonium nitrate until 1979, when the recommendation changed to 200 kg diammonium phosphate per hectare. Maize intercropped with beans was grown as recommended by the Ministry of Agriculture (1977) at a row spacing of 75 cm and an intrarow distance of 30 cm. Superphosphate and calcium-ammonium nitrate were applied at rates of 40 kg P_2O_5 and 40 kg N per hectare respectively. Beans were planted until 1979 in single rows between two maize rows with 15 cm between plants and without extra fertilizer. Since 1979 two rows of beans have been sown between the maize rows at 25 cm spacings and with 10 cm between the rows. Diammonium phosphate was applied at 100 kg/ha to the beans.

The climatic data during the growing seasons of the short and long rains from 1976 to 1983, relative to bean-disease development at the Katumani station, are presented in Fig. 2 and Table IV. Only the first two months are given, as most disease scores were carried out either late in May or early in June for the long rains, or late in December and early in January for the short rains. Fig. 2 shows total rainfall over each 10-day period of the 60 days of the growing seasons. Normally, beans are planted in the last week of March and October. Growth to flowering for all varieties is about 30–45 days. During this period the plants are most susceptible to the diseases discussed in this paper. The number of days with 5 mm or more rainfall in each 10-day period is also shown in Fig. 2. Five mm rainfalls are considered to be approximately the minimum for effective dissemination of rain-splashed pathogens. Table IV shows the temperature means and number of days with 5 mm or more precipitation for the 60-day periods of the growing seasons.

The GLP trials at Katumani were not always planted over successive years in the same location. Thus the possibility or importance of build-up of pathogen inoculum in a particular location could not be evaluated.

The severity of all diseases in the trials was scored on a scale from 0 to 5, where 0 was an absence of symptoms and 5 indicated very heavy infection or death caused by disease. Although more exact disease-assessment keys for beans have been published (James, 1973; Larios and

Fagundo, 1979), the 0—5 scale provides a sufficient estimate of disease severity expressed by visual symptoms and is the only practical system for scoring many plots or cultivars.

TABLE II—ECONOMIC IMPORTANCE OF BEAN DISEASES IN KENYA

Diseases	Pathogen	Importance*
A. *Bacterial diseases*		
Halo Blight	*Pseudomonas phaseolicola*	I
Common Blight	*Xanthomonas phaseoli*	M
Bacterial Brown Spot	*Pseudomonas syringae*	O
Brown Rot	*Pseudomonas solanacearum*	O
B. *Fungal diseases*		
Angular Leaf Spot	*Phaeoisariopsis griseola*	I-M
Anthracnose	*Colletotrichum lindemuthianum*	I-M
Rust	*Uromyces appendiculatus*	I-M
Scab	*Elsinoë phaseoli*	M
Ashy Stem Blight	*Macrophomina phaseolina*	M
Fusarium Yellows	*Fusarium oxysporum* f. sp. *phaseoli*	M
Fusarium Root Rot	*Fusarium solani* f. sp. *phaseoli*	M
Rhizoctonia Root Rot	*Rhizoctonia solani*	M
Southern Blight	*Sclerotinia rolfsii*	M
Black Node Disease	*Phoma exigua* var. *diversispora*	O
Powdery Mildew	*Erysiphe polygoni*	O
Speckle Disease	*Phoma exigua* var. *exigua*	O
Leaf Spot Disease	*Stagonosporopsis hortensis*	O
Pythium Root Rot	*Pythium* spp.	O
White Mould	*Sclerotinia sclerotiorum*	O
Alternaria Leaf Spot	*Alternaria* spp.	O
Floury Leaf Spot	*Mycovellosiella phaseoli*	O
Yeast Spot	*Nematospora coryli*	O
Cercospora Leaf Spot	*Cercospora* spp.	O
C. *Virus diseases*		
Bean Common Mosaic	Bean Common Mosaic Virus (BCMV)	I
Bean Yellow Spot	Bean Yellow Spot Virus (BYSV)	O

Source: Stoetzer, 1983
*I = Important and very prevalent
M = Moderately important, regularly locally important
= Less important, occasionally locally important

The diseases observed are listed in Tables VI—XV, and are further described under "Results". Only monocrop scores are given, as the incidence in monocultures of beans is for most diseases severer than when the crop is interplanted with maize (van Rheenen *et al.*, 1981). Tables VI, VIII—XI, XIII, and XV indicate observed susceptibility and resistance to the seven diseases under consideration. Where severity scores were low, only the most susceptible entries are indicated. The degrees of resistance are not absolute for each entry but are in comparison with the other entries in the trials of the same season. All observations were made in plantings under natural growing conditions, without additional irrigation or artificial inoculation.

RESULTS

The scoring results are presented in the Tables. Each disease was scored separately on a season and trial basis and is shown in the Tables as an average per season. The information provided in Tables VI, VIII—XI, XIII and XV is the average

TABLE III—MAIN CHARACTERISTICS OF THE BREEDING TRIALS OF THE GRAIN LEGUME PROJECT FOR LONG AND SHORT RAINS, 1976–1983

Number of trial	Name of trial	Years*	Design	Objectives
1	Bean cultivar trial	LR1976–SR1979/80**	Split plot	Test cultivars against a local selection, in pure stand and in association with maize
2	Selections from farmers' fields	SR1976/77–SR1977/78	Systematic, not replicated	Test and select local bean germplasm
3	Screening germ-plasm for suitability in mixed cropping	LR1977–SR1978/79	Split plot	Test germ-plasm under mono and mixed cropping
4	Evaluation of germ-plasm collection	LR1977–SR1978/79, LR1980–SR1981/82	Stystematic, not replicated	Evaluate the germ-plasm collection in observation plots
5	Selections from farmers' fields	LR1978–SR1979/80	Ramdomized block	Test and select local bean germ-plasm
6	Evaluation of germplasm collection	SR1979/80	Systematic, 3 replications	Evaluate marketable cultivars selected from previous years' trials
7	National Bean Performance Trial	LR1980–LR1983	Split plot	Compare new cultivars with recommended ones
8	Red haricot variety trial	SR1980/81–LR1982	Systematic, 2 replications	Test red haricot cultivars with pure stand and in association with maize
9	National Performance Trial Red Haricot	SR1982/83, LR1983	Split plot	Test red haricot bean cultivars

*LR = long rains
SR = short rains
**Trial was not carried out during LR1979

disease score, which gives an indication of disease resistance (R) or high levels of susceptibility (VS). Where entries are not indicated there was less susceptibility but resistance was not noted. The mean incidence of halo blight, scab, and angular leaf spot as correlated with seed type and origin are summarized in Tables VII, XII and XIV respectively. Table V identifies the bean germ-plasm evaluated in Tables VI, VII–XI, XIII, and XV, indicating the GLP number, name and year of introduction, country or district in Kenya of origin, and seed type. A brief description of each disease evaluated is given before the results of disease incidence, as indicated in the Tables.

Halo Blight (*Pseudomonas phaseolicola* (Burk.) Dows.

This bacterium is favoured by cool to moderate temperatures, less than 28°C; invasion of the pathogen occurs directly through the leaf stomata in the presence of free water. On the leaves, small soaked spots appear, generally on the lower surface, and are surrounded by a halo of greenish-yellow tissue. These spots generally enlarge and coalesce with others. Stem lesions may appear as water-soaked spots that gradually enlarge, become dry, and split longitudinally along the stem. Infected pods commonly exhibit

TABLE IV—CLIMATIC DATA FOR KATUMANI STATION: TEMPERATURE MEANS AND NUMBER OF DAYS WITH RAINFALL OVER 5 mm DURING THE TWO OBSERVATION MONTHS OF THE SEASON

Season and year	Average maximum temperature						Average minimum temperature						Average mean temperature						No of days with 5 mm+ rainfall
	Apr.	May	Apr. + May	Nov.	Dec.	Nov. + Dec.	Apr.	May	Apr. + May	Nov.	Dec.	Nov. + Dec.	Apr.	May	Apr. + May	Nov	Dec.	Nov. + Dec.	
LR76	25.1	24.5	24.8	—	—	—	15.7	14.2	14.9	—	—	—	20.4	19.3	19.8	—	—	—	6
SR76/77	—	—	—	25.7	23.5	24.6	—	—	—	15.7	15.2	25.4	—	—	—	20.7	19.3	20.0	15
LR77	24.3	23.9	24.1	—	—	—	16.1	14.6	15.4	—	—	—	20.2	19.3	19.7	—	—	—	17
SR77/78	—	—	—	23.5	23.2	23.4	—	—	—	15.3	14.8	15.0	—	—	—	19.4	19.0	19.2	16
LR78	24.1	23.0	23.6	—	—	—	15.6	13.1	14.4	—	—	—	19.9	18.1	19.0	—	—	—	11
SR78/79	—	—	—	24.0	22.9	23.5	—	—	—	14.8	14.5	14.7	—	—	—	19.4	18.7	19.1	13
LR79	24.3	22.9	23.6	—	—	—	15.7	13.9	14.8	—	—	—	20.0	18.4	19.2	—	—	—	17
SR79/80	—	—	—	24.0	24.9	24.5	—	—	—	14.6	14.4	14.5	—	—	—	19.3	20.2	19.8	11
LR80	26.1	24.4	25.3	—	—	—	15.6	15.2	15.4	—	—	—	20.8	19.8	20.3	—	—	—	11
SR80/81	—	—	—	24.3	24.4	24.4	—	—	—	15.3	14.6	15.0	—	—	—	19.8	19.5	19.7	12
LR81	23.9	23.0	23.5	—	—	—	18.1	14.6	16.3	—	—	—	21.0	18.8	19.9	—	—	—	10
SR81/82	—	—	—	24.8	24.7	24.8	—	—	—	14.5	14.5	14.6	—	—	—	19.7	19.6	19.	7
LR82	24.7	22.9	23.8	—	—	—	15.5	14.5	15.0	—	—	—	20.1	18.7	19.4	—	—	—	13
SR82/83	—	—	—	24.2	23.9	24.0	—	—	—	15.1	14.7	14.9	—	—	—	—	—	—	18
LR83	27.0	24.6	25.8	—	—	—	16.0	14.6	15.3	—	—	—	21.5	19.6	20.6	—	—	—	7
Mean 76–83	24.9	23.7	24.3	24.4	23.9	24.2	16.0	14.3	15.2	15.0	14.7	14.9	20.5	19.0	19.7	19.7	19.4	19.6	12
Mean 6 years (1)	24.7	24.7	24.7	23.9	24.6	24.3	15.6	14.2	14.9	14.9	14.1	14.5	20.2	19.5	19.9	19.4	19.4	19.4	
Average 14 Years	24.8	24.1	24.5	24.2	24.2	24.2	15.8	14.3	15.1	15.0	14.4	14.7	20.4	19.2	19.8	19.6	19.4	19.5	

*SR = short rains, LR = long rains
(1) *Source:* Siderius and Muchena, 1977.

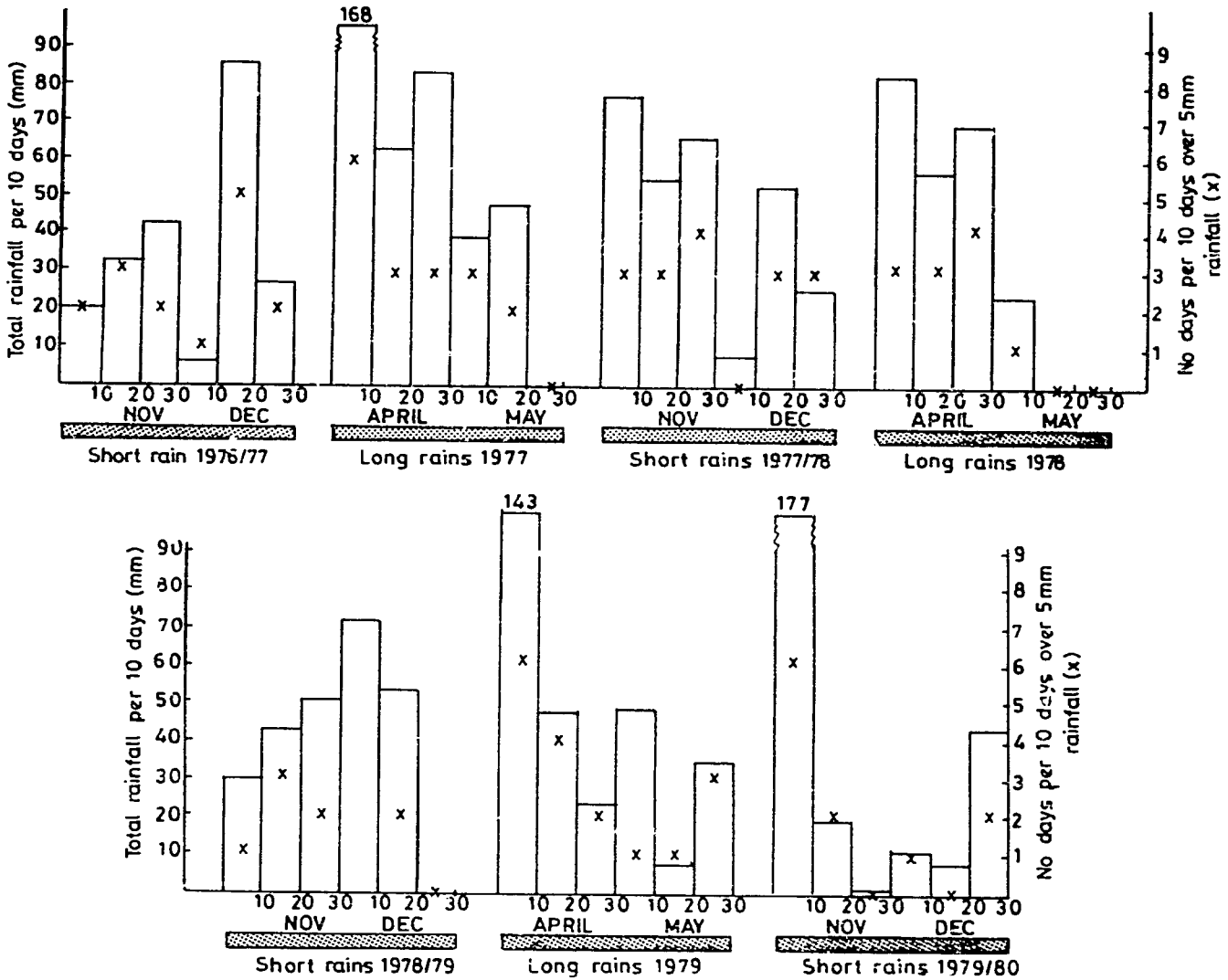


Fig. 2. Rainfall totals (long and short rains, 1976/83) for 60 days of bean growing season, showing numbers of days with 5 mm or more precipitation

water-soaked spots having a typical greasy appearance. Infection may become systemic, with severe leaf chlorosis and without the appearance of much external infection. Seeds are readily infected and are an important primary source of inoculum. Infected plant debris is also important as a source of the bacteria, which must be disseminated to and between plants by splash dispersal and winds during periods of rainfall. Tables VI and VII refer to the results for halo blight.

TABLE V—GRAIN LEGUME PROJECT (GLP) IDENTIFICATION INFORMATION FOR BEAN GERM-PLASM EVALUATED IN TABLE VI– XV

	Variety or varietal group name	Introduction		Seed type*
		Year	Origin	
1	Renka	1972	Netherlands	rc
2	K 20	1972	Netherlands	rc
3	Wairimu	1972	Kenya	rh
4	Gitune	1972	Kenya	cw
7	Ganadian Wonder	1972	Kenya	cw
8	Black Foodbean	1972	Kenya	bl
10	Mwezi Moja	1972	Kenya	mm
12	Kambumbu	1972	Kenya	rc
16	Kaw Panmix × Confinel	1972	Uganda	rc
18	S 40 × Confinel	1972	Uganda	cw
20	Confinel × S 153	1972	Uganda	rc
21	Kenseed 10	1974	Kenya	cw
22	Kenseed 74	1974	Kenya	rc
24	GLP-6 selection	1974	Kenya	cw
25	GLP-18 selection	1974	Kenya	cw
26	Canadian Wonder	1974	Kenya	cw
32	White Haricot	1972	Kenya	wh
37	Saginaw	1972	Kenya	wh
38	White Haricot	1972	Kenya	wh
42	Diacol Nima × Verdon	1972	Uganda	wh
53	Great Northern Jules	1975	U.S.A.	wh
54	Great Northern Nebraska No. 1	1975	U.S.A.	wh
64	Top Crop	1975	U.S.A.	br
65	Dark Red Kidney	1975	U.S.A.	cw
67	Michelite	1975	U.S.A.	wh
69	Santa Ana	1975	Puerto Rico	rh
70	Charleroix Dark Red Kidney	1974	U.S.A.	cw
71	Macosta Light Red Kidney	1974	U.S.A.	cw
72	Manitou Light Red Kidney	1974	U.S.A.	cw
78	S 129 × S 68D-Tk 16	1972	Uganda	rc
79	S 40 × Confinel, Tk 21	1972	Uganda	bl
96	Mwezi Moja	1972	Kenya	mm
99	Kawanda Penmix × Confinel	1972	Uganda	rc
110	Gikara	1975	Kenya	rc
154	45/9/2/3 Cream	1975	Kenya	cr
161	Dura Cream	1975	Kenya	cr
171	22/7/5/5 Cream	1975	Kenya	cr
230	P-326-B-L	1975	Colombia	bl
231	P-449-A-L	1975	Colombia	pu
234	P-498-A-L	1975	Colombia	gr
240	Canadian Wonder	1975	Kenya	cw
242	Canadian Wonder	1975	Kenya	cw
245	Canadian Wonder	1975	Kenya	cw
249	Canadian Wonder	1975	Kenya	cw
253	Rose Coco	1975	Kenya	rc
261	Rose Coco	1975	Kenya	rc

Table 5 Cortd.

Variety or varietal group name		Introduction Year	Origin	Seed type*
263	Rose Coco	1975	Kenya	rc
267	Rose Coco	1975	Kenya	rc
276	Mwezi Moja	1975	Kenya	mm
288	Rose Coco	1975	Kenya	rc
291	Rose Coco	1975	Kenya	rc
292	Rose Coco	1975	Kenya	rc
301	Rose Coco	1975	Kenya	rc
303	Rose Coco	1975	Kenya	rc
305	Rose Coco	1975	Kenya	rc
306	Rose Coco	1975	Kenya	rc
308	Rose Coco	1975	Kenya	rc
310	Rose Coco	1975	Kenya	rc
311	Rose Coco	1975	Kenya	rc
312	Rose Coco	1975	Kenya	rc
317	Rose Coco	1975	Kenya	rc
322	Rose Coco	1975	Kenya	rc
326	Rose Coco	1975	Kenya	rc
331	Rose Coco	1975	Kenya	rc
332	Rose Coco	1975	Kenya	rc
333	Rose Coco	1975	Kenya	rc
336	Rose Coco	1975	Kenya	rc
344	Rose Coco	1975	Kenya	rc
346	Rose Coco	1975	Kenya	rc
347	Rose Coco	1975	Kenya	rc
348	Red Haricot	1975	Kenya	rc
349	Red Haricot	1975	Kenya	rh
350	Red Haricot	1975	Kenya	rh
353	Red Haricot	1975	Kenya	rh
354	Red Haricot	1975	Kenya	rh
356	Red Haricot	1975	Kenya	rh
359	Canadian Wonder	1975	Kenya	rh
360	Canadian Wonder	1975	Kenya	cw
362	Canadian Wonder	1975	Kenya	cw
363	Canadian Wonder	1975	Kenya	cw
364	Canadian Wonder	1975	Kenya	cw
365	Canadian Wonder	1975	Kenya	cw
367	Canadian Wonder	1975	Kenya	cw
369	Canadian Wonder	1975	Kenya	cw
389	Black Bean	1975	Kenya	cw
414	75-N2A-Mex-235-1-2-1BK	1976	Puerto Rico	bl
418	Red Mexican UI 37	1976	Netherlands	rh
423	Light Red Kidney	1976	Netherlands	rh
425	75-N2B-2829-5-1BK-1BK	1976	Puerto Rico	cw
438	75-N2B-2829-5-2BK-1BK	1976	Puerto Rico	rh
455	75-N2B-48-R27-2BK-2BK	1976	Puerto Rico	rh
456	75-N2B-48-R27-6BK-1BK	1976	Puerto Rico	bl
462	75-N2B-10R-29-1-4-3BK	1976	Puerto Rico	bl
463	75-N2B-2829-16-1BK-1BK	1976	Puerto Rico	mw
481	Thika LR/74 520	1976	Kenya	rc
527	Black Turtle Soup	1976	U.S.A.	cw
536	P 270-A-L	1976	Colombia	bl
546	Pinto 111	1976	U.S.A.	rc
547	Pinto 114	1976	U.S.A.	mw
562	Epicure	1976	U.S.A.	mw
570	Manitou	1976	U.S.A.	br
574	P.I. 150414	1976	U.S.A.	cw
582	Red Mexican UI 36	1976	U.S.A.	rh
				rh

Table 5 Contd.

Variety or varietal group name type*		Introduction Year		Seed type*
584	Royal Red	1976	U.S.A.	cw
585	Rufus	1976	U.S.A.	rh
593	U.S. No. 5 Pinto	1976	U.S.A.	mw
621	G.L.P. LR.-74-748	1976	Kenya	wh
621	G.N. Tara	1976	Ethiopia	wh
639	Holetta	1976	Ethiopia	rc
640	Canadian Wonder	1976	Ethiopia	cw
649	Bountiful	1976	Ethiopia	cr
650	Field 18-P29	1976	Ethiopia	rc
654	Small Wado	1976	Ethiopia	rc
662	Pinto	1976	Ethiopia	mw
681	Wollamo Soddo Melkassa	1976	Ethiopia	rh
683	Field P 18-P50 Holetta	1976	Ethiopia	rh
693	*Phaseolus multiflorus*	1976	U.S.A.	wh
694	G.L.P. LR.-74-510	1976	Kenya	rc
697	Red Mexican UI 36	1976	U.S.A.	rh
703	Mwitemania	1976	Kenya	mw
705	Mwezi Moja	1976	Kenya	mm
706	Kikala	1976	Kenya	rc
707	Kamala (Bean 144)	1976	Kenya	mw
709	LFB LR.-73-113	1977	Kenya	rc
736	LFB LR.-73-145	1977	Kenya	cw
766	LFB LR.-73-218	1977	Kenya	rh
868	Michelite 62	1977	U.S.A.	wh
870	Red Mexican UI 34	1977	U.S.A.	rh
884	SR/72/LKY 14	1977	Kenya	rc
902	51051	1977	Colombia	bl
909	FF 00004-22-1-mF 5	1977	Colombia	bl
940	FF 00016-11 F3	1977	Colombia	bl
973	Mountenier White Half Runner	1978	U.S.A.	wh
981	Mexico 235	1978	U.S.A.	cw
1004	Katumani Local	1978	Kenya	mm
X.1	Panameno	1976	Colombia	rc
X.2	Highvillo	1976	Colombia	rc
X.4	NB-4	1976	Turkey	wh
X.33	Kabanima	1976	Uganda	rc
X.41	Rose Coco	1976	Kenya	rc
X.44	Gituru	1976	Kenya	cw
X.48	Canadian Wonder	1976	Kenya	cw
X.49	Canadian Wonder	1976	Kenya	cw
X.55	Canadian Wonder	1976	Kenya	cw
X.60	Canadian Wonder	1976	Kenya	cw
X.62	Canadian Wonder	1976	Kenya	cw
X.78	Mwezi Moja	1976	Kenya	mm
X.81	Mwezi Moja	1976	Kenya	mm
X.84	Mwezi Moja	1976	Kenya	mm
X.85	Mwezi Moja	1976	Kenya	mm
X.88	Mwezi Moja	1976	Kenya	mm
X.89	Mwitemania	1976	Kenya	mw
X.90	Rose Coco	1976	Kenya	rc
X.92	Mwitemania	1976	Kenya	mw
X.97	Gikara	1976	Kenya	rc
X.102	Rose Coco	1976	Kenya	rc
X.117	Red Haricot	1976	Kenya	rh
X.136	Mwezi Moja	1976	Kenya	mm
X.139	Gacheru	1976	Kenya	wh
X.143	Michelite	1976	Kenya	wh

Table 5 Contd.

Variety of varietal group name		Introduction		Seed type*
		Year	Origin	
X.144	Krobesta	1976	Kenya	wh
X.146	Mexican 142	1976	Kenya	wh
X.152	White Haricot	1976	Kenya	wh
X.188	Black Rose Coco	1976	Uganda	re
X.202	Black Rose Coco	1976	Uganda	re
X.224	'Breeding material Leakey'	1976	Uganda	wh
X.263	'Breeding material Leakey'	1976	Uganda	re
X.264	'Breeding material Leakey'	1976	Uganda	re
X.265	'Breeding material Leakey'	1976	Uganda	re
X.271	'Breeding material Leakey'	1976	Uganda	er
X.321	Red Mexican UI 35	1976	Netherlands	rh
X.322	Red Mexican UI 35	1976	Netherlands	rh
X.323	Red Mexican UI 34	1976	Netherlands	rh
X.324	Red Mexican UI 3	1976	Netherlands	rh
X.349	—	1976	Machakos District	re
X.359	—	1976	Machakos District	mm
X.364	—	1976	Machakos District	mm
X.370	—	1976	Machakos District	mw
X.373	—	1976	Machakos District	mw
X.378	—	1976	Machakos District	mw
X.380	—	1976	Machakos District	mw
X.392	—	1976	Machakos District	mm
X.393	—	1976	Machakos District	mm
X.395	—	1976	Machakos District	mm
X.436	—	1976	Embu District	re
X.451	—	1976	Embu District	er
X.459	—	1976	Embu District	re
X.464	—	1976	Embu District	re
X.469	—	1976	Embu District	cw
X.491	—	1976	Embu District	re
X.495	—	1976	Embu District	re
X.501	—	1976	Embu District	rh
X.505	—	1976	Embu District	rh
X.506	—	1976	Embu District	rh
X.524	—	1976	Embu District	re
X.541	—	1976	Embu District	re
X.542	—	1976	—	re
X.568	—	1976	Embu District	cw
X.579	—	1976	Embu District	cw
X.597	—	1976	Embu District	re
X.602	—	1976	Embu District	re
X.604	—	1976	Embu District	re
X.606	—	1976	Embu District	re
X.608	—	1976	Embu District	rh
X.609	—	1976	Embu District	re
X.613	—	1976	Embu District	re
X.616	—	1976	Embu District	re
X.634	—	1976	Kisii District	ze
X.639	—	1976	Kisii District	rh
X.640	—	1976	Kisii District	re
X.655	—	1976	Kisii District	rh
X.662	—	1976	Kisii District	bl
X.664	—	1976	Kisii District	re
X.679	—	1976	Kakamega District	re
X.688	—	1976	Kakamega District	ye
X.693	—	1976	Kakamega District	re
X.696	—	1976	Kakamega District	re

Table 5 Contd.

Variety or varietal group name		Introduction Year	Introduction Origin	Seed type*
X.730	—	1976	Kiambu District	cw
X.731	—	1976	Kiambu District	cw
X 732	—	1976	Kiambu District	cw
X.733	—	1976	Kiambu District	cw
X.734	—	1976	Kiambu District	cw
X.743	—	1976	Kiambu District	rh
X.749	—	1976	Kiambu District	rc
X.753	—	1976	Kiambu District	rc
X.754	—	1976	Kiambu District	rc
X.765	—	1976	Kiambu District	rh
X.769	—	1976	Kiambu District	rh
X.778	—	1976	Kiambu District	rc
X.783	—	1976	Kiambu District	rc
X.784	—	1976	Kiambu District	rc
X.806	—	1976	Kiambu District	ze
X.807	—	1976	Kiambu District	rh
X.808	—	1976	Kiambu District	ze
X.811	—	1976	Kiambu District	rc
X.903	—	1976	Embu Show	cw
X.921	—	1976	Embu Show	mm
X.1129	(GLP-2 × GLP-16)	1976	GLP	rc
RH-7	(GLP-574 × GLP-4)	1977	GLP	rh
RH-27	NB-84**	1976	Not known	rh

*bl = black bean
br = brown bean
cr = cream bean
cw = Canadian Wonder
gr = grey bean
mm = Mwezi Moja
mw = Mwitemania (= Pinto)
pu = purple bean
rc = Rose Coco
rh = red haricot
wh = white haricot
ye = yellow bean
ze = zebra bean
**NB number in the collection of the Faculty of Agriculture, University of Nairobi (Dr. Mukunya).

Common blight (*Xanthomonas phaseoli* (E.F. Sm.) Dows)

The common-blight bacterium is favoured by higher temperatures than those optimum for the halo-blight pathogen. Initial infection is evident as water-soaked spots on the underside of leaves. The spots enlarge irregularly and coalesce with adjacent lesions. At first the lesions are surrounded by a narrow zone of yellow chlorotic tissue which eventually becomes necrotic. Pod lesions appear as water-soaked spots which enlarge and become darkened and slightly sunken. Seeds are typically infected through the pedicel and the bacteria pass into the seed coat. Light-coloured bean cultivars exhibit discoloration on the seed coat, but this may be difficult to observe in the darker cultivars. Stem infection may result in girdling and subsequent wilting of the plant. Stem rot may develop at cotyledonary nodes if the plants originate from infected seed. As with halo blight, infected plant debris is important in the carry-over of the bacteria in fields, where wind and splash dispersal are important in spreading the disease. The results for common blight are given in Table VIII.

TABLE VI—HALO BLIGHT (*PSEUDOMONAS PHASEOLICOLA*) INCIDENCE AT KATUMANI STATION

Season and year*	Trial(s)**	Average disease score	Number of entries	Observed resistance (R) or susceptibility (VS)
LR 1977	1,2,3,4	1.9	346	R: GLP-2, 3, 332, 585, 662, 683, 703, X.62, X.92, X.102, X.202, X.506, X.696. VS: GLP-1, 4, 21, 24, 65, 70, 110, 240, 349, 423, 570, 584, 639, 706, X.33, X.90, X.263, X.501, X.524, X.608, X.743.
SR 1977/1978	1, 2, 3, 4,	1.9	346	R: GLP-12, 26, 253, 263, 292, 301, 305, 308, 310, 311, X.370, X.451, X.495, X.505, X.604 VS: GLP-2, 10, 24, 65, 96, 110, 245, 276, 331, 546, 593, 640, 649, 705, X.78, X.188, X.469, X.608, X.639, X.730, X.743, X.807, X811.
SR 1978/1979	3	0.5	15	no reliable data

*LR = long rains
SR = short rains
**See Table 3 for descriptions

TABLE VII—HALO (*PSEUDOMONAS PHASEOLICOLA*) INCIDENCE AT KATUMANI STATION IN RELATION TO ORIGIN AND/OR SEED TYPE

		Mean scores*			
Origin of seed	Type of seed	Origin**	Seed Type** *****	Origin and seed type****,****	Origin and seed Type ****, *****
Kiambu District	Mixed Types	2.5 a	—	—	—
Embu District	Mixed Types	1.8 ab	—	—	—
Kakamega District	Mixed Types	1.3 b	—	—	—
Machakos District	Mixed Types	1.3 b	—	—	—
Kisii District	Mixed Types	1.2 b	—	—	—
U.S.A.	Canadian Wonder	—	—	3.2 a	—
Kenya	Mwezi Moja	—	—	3.0 a	1.8 a
Kenya	Canadian Wonder	—	1.6 a	2.3 b	1.4 a
Uganda	Rose Coco	—	—	1.8 bc	—
Kenya	Red Haricot	—	2.1 a	1.7 c	—
Kenya	Mwitemania	—	—	1.3 c	0.5 a
Kenya	Rose Coco	—	1.5 a	1.8 c	—
Kenya/Uganda	Rose Coco	—	—	—	1.2 a

Treatment means not followed by the same letter vertically differ significantly (P = 0.05) according to L.S.D.—test for samples of unequal size.

*Means for trials of long rains 1977 and short rains 1977/1978
**Trial 2 (see Table 3)
***Trial 4 (see Table 3)
****Trial 3 (see Table 3)
*****For the same origin and/or seed type different lines within the same type were tested in the three trials.

TABLE VIII—COMMON BLIGHT (*XANTHOMONAS PHASEOLI*) INCIDENCE AT KATUMANI STATION

Season and year*	Trial(s)**	Average diseases score	Number of entries	Observed resistance (R) or susceptibility (VS)
SR 1977/1978	2, 3	1.0	84	R: GLP-3. VS: GLP-X.102.
LR 1978	1, 3, 5	1.1	48	R: GLP-24, X.62, X.602, X.616. VS: GLP-10, 1004, X.48, X.85, X.89, X.604, X.732, X.734.
SR 1978/1979	1, 3, 4, 5	0.7	147	R: GLP-3, 24, X.48, X.60, X.92, X.152, X.602, X.616. VS: GLP-2, 79, 99, 1004, X.81, X.85, X.734.
LR 1980	4, 7	0.5	1,017	R: GLP-X.380. VS: GLP-22, 154, 161, 171, 230, 231, 322, 350 354, 356, 389, 527, 561, 621, 650, 709, 736, 909, 940, X.33, X49, X364.
LR 1981	8	0.5	86	VS: GLP-870, Rh-7.
LR 1982	7	0.5	12	VS: GLP-X.1129.

*LR = long rains
SR = short rains
**See Table 3 for descriptions

TABLE IX—ANTHRACNOSE (*COLLETOTRICHUM LINDEMUTHIANUM*) INCIDENCE AT KATUMANI STATION

Season and year*	Trial(s)**	Average disease score	Number of entries	Observed resistance (R) or susceptibility (VS)
SR 1982/1983	9	0.5	12	VS: GLP-343

*SR = short rains
**See Table 3 for descriptions

TABLE X—BLACK NODE DISEASE (*PHOMA EXIGUA* VAR. *DIVERSISPORA*) INCIDENCE AT KATUMANI STATION

Season and year*	Trial(s)**	Average disease score	Number of entries	Observed resistance (R) or susceptibility (VS)
SR 1978/1979	1,3	2.0	27	R: GLP-10, 1004, X.81, X.85. VS: GLP-8, 12, X.78, X.90, X.152, X.542.

*SR = short rains
**See Table 3 for descriptions

TABLE XI—SCAB (*ELSINOE PHASEOLI*) INCIDENCE AT KATUMANI STATION

Season and year*	Trial(s)**	Average disease score	Number of entries	Observed resistance (R) or susceptibility (VS)
SR 1976/1977	1, 2	2.1	541	R: GLP-8, X.349, X.373, X378, X392, X.395, X. 753, X.754. VS: GLP-1, 2, 4, 10, 12, local **, X.393, X464, X.541, X.579, X.662, X.688, X.693, X.749, X.769, X.778, X.783, X.784.
LR 1977	4	0.7	250	VS: GLP-65, 70, 71, 72, 96, 288, 303, 305, 312, 317, 322, 336, 346, 423, 438, 481, 570, 639, 705.
LR 1977	1, 2, 3	0.8	96	R: GLP-3, 8, X.62, X.92, X.102, X.117, X.152, X.202, X.263, X.264, X.265, X.321. VS: GLP-1, 10, local **, X.49, X.78, X.81, X.90, X.359, X.609, X.634, X.808.
SR 1978/1979	5	0.5	15	no reliable data.
SR 1979/1980	6	0.5	70	VS: GLP-21, 23, 26, 249, 267, 306, 309, 329, 344, 359, 360, 362, 364, 365, 536.

*LR = long rains
SR = short rains
**See Table 3 for descriptions
***Local: local Mwezi Moja, from which GLP-1004 was selected.

Anthracnose (*Colletotrichum lindemuthianum* (Sacc. & Magh.) Scrib.)

Bean anthracnose development is especially favoured by temperatures between 13° and 26°C; temperatures above 30°C limit infection and development of the fungus. High humidity, greater than 92%, or free moisture is necessary for infection. Symptoms of the disease may appear on any part of the plant. Initial symptoms on leaves are small black lesions, especially on cotyledonary leaves. On older leaves large necrotic spots may occur in addition to lesions along the surfaces of the veins. Petiole and branch infection is also common. Pod infection appears as pink or rust-coloured to dark-brown or black spots which develop into sunken cankers containing masses of pink or orange-coloured spores. In cases of severe infection, young pods may be completely shrivelled and dried. Infected seed and crop debris are primary sources of inoculum. The fungus is readily seed-borne. Free water is necessary for the dissemination of the spores from these sources of inoculum and between infected plants. Several races or biotypes of the fungus are known to occur. Table IX shows the observations of anthracnose at Katumani Station.

Phoma leaf spot or black node disease (*Phoma exigua* var. *diversispora* (Bub.) Boerema)

This fungus is not widely distributed in bean-producing areas throughout the world. Nevertheless, it is reported to be endemic in East Africa (Boerema *et al.*, 1981). Under conditions of high humidity the fungus can cause large, rapidly developing necrotic spots on the leaves. These are greyish or brown in colour and often show concentric rings of fungus sporulation. Stem infections can also occur. Affected leaves turn yellow, dry up, and fall. Infected pods may be blackened and shrivelled at both ends. Infection may kill the plant while still in the pod-forming stage. The fungus has been shown to be seed-borne, and infected seed produced in East Africa is reported to have caused disease outbreaks in Europe. While information on the importance of infected plant debris as a hold-over of the fungus in bean fields is not reported in the

little that has been published, it is almost certain that debris is important as a source of inoculum. Table X shows the observations at Katumani Station.

Scab (*Elsinoë phaseoli* Jenkins)

Detailed temperature and humidity requirements for disease development have not been determined, although in general it has been observed that high temperatures and humidities favour development of the fungus (Mutitu and Mukunya, 1979). Probably a period of at least several hours of wetness is necessary for fungal penetration. The fungus attacks all parts of the foliage, but not the flowers. On the pods greyish to brown raised or sunken lesions are up to 1 cm in diameter and are usually irregularly distributed, producing a scabby appearance. The small elongated lesions on stems may coalesce and sometimes completely encircle the stem. The seed-coat surface may be invaded by the fungus, but lesions have not been observed on the ovary wall. Little of the biology of *E. phaseoli* is known. However, several races or biotypes of the fungus are known to occur, based on their ability to infect particular species of legumes. The observations for this disease are shown in Tables XI and XII.

TABLE XII—SCAB (*ELSINOE PHASEOLI*) INCIDENCE AT KATUMANI STATION IN RELATION TO THE ORIGIN AND/OR SEED TYPE

		Mean disease scores			
Origin of seed	Type of seed	Origin*	Seed type*, ***	Origin and seed type*	Origin and seed type **, ***
Kiambu District	Mixed Types	2.4 a	—	—	—
Kakamega District	Mixed Types	2.2 a	—	—	—
Embu District	Mixed Types	2.2 a	—	—	—
Kisii District	Mixed Types	1.9 a	— —	— —	—
Machakos District	Mixed Types	1.2 b	—	—	—
Kenya	Rose Coco	—	2.2 a	—	0.8 b
Kenya	Canadian Wonder	—	2.1 ab	—	0.6 bc
Kenya	Red Haricot	—	1.9 bc	—	0.4 bc
Kenya	Zebra	—	1.8 abc	—	—
Kenya	Mwezi Moja	—	1.4 c	—	1.8 a
Kenya	Mwitemania	—	0.3 d	—	0.0 bc
Kakamega District	Rose Coco	—	—	2.5 a	—
Embu District	Canadian Wonder	—	—	2.5a	—
Embu District	Rose Coco	—	—	2.2ab	—
Kiambu District	Red Haricot	—	—	2.1ab	
Machakos District	Rose Coco	—	—	2.1abc	—
Kakamega District	Red Haricot	—	—	2.0abcd	—
Kiambu District	Rose Coco	—	—	2.0abcd	—
Kisii District	Red Haricot	—	—	1 6abcd	—
Kisii District	Rose Coco	—	—	1.6 bcd	—
Kiambu District	Canadian Wonder	—	—	1.6 bcd	—
Machakos District	Mwezi Moja	—	—	1.4 d	—
Kisii District	Canadian Wonder	—	—	1.4 bcde	—
Embu District	Red Haricot	—	—	1.4 cd	—
Machakos District	Mwitemania	—	—	0.3 e	—
Uganda	Rose Coco	—	—	—	0.1 c
U.S.A.	Canadian Wonder	—	—	—	2.6 a

Treatment means not followed by the same letter vertically differ significantly (P = 0.05) according to L.S.D.—test for samples of unequal size.

*Trial 2, short rains 1976/1977

**Trial 4, long rains 1977

***For the same origin and/or seed type different lines within the same type were tested in the two trials.

TABLE XIII—ANGULAR LEAF SPOT (*PHAEOISARIOPSIS GRISEOLA*) INCIDENCE AT KATUMANI STATION

Season and year*	Trial(s)**	Average disease score	Number of entries	Observed resistance (R) or susceptibility (VS)
SR 1977/1978	2,3	0.5	84	VS: GLP-X.459, X.495, X.597, X.734.
SR 1978/1979	1, 3, 4, 5	2.0	156	R: GLP-7, 22, 24, 26, 78, 261, 414, 574, 681, 694, X.62, X.78, X.92, X.102, X.616, X.655, X.696.
				VS: GLP-10, 18, 20, 65, 71, 72, 326, 344, 346, 359, 360, 362, 363, 364, 365, 369, 463, 640, 1004, X.81, X.85, X.90, X.202, X.265, X.730, X.731, X.733, X.734.
LR 1979	5	2.0	20	R: GLP-X.542, X. 568, X.696.
				VS: GLP-1004, X.364, X.393, X.436, X.640, X.730, X.806.
SR 1979/1980	1, 6	0.5	82	VS: GLP-21, 79, 333, 347, 359, 360, 364, 369,
LR 1980	4	0.5	1,005	VS: GLP-12, 20, 37, 38, 53, 54, 64, 67, 161, 291, 353, 455, 456, 462, 868, 884, 902, 973, 981.
LR 1981	8	0.5	86	VS: GLP-425, 585.

*LR = Long rains
SR = short rains
**See Table 3 for descriptions

TABLE XIV—ANGULAR LEAF SPOT (*PHAEOISARIOPSIS GRISEOLA*) INCIDENCE AT KATUMANI STATION IN RELATION TO THE ORIGIN AND/OR SEED TYPE

		Mean disease scores			
Origin of seed	Type of seed	Seed type*, ****	Origin and seed type **, ****	Origin and seed type ***	Origin and seed type***, ****
Kenya	Rose Coco	1.8	2.1	—	1.6
Kenya	Canadian Wonder	2.1	—	—	2.0
Kenya	Mwezi Moja	2.0	3.6	—	—
Uganda	Rose Coco	2.5	3.3	—	—
Embu District	Mixed Types	—	—	1.4	—
Machakos District	Mixed Types	—	—	2.8	—
Kiambu District	Mixed Types	—	—	2.1	—
Machakos District	Mwezi Moja	—	—	—	3.1
Machakos District	Mwitemania	—	—	—	2.5

All treatment means do not differ significantly (P = 0.05) according to L.S.D. test for samples of unequal size.
Trial 4, short rains 1978/1979
** Trial 3, short rains 1978/1979
***Trial 5, long rains 1979
****For the same origin and/or seed type different lines within the same type were tested in the three trials.

Angular leaf spot (*Phaeoisariopsis griseola* Sacc.)

This fungus is favoured by moderate temperatures (18° – 25°C) and periods of high humidity or moisture; it infects the plant through the leaf stomata. Leaf spots generally appear first on the lower leaf surfaces as grey spots which later turn brown. At first the lesions are angular in shape, being delineated by the veins and veinlets of the leaf. Brown, angular or more round-shaped

TABLE XV—RUST (*UROMYCES APPENDICULATUS*) INCIDENCE AT KATUMANI STATION

Season and year*	Trial(s)**	Average disease score	Number of entries	Observed resistance (R) or susceptibility (VS)
SR 1976/1977	1	0.5	12	VS: GLP-3, 4.
LR 1977	1, 2, 3, 4	0.5	346	VS: GLP-4, 242, 367, 418, 547, 582, 707, X.321, X.370, X.602, X.743.
SR 1977/1978	2, 3	0.5	84	VS: GLP-X.224, X451.
LR 1978	1, 3, 5	0.5	47	VS: GLP-X.89, X.92, X.152, X.370.
SR 1978/1979	1, 4, 5	0.5	127	VS: GLP-2, 253, 1004, X.60, X.90, x.92, X.602, X616, X.732.
LR 1979	5	1.6	21	R: GLP-X.393, X.903, X.921. VS: GLP-X.370, X.380, X.765.
LR 1980	4, 7	0.5	1017	VS: GLP-32, 38, 42, 234, 635, 654, 831, X.92, X.102, X.380, X.491.
LR 1981	7, 8	0.5	98	VS: GLP-69, 418, 697, 831, 870, X.380, X.491, X.730.
SR 1981/1982	4, 8	0.5	372	VS: GLP-348, 350, 766, X.1, X.2, X.4, X.41, X.44, X.49, X.55, X.84, X.88, X.92, X.97, X.136, X.139, X.143, X.144, X.146, X.271, X.309, X.323, X.324, RH-27.
SR 1982/1983	9	0.5	12	No reliable results.

*LR = long rains
SR = short rains
**See Table 3 for descriptions

spots develop on the upper surface of the leaf. Under very favourable conditions of high humidity, stems and pods may be affected, although this condition has only rarely been observed in Machakos District. Lesions become evident by 9 days after infection on all plant parts. Leaf lesions may increase in size, coalesce, and result in yellowing and drying of the leaves, followed by premature defoliation in extreme cases. The fungus is seed-borne but survives primarily in bean-producing areas on infected plant debris and in the soil. It is disseminated by splashing water or soil particles and, from sporulating lesions, by wind. The data from Katumani Station for angular leaf spot are compiled in Tables XIII and XIV.

Rust (*Uromyces appendiculatus* (Pers.) Unger. = *U. phaseoli* (Reben) Wint.)

Infection by this fungus is favoured by moderate temperatures between 17° and 27°C and prolonged periods of high relative humidity. It is reported that temperatures above 32°C may kill the fungus. Early symptoms of rust infection are small chlorotic spots on both sides of the leaf which rapidly develop into typical rust pustules consisting of thousands of spores. If infection occurs early in the growing season, before the period of flowering, severe losses may result after defoliation of susceptible cultivars. Pod infection may also occur. Numerous physiological races of the fungus are known; Howland and Macartney (1966) identified eight races of bean rust in East Africa. Depending upon these races, the cultivar of bean, and the environmental conditions existing, pustules may be surrounded by a chlorotic or necrotic border. The rust pathogen can survive in dried plant debris in fields, but both primary and secondary inoculation is largely due to spores being blown in by wind over long distances. The fungus is not seed-borne. The Katumani Station observations are presented in Table XV.

Some Other Potentially Important or Minor Diseases of Bean Occurring in Semi-arid Areas but not Evaluated in This Report

Ashy stem blight (*Macrophomina phaseolina* (Tassi) Goid)

Ashy stem blight infection occurs in regions with high temperatures (above 30°C) and moderate to high moisture conditions. Typically, young

plants or seedlings are invaded near the base of the stem or at the point of emergence of the cotyledons. Sunken cankers with sharply defined margins typically occur on the stems. Older seedlings and plant infections may also result in stunting, chlorosis, defoliation, and root rot. Older enlarged lesions may cover almost the entire stem. These become grey in colour and contain the small black sclerotia or phycnidial fruiting structures of the fungus. The pathogen can also invade the seeds, which can therefore serve as an important primary source of inoculum. In semi-arid areas, the disease becomes especially apparent in mature plants and at flowering if soil-moisture levels are too low and the plants are under drought stress.

In a drought-resistance trial at Thika Station with different water-application levels, ashy stem blight incidence was significantly higher under lower water-application levels than under higher levels (Floor-Drees, personal communication, 1983). Severe outbreaks of the disease have been locally observed in Machakos and Kitui Districts, especially in the more poorly-drained areas of bean fields. During the long rains of 1983 the drought resistance trial at Kampi ya Mawe was severely affected by ashy stem blight. Initial results show that differences in resistance between the cultivars exist (Stoetzer and Floor-Drees, unpublished data, 1983), e.g. GLP-1004 is more susceptible to this disease than GLP-2 or GLP-X.92.

Bean Common Mosaic (Bean Common Mosaic Virus, BCMV)

Symptoms of bean common mosaic may vary according to the strain of the virus, the degree of resistance of the host cultivar, age of the plant, and different environmental conditions (especially temperature). Symptoms include light and dark leaf mottling typical of mosaics in general. In addition, there may be leaf puckering, blistering, and reduction in leaf and plant size. Leaves may also be abnormal in shape and exhibit a downward cupping from the margins. Occasionally, necrosis of the growing tip of the leaves occurs, resulting in wilting of the plant. This symptom is called black root disease, caused by a necrosis-inducing strain of the virus on hosts with the dominant I gene. Transmission of the virus through seeds constitutes the primary means of dissemination. The virus is also transmitted in pollen grains. Aphid species are responsible for secondary dissemination of the virus from infected to healthy plants. Susceptible weed hosts may serve as reservoirs of the virus during periods free of bean growth in particular areas. Disease incidence in bean plants may vary from a few scattered plants affected to 100%. However, in Machakos District the incidence noted has been very low.

Root and Stem Rots

Fusarium root rot (*Fusarium solani* f. sp. *phaseoli* Snyder and Hansen) produces symptoms of reddish-coloured lesions on primary roots soon after germination. Eventually these cover the entire root system. Severe cracking of the taproot may occur and secondary roots develop above the lesions of the primary root. Plants are usually not killed but yields are greatly reduced.

Rhizoctonia root rot (*Rhizoctonia solani* Kuhn) consists of the production of reddish-to-brown cankers on the main root and hypocotyl. These have a well defined border and may advance into the pith. The fungus causes damping off in young bean plants.

Southern blight (*Sclerotium rolfsii* (Curzi) West.) initially results in water-soaked lesions on the stem or hypocotyl below the soil surface. Yellowing and wilting of leaves occurs as infection proceeds into the taproot and cortex, followed by death of the plant.

Crop rotation and wider spacings between plants in the row result in lower disease incidence for the above three diseases. Drought stress can increase disease incidence (Floor-Drees, personal communication, 1983).

CONCLUSIONS AND DISCUSSION

Disease Incidence in Relation to the Growing Seasons: Short Rains 1976/77—Long Rains 1983

The short rains of 1976/77 were medium wet (211 mm), with the rainfall evenly distributed during the season and lasting through December. During the two months of the season there were 12 days with more than 5 mm of rainfall. The maximum temperatures of November were 1.5°C. higher than the 14-year averages, while the minimum temperatures of November and December were above average, resulting in one of the warmest seasons. Scab incidence was quite high, agreeing with the observations of Mutitu and Mukunya (1979) that the disease is favoured by warm and wet conditions. Rust incidence was very low, only one line being susceptible.

Heavy precipitation (412 mm) occurred during

the long rains of 1977, which were evenly distributed with 17 days having more than 5 mm. Mean temperatures were about the same as for the 14-year average, although the mean maximum was slightly under average and the mean minimum was slightly over. Halo blight was relatively severe, probably due to continuous favourable rainfall for the pathogen. Also, the seed for these trials was partly selected from farmers' fields throughout Kenya during 1976, and may have been somewhat infected with halo blight. Scab incidence was low (less than 1.0 for pod and leaf readings). There is no clear explanation for the low incidence of scab under these conditions, which should have favoured its development. Possibly this was due to low inoculum potential of the scab fungus in the plots and the somewhat low temperatures. Rust incidence was also slight.

Precipitation for the short rains of 1977/78 was high (284 mm), with one 10-day dry period in early December, resulting in a fairly even distribution over the season. There were 16 days with more than 5 mm of rain. Maximum day temperatures were slightly lower than average, while minimum readings were near average. Halo blight was relatively severe, possibly due to these favourable temperatures and rainfall. Common blight was light, and incidences of angular leaf spot and rust were also very low.

The unevenly distributed rainfall (229 mm) for the long rains of 1978 was lower than that of the previous two seasons and was concentrated in the first 40 days, with 11 days having over 5 mm for the entire season. Mean temperatures were lower for all months, resulting in the coolest observed season. There was a low incidence of common blight and a very low incidence of rust. Probably the medium rainfall was too unevenly distributed over the season for the development of most diseases.

The short rains of 1978/79 were considered an intermediate season, with a total rainfall of 245 mm, evenly distributed over the season. A period without rain occurred at the end of December, but there were 13 days in the season with more than 5 mm precipitation. Maximum temperatures were somewhat lower than average, and the average mean below normal, resulting in a relatively cool season. Incidence of halo blight and common blight was very low, but black node disease and angular leaf spot were rather severe. Black node disease is reported to be favoured by cool and humid conditions (Boerema *et al.*, 1981). Scab and rust incidence was low.

The long rains of 1979 were favourable for bean growth, with 17 days with more than 5 mm of rainfall, which occurred particularly in April, resulting in a very wet season (304 mm) with a somewhat uneven distribution of the precipitation. Halo blight incidence was not noted. Common blight and scab were also not evident; but incidences of angular leaf spot and rust were high. The sudden increase in rust was especially noteworthy, for unknown reasons.

The long rains of 1980 were very low at the onset but tapered off until the end of December; there were 11 days with more than 5 mm of rainfall, 6 of these occurring during the first 10 days of the season. The total precipitation was 200 mm. There were no important differences from the average in the maximum temperatures, although it was slightly warmer in December. The minimum temperatures were normal. It was a poor season for disease development; scab and angular-leaf-spot incidence was very low and no rust was recorded.

The long rains of 1980 were very low at the onset. Rainfall, amounting in total to 196 mm, was largely concentrated over a 4-week period from about 10 April to 10 May, with 11 days having over 5 mm precipitation. Maximum temperatures were slightly higher than normal, especially in April. The minimum temperatures of May were also slightly higher, resulting in slightly higher temperatures for the mean of the entire season. A very low incidence of common blight was recorded, and angular-leaf-spot and rust incidence was slight.

The 1980/81 short rains were heavy at the onset but dropped off rapidly by the end of November. There were 12 days with more than 5 mm of rainfall but 7 of these occurred during the first 7 days of November. The total precipitation was 178 mm. Maximum and minimum temperatures were about normal. No diseases were observed.

The long rains of 1981 were moderate at onset but the period 10–20 April had heavy rains, resulting in a total of 270 mm unevenly distributed over the season. There were 10 days with precipitation of more than 5 mm. Mean temperatures were average for the season, although the average of the maxima was one degree below the 14-year average, while the minima were more than one degree above average. Incidences of common blight, angular leaf spot, and rust were slight. It was a poor season for disease development.

The 1981/82 short rains season was very dry (96 mm), with 7 days over 5 mm of rainfall. The little rain was evenly distributed over the season. Temperatures were close to the means for the season. Only a slight incidence of rust was noted.

The long rains of 1982 were not heavy (192 mm), but were well distributed over the period. There were 13 days with more than 5 mm of rain. Maximum temperatures were slightly below normal, especially in May, while minima were about average. Incidence of common blight was very slight, and no rust or angular leaf spot was recorded.

Apparently the prolonged period of relatively low rainfall from the short rains of 1979/80 to the 1982 long rains was responsible for the low incidence of all diseases.

The short rains of 1982/83 were heavy (352 mm), with 18 days having more than 5 mm, unevenly distributed over the season. The temperatures were normal. In spite of highly favourable conditions for disease development there was no halo blight, while anthracnose and rust incidence was slight. This could be due to lack of inoculum residue in the area because of previous low-rainfall seasons, and to the clean seed planted.

The long rains of 1983 were a failure (120 mm). Almost all the rain for the season fell in one 10-day period at the end of April. May was hot and dry, although minimum temperatures for the season were about average. No disease incidence was recorded.

Some diseases not observed in the trials during the 14 seasons are considered of potential importance for the semi-arid zones. The most important is ashy stem blight, which reached a high incidence during the extremely dry 1983 long rains at the Kampi ya Mawe Substation and in farmers' fields in Machakos and Kitui Districts, as observed by the authors. Observations by the authors and by Floor-Drees (personal communication, 1983) at various sites under dry conditions confirm the conclusions by Palti (1981) that ashy stem blight is aggravated by drought stress of the host.

After the short rains of 1977/78 halo blight did not reach epidemic levels at the Katumani Station. Even during the very wet short rains of 1982/83 halo blight was not recorded at the Katumani Station, although in farmers' fields in Machakos and Kitui Districts it was often observed by the authors and also by Gathuru and Mukunya (1983), suggesting that even after a couple of rather dry seasons enough seed-borne inoculum remains present to cause high disease incidence under favourable conditions for halo blight. Muthangya (1980) observed that blight of beans associated with *Xanthomonas* (probably common blight) was more severe in areas where the farmers were using their own seed season after season, and also where farmers purchased the seeds from local markets. From the comments on disease incidences for the short and long rains given above, it is evident that predictions of outbreaks (based on total rainfall, distribution of rainfall, and temperature variations) for any particular disease are difficult. The only general conclusion that can be made is that drier seasons at Katumani favour reduced incidence for all bean diseases, with ashy stem blight as an exception. However (for reasons unknown), this disease has not been observed during drier seasons at Katumani Station.

Incidence of Disease in Relation to Origin and Seed Type

In Kenya, plants grown from seed of mixed types selected in Kiambu District are more susceptible to halo blight than those selected from other districts (Table VII). If seed transmission of the halo-blight pathogen were a factor, it would be expected that the seed produced in Kisii District would result in a higher disease incidence, since that district has a long history of seed infection by the bacterium. Thus it can be concluded that increased susceptibility of plants from Kiambu selected lines is due to genetic reasons. Plants grown from Canadian Wonder types originated from the U.S.A. and those from Mwitemania lines selected in Kenya also appear to be more susceptible to halo blight. The other seed types from Kenya and Uganda, in general, produced plants with lower halo-blight incidence (Table VI).

Scab incidence in Mwitemania and Mwezi Moja plants from lines selected in Machakos District appeared to be lower than in lines originating in other districts (Table XII). However, this was not evident for Rose Coco from Machakos District. In addition, we cannot in general state that plants grown from Mwezi Moja seed, produced from lines originating from Kenya, are more resistant than plants from other seed-type groups. The Rose Coco group of lines from Kenya appears to be relatively susceptible to scab when compared to the lines from Uganda. Canadian Wonder lines from the U.S.A. are also very suceptible to scab, while Mwitemania lines

from Kenya are the most resistant of all bean group types tested. No other general conclusions can be made from the data in Table XII for the remaining seed types and origins because of the short period of observations.

There were no significant differences in angular-leaf-spot incidence in plants from seed selected in the different districts of Kenya or among the bean types (Table XIV). Angular leaf spot is widespread throughout the country and the continuous exposure of local germ-plasm to the pathogen would be expected to result in some level of resistance in lines originating from all areas in Kenya. The results appear to show that Rose Coco lines from Kenya are more resistant than Rose Coco lines from Uganda or Mwezi Moja lines from Machakos District. However, these differences are probably not significant, due to the small sample size taken in this particular evaluation for angular-leaf-spot incidence.

Disease Resistance

The observed resistance to halo blight in GLP-X.92 (Table VIII) has proved to be very reliable. This cultivar, which may be released soon, withstood the severe halo-blight epidemics of race 1 and race 2 in Kisii (Kinyua *et al.*, 1981; Stoetzer *et al.*, 1983).

Ten entries showed resistance to common blight (Table VIII), but as the average disease scores were low the observations should be treated with caution. However, the resistance of GLP-3, GLP-24, GLP-X.602, and GLP-X.616 appears to be fairly consistent. It should be mentioned that GLP-24 (a Canadian Wonder type) is one of the cultivars released by the Grain Legume Project.

Four cultivars showed some resistance to black node disease (Table X), including GLP-1004, a Mwezi Moja type released by the Grain Legume Project for the semi-arid regions.

The scab resistance as observed during the short rains of 1976/77 can be considered as reliable (Table XI); however, the observations during the long rains of 1977 should be treated with caution. The resistance of the black-seeded cultivar GLP-8 is consistent.

The resistance to angular leaf spot (Table XIII) includes the above-mentioned GLP-24 and GLP-X.92 cultivars.

As disease incidences for bean rust were low during most seasons, only a few resistant lines were observed (Table XV). It should be noted that GLP-X.92, which was recorded as rust-susceptible during several seasons, has been observed to be resistant in some other areas by the authors. Probably this can be attributed to pathotype differences.

SUMMARY

Observations on bean diseases during 14 bean-growing seasons over 7 consecutive years in trials of the Grain Legume Project at the National Dry-land Farming Research Station, Katumani, showed that the severity of the different bean diseases is highly variable from one season to another. During the 14 seasons the total amounts of rainfall and its distribution within the season were also variable. Five seasons were relatively wet (250–300 mm) to very wet (>300 m). Three seasons had medium rainfall (200–250 mm), while 6 seasons were dry (150–200 mm) to very dry (<150 mm). Mean disease scores are given for halo blight, common blight, angular leaf spot, rust, scab, black node disease, and anthracnose. Halo blight was rather severe during two wet seasons with an even rainfall distribution. Common blight was observed during six seasons, but disease severity was low to very low. Angular leaf spot was severe in only 2 seasons, while it was at a very low incidence during 3 other seasons. Rust severity was always low, except during one season when a medium score was recorded. Scab was severe during one wet season with evenly distributed rainfall and a fairly high mean temperature. Black node disease appeared during only one season with rather high scores. This season was cool compared with the 14-year mean. Anthracnose was observed during only one very wet season, and incidence was low. In general, in the drier seasons there appear to be lower disease incidences for all bean diseases, with the possible exception of ashy stem blight.

Resistant germ-plasm is indicated for halo blight, common blight, angular leaf spot, rust, scab, and black node disease.

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BEAN SEED QUALITY LOSS IN KENYA DUE TO YEAST INFECTION *(NEMATOSPORA CORYLI)* AND ITS EFFECT ON YIELD (ASBTRACT)

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Seed of common bean (*Phaseolus vulgaris*, variety Mwezi Moja) produced in Katumani (Eastern Province, Kenya) was found to be infected by the yeast *Nematospora coryli*. Pathogenicity was confirmed by needle inoculations of cultured yeast cells and transmission by the pod-sucking bugs *Acanthomia tomentosicollis* and *Nezara viridula* on developing seed pods. Seeds were graded into three categories, based on the severity of external symptoms. The emergence of heavily infected seeds and the survival of seedlings was greatly reduced in greenhouse tests. In field trials, severity of seed infection was correlated with poor emergence and reduction in yield per plant. At Katumani, plants grown from the most severely affected seeds produced a proportionately larger number of poor-quality seeds, while at the National Agricultural Laboratories (NAL), Nairobi, plants grown from severely affected seed did not produce proportionately larger numbers of poor-quality seed. This difference could be attributed to higher insect activity at Katumani as compared to the NAL. Small farmers in Kenya can reduce losses in yield by planting only seeds free of disease symptoms.

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SOME OBSERVATIONS OF DISEASES OF MAIZE, SORGHUM AND MILLET IN THE DRYLAND AREAS OF EASTERN PROVINCE

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INTRODUCTION

Over the past several years, general observations of the most prevalent diseases of maize, sorghum and millet have been made in small farms of the Machakos, Kitui, Embu and Meru Districts. Although little quantitative information on disease incidence in these crops has been obtained, reasonably reliable conclusions have been reached about the importance of these diseases.

Descriptions of the diseases, with comments on their relative importance and possible means of control, are outlined below for each of these crops.

Maize

Virus diseases

Maize mosaic, maize stripe, and maize streak are all reported to be present in the area (Louie, 1980; Kulkarni, 1973). The "maize mosaic", which is more properly called sugar-cane mosaic in maize (SCMV), can easily be confused on the basis of symptoms with true maize mosaic (MMV) and with maize stripe, which also occurs in Kenya. Symptoms appear as chlorotic spots, short lines, and broken to nearly continuous, fine to broad chlorotic stripes along the leaves. Sugan-cane mosaic is transmitted by aphids, while stripe is spread by leafhoppers. Maize streak (MSV) is typified by long discontinuous chlorotic streaks which may fuse partially or completely to leave irregular green areas between the veins. It is also transmitted by a leafhopper. The separation of these three viruses by eye is very difficult and can only be done reliably using clinical techniques. These viruses can also occur on sorghum and wild grasses.

General observations in the Katumani, Kampi ya Mawe, Kitui, and Makueni areas in the period of the long and short rains, 1979—1982, did not reveal any incidence of virus diseases in maize. Louie (1980) reported no incidence of SCMV in 16 fields examined in Kitui and Machakos Districts in 1977—78 and less than 2% MSV/MMV. We therefore concluded that virus diseases in these dryland areas are of little importance. When they occur locally, the individual diseased plants should be rogued.

Leopard spot, which could be confused with a leaf disease caused by a virus or fungus, is a physiological disorder characterized by numerous yellow spots between the veins which may coalesce to form streaks. Occasional individual plants appear among otherwise completely healthy-looking plants. All the leaves of these single affected plants may exhibit the symptoms. The disorder is not spread between plants and no control measures are necessary.

Turcicum leaf blight, caused by *Helminthosporium turcicum*, occurs particularly under conditions of high humidity and low temperatures during the earlier growing stages. If conditions are favourable during the silking stage, leaf damage can be of economic importance. The large elongated lesions are typical of the disease. These occur first on the lower leaves and continue to increase in size and number as the plant develops.

Evaluations of blight were made in performance trials with three maize entries at Katumani and Kampi ya Mawe in the long rains of 1981. Results are shown in Table I.

From the results in Table I it can be concluded that DLC 1 was more susceptible to blight than KCB or 7 × 8. However, since yields were not affected it was concluded that the incidence of the disease was not important. Observations at Katumani in subsequent seasons have confirmed the relative unimportance of turcicum leaf blight.

Rust, caused by *Puccinia sorghi*, is also

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TABLE I—INCIDENCE OF TURCICUM BLIGHT IN THREE MAIZE ENTRIES, LONG RAINS, 1981

		Entry and disease incidence		
Location	Rep.	KCB*	7 × 8*	DLC 1*
Katumani	1	3**	2	4
	2	3	1	5
Kampi ya Mawe	1	1	1	3
	2	0	1	2

*KCB = Katumani Composite B; 7 × 8 = hybrid 7 × 8; DLC 1 = Makueni Composite
**Disease rating scale 1–10: 0 = no blight; 10 = heavy blight

favoured in its development by cooler temperatures and high relative humidity. Under these conditions, the lower leaves of young plants can produce the powdery pustules which are typical of the disease. These are brown in the early stages of infection but later turn darker as the leaf epidermis is ruptured.

Rust has frequently been observed in young, actively growing maize at Katumani on lower leaves, but incidence has been light. It is concluded, therefore, that the disease is of little or no importance in this area.

Charcoal rot, a stem decay of maize, is caused by the fungus *Macrophomina phaseolina*. It is commonest during hotter periods and incidence increases when plants are near maturity and are undergoing water stress during periods of drought. The internal parts of the stems, especially near ground level, show a black discoloration and shredding of the vascular bundles. This often results in a tip-over of the stalk. Once established in the soil, the fungus always becomes active when conditions are favourable for rot development. Therefore maize should not be repeatedly planted in areas where there is a history of disease or if drought stress is frequent. On the other hand, moist soils during dry periods, especially after tasselling, result in reduced incidence of charcoal rot.

Losses to charcoal rot in Machakos and Kitui Districts have not been evaluated, but it is apparent that they could be locally important.

Fusarium ear rot, caused by several species of the *Fusarium* fungus, is the commonest disease of maize ears. *Fusarium roseum* is favoured by cool, humid conditions, while *Fusarium moniliforme* produces more rot under hot, dry conditions. The latter is commonest in Machakos and Kitui Districts. Infected kernels develop a cottony, often pink, but usually white mould while still on the cob. Kernels infected late in their development may develop whitish streaks on the pericarp. Infection may follow injuries by earworms, borers, or other insects, as well as by birds.

On the whole, disease incidence is negligible while ears are still on the plant, but rot may increase under storage to result in a problem of considerable importance. Proper storage (below 18% moisture for ears and 15% for shelled kernels) will prevent further growth of the fungus following harvest.

Sorghum

Charcoal rot (*Macrophomina phaseolina*): the description of this disease in maize applies also to sorghum. Poor grain filling is characteristic of stalks which do not lodge. However, a high incidence of lodging may result in practically entire loss of the crop.

Covered kernel smut, caused by the fungus *Sphacelotheca sorghi*, was widespread in sorghum-producing areas of Meru and Embu Districts in 1982. The fungus enters the plant at an early stage of growth but does not become evident until it enters the flower heads. The individual developing grains become filled with fungus spores and are covered with a light-coloured skin which often persists up to the time of threshing. The smutted grains can be few to many in number on the head. Smut incidence is reduced when seed is planted in progressively warmer, damp soils. Varietal resistance is reported in the literature to be important where the disease is common and incidence may be high. Seed treatment with Captan or Thiram fungicides is also feasible where disease may be severe. Spores from infected seeds easily pass to healthy seed during threshing operations. Farmers should never use seed from an area where the disease is present.

Anthracnose is produced by the fungus *Colletotrichum graminicola*, which causes both a leaf-spot disease and a red stalk rot. Under warm, humid conditions the disease can be very destructive. The leaf spot may appear at any stage of plant development as small circular to elliptical spots. If favourable humid conditions exist these may increase in number and enlarge to cover much of the leaf. The midribs of the plants may also be infected. The red-rot phase

may occur in stalks as well as flower heads and is characterized by large reddish coloured circular cankers. When split open, infected stems show red discoloration, which may be continuous over a large area, giving a marbled appearance throughout the affected portions. Diseased stalks frequently break below the seed head. The fungus survives on various grass species, including maize, and may be carried on the seed. Varietal resistance is important in control.

Turcicum leaf blight (*Helminthosporium turcicum*) can also affect sorghum as well as maize. Sorghum, however, is considered to be generally more resistant to the fungus than maize. Nevertheless, during particularly favourable damp periods which make for rapid development of the fungus, damage can be extensive. Although most sorghum varieties show some resistance to the fungus, this may vary according to the environmental conditions.

Rust, caused by *Puccinia purpurea*, is similar to rust in maize, although in sorghum rust is caused by a different species of the fungus. In the most susceptible varieties of sorghum the typical rust pustules develop mainly on the lower leaf surfaces. These rupture to release the powdery masses of spores. In highly susceptible varieties the pustules can occur so densely that almost the entire leaf tissue is destroyed. In resistant varieties only small flecks, which are more noticeable on the upper leaf surface, occur, mainly on the lower leaves of the plant. Rust usually appears too late in the growing season to cause much injury.

Millet

Charcoal rot (*Macrophomina phaseolina*): Localized medium to heavy losses due to lodging caused by this disease were observed in 1982 in Embu and Meru Districts, following a period of severe drought stress. This is the first known report of charcoal rot in millet in Kenya.

Smut, caused by *Tolyposporium penicillariae*, was also observed to be the cause of medium to severe losses in Embu and Meru Districts. The fungus pathogen infects the flowers and transforms them into large sacks containing the black smut spores. These sacks (sori) are larger than the non-infected developing seeds and are easily distinguished from them. Control measures are the same as those applied to sorghum for the control of covered kernel smut.

SUMMARY

The diseases observed in maize, sorghum and millet in farmers' fields since 1979 are briefly described and, where possible, estimates of their relative importance are considered. Comments apply mainly to outbreaks in the Katumani area but reports are also given for disease incidence in the other dry areas of Eastern Province. Charcoal rot represents the greatest threat to all hosts, often resulting in excessive lodging. Covered smut of sorghum and smut of millet have been observed locally to cause severe losses. Anthracnose and grey leaf spot of sorghum can also result in yield reduction in severe outbreaks, while leaf blast is the most important disease affecting finger millet.

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EVALUATION OF RESISTANCE OF SORGHUM VARIETIES TO CHARCOAL ROT (*MACROPHOMINA PHASEOLINA*)

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INTRODUCTION

Recent increases in the dryland farming of sorghum in Kenya as well as further progress in the breeding and selection of sorghum for semi-arid areas have emphasized the importance of charcoal-rot disease in the production of this crop.

The disease was first recognized as being due to *Macrophomina phaseolina* in the sorghum-breeding trials at the Kampi ya Mawe agricultural substation following the long rains of 1981. Prior to that date it was not realized that the excessive lodging in the trials could be related to a fungus pathogen. Field trips in the Ishiara and Tharaka areas of Embu District following the short rains of 1981/82 revealed a high incidence of charcoal rot in farmers' fields. As a result of these observations, there was an increasing consciousness of the problem in the sorghum-breeding programme at the National Dryland Farming Research Station (NDFRS), Katumani. The resistance of selected sorghum lines to charcoal rot, using artificial inoculation methods, was further evaluated at the Kiboko substation, Machakos District, with a view to identifying types and sources of resistance that could be used in a breeding programme. Results of these inoculation studies are reported in this paper.

Cause and Symptoms of Charcoal Rot

Charcoal rot is caused by the fungus *Macro phomina phaseolina* (Tassi) Goid. (Synonomy: *Macrophomina phaseoli* (Maub.) Ashby; *Macrophoma phaseolina* Tassi; *Sclerotium bataticola* Taub.; *Rhizoctonia bataticola* (Taub.) Briton-Jones). The fungus is typified by the production of numerous small, hard, black, shiny bodies composed of fungus tissue rich in oil globules which are called sclerotia. These constitute the principal propagules of dissemination and are resistant to temperature and humidity extremes. Under natural conditions, sclerotia tend to appear in great quantities when the host tissue is drying out and may be produced in such large amounts as to blacken the tissue; hence the name for the disease: charcoal rot. In some countries, pycnidia (small flask-shaped structures producing conidial spores) are produced in infected sorghum tissue, but these have not been observed in the semi-arid areas of Kenya. The sclerotia are transported through the soil, in water, on plant debris and through the air by wind.

The most common symptoms of charcoal rot in sorghum are stalk lodging, poor grain filling, and the premature senescence of leaves. In advanced stages of the disease, the stem pith is disintegrated and the remaining fibro-vascular bundles are covered with numerous black sclerotia, barely visible to the naked eye. In some varieties of sorghum the diseased stalks are dry and brittle, while in others they remain soft and spongy.

The fungus enters through the feeding roots of growing plants and thereafter ascends into the stem. Although the base of the stalk may be invaded by the fungus early in its development, symptoms of stalk rot and lodging do not appear until plants are approaching maturity.

Factors Influencing Disease Development

Roots weakened by adverse soil conditions or those of plants subjected to poor growing conditions, especially water stress, are most liable to invasion (Edmunds, 1964; Odvody and Dunkle, 1979). However, root-infection phenomena are not completely understood and may involve additional interactions of the soil environment, soil microflora, host roots, and the fungus sclerotia (Odvody and Dunkle, 1979). In addition to moisture stress and high temperature, normal

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seed production is also essential to predisposition to charcoal rot (Edmunds and Voight, 1966).

In greenhouse tests under controlled conditions, it has been determined that no infection occurs at 80% or more available soil moisture. At 25% available soil moisture, plants that bloomed 14–28 days before inoculation were killed within 5–6 days or 3–5 days after inoculation at soil temperatures of 35°C and 40°C respectively. No appreciable stalk rot occurred in inoculated plants that had bloomed less than two weeks earlier at either soil temperature. Only negligable saprophytic growth of *Macrophomina phaseolina* occurs in dead sorghum stalks, as evidenced by cessation of rot and rapid development of sclerotia after death of the host. The entire rot process through to formation of sclerotia may be completed in 24–48 hours (Edmunds, 1964).

Soil structure has an influence upon the development of charcoal rot. Well-drained soils during periods of drought are more likely to lead to plant stress. Heavier soils do not react to drought conditions as rapidly and therefore tend to retard the effects of drought stress on plants.

Control with Resistant Varieties

Resistance to charcoal rot in sorghum has largely been tested in the United States (Texas, New Mexico, and Oklahoma) and in India. Rao, Reddy, Williams and House (1978) reviewed these reports of screening for resistance and have developed their own procedures for resistance testing. Based on the results in their publication, they designed a breeding programme to produce superior resistant varieties, and this was initiated in the 1977/78 growing season at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India.

MATERIALS AND METHODS

Selection of Sorghum Lines for Testing

A series of collections of local and exotic sorghum lines was screened for different agronomic characteristics at Katumani and at six other localities in dryland areas of Machakos, Kitui, Embu, and Meru Districts during the period 1978–1981 (NDFRS annual reports, 1979–1983). During periods of drought stress in these localities it was noted that most of the high-yielding exotic and local lines showed a high percentage of lodging due to charcoal rot. Accordingly, 105 agronomically superior lines from these two groups were selected for further disease-resistance trials. Both groups contained early- and medium-maturity types. Eighty-four were exotic lines, mostly from the ICRISAT world collection; 21 were local land races collected from farmers' fields.

The 105 lines were planted during the short rains of 1982/83 at the Kiboko field station. Because of the high temperatures favourable to sorghum growth, combined with frequent periods of drought stress, Kiboko was considered to be an ideal site for evaluations of charcoal rot resistance. Average rainfall during November-December, the period most favourable to sorghum growth, is about 300 mm, with November as the month with highest rainfall (average 145 mm). Maximum temperatures during these months are about 28°C and minima are 18°C. The elevation at the Kiboko station is 980 m.

Seed was planted in an area where sorghum or other host plants of the pathogen were not known to have been previously cultivated. Plots for each line consisted of two rows, 3 m in length. Each plot was replicated twice. Planting distances between rows were 75 cm, with 20 cm between plants. Date of planting was 24 October 1982. Rains ceased 59 days after planting and no supplemental irrigation was applied thereafter; total October-December rainfall was 430 mm.

When about half of the plants were in the "boot stage" of flowering, inoculations with *Macrophomina phaseolina* were made on each plant in the row. At least 20 plants of each line were inoculated. Inoculations were made on 31 January 1983, and recordings of disease severity on 2 and 3 March, 129 days after planting (30 days after inoculation). The data recorded were days to 50% flowering, mean plant height, mean number of stem nodes crossed by the rot, mean length of rot spread from point of stem inoculation, percentage of plants lodged, and charcoal-rot ratings based on a scale of 1–9. Although all 105 lines were inoculated and evaluated, only 36 elite lines, representing a single maturity growth group, were selected for evaluation in this report.

Preparation of Inoculum and Inoculation Procedure

Bits of fibrovascular bundles covered with the small black sclerotial bodies were obtained from field-infected sorghum plants, surface sterilized with 1% sodium hypochlorite, and placed on the surface of potato-dextrose agar for the culture of *Macrophomina phaseolina*. After 5 days' growth in the laboratory, the fungus was further subcultured to remove any possible contaminating fungi or bacteria. A liquid culture medium

(peptone 1 g, honey 5 ml, distilled water 94 ml) was prepared as described by Rao, Reddy, Williams and House (1978). Match sticks with the heads removed were boiled twice to remove impregnated wax, packed upright into wide-mouthed Kilner jars, and sterilized at 15 psi for 20 minutes. Small bits of the fungus culture from the potato-dextrose agar were suspended in the sterilized liquid medium, shaken to allow even distribution of the inoculum, and poured under asceptic conditions into the Kilner jars containing the match sticks. Enough medium with the added fungus was poured into the jars to cover about one-third of the length of the match sticks. The jars were then placed in an incubator at 35°C. Within several days a thick fungal growth began to cover the match sticks. Within 7 days they were covered with mycelia and sclerotia of *M. phaseolina* and were ready for use to inoculate the field-grown sorghum plants.

The match sticks were inserted into a hole punched obliquely into the stalk by a nail 1 cm in length. Inoculations were made just above the first node. Care was taken to avoid emergence of the match stick through the other side of the stem, which would have resulted in rapid drying of the inoculum.

RESULTS AND DISCUSSIONS

Results of the inoculations of the 36 lines are shown in Table I. The disease failed to cross any node from the point of inoculation in only two lines, 80/65 and 80/139—4. Both are high-quality local selections from Meru District. Line 80/65 was rated as the most promising early line according to the scoring system, because of least spread of rot and low percentage of lodging. Although lodging was 100% in 80/139—4, only 12% of the length of the stem above the point of inoculation was affected and lodging could be attributed primarily to the tall stature of the variety rather than to the intensity of charcoal rot.

Seven lines, consisting of two local tall types and five exotic short types showed the disease crossing only one or two nodes. Lines 80/102—7, 80/139—4, and Lulu Dw. had a low number of nodes crossed and a low percentage of plants lodged.

All the exotic short-statured types exhibited lodging, varying from 12% (TX 430) to 60% (M 90895). These lines are from Texas and the ICRISAT collection respectively. Among the promising Serere lines, 2KX17, a short-statured type, showed a high number of nodes crossed but a very low percentage of lodging, in spite of the extended spread of the disease in the stem. It appears, therefore, that this line has a degree of field tolerance to charcoal rot which could be utilized in a breeding programme.

Serena, a popular local variety grown in the drier areas of Kenya, showed high susceptibility to stalk rot and a high percentage of lodging. In contrast, P10/T.Sel. had heavy stalk rot but lodging was low.

In the evaluations shown in Table I it is evident that sorghum response to charcoal-rot infection may be evaluated on the basis of either (a) spread of rot within the stalk, or (b) degree of lodging. Table II shows the most promising lines that fall into one or the other of these two categories.

Two lines, 80/133—4 and TX 430, both showed high levels of resistance to spread of the disease in stalks as well as high lodging resistance. However, both varieties are lacking in grain quality and yield when grown in very dry areas. Nevertheless, they may be useful in a breeding programme. Line 80/139—4, with moderate resistance to stalk rot, and 2KX17, with high resistance to lodging, could also be used to study the genetic mechanisms responsible for resistance to both spread of stem rot and lodging.

The evaluation results strongly suggest the need for further studies on the genetics of sorghum in relation to charcoal-rot resistance. As part of this effort, all agronomically elite materials for breeding programmes or new introductions should be field tested early for resistance to the disease. Further, there is a need to investigate the possibility of the association of charcoal-rot susceptibility with other characters, such as earliness of maturation, height, plant senescence, drought resistance, and larger sink size.

The typical rainfall and temperature conditions of the Kiboko area (as well as of other areas in Eastern Province) are highly favourable for charcoal-rot development. These involve sufficient rainfall and high temperatures during the early growth of the plants, followed by drought stress during the later period of growth when grain filling occurs.

Although it has been argued that artificial stem inoculations with the charcoal-rot fungus do not simulate natural conditions, and may bypass some host resistance, it is also recognized that such inoculations are useful in that they identify host genes conditioning levels of resistance.

TABLE I—RESULTS OF INOCULATION OF SELECTED ELITE SORGHUM LINES WITH CHARCOAL ROT, KIBOKO, 1982/83 SHORT RAINS

Line	Days to 50% flowering	Mean plant height (cm)	Mean No. of nodes crossed	Mean length of spread in stem (cm)	% of stem length rotted	% of plants lodged	Field Rating at Kampi ya Mawe (natural infection)*
80/96-2	54	210	1.3	23.0	11	57	5
80/102—7	55	218	1.0	16.3	8	56	4
80/102—8	55	212	2.3	36.6	17	75	5
80/111—2	57	223	2.1	38.8	17	95	5
80/118—4	54	190	1.5	24.9	13	75	4
80/119—5	53	205	2.2	35.6	17	93	4
80/133—5	53	215	1.2	23.6	11	63	3
80/135	56	200	1.9	29.0	15	50	5
80/65	58	195	0.5	14.2	7	29	6
80/139—4	50	190	0.1	23.6	12	100	1
80/32	54	165	2.6	36.4	22	95	—
80/44—4	46	222	1.6	32.1	15	54	—
80/68	53	195	2.1	36.6	19	81	—
80/133—4	54	200	3.3	21.7	11	14	—
80/225A—2	53	186	3.2	36.7	20	75	—
Makueni local	58	243	2.2	35.9	15	89	6
Katengu local	55	200	2.9	38.4	19	83	—
2KX17	55	118	4.0	30.5	26	15	7
954063	54	123	3.0	24.1	20	42	3
76T1—23	50	132	2.3	25.8	20	76	1
NES 7360	50	138	2.9	23.9	17	85	3
IS 8595	49	205	1.8	24.0	12	54	7
PP—1—662	56	123	1.6	13.7	11	44	—
Lulu DW.	55	118	1.8	18.8	16	22	7
SPV 260	51	117	2.9	27.0	23	67	7
TX 430	58	102	1.4	10.6	10	12	7
M 90894	55	145	3.0	28.9	20	92	6
M 90895	54	123	2.3	20.4	17	60	7
Serena	50	153	2.9	37.3	24	90	5
Seredo	50	143	1.7	20.1	14	47	7
P10/T. Sel.	51	160	2.8	28.6	18	20	7
110	51	123	4.2	40.6	33	56	7
IS 16233	50	207	2.7	40.7	20	82	2
V—70—1—1—1	52	150	2.7	37.7	25	100	4
E 525 Ht. Red.	54	155	3.2	32.1	21	48	4
SC 566—14	49	127	2.7	21.1	17	95	5

*Based on a 1—9 scale: 1 = slightly infected; 9 = heavily infected.

Further, direct stalk inoculation measures the degree of stalk-tissue senescence, a factor of primary importance in the development of the pathogen (Rao *et al.*, 1978). Thus disease resistance studies at Kiboko should continue to incorporate artificial inoculation methods as well as take advantage of the natural inoculum of *Macrophomina phaseolina* now present in the soil where the experiments reported in this paper were carried out.

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TABLE II—CLASSIFICATION OF CHARCOAL-ROT RESISTANT SORGHUM LINES

Entry	Stem spread*	Lodging*	Nodes crossed**	Source and growth characteristics
80/96–2	HR	MR	L	Local, very tall
80/133–5	MR	MR	M	Local, very tall
80/65	HR	MR	L	Local, very tall
80/139–4	MR	LR	L	Local, very early, very tall
80/133–4	HR	HR	H	Local, very tall
2KX17	LR	HR	H	Serere, short statured
PP–1–662	HR	MR	M	ICRISAT, medium
Lulu Dw.	HR	MR	M	Serere, short statured
TX 430	HR	HR	M	Texas, short statured
M 90895	HR	MR	M	ICRISAT, short
Serena	LR	LR	H	Serere, very early
Seredo	HR	MR	M	Serere, very early (5D × 135/13/1/3/1)
P10/T. Sel.	MR	HR	M	Serere, very early
SC 566–14	HR	LR	M	Texas, very early

*HR = High resistance to stem spread/lodging
MR = Moderate resistance to stem spread/lodging
LR = Low resistance to stem spread/lodging

**H = Many nodes crossed by rot
M = Few nodes crossed by rot
L = One or no nodes crossed by rot

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PRINCIPAL DISEASES OF PIGEONPEA, COWPEA, CHICKPEA AND GREEN GRAM IN THE SEMI-ARID AREAS IN KENYA

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INTRODUCTION

In addition to common bean (*Phaseolus vulgaris*), four other grain legumes are of increasing importance to the agriculture of the semi-arid and arid areas of Central and Eastern Provinces. Pigeonpea (*Cajanus cajan*) and cowpea (*Vigna unguiculata*) are the most important of these crops, although production of green gram (*Vigna radiata*) and chickpea (*Cicer arietinum*) is increasing substantially.

Kenya is reported to be the world's second-largest pigeonpea producing country (Remanandan, Shakoor and Ngugi, 1982), exceeded only by India. The Kenya Ministry of Agriculture (1981) reported 164,000 ha under pigeonpea. The crop is grown over a wide range of soil types and is almost always intercropped with such crops as maize, bean, or sorghum. It is also grown as a hedge or as a windbreak on small farm holdings. The development of early-maturing pigeonpea lines at the National Dryland Farming Research Station, Katumani, has been reviewed by Shakoor, Muthoka, and Ngugi (1983). Onim (1983) has also reported on the release to farmers of a new short-season variety for marginal rainfall areas in Kenya. Diseases and insect pests are increasingly destructive in all pigeonpea areas.

Cowpea rates second to pigeonpea in productivity. The hectarage under cowpea production for 1981 was reported by the Kenya Ministry of Agriculture to be 106 000 ha. Of Kenya's cowpea production 80% is in the arid and semi-arid areas of Eastern and Central Provinces (Pathak, 1974).

In all areas where cowpea is produced, the leaves and green pods as well as the dried grain are utilized for food. Muruli (1983) reported that of the three most common vegetables sold at the Westlands City Council market, Nairobi—cabbage, cowpea leaves, and 'sukuma wiki" (kale)—cowpeas are the most expensive. This is an indication that cowpea production for use as a vegetable should be encouraged. For both vegetable and dry-grain production the cowpea varieties grown in the drier areas of Kenya are usually indeterminate in growth as well as drought resistant. Because of the use of leaves as a vegetable, even minor diseases of the plant are economically important.

Chickpea production remains relatively low in Kenya compared to that in Asia, but market demand is steadily increasing. Although chickpea production for Kenya does not appear in FAO Production Yearbook statistics, this country appears to have a much greater area of the crop than has previously been reported (Shakoor and Kumar, 1982). Chickpea is grown almost entirely on the heavy black cotton soils of Machakos and Embu Districts. One centre of production is on the Mwea plains, while another is around the township of Machakos. Chickpea is planted near the end of the long rains to utilize the residual soil moisture and to take advantage of the cooler temperatures during the period of growth. However, on the Yatta plateau (Masinga area) planting in an area of about 160 sq km follows both the long and short rainy seasons, mainly in a maize-chickpea intercrop (Shakoor and Kumar, 1982). Almost all chickpeas in Kenya are of the small brown-seeded desi types. Wilt diseases are controlling factors in the production of chickpea.

Green gram (sometimes called mung bean) is another grain legume which is becoming increasingly important as a food crop in drier areas. Production still remains low. The Kenya Ministry of Agriculture Report for 1981 gives 46,000 kg as the total production of all grams, presumably including chickpea. Green gram is highly drought resistant, some varieties perhaps even more than cowpea. The close botanical relationship of green gram to cowpea accounts for disease problems which are common to both crops.

To date, field trials have been carried out by the authors of this paper to determine possible sources of resistance in (a) pigeonpea against

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Fusarium wilt (b), cowpea against yellow mottle virus, septoria leaf spot, *Ascochyta* leaf spot, scab, rust, and powdery mildew, (c) chickpea against *Fusarium* wilt, and (d) green gram against yellow mottle virus. These diseases are described and the results to date of the field trials given. In addition, other principal diseases of these crops are described, although experiments to determine resistance to them have not been carried out.

Principal diseases, their economic importance, and means of control

PIGEONPEA

Fusarium wilt, caused by *Fusarium udum* Butler

The pathogenicity of this, the most important disease of pigeonpea, is similar to infections by physiological biotypes of *Fusarium oxysporum* in other crops. Hence the pathogen is sometimes referred to as *Fusarium oxysporum*, forma specialis *udum*. Wilt symptoms can occur at the seedling stage and at all subsequent stages of growth. Plants may not flower or may drop their flowers before plant maturity. Leaves become yellow, wilted, and eventually shrivelled. Discoloration of the vascular system can be traced from the root zone and up one or more of the stems. Often only one branch or stem shows symptoms, although the entire plant will eventually wilt and die. Frequently, the vascular discoloration may be traced externally by the presence of a dark purple streak extending along one side of a branch. Sporulation of the fungus, as evidenced by a brick-reddish discoloration, is sometimes observed along this streak.

The pathogen is a soil-borne fungus apparently capable of surviving in the soil for at least eight years (Nene, 1980). There are indications that races of the fungus, with preferential ability to infect only specific varieties of the host, may exist (Nene and Kannaiyan, 1982). Although infection can only take place through the root system, *Fusarium udum* has been detected on the seed (but not internally) as a contaminant (Nene, 1980).

Economically, *Fusarium* wilt is very important. Plant losses on small farms in Kenya vary from 5% (Katumani) to 90% (Kampi ya Mawe) with an average of about 16% (Kannaiyan, Nene, Reddy and Raju, 1981). For the three countries of Kenya, Tanzania and Malawi, annual loss from the disease has been estimated at $US 5.2 million (Kannaiyan, Nene, Reddy and Raju, 1981). Incidence of disease is higher on the lighter sandy loam soils, although the wilt occurs on all soil types.

To date, control has been accomplished almost entirely through field resistance to the pathogen. Early attempts at reducing wilt incidence through crop rotations and the incorporation of additives to the soil have met with some success (Nene, 1980) but these methods are not recommended for control.

Wilt resistance field trials

MATERIALS AND METHODS

A wilt-disease plot for the evaluation of pigeonpea lines for disease resistance was established in August 1980 at Katumani in an area where the crop had previously not been grown. Stems and roots of diseased plants from farmers' fields in Kitui and Machakos Districts were brought to Katumani, chopped into small pieces and incorporated into the soil to build up an inoculum source of the pathogen. The lines tested were planted in October 1980. These included lines with known resistance from the International Centre for Research in the Semi-Arid Tropics (ICRISAT), local land races from Kenya, and improved strains from the breeding programme at Katumani. No known highly susceptible controls were incorporated into this planting. Pigeonpea plants were grown in 5 m rows, with 75 cm between rows, and 50 cm between plants. Each line was replicated three times. However, germination varied greatly among the different lines, as did the numbers of plants subsequently evaluated. Since 1980, known highly susceptible lines from ICRISAT have been included as controls in the planting system in every fifth row. These are ICP-2376 and ICP-6997 (Nene and Kannaiyan, 1982).

Wilt incidence was evaluated 2 weeks after germination and every 10 days thereafter to maturity. Lines with less than 20% wilt incidence were scored as resistant. Random samples of tissue were taken from diseased plants to confirm the presence of *Fusarium udum* by laboratory culture of the pathogen.

Starting with the 1980 short rains and through the long rains of 1981, 38 lines from ICRISAT and 77 local land races were tested. In the short rains of 1981 and during 1982, an additional 28 ICRISAT lines were tested as well as 44 new local land races and 21 improved Katumani lines. In 1982 and during the long rains of 1983, 57 ICRISAT lines and 52 improved Katumani lines, but no additional local land races, were tested. Twenty-three of the ICRISAT lines had been previously tested in 1981–1982; thus these were double checked for resistance in 1983.

After scoring for resistance, diseased plants were further incorporated into the soil in the test plot to increase the fungus inoculum for future evaluation trials.

RESULTS

Of the material planted during the short rains cf 1980 and the long rains, 1981, 7 lines from ICRISAT and 11 local land races were resistant. With the addition of more local material and ICRISAT lines in 1981–1982, 15 lines from ICRISAT (Table I), 11 local land races, and 5 improved Katumani lines showed resistance (Table II). During 1983, wilt incidence was very high, due to increase in soil inoculum and favourable conditions for wilt development. Only 2 of the ICRISAT lines were resistant (Table I). Undoubtedly, many lines had escaped infection because of low inoculum in earlier plantings.

TABLE I—INCIDENCE OF WILT IN INCRISAT *FUSARIUM*-RESISTANT PIGEONPEA LINES IN WILT-DISEASE PLOTS, KATUMANI

Accession No.	No. of plants evaluated	1981/82 % wilt	No. of plants evaluated	1982/83 % wilt
ICP 11290	21	28.5	12	75.0
ICP 2376*	21	43.8	21	47.6
ICP 9156	13	7.6	18	22.2
ICP 11299	24	8.3	10	10.0
ICP 9142	13	6.25	4	100.0
ICP 11294	19	26.3	13	53.8
ICP 10960	22	9.1	9	22.2
ICP 10957	10	0.0	24	87.5
ICP 11295	21	33.3	11	63.6
ICP 11292	28	40.2	14	100.0
ICP 9145	7	0.0	19	47.3
ICP 9155	25	20.0	8	62.5
C No. 74363	17	5.8	15	33.3
ICP 11287	25	16.0	15	66.6
ICP 9147	13	30.7	1	100.0
ICP 9149	7	42.8	12	50.0
GP 125D	17	23.3	24	100.0
ICP 11288	21	4.7	19	36.8
C. No. 74360	19	21.0	10	50.0
ICP 6997*	10	10.0	16	50.0
ICP 10958	21	28.5	16	12.5
ICP 11297	14	0.0	4	100.0
ICP 9141	16	6.25	17	64.0
ICP 8864	19	5.2	21	71.4
ICP 9177	8	0.0	21	66.6

*Lines of known high susceptibility to wilt at ICRISAT, India.

Cercospora leaf spot, caused by *Mycovellosiella cajani* (P. Henn.) Rangel ex Trotter (synonym: *Cercospora cajani* P. Henn.)

This leaf spot consists of small dark-brown round or irregularly shaped lesions with a black border. Spots may enlarge to several mm in diameter. Older spots have ashy centres. Heavily spotted leaves quickly become chlorotic, resulting in leaf drop. When infection is severe, green pods may become infected and ripen prematurely. Infection occurs first on older leaves and is mostly confined to the centre of the plant or to those branches exposed to higher humidity.

Spores of the fungus are carried by wind during periods of excessive moisture in the rainy seasons. Unless favourable moisture conditions prevail over extended periods of time, disease incidence remains low or disappears. Thus the disease has become of only sporadic importance

TABLE II—*FUSARIUM* WILT-RESISTANT SELECTED LAND RACES AND IMPROVED PIGEONPEA LINES, DISEASE-PLOTS, KATUMANI, 1981/82

Local land races	No. of plants evaluated	% wilt
KCC 45–1	20	10.5
KCC 83–3	8	12.5
KCC 81–3	14	14.2
KCC 52–1	16	18.7
KCC 364–3	25	12.0
KCC 69	7	14.2
KCC 33	11	18.1
KCC 54	9	11.1
KCC 34	11	9.1
KCC 59	19	21.0
KCC 80	16	12.5
Improved lines	—	—
KCC 423–18–9	17	5.8
KCC 423–17–4	25	8.0
KCC 423–78–12	18	11.1
KCC 423–109–1	24	20.0
KCC 466–14	8	0

in localized areas of Central and Eastern Provinces during relatively short periods in the rainy seasons or during prolonged cool cloudy periods at mid-year. At higher elevations, where rainfall is more prolonged, disease incidence increases.

In general, *Cercospora* leaf spot is not consistently of economic importance in the arid and semi-arid areas of Kenya, although periods highly favourable to the spread of the disease may result in excessive defoliation of pigeonpea plants (Kannaiyan, Nene and Raju, 1981). Infrequent outbreaks of leaf spot have been noted in the Katumani Research Station variety plots which resulted in heavy leaf drop after extended wet periods from June to August. The return of dry, warmer weather resulted in recovery. Serious yield losses in the wetter areas of Kenya, Uganda and Tanzania as a result of the disease in localized areas have been reported in past years (Onim and Rubaihayo, 1976). No trials have been carried out by the authors of the present paper to determine possible sources of resistance.

Powdery mildew, caused by *Leveillula taurica* (Lev.) Arnaud.

Powdery mildew is characterized by yellow chlorotic spots on the upper leaf surface which develop necrotic centres. On the lower surface the spots have a faint white, powdery appearance which may be difficult to discern due to the normal leaf hairs of the pigeonpea. The spots may be diffuse or delimited by the veins. Older leaves become more susceptible with maturity.

The fungus is favoured by conditions of relatively low humidity during the day followed by cool, humid nights but complete absence of rain. Disease incidence is usually patchy due to the exacting environmental conditions favouring fungal growth. Slight to medium infection was noted in a 1979–1980 survey report in the drier areas of Kenya (Kannaiyan, Nene, Reddy and Raju, 1981). In this report, heavier infection was noted in the Kitui area. However, no losses of economic importance have been reported. There is no evidence of differences in susceptibility among the pigeonpea lines grown in this area.

Virus mosaic

A mild yellow mottling on some of the leaves of pigeonpea plants has been occasionally noticed in the variety trials at the Katumani Research Station. During the 1979–1981 survey on the incidence of pigeonpea diseases in Kenya, only one locality (Wamunyu) reported the mosaic. Dr. K. R. Bock, plant virologist (personal communication), has only once determined a virus on pigeonpea; cowpea mild mottle virus was isolated from a plant of pigeonpea in Coast Province. Bock considers that pigeonpea is highly resistant to legume viruses and that there is no evidence that they are of importance in the cultivation of the crop.

COWPEA

Virus diseases

Several virus diseases of cowpea have been recognized in Kenya but not all have been identified or their insect vectors determined.

The most commonly observed virus disease at the Katumani Research Station and in the surrounding Machakos District has been termed yellows or yellow mottle. Leaves exhibit a slight to severe bright yellow chlorosis, but leaf distortion or blistering has not been noted. The virus has not been identified to date nor the vector relationships determined. Attempts to transmit the virus by *Aphis craccivora*, a common insect pest of cowpea in Central and Eastern Provinces, were not successful. Transmission through seed or by mechanical inoculation under greenhouse conditions at KARI was also unsuccessful. Three samples of infected leaves from the Katumani Research Station were sent to R. D. Woods at the Rothamsted Experimental Station, England, for electron-microscope observation. Virus particles were observed in only one sample. These were spherical in shape and of two sizes, 28 and 42μm. The smaller particle size fits the description of cowpea mottle virus found in Nigeria, according to Bock. However, unlike the Kenya yellow mottle virus, the Nigerian cowpea mottle virus is readily transmitted mechanically. Smithson (1978), cowpea breeder from Nigeria, noted the presence of the leaf yellows of cowpea in the interior of Kenya but not on the coast. He indicated that the disease appears to be different from that recorded in West Africa. Pathak (1974) indicated that all cowpea varieties received from the International Institute of Tropical Agriculture (IITA), Nigeria, and tested by the University of Nairobi in semi-arid and arid areas of Kenya were susceptible to the local yellow mottle virus. Extreme susceptibility to yellow mottle virus was noted in all varieties from the IITA Cowpea Uniform Cultivar Trial No. 1, carried out at Katumani during the short-rains season of 1977 by Muruli and his colleagues (1980). The accumulated evidence from published references and trip reports indicates that the yellow mottle virus disease of Kenya has not been described elsewhere and remains unidentified.

To identify or characterize the yellow mottle virus will require a lengthy research investigation. The availability of high-yielding resistant varieties for the drylands areas, however, has precluded the immediate need for such studies. Thus priority has been given to field plot screening of varieties for resistance combined with high yield.

Several viruses have been identified from infected cowpeas in Coast Province (Bock, personal communication). East African cowpea aphid-borne mosaic virus is mechanically and aphid transmitted. It is a potyvirus with long flexuous rods, related to potato virus Y (Kulkarni, 1972). Symptoms of mottling and vein banding, characteristic of this virus, have been observed at Katumani. Identification has been confirmed by mechanical inoculation and aphid transmission by *Aphis craccivora* (J. G. M. Njuguna, personal communication), and by electron microscopy (R. D. Woods, personal communication).

Cowpea (yellow) mosaic virus has also been isolated by Bock from cowpeas grown at the coast. The virus particles are isometric and belong to the comovirus group. It is transmitted by beetles. Singh and Allen (1979) and Williams (1975) report that different isolates of this virus and different cowpea cultivars show variations in symptoms ranging from an inconspicuous green mottling to severe mosaic, leaf distortion and blistering. The occurrence of cowpea (yellow) mosaic virus in Central and Eastern Provinces remains to be demonstrated.

Cowpea mild mottle, mechanically and whitefly transmitted, has been identified only from the coast (Bock, personal communication). The virus particles are flexuous rods belonging to the carlavirus group.

A golden mosaic of cowpea with which a geminivirus is associated, similar to the cowpea golden mosaic described by Singh and Allen (1979) and transmitted by whitefly (*Bemisia tabaci*) has also been described by Bock from Coast Province (personal communication). To confirm the presence of the coastal viruses in cowpea from Central and Eastern Provinces requires further intensive investigation.

Septoria leaf spot, caused by *Septoria vignae* P. Henn.

This is the commonest leaf spot of cowpea in Central and Eastern Provinces. It is characterized by dark red or reddish-brown circular or irregular spots, 2–5 mm in diameter. Individual spots may coalesce to form large areas of blight. Spots are almost identical on both upper and lower leaf surfaces. Lower leaves become infected first, the disease then moving to the younger leaves. Severely spotted leaves turn yellow and abscise.

Spores of *Septoria* are readily moved from plant to plant during periods of wetness. The fungus is reported by Emechebe and McDonald (1979) to be seed-borne only to a minor extent. Primary sources of infection in Kenya are undoubtedly the infected plant debris from previous cowpea crops.

Scab caused by *Elsinoë phaseoli* Jenkins (*Sphaceloma* sp).

This disease can be very severe even in areas of low annual rainfall. However, development of the disease is dependent upon relatively prolonged periods of leaf wetness. Symptoms consist of silvery or grey scabby lesions, usually circular or oval in shape, on the stems, peduncles, and petioles. These may coalesce to girdle the tissues and result in distortion. Leaves are often distorted and cupped, with numerous lesions along the veins. Flower production may be prevented by the infection or flowers may abort. Pods may be infected at any stage of development.

The perfect or sexual stage of the fungus is *Elsinoë phaseoli*, while the imperfect, conidial stage, *Sphaceloma*, is responsible for disease dissemination (Emechebe, 1980).

The biotype of the fungus attacking the common bean is apparently not able to infect cowpea (Mutitu, 1979). Both bean scab and cowpea scab can be observed at the same time, however, attacking their respective hosts in the semi-arid and arid areas during the long and short rains. Symptoms in the two are practically identical. The pathogen can be carried on the surface as well as within the seed coat. The fungus spores are carried in drops of water by wind to infect neighboring plants. Probably survival of the pathogen on host debris is the most important means of holdover between crops of cowpea.

Rust, caused by *Uromyces appendiculatus* (Pars.) Frios (synonym: *Uromyces vignae* Barcl.)

Although rust is widespread throughout all cowpea-producing areas in the dryland zone, severe outbreaks appear to be only sporadic. Dispersal of rust is reported to be highly favoured by cloudy weather with heavy dew and temperatures of 21–27°C (Singh and Allen, 1979). Pustules develop on both leaf surfaces and where infection is severe can result in heavy defoliation by mid-flowering time. The pustules are characteristically reddish brown and may be surrounded by a yellow halo. The uredospores produced in the pustules are readily disseminated by wind from infected leaves and constitute the principal source of inoculum. The cowpea rust fungus, which can infect bean and other *Phaseolus* spp., is reported to have over 35 physiologic races (Laundon and Waterson, 1965), which complicates breeding for resistance. However, we have no knowledge of the number of races attacking cowpea in Kenya. Because of the factor of race distribution, cowpea varieties found to be resistant to rust in one area may prove to be susceptible in another.

Ascochyta leaf blight, caused by *Ascochyta phaseolorum* Sacc.

This fungus causes a leaf and pod spot on a wide range of leguminous plants. The leaf spot is pale brown to grey with a darker margin and is often surrounded by a yellow or light-green halo. Lesions may be zonate (hence the name target spot) and torn in the centre as they enlarge. Fully developed lesions may be 2–3 cm in diameter. Excessive leaf attack results in defoliation.

The disease is favoured by cool humid conditions and is thus limited in distribution in the drier areas of Kenya. Control is largely cultural through the planting of disease-free seed and the removal of infected debris from areas of previous infection before planting a new crop. Localized pockets of infection have been noted in the Katumani area following periods of excessive humidity but no reduction in yield as a result of the disease has been evident.

Powdery mildew, caused by *Erysiphe polygoni* DC ex St.-Am.

This disease is worldwide on cowpea but is favoured by relatively dry, rainfree conditions. The pathogen is reported to germinate on the leaf surface and penetrate under a wide range of relative humidities but not under rainfall. Powdery mildew is an unmistakable disease. The fungus at first forms superficial powdery white patches on the leaf surface which may eventually cover the entire leaf. Severe infection of cowpea in Kenya has occasionally been noted in semi-arid areas, resulting in leaf drop. Differences in varietal susceptibility to the disease can be striking. Specialized physiological races of the fungus are known to exist but these have not been shown to occur on cowpea.

Another powdery-mildew fungus, *Leveillula taurica*, is present on pigeonpea and guar in the

same areas where cowpeas are grown. Possibly this species may also be pathogenic on cowpea. Spore dissemination of both powdery mildews is by wind. Weed hosts may play a role in the survival of the fungus in the absence of cowpea in some areas.

Disease-resistance field trials

MATERIALS AND METHODS

One hundred and ten local land races of cowpea selected from farmers' fields were planted during the short rains of 1981 and long rains of 1982 at Katumani. In 1982 supplementary overhead irrigation was necessary due to insufficient rainfall. Plants were grown in 4 m rows, with 50 cm between rows, and 20 cm between plants in the rows. The plants were continuously scored throughout the growing period for incidence of yellow mottle virus, *Septoria* leaf spot, *Ascochyta* leaf spot, and scab.

Table III lists the cowpea lines, all indeterminate in growth habit, which were noted to be completely resistant to all four diseases, i.e. no symptoms were observed.

During the short rains of 1982, 203 local selections of cowpea were also planted for disease evaluation at Kiboko substation, with the same planting distances as those used at Katumani. Because of differences in the environment between the two localities, evaluations of disease incidence for the same lines cannot be compared. Table IV lists those promising agronomic lines which showed the highest degree of susceptibility to *Septoria* leaf spot and rust. No other diseases were noted.

During the long rains of 1983, 80 improved cowpea lines from IITA, Nigeria, and the Katumani field station were planted in several nursery yield trials at Katumani. Because of the late onset of rains, planting was delayed and growth and maturity of the crop occurred to a great extent during the post-rainy period under lower temperatures and cloudy skies, conditions favourable for powdery-mildew development. General observations on susceptibility to powdery mildew were made and are discussed below.

TABLE III—LOCAL COWPEA LINES OBSERVED TO BE RESISTANT TO YELLOW MOTTLE VIRUS, *SEPTORIA* LEAF SPOT, *ASCOCHYTA* LEAF SPOT, AND SCAB, KATUMANI, LONG RAINS 1982*

Line	Maturity
285—4	late
285—3	late
289—4	late
246—2	medium
294—2	late
245—1	medium
283—1	late
241—1	medium
335—2	late
334—1	late
342—1	medium

*110 local land races were evaluated in this trial.

TABLE IV—SOME OF THE PROMISING LINES FROM THE COWPEA IMPROVEMENT PROGRAMME SHOWING SUSCEPTIBILITY TO LEAF SPOT OR RUST, KIBOKO, SHORT RAINS 1982/83

Line	Leaf spot	Rust	Growth habit
352	S*	—	erect
Machakos 66	S	S	intermediate
Kathoka	S	R	indeterminate
Makueni 39	S	R	determinate
14—1	S	R	determinate
Vita-3	—	S	indeterminate
254—2	R	S	intermediate
TVX 1999—20E	S	—	intermediate
Machakos 68	R	S	intermediate

*S = susceptible
R = resistant

RESULTS

Of the 80 improved lines planted in the yield nurseries only three were resistant to powdery mildew. These were accession numbers TVX-466-07E and IT82E-27, both from IITA, and Katumani-80, from Kenya. All three are medium-maturing, dual-purpose lines (for seed and leaf consumption), with good grain characteristics.

CHICKPEA

Fusarium wilt, caused by fungus *Fusarium oxysporum* f. sp. *ciceri* Snyder and Hansen

Wilt is the most serious and common disease of chickpea in Kenya. The disease is reported to be identifiable about three weeks after sowing (Nene, Haware and Reddy, 1978). However, observations of *Fusarium* wilt in Kenya have only been made on older plants approaching flowering. Adult plants show dropping of leaflets, chlorosis of the older leaves, and eventual dying and drying of all leaves. External root symptoms before complete drying are not evident. Internally, the central portion shows a dark-brown discoloration in the pith and xylem. This is mainly evident in the collar region of the plant but may extend into the main stem and branches as well as down into the taproot. Occasionally only a few branches are affected, the remaining being apparently healthy.

The disease is caused by a soil-borne vascular wilt pathogen, similar to *Fusarium udum* in pigeonpea. Like *F. udum*, the fungus can survive in the soil for many years in the absence of the host. At least four physiological races of the fungus have been reported from India, based on their ability to cause disease in 10 chickpea cultivars (Haware, 1982), but race determinations have not yet been made in East Africa.

The wilt pathogen has been reported by Haware, Nene and Rajeshwari (1978) to be transmitted internally in the seeds of chickpea.

Wilt-resistance field trials

MATERIALS AND METHODS

A wilt disease plot for the evaluation of chickpea lines received from ICRISAT as part of the international *Fusarium* wilt screening nursery was established at Katumani for the short rains of 1981. Stems and roots of diseased plants from farmers' fields were chopped into small pieces and incorporated into the soil in the same manner as that used for pigeonpea wilt. No chickpea had previously been grown in the area. Three rainy seasons were necessary to build up sufficient inoculum for reliable evaluations to be made. At the end of each growing season the diseased plants grown in the plot were incorporated into the soil to increase inoculum potential. Because of low disease incidence no evaluations were made for the first two seasons. Chickpea plants were grown in 5 m rows, with 50 cm between rows, and 20 cm between plants. A known *Fusarium* (race unknown) susceptible control line from ICRISAT, 4951, was planted in every sixth row. Results of determination of wilt incidence for the 23 lines from ICRISAT planted during the long rains of 1983 are shown in Table V. Lines with less than 20% wilt incidence were scored as resistant.

Virus stunt, reported to be caused by pea leaf-roll virus

Diseased plants are typically stunted and with yellow or reddish-brown foliage. Leaflets may be smaller than normal in size and stems and leaflets stiffer or thicker than normal. Discoloration of the phloem near the collar region of the stem is the most noticeable diagnostic symptom. This can be observed by scraping away the outer cortex tissue with a finger-nail until the phloem is exposed. Unlike *Fusarium* wilt, the woody cylinder, including the xylem, is not discoloured when plants are infected only with stunt. Both stunt and *Fusarium* wilt may occur in the same plant, however. In addition, other root-attacking fungi can produce wilt symptoms. Thus the precise cause of wilt diseases under field conditions is not always easy to determine. In India, references are sometimes made to "wilt complexes" in chickpea. *Fusarium* wilt can be confirmed by laboratory culturing of the fungus pathogen, but there are no readily easy methods of identifying the stunt virus from diseased plants. Complete descriptions of both diseases are given by Nene, Haware and Reddy (1978).

Although pea leaf-roll virus has been reported to be the cause of stunt in chickpea in Ethiopia and Sudan (Nene, 1980), Bock (personal communication) indicates that to his knowledge this virus has not been proven to occur in Kenya to date. In Asia the virus is reported to be a pathogen of other legumes, including cowpea (Kaiser and Danesh, 1971). One of the aphid vectors of the virus, *Aphis craccivora*, is a common pest of cowpea in the drier areas of Kenya.

No experimental trials have been conducted in Kenya to determine possible sources of resistance

TABLE V—INCIDENCE OF WILT IN ICRISAT *FUSARIUM*-RESISTANT CHICKPEA LINES IN WILT-DISEASE PLOTS, KATUMANI, LONG RAINS, 1983

Accession No.	No. of plants evaluated	No of plants wilted	% wilt
ICC 10136	13	7	53.8
ICC 4918	16	10	62.5
ILC 519	14	14	100.0
ICC 11529	15	11	73.3
4951 (control)*	17	8	47.0
ILC 1922	12	10	83.3
ICC 1932	14	10	71.4
ICC 5810	19	13	68.4
4951 (control)	11	3	27.2
ICC 5003	10	7	70.0
ILC 482	14	14	100.0
ILC 1929	11	10	90.9
ILC 1934	12	9	66.6
ICC 4948	18	10	55.5
4951 (control)	17	10	58.8
1931	16	13	81.2
ICC 11524	16	5	31.2
ILC 1919	13	8	61.5
ILC 3256	11	10	90
Gram Pusa 209	10	4	40.0
4951 (control)	8	4	50.0
Gram Pant – 114	8	4	50.0
Gram C235	12	4	33.3
Gram Pusa – 212	11	7	63.6
Gram JG. 62 – 404	10	2	20.0
Gram H 208	9	6	88.8
4951 (control)	20	14	70.0

*A line of known high susceptibility to wilt at ICRISAT.

to virus stunt. General observations in farmers' fields have led to the conclusion that the disease is widespread and losses are often heavy.

Rust, caused by *Uromyces ciceris-arietini* (Grogn.) Jacz. and Boy)

Heavy rust infections occur in localized areas when the maturation period of the plants coincides with cool weather. Leaves may become heavily blighted with numerous brown rust pustules, resulting in the death of the leaves.

Rust incidence has been noted to date in plants grown at Katumani. No trials have been conducted to determine possible resistance in lines of chickpea, since disease intensity was low and was noted only in 1981.

Blight, caused by *Ascochyta rabiei* (Pass.) Labrousse

Ascochyta blight has not been reported in Kenya. However, this extremely destructive disease has been recorded in Ethiopia and Tanzania and the possibility of the pathogen being introduced into Kenya on infected seed is strong. All above-ground parts of the plant are attacked. Leaf lesions can result in complete defoliation. Stem lesions can girdle the stems so that in severe attacks the plants are killed. The disease is particularly destructive in the Mediterranean region, South West Asia, and the Indian subcontinent. Seed infection, both on the surface and within the seed, is very important in transmitting the disease into new areas. Infestation of seed has been reported to be 50–60%. Thus strict quarantine measures should be undertaken in introducing chickpea seed into Kenya from other countries. Sources of resistance in some countries have been reported (Holliday, 1980).

GREEN GRAM

As indicated earlier, to our knowledge yellows or yellow mottle virus of cowpea is the same virus

that causes yellow chlorosis of green gram at Katumani station. In green gram yellowing in the early stages of growth tends to increase in severity to the flowering stage. Thereafter symptoms usually become less distinct. Consequently, the effect on grain yield appears to be negligible.

Fifty-one local selections of green gram and 19 introduced exotic lines (from India, Pakistan, and Tanzania) were planted in the short and long rains of 1982 and 1983 for agronomic and disease evaluation. Seeds were planted in rows 50 cm apart and 20 cm maintained between plants. The exotic lines KVR 9 and KVR 10 showed severe symptoms of yellowing before flowering, while most of the local lines were relatively resistant. However, yields of the KVR lines were high in spite of the disease.

Powdery mildew, *Leveillula taurica*, may be severe on green gram if early growth of plants occurs during cool cloudy periods at the end of the long rains. Disease attack may be severe enough to result in excessive leaf drop, thus leading to reduction in yield. No lines have been observed to be completely resistant to powdery mildew.

DISCUSSION

Pigeonpea. Although the numbers of plants evaluated for wilt varied among the different lines due to irregular seed germination, there is evidence to date that ICRISAT lines ICP-11299 and ICP-10958 are somewhat resistant under Katumani conditions. The remainder of the ICRISAT lines in Table I were all more than 20% infected during the 1982/1983 testing seasons. ICP-8864, reported to be resistant in India (Nene and Kannaiyan, 1982), was not resistant at Katumani. It is possible that local physiological strains or races of *Fusarium udum* occur in Kenya which are not present in India. Thus it is imperative that the races of the fungus be identified in greenhouse experiments using as inocula pure single spore cultures of *Fusarium udum* isolated from diseased pigeonpea lines from different areas. Screening all lines for resistance to the specific races of the fungus should follow the procedures described by Nene and Kannaiyan (1982). It is interesting to note in their studies, however, that of 11,000 lines which were field-tested in India, only 33 were resistant to the one strain of *Fusarium udum* occurring at ICRISAT.

Obviously the soil characteristics at Katumani, as well as temperature and rainfall during the period of wilt evaluation, have been favourable for wilt development. However, these factors vary within the pigeonpea-producing areas of Kenya and must be considered in relation to disease incidence. Also, if physiological races of the fungus do exist in Kenya, it is possible that they are not equally distributed in all areas. One or more races might be present in a particular area and absent in another.

Cowpea. Under the 1981/1982 testing conditions at Katumani, only about 10% of the locally collected cowpea land races were apparently completely resistant to the four major diseases of interest. Since the environmental conditions for the development of these diseases were favourable during the period and inoculum potential of the pathogens was in general high, it can be concluded that resistance in all these lines will probably hold up in Machakos and Kitui Districts during most rainy seasons. However, unusually favourable seasons for the pathogens could result in varying degrees of disease incidence in cowpea-producing areas.

The 1982 short rains at Kiboko were unusually favourable for cowpea growth, although conditions did not remain sufficiently wet over extended periods for the build-up of *Septoria* leaf spot. Ideally, complete resistance to leaf spot should be sought for all semi-arid areas in Eastern Province, since the major use of the plant in these areas is as a green vegetable. If only grain use is under consideration, low to medium incidence of *Septoria* leaf spot would probably not be a factor in reduction of yield.

Rust has only appeared as a problem at Kiboko and not at Katumani. It has also been observed in Matiliko sublocation in the Makueni area. At present, there are no indications that rust could become a problem in those parts of Machakos and Kitui Districts which receive ample rainfall for good growth and maturation of cowpea. As with *Septoria* leaf spot, however, even a very low incidence of rust would not be acceptable for cowpea as a leaf vegetable, although low incidences of the disease would have little or no effect on grain yield.

The late arrival of the 1983 long rains and low rainfall for the entire season, followed by low temperatures and cloudy skies, resulted in a high incidence of powdery mildew in varieties that ordinarily would not be affected under favourable growing conditions. The three lines that were highly resistant to mildew should be further field-tested in different areas of Machakos and Kitui Districts under conditions favourable to build-up

of mildew to confirm the results obtained at Katumani.

Chickpea. Results of the chickpea trials at Katumani indicate that possibly only one line of the ICRISAT accessions, Grame JG-62-404, is somewhat resistant to *Fusarium* wilt. Lines must be tested in wilt-disease plots for at least five years before reliable determinations of resistance can be made.

Numerous factors are operating in the Katumani wilt-disease plot which have a bearing on the evaluation of disease resistance. We have no knowledge of the physiological race identification of *Fusarium oxysporum* f. sp. *ciceri* in Kenya. Virus stunt has been confirmed in some plants on the basis of visual observations of phloem discoloration. However, wilt incidence due to *Fusarium* alone, or to *Fusarium* and virus, or to one of these two pathogens with possibly other root-disease fungi has not been determined.

As with the *Fusarium* wilt of pigeonpea, it is essential that the races of *Fusarium oxysporum* f. sp. *ciceri* be identified in Kenya, following the procedures of Nene, Haware and Reddy (1981) and Haware (1982). If more than one race is determined to be present, these should be incorporated into the disease-evaluation plot at Katumani.

In addition, local chickpea land races, exhibiting possible wilt resistance in chickpea-growing areas of Kenya, should be incorporated into future evaluations for disease resistance at Katumani. A knowledge of race identification of the *Fusarium* wilt pathogen is essential for any consideration of resistance breeding, but local and imported chickpea lines should be evaluated for resistance to the entire complex of virus and fungal pathogens.

Green Gram. Evaluations for field resistance to virus yellows as well as powdery mildew should be continued in different parts of the drylands area. There will be some seasons particularly favourable to the development of these diseases while others will be unfavourable. Therefore, a testing period of four or five years is necessary for proper evaluations.

SUMMARY

The principal diseases of pigeonpea, cowpea, chickpea and green gram have been identified in the semi-arid areas of Eastern Province. Field trials have been carried out at the Katumani research station and/or Kiboko to determine possible sources of resistance of these crops to some of the diseases: a) pigeonpea against *Fusarium* wilt, b) cowpea against yellow mottle virus, *Septoria* leaf spot, *Ascochyta* leaf spot, scab, rust, and powdery mildew, c) chickpea against *Fusarium* wilt and d) green gram against yellow mottle virus. The symptoms of these diseases are described and the results to date in the continuing evaluations of resistance are given. In addition, other diseases of these crops in the semi-arid areas of Kenya are described although experiments to determine resistance to them have not been carried out. Recommendations for future field and green-house research to determine sources of resistance in the crops are discussed.

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STRATEGIES OF INSECT-PEST CONTROL IN THE DRYLAND AREAS OF KENYA (ABSTRACT)

G. N. Kibata[1]

Soil pests can be controlled by the use of persistent insecticides, e.g. Aldrin or Dieldrin, applied as seed-dressing or spot-spray treatment. Crop rotation as a means of alleviating soil-pest problems could be further explored. The breeding and selection of insect-resistant sweet-potato lines will be a major contribution to the improvement of sweet-potato production. The use of planting materials free from cassava mosaic disease is recommended as a means of reducing the spread of the disease and ensuring increased production.

The recommended measures for the control of maize stalk-borers are effective, but further research into the population dynamics of the pest would contribute to improve control. The use of insecticides applied at appropriate regimes to coincide with the incidence of major pulse-crop pests reduces crop losses. It is, however, envisaged that the discovery of a source of resistance to pod-sucking bug in local pigeonpeas will be extended to other major pests of pulse crops and provide a long-term basis for insect-pest management.

The implications of farm surveys, insecticide trials, host resistance, and cultural practices are discussed in the context of establishing appropriate insect-pest control strategies for dryland farming in Kenya.

1. National Agricultural Laboratories, Nairobi

GRAIN STORAGE IN THE DRYLAND AREAS OF KENYA (ABSTRACT)

S. K. Muhihu[1]

Post-harvest losses are of great economic importance in the cereal grains, maize, sorghums, and millets, and in the pulse grains, cowpea, pigeonpea, grams, and *Dolichos lablab*. Both the cereal grains and the pulse grains form important staple foods for the region. In maize, a 4.6% weight loss is incurred in this area through insects and 1.45% through rodent pests, and higher losses, up to 17% weight, have also been estimated nationally. In the study reported, it was found that for cereal grains *Sitophilus zeamais*, *Sitophilus oryzae*, and *Sitotroga cerealella* contribute most to these losses, and that bruchids, particularly a *Callosobruchus* sp., are most important for pulse grains. Parasites on these insects, though common, are insignificant as control agents. Preharvest loss is important, especially on cereal grains, and up to 11.8% damage due to *Sitophilus zeamais* has been observed on maize at harvest.

Traditional farm storage structures require detailed testing to determine suitable modifications in relation to drying efficiency and ease of pest control. Structures in current use are not durable and do not incorporate features to minimize storage losses.

Insecticide dusts are important as a practical tool for use in small-scale farm storage, since infestation under the present storage systems is inevitable. Malathion, bromophos, pirimiphos-methyl, tetrachlorvinphos, and etrimiphos have been tested and found effective and are recommended for use. Wood ash and diatomite dust were found to be inferior to these chemicals.

On the whole, studies on the biology, ecology and economic importance of insect and rodent pests are incomplete in this region. The entire storage system for the preharvest period to the stage of food utilization should be studied, suitable storage designs determined and effective pest-control measures, which should incorporate physical and chemical methods, determined, taking into consideration the socio-economic and cultural factors.

1. National Agricultural Laboratories, Nairobi

TECHNICAL SESSION 5: REPORT ON DISCUSSION

Chairman (Mr G. N. Kibata): Named pests and diseases have been found to be of economic importance in the dry areas of Kenya. Observations and screening trials have been conducted in order to identify the best control measures. During the session the following issues were raised.

Dr F. H. C. Scott: I understand that the University of Nairobi has been working on *Fusarium* wilt on pigeonpea for some time. Are you working in conjunction with the University of Nairobi on this disease?

Dr B. H. Waite: Because of administrative reasons and lack of an official working agreement with the University of Nairobi we have not co-operated with Dr Onim and his group in the study of pigeonpea wilt. In the future, however, I strongly suggest closer co-operation.

Mr S. C. Ondieki: Is the research on legume diseases considering intercropping systems and the possible effects other crops might have on disease incidence?

Dr Waite: Yes, most leaf blights of legumes are reduced in severity when intercropped with maize. In other cases certain legume viruses may be increased by build-up of insect vectors, such as aphids, which build up on maize.

Mr Ondieki: When was chickpea introduced to Kenya and what is its relative importance to Kenya's agriculture with particular reference to arid and semi-arid areas?

Dr Waite: I don't know exactly, but chickpea is a popular pulse with Asians and probably came to Kenya early with Indian settlers. It is an increasingly important crop for Asians in Kenya and well suited to black-cotton soils during the cooler months following the long rains.

Mr P. A. Omanga: A number of pigeonpea lines of Kenyan origin have been found to be resistant to wilt under ICRISAT conditions. Were these inlcuded in your screening? How did they perform?

Dr Waite: Almost all of these were included in the screening trials at Katumani and will continue to be screened there. Practically all of them are susceptible to wilt in Kenya, which suggests that different races of the *Fusarium* wilt fungus occur at ICRISAT in India.

Mr J. O. Mugah: The effect of "burning" observed on leaf margins shown in some of your slides is very similar to boron toxicity symptoms. How do you tell if the symptoms you are showing are due to boron toxicity or to disease?

Dr Waite: By experience with the diseases studied (often confirmed in the laboratory) we are able to recognize them in the field. We have not noticed boron toxicity to date in the Katumani areas where the studies were carried out

Mr Ondieki: In the last two years, black larvae with black stinging hairs, the adult quite large and beautifully coloured (orange, purple, and cream), have been observed to do considerable damage on legumes (cowpea and beans) in Kitui District. It tends to appear during the short rains. Are researchers aware of this and has any work been initiated? Also, it is said to have been introduced during the yellow-maize importation. What role is the plant-quarantine unit playing, particularly when such big amounts are imported into the country, so as to avoid further introduction of such pests?

Mr G. N. Kibata: Your description of the larvae can fit a wide range of pests; for example, *Bacharoa quadripunctata* Wallgr. (Lymantriidae) has stinging hairs and appears in great numbers on crops and at homesteads. The best identification would be based on specimens. This pest, unless you are referring to a different one, is indigenous and not imported.

The National Plant Quarantine Service is still effective in the role of preventing introduction of exotic pests and diseases. However, the system in not foolproof and we occasionally observe that knowledgeable persons introduce infected plant materials without due regard to our phytosanitary regulations. The situation is made even more difficult when large amounts of emergency food grains have to be imported and distributed urgently.

Mr L. O. Sese: In the past two seasons in Meru District the incidence of cutworms has been prevalent as compared to the previous year. What reason do you think has led to this incidence?

Mr Kibata: One of the causes of cutworm population increase could be continuous cropping of a susceptible crop without any rotation. The other could be introduction of pest through manures. Cutworm outbreaks occur in patches, which could be controlled by spot treatment with

Aldrin 2.5% dust applied into seed rows or planting holes.

Mr W. Makokha: What is the best strategy to control large mammal pests, such as squirrels and baboons in dryland areas? What repellants could be used?

Mr Kibata: Control of large mammal and bird pests is internationally difficult. One method of scaring, snares and traps, though costly, is effective. A few chemicals have been tested in Kenya and appear to repel mammals and birds, for example, methiocarb—sold as Mesurol by Bayer Chemicals.

Mr J. N. Chui: I would like you to comment on the economics of pesticide application by a small-scale farmer. Does the crop damage experienced by a small-scale farmer warrant the application of pesticides? Also, pesticide technology is not new, but small-scale farmers rarely use it to protect their crops. Could you guess about the adoption of pesticide application by small farmers in the dryland areas of Kenya?

Mr Kibata: As agricultural practices improve, in the large- or small-scale sector, the farmer realizes the loss caused by pests and will readily use effective pesticides. It must be emphasized that some form of pest scenting is important to avoid excessive use of pesticides by routine sprays which are not most effective. The small farmer will therefore adopt this technology and use pesticides if he is convinced by the agricultural staff through continous training.

Mr Makokha: How much work has been done in biological pest control, and in your view how does this approach compare with pest control by resistant varieties in the short run?

Mr Kibata: Biological control or management occurs naturally, but in most cases it has to be enhanced by introducing exotic and superior parasites and predators. Current work reveals that existing biological control is inadequate. However, resistant varieties will go a long way towards improving pest management in dryland farming. The two approaches are complementary and should be improved for successful control of pests.

Mr Ondieki: (1) Recently there has been talk about cassava bacterial wilt disease in western Kenya. What is the extent of infection in eastern Kenya? (2) In some parts of the country, there is a type of cassava which is poisonous (high cyanide content); are you making sure that this is not incorporated in your breeding programm? And has this variety been identified?

Dr A. Shakoor: At present bacterial blight disease of cassava is confined to western Kenya and has not been reported in Eastern Province. Strict control measures should be taken when introducing cassava cuttings for propagation from western Kenya to other parts of the country to check its spread. Breeding for low cyanide content is receiving equal importance in our programme. Preliminary observations have shown that these CMD resistant clones have sweet tubers.

Mr Makokha: Traditionally, very closely woven cylindrical structures were used for storage and grain was dusted with cow-dung ashes and could keep for about a year. Could this technology be recommended to the farmers?

Mr S. K. Muhihu: Some control is obtained through the use of wood ash and cow-dung ash, but this is by far less effective than the use of dilute insecticide dusts like melethrin and pirimiphosmethyl, which are quite safe when used at the recommended doses. Hence, while the use of traditional materials is not to be discouraged, it should be emphasized that better control is obtained through the use of insecticides.

Mr B. M. Ikombo: It has been reported that under Katumani conditions, malathion tends to disintegrate with time, thus becoming ineffective. Under what conditions is malathion effective? After how long will the seeds need to be retreated?

Mr Muhihu: The instability of malathion, especially when used on partially dried grain (15%) is common. Under dryland conditions the control obtained from dilute dusts, including malathion, tends to break down faster than in other areas, probably due to the high temperatures and high rates of development and multiplication of insects. A reapplication of these insecticides becomes necessary any time after 6 months. Farmers should inspect their grain stores regularly for timely retreatment.

TECHNICAL SESSION 6

IMPROVEMENT OF PASTURE AND ANIMAL PRODUCTION SYSTEMS

THE INFLUENCE OF STOCKING RATES AND GRAZING MANAGEMENT ON LIVEWEIGHT CHANGES IN CATTLE, SHEEP AND GOATS GRAZING NATURAL PASTURES

S. Tessema[1] *and E. E. Emojong*[2]

INTRODUCTION

Natural pastures are the primary source of feed for livestock owned by small-scale farmers in the dryland areas of Eastern Province, Kenya (Machakos, Kitui and the lower parts of Embu Districts). On 51% of the farms surveyed in lower Machakos (Rukandema *et al.*, 1981), about 75% of the holdings were under natural grazing. In Machakos District, 81% of the livestock owners graze their animals exclusively on their own land, while in lower Embu District more than 95% of the owners graze their animals on communal grazing land outside the boundaries of their farms. These differences arise because of differences in land adjudication. In Machakos District there is little communal grazing land, whereas in Kitui and the drier parts of Embu Districts land adjudication is less advanced. Such varying degrees of adjudication have resulted in different forms of usage, which are in most cases not appropriate. Farmers close to communal grazing lands keep as many livestock as they possibly can. They have neither the incentive for nor the responsibility of looking after the grazing lands and tend to maximize their share from the common grazing land by increasing their herd sizes. This has resulted in degraded pastures and eroded soils. Farmers who graze their livestock within the boundaries of their farms also tend to keep livestock at a stocking rate that far exceeds the best use of their grazing lands. From the survey in lower Machakos, Rukandema *et al.* (1981) estimated a stocking rate of 0.64 ha per livestock unit for the average farm.

The pattern of utilization of the natural grasslands is very similar throughout the dryland areas. Livestock herds are grazed extensively by day and returned at night to an enclosure, as a security against predators and theft. Grazing takes place wherever edible herbage is available. Stock numbers are not normally reduced in the dry season, and supplementary feeding is not normally given, except perhaps small amounts of crop residues to a few selected animals. Regularly grazed lands become progressively overgrazed and during the dry season the stock are forced to roam increasingly greater distances in search of grazing.

Water is a major problem for the majority of the livestock owners, particularly during the long dry season. Its scarcity in the uninhabited hilly areas often causes poor herbage utilization, because livestock are concentrated and overgraze grasslands near settled farming areas while pasturage some distance from water may not be utilized.

As population pressure and land shortages in the higher-potential areas push people out from them into the drier and marginal areas, the better and more accessible grasslands are being directed to the production of food crops. Although this process is continuing, there still remain large tracts of less tillable natural pasture land and grazing on or off the farm still remains the basis for small-scale stock feeding in the dryland areas of the Province. It is therefore essential to regard the natural pasture as an important starting-point in a rational approach to improved and more productive animal-feeding systems for small-scale farms.

Earlier research work on the natural grasslands of dryland areas of Eastern Province reveals limited animal-performance trials conducted for short periods (Katumani Research Station Annual Reports, 1956—76). A number of ecological surveys have been made (Kenya Marginal/Semi-Arid Lands Pre-investment Inventory: Livestock and Range Management, Report No. 8 1978).

1. FAO/National Dryland Farming Research Station, Katumani
2. National Dryland Farming Research Station, Katumani

These surveys tended to be floristic in nature and did not provide information on seasonal dry-matter yields, nutritional values, or animal performances.

The experiments reported in this paper are part of a series of trials designed to assess the productivity and value of these natural grazing lands in planning their contribution to year-round feeding systems. Four experiments were projected in this study. A stocking-rate trial was conducted during 1981/82 and a grazing-management trial during 1982/83; both are reported in this paper. A supplementation trial is now under way and will be concluded in mid-1984. These experiments were designed to generate information on animal live-weight production potentials of natural pastures at optimum stocking rates and on the advantages or disadvantages of some forms of grazing systems and the benefits, if any, of supplemental feeding during the dry season. From basic information collected from these trials a fourth trial is planned, which is intended to integrate and test the effects of the various variables studied and their interaction in the production system. At that stage it may be possible to use results of the studies done at the Research Station to develop models which can extrapolate and predict animal-production responses for other areas of the Province by merely using knowledge about pasture species and climatic factors. This, to a certain degree, may obviate the necessity of having to carry out grazing experiments at other sites in the Province.

Experimental methods

1. Stocking rate trial (1981/82)

Two stocking rates were selected, i.e. .54 and .35 livestock units (LU)* per hectare. These rates were selected on the assumption that they were close to the optimum, as our interest was to define the response relationships closely about this assumed optimum.

Fixed stocking rates were used and animal numbers were adjusted on fixed areas of land. Small-scale farmers do not have the elasticity in stock numbers or management capability to enable them to reduce or increase animal numbers at will during different seasons of the year. In view of this it was important to use fixed stocking rates and carry out the grazing experiment in the context of the actual farming system. Below is the design of the experiment showing the number of animals and the land areas at the different stocking rates.

Stocking rate	Land area and replication	Animal types and numbers		
		Zebu steers	Red Masai sheep	Galla and Small E.A. goats
1) .54 LU/ha	Rep. I = 19.0 ha	7	14	14
	Rep. II = 19.0 ha	7	14	14
	Total 38 ha.	14	28	28
2) .34 LU/ha	Rep. I = 19.0 ha	5	10	10
	Rep. II = 19.0 ha	5	10	10
	Total 38 ha	10	20	20

The major treatment in the experiment was the effect of stocking rate on live-weight changes. The treatments were replicated, and a randomized complete block design was used. The replications were mainly for removing the effects of pasture differences and to use the interactions as a basis for measuring experimental errors.

Grazing pressures on the replicated paddocks were adjusted so that the mean initial liveweights of the stock in each treatment group were similar. Mixed species of livestock consisting of cattle (steers), sheep and goats were grazed together and assigned to the various stocking rates. Each species was divided into 4 weight groups and

*One LU = an animal of 250 kg liveweight.

allocated to the treatment. All animals were drenched with antihelminthics to control internal parasites prior to the start of the experiment and this was continued at intervals. All animals were also dipped twice a week to control external parasites. Weights were measured on the same day every two weeks. Initial and final weights were averages of weights of three consecutive days.

Liveweight data used for analysis were derived from animals that completed the period with no apparent problems. Animals that became demonstrably sick or died in the course of the experiment were eliminated from analysis. In such instances, replacements with animals of similar weight were immediately made in order to maintain the prescribed grazing pressure. Data from the replacement animals were, however, not used in the analysis.

The experiment was carried out on the eastern hillside grazing lands of the Katumani Research Station on an area of 76 hectares. The pasture land was cleared of bushes and shrubs and divided into 6 paddocks. Grazing time approximated to what is generally practised by small-scale farmers, i.e. animals were kept in *bomas* at night. The grazing time was an average of 8 hours each day. Water was provided in troughs at all times.

Herbage samples from the different paddocks were collected at 22-day intervals for dry-matter and nutrient-content determinations. These samples were clipped at 2 cm stubble height from 10 enclosures ramdomly placed in the grazing paddocks. The samples from each plot were combined and weighed immediately for green weight and then a subsample was oven dried for 48 to 72 hours at 65°C for laboratory analysis.

The basic experimental data used for statistical analysis were average daily liveweight gains or losses during each of the four seasons and for each of the three species of animals at each stocking rate. The data are analysed and presented in terms of mean figures with the appropriate analysis of variance.

2. *Grazing management trial (1982/83)*

This trial was not replicated. There were two groups of animals composed of 4 dairy cows, 18 sheep and 18 goats each. The initial average weight of each group was adjusted so that the livestock units per treatment were similar. Treatments were allocated to the pastures strictly at random and the paddocks were arranged so as to equalize size differences as much as possible. The group on the continuous grazing treatment were kept on a 19 hectare pasture and the group on rotational grazing were rotated between two paddocks of 9.5 ha each. The rotation schedule followed was such that the paddock which had been grazed was allowed a rest period. Part of this rest period was during a growing season so that the pasture had a chance to regrow. The schedule was as follows:

Dates	Paddock No.	Rotational schedule
2 August to 15 November	1	grazed
2 August to 15 November	2	rested
16 November to 15 February	1	rested
16 November to 15 February	2	grazed
16 February to 2 May	1	grazed
16 February to 2 May	2	rested
3 May to 2 August	1	rested
3 May to 2 August	1	grazed

The stocking rates for both continuous and rotational grazing were similar and were adjusted to .54 LU per hectare.

RESULTS AND DISCUSSION

Rainfall amounts and distribution

Rainfall amounts and distribution are the climatic factors most closely related to the total amount of herbage produced and the length of time forage maintains high quality. The dryland areas of Eastern Province as a whole are characterized by a bimodal pattern of rainfall with two peaks occurring in April and November, for the long rains and short rains respectively. The long rains last from March to May while the short rains begin in mid-October and continue up to the end of December. The short rains are considered

to be more reliable than the long rains but for both seasons the rains are very erratic in distribution and intensity.

Table I gives the mean monthly rainfall for 19 years (Dennet *et al.*, 1982). We observe that April and November are the rainiest months. According to the above authors, although the mean monthly rainfalls in January, February, and March are about 50 mm, rainfall is neglible in about 20% of the years. Rainfall is unlikely in July and August and therefore there is a distinct dry season between the long and short rains. In 50% of the years, soil moisture was reduced to zero by 15 January, after the short rains, and 1 June, after the long rains. The number of days in the short-rains period varied from 21 to 143, with 50% of the years having less than 65 days. For the long rains the corresponding numbers were 5 and 126, with 50% of the years having less than 72 days. There appears to be little difference in the lengths of the two seasons despite the commonly used terms of short and long rains.

TABLE I—RAINFALL AMOUNTS AND NATURAL PASTURE PARAMETERS AFFECTING LIVEWEIGHT GRAINS OF GRAZING ANIMALS AT KATUMANI RESEARCH STATION

Months	Season	Rainfall amounts (19 years average) (mm)	Dry-matter (kg/ha)*	Crude protein (%)	Neutral detergent fibre (%)	*In vitro* dry-matter digest
January	Green	56	876	4.5	75	51
February	Dry	43	410	3.4	75	49
March	Dry	75	330	7.6	70	56
April	Green	115	750	10.2	71	71
May	Green	64	1205	6.4	74	58
June	Green	11	1080	5.9	74	56
July	Green/dry	4	752	5.3	73	56
August	Dry	4	342	5.3	72	51
September	Dry	7	250	5.0	71	51
October	Dry	29	21[illegible]	4.7	74	48
November	Dry/green	154	663	10.2	68	63
December	Green	80	909	9.9	75	61
Annual		642	2147			

*On dry-matter basis.

It has been suggested that "green season" be used instead of "wet season" when discussing the relationship between climate and herbage production (McCown, 1980). This is because the common terms "wet" and "rainy" ignore the fact that when rain has ceased, there remains a period when there is still a substantial amount of stored moisture for herbage growth. The effects of rainfall amounts and distribution in relation to pasture growth and quality seem to be best described by the term "green season", and this term is therefore used in Table I to divide the year into seasons corresponding to the availability of pasture herbage.

Vegetation

The vegetation of the natural grasslands of the dryland areas is generally described as a tree savannah (Rossiten, 1974), defined as a continuous grassy ground cover with scattered trees and shrubs of variable size and density. The grasses, varying widely in height, are for the most part coarse tufted perennials. These plants are growing on soils that are frequently senile, strongly leached and deficient in nutrients, especially in nitrogen and phosphorus, a characteristic transferred to the grasses growing in them.

The plants that were most commonly found in the experimental paddocks are listed below. Although Katumani Research Station is not entirely typical of the semi-arid areas of the Province as a whole (it has a slightly higher rainfall in normal seasons) and though the experimental grazing

lands are cleared of bush and relatively improved, the plant species found in the paddocks also exist in other grazing lands of the region, though perhaps at different percentage composition.

Grass species

1. *Themeda triandra*
2. *Aristida adoensis*
3. *Pennisetum mezianum*
4. *Sporobolus fimbriatus*
5. *Eragrostis superba*
6. *Cynodon dactylon*
7. *Bothriochloa insculpta*
8. *Harpachne schimperi*
9. *Rhyuchelytrum roseum*
10. *Chloris pycnothrix*
11. *Hyparrhenia filipendula*

Trees, shrubs and herbs

1. *Acacia tortilis*
2. *Acacia gerrardii*
3. *Acacia brevispica*
4. *Acacia drepanolobium*
5. *Acacia nilotica*
6. *Combretum* spp.
7. *Commiphora africana*
8. *Indigofera endecophylla*
9. *Solanum incanum*
10. *Ocimum americanum*

The monthly rates of dry-matter accumulation are shown in Table 1 and marked seasonal variations are observed. Plant growth in one month depends upon water stored in the soil and/or the precipitation which fell in the previous two or three months. When looked at in this manner, the data show that forage yield was most closely correlated with total precipitation. The rate of growth was highest in May and June as a result of the long-rains precipitations in March and April. This fact indeed gives support for the use of the term "green season" in reference to pasture production. In this particular situation, if we accept that the short rains are more reliable than the long rains, then we can use this phenomenon to predict and describe pasture dry-matter yields of the dry season between the short and long rains. The gap in the availability of forage between the short and long rains as seen in the table is indeed not as serious as the one between the long and short rains. The second dry season, which lasts for about 156 days from July to November, is therefore the critical period in the feed cycle in so far as the grazing animal is concerned.

Table II shows the total dry-matter yield per hectare per year as determined by measuring regrowth herbage from the ten cages placed in the experimental grazing paddocks. The herbage was cut from metre quadrants with regrowth herbage cut every 88 days. The herbage was cut on four successive dates, 22 days apart, during a season. The sum total of the initial cutting and three regrowth cuttings was taken as the annual yield.

TABLE II—DRY-MATTER YIELD OF NATURAL PASTURE HERBAGE AT DIFFERENT SEASONS OF THE YEAR (KATUMANI RESEARCH STATION 1981/82)

1st cut		1st regrowth		2nd regrowth		3rd regrowth		Total
Date	kg/ha	Date	kg/ha	Date	kg/ha	Date	kg/ha	kg/ha
9/12/81	670	7/3/83	149	3/6/82	1410	31/8/82	203	2432
31/12/81	750	29/3/82	308	25/6/82	814	21/9/82	178	2050
13/2/82	672	12/5/82	1030	8/8/82	326	3/11/81	155	2183
Average yield (kg/ha)	663		497		789		189	2147

Pasture yield per unit of land is a reflection of the number of animals a pasture will carry when grazed at optimum pressure to permit maximal performance. The total annual dry-matter yield (2,147 kg/ha) shows a reasonably high rate of dry-matter accumulation from natural pastures. This is undoubtedly a function of the bimodal rainfall pattern and its favourable effect on the growth cycle. If we assume a dry-matter intake of 2.5% of body weight for a 250 kg steer,

plus a grazing wastage of 25% of that intake, the daily dry-matter requirement for one such animal would be 7.8 kg. Based on these assumptions, therefore, the number of steer-days per hectare for each of the periods shown in Table II would be equal to 85 days during the first growing season (9/12 to 13/2); 64 days during the first growth period (7/3 to 12/5); 102 days during the second regrowth period (3/6 to 8/8); and 24 days during the third regrowth period. Of course these are only theoretical estimates. Intake of forage, which is influenced by its quality, varies considerably throughout the seasons and as a consequence the carrying capacity cannot be a constant figure throughout the season. We shall see later the potential output per animal and per hectare from herbage produced in the paddocks during the experimental period.

Some measures of the nutritive value of the natural vegetation are given in Table I. Crude protein determination was by the Kjeldahl method. The procedures described by Goering and van Soest (1970) were used for determinations of NDF (neutral detergent fibre). *In vitro* digestibilities were carried out at the Kiboko Range Research Station, using the nylon-bag technique.

It is seen from the table that the times of high nutritional value of the natural vegetation are limited to short periods of rapid growth which last not more than two months at most. A rapid and very appreciable increase in crude-protein content is observed in response to the first rains, during November (10%) and December (9.9%). From then onwards the drop was very rapid, rising again in March (7.6%) and April (10.2%). The crude-protein values go down as low as 3.4% and 4.7% for March and October respectively.

The fibre (NDF) fraction showed little trend with maturity and generally high values were observed for all months. Even during young stages of growth (i.e. November and April) the fibre contents were unexpectedly high. The pasture passed quickly from the succulent stage of high protein and digestibility, to the more carbonaceous and fibrous stage of development.

Mature grasses in February and October dropped to 49 and 48% digestibility and crude-protein levels of 3.4% and 4.7% respectively. A highly significant coefficient of correlation (r= .911) was observed between the crude protein content and *in vivo* dry-matter digestibility. The correlation coefficient between fibre and digestibility, on the other hand, was not significant (r= .39), confirming that crude-protein content is a more limiting factor than fibre content in so far as digestibility is concerned.

The chemical composition and digestibility of clipped herbage is an unreliable index of the chemical composition of herbage selected by the grazing animals and may therefore be quite misleading with regard to estimating the value of pasture under grazing conditions. Through selective grazing, the animal eats forage which is appreciably higher in nutritive value than that of the total grass cover. According to Ried *et al.* (1968), at optimum stocking rates the opportunity for selective grazing results in an upgrading of the diet by 10 to 25% in total digestible nutrients.

Stocking-rate trial (1981/82)

Live-weight gain per animal

The influence of stocking rates on the live-weight changes of livestock grazing the natural pastures at different seasons of the year is shown in Tables III, IV and V, for steers, sheep and goats respectively. Stocking rate, as shown in the table, is defined as the number of animals per hectare. Although the performance of each species is shown on separate tables, it should be remembered that all three species in each treatment group were grazed together in the paddock.

The analysis represents mean liveweight measurements of 25 successive weighing dates at 2-week intervals during four consecutive seasons starting in the long dry season. Analysis of variance comparing the differences among treatments and between seasons as well as the interactions between various factors in respect to weight of the various species are also shown in the tables.

For the analysis, the continuous data on weights were converted into four seasonal classes according to the approximate dates on which one season ends and another begins. The final weight taken at the end of one season was used as the initial weight of the next season. We are aware that this method of analysis is problematic, as liveweight gains may not be sequentially independent. The method can also create differences in initial liveweights between treatments after the first season. This can make the data somewhat erratic and difficult to interpret, and has indeed done so. But since the effect of seasons on liveweight gains is of prime interest, this was the only way to extract the information from the experiment even if it was not very

TABLE III—THE INFLUENCE OF STOCKING RATES ON THE WEIGHT GAINS OF STEERS AT DIFFERENT SEASONS OF THE YEAR WHEN GRAZING NATURAL PASTURES AT THE NATIONAL DRYLAND FARMING RESEARCH STATION, KATUMANI

	Dry		Green		Dry		Green		Whole year	
Period (seasons)	13/8/81—7/11/81		7/11/81—28/1/82		28/1/82—9/4/82		9/4/82—2/7/82		13/8/81—2/7/82	
Number of days	87		82		71		85		323	
Treatments	I	II	I	II	I	II	I	II	I	II
Stocking rates in stock units (*) per hectare	.54	.35	.54	35	.54	.35(TI)	.54	.35	.54	
Number of animals	14	10	14	10	14	10	14	10		
Initial average weight (kg)	246	260	279	277	299	297	299	298	246	260
Final average weight (kg)	279	277	299	297	299	298	308	312	308	312
Average daily gain (g)	369	198	250	241	−2	20	104	162	189	161

Summary of the analysis of variance

Source	d.f	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f	MSS(F)
Treatments	1	170516*	1	402(NS)	1	35853***	1	19565**	1	4882(NS)
Field	1	913(NS)	1	5192(NS)	1	792(NS)	1	96(NS)	1	51(NS)
Treatment × fields	1	973731***	1	215776**	1	4338(NS)	1	3710(NS)	1	7375(NS)
Error	20	38869	20	19025	20	1334	20	2234	20	5857
S.E.	52.7	62.3	8.6	10.2	6.9	8.2	12.6	15.0	20.5	24.2

(*)= One livestock unit = 250 kg
* = 5%
** = 1%
***=.1%
NS = not significant

TABLE IV—THE INFLUENCE OF STOCKING RATES ON THE WEIGHT GAINS OF SHEEP AT DIFFERENT SEASONS OF THE YEAR WHEN GRAZING NATURAL PASTURES AT THE NATIONAL DRYLAND FARMING RESEARCH STATION, KATUMANI

	Dry		Green		Dry		Green		Whole year	
Periods (seasons)	13/8/81–7/11/81		7/11/81–28/1/82		28/1/82–9/4/82		9/4/82–2/7/82		13/8/81–2/7/82	
Number of days	87		82		71		85		323	
Treatments	I	II	I	II	I	II	I	II	I	II
Stocking rate in livestock units (*) per hectares	.54	.35	.54	.35	.54	.35	.54	.35	.54	.35
Number of animals	28	20	28	20	28	20	28	20	28	20
Initial average weight (kg)	31	32	32	31	39	38	37	39	31	32
Final average weight (kg)	32	31	39	38	37	39	41	41	42	42
Average daily gains (g)	6	−17	88	90	−29	13	41	37	30	31

Summary of the analysis of variance

Source	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)
Treatments	1	15600***	1	83(NS)	1	17396***	1	200(NS)	1	9(NS)
Fields	1	3834(NS)	1	1610(NS)	1	161(NS)	1	4961*	1	30(NS)
Treatment × fields	1	276(NS)	1	537(NS)	1	28867***	1	3474*	1	239(NS)
Error	44	2541	44	2080	44	1094	44	729	44	239
S.E.	9.5	11.3	8.6	10.2	6.3	7.4	5.1	6.0	2.9	3.5

(*)= One livestock unit = 250 kg
* = 5%
** = 1%;
*** = .1%
NS = not significant

TABLE V—THE INFLUENCE OF STOCKING RATES ON THE WEIGHT GAINS OF GOATS AT DIFFERENT SEASONS OF THE YEAR WHEN GRAZING NATURAL PASTURES AT THE NATIONAL DRYLAND FARMING RESEARCH STATION, KATUMANI

	Dry		Green		Dry		Green		Whole year	
Periods (seasons)	13/8/81—7/11/81		7/11/81—28/1/82		28/1/82—9/4/82		9/4/82—2/7/82		13/8/81—2/7/82	
Number of days	87		82		71		85		323	
Treatments	I	II	I	II	I	II	I	II	I	II
Stocking rates in livestock units(*) per hectare	.54	.35	.14	.35	.54	.35	.54	.35	54	.35
Number of animals	28	20	28	20	28	20	28	20	28	20
Initial average weight (kg)	30	28	31	31	35	40	34	39	30	29
Final average weight (kg)	31	30	35	40	34	39	38	42	38	42
Average daily gain (g)	18	−91	57	112	−17	−9	45	28	25	36

Summary of the analysis of variance

Source	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)
Treatments	1	8362*	1	35853***	1	718(NS)	1	13282**	1	1509(NS)
Fields	1	520(NS)	1	792(NS)	1	35(NS)	1	13282**	1	1509(NS)
Treatment × fields	1	533(NS)	1	4388(NS)	1	2538(NS)	1	76(NS)	1	240(NS)
Error	44	1489	44	1334	44	1376	44	1302	44	140
S.E.	7.3	8.6	6.9	8.2	7.0	8.3	6.8	8.1	2.2	2.6

(*)One livestock unit = 250 kg
* = 5%
** = 1%
*** = 1%
NS = not significant

precise. However, of major importance was the analysis of variance that pointed out differences between stocking rates for the whole grazing period.

The mean liveweight response of all groups shown in the tables illustrates the pronounced seasonal differences. Rates of weight change reflect the intake and digestible dry matter (Minson *et al.*, 1976). The relation between weight gain and digestible-dry-matter intake is linear over a range of liveweight gains encountered in grazing trials. The steers in both stocking rates made unexpectedly high rates of gain during the dry season of August to November. Average daily gains were 379 and 195 g for the 54 LU/ha and 35 LU/ha stocking rates respectively. The differences were highly significant ($P<.01$). Gains of this magnitude during the dry season as well as the observed higher rate of gain at higher grazing pressures were contrary to expectations. Prior to the commencement of the grazing trial, animals were excluded from the experimental paddocks for 6 months, until fencing and the provision of watering facilities were completed. It is believed that the unused pasture provided sufficient good-quality herbage for the animals to make such gains during the dry season. In addition, such a high rate of gain during a dry period may also be explained by the phenomenon of compensatory growth, as the steers had been kept on rough grazing land at a high stocking rate prior to the beginning of the trial.

Although the reasons given above may explain the weight gains made during the dry season, they do not explain the higher rates of gain made at higher grazing pressure. Generally, as stocking rate is increased, gain per animal is decreased, and the relationship has been accepted as linear by several workers (Jones and Sandland, 1974; Riewe, 1961; McMeekan and Walshe, 1963; Mott, 1961). Cowlishaw (1962) has shown this relationship to be curvilinear. These linearities were not observed in this study. Differences in pastures that could affect the results were initially minimized by distributing the size variations among groups. In the analysis of variance, the presence or absence of field-time/stocking-rate interaction was examined, in order to see if pasture differences were responsible for the observed but unexpected higher weight gains of steers at the higher stocking rate. The interaction was found to be highly significant ($P<.01$), which meant that the effect of the stocking rate was dependent upon the pasture differences. A further examination of the data also shows that the variance among animals within the lower-stocking-rate (.35 LU/ha) groups was much larger than that of the groups on the higher stocking rate (.54 LU/ha) and contributed to the error in the analysis of variance. It seems therefore that the differences observed in rates of gain during the dry season between the two treatments were due to experimental error.

The rate of liveweight gain of the steers during the following green season again showed a bias towards the group on the higher stocking rate. The differences were not significant. However, the interaction between the stocking rate and the field was highly significant, indicating that the slightly larger gains made by the steers on the high stocking rate was due to the fact that the field they were grazing on was better than the field on which the group on low stocking rate were grazing. During this period, which was the growing season, there was sufficient herbage for the animals to make gains even when they were grazed at a high stocking rate.

The dry season between the short and long rains resulted in little or no gain, although highly significant differences ($P<.01$) were observed between the stocking rates. Steers on the low stocking rates made small (20 g) daily gains while the steers on the high stocking rate made insignificant losses (2 g daily).

The steers in both treatments made gains during the following green season and the differences between stocking rates were highly significant ($P<.01$), with steers on the low stocking rate gaining more (162 g daily) than those on the high stocking rate (104 g daily). These gains were not as high as those during the first green season, perhaps because the steers were approaching mature weights.

The analysis of variance for the whole year indicates that there were no statistically significant differences in rates of liveweight gain of steers between the two stocking rates. However, the steers on the higher stocking rate gained slightly more (189 daily) than those on the lower stocking rate (161 g daily). We have observed earlier that there were significant interactions between treatments and fields where higher rates of gain were made at high stocking rates. It was concluded therefore that the fields grazed by the group on the higher stocking rate were better and that there was abundant good-quality forage enabling the animals to make larger gains than those on the lower stocking rate fields.

Sheep on low stocking rates lost weight (17 g daily) and those on high stocking rates gained weight (6 g daily) during the long dry season. The differences were highly significant ($P<.01$). It will be remembered that steers, sheep and goats were mixed in each treatment group in this experiment and grazed the assigned paddocks together. The performance of the sheep was therefore similar to that of the steers discussed above, i.e. animals on high stocking rates performed better than those on low stocking rates We will notice that quite the reverse happened during the short dry season (February/March). Sheep on the high stocking rate lost weight (26 g daily) while those on the low stocking rate made gains (13 g daily). The differences were highly significant ($P<.01$). The analysis of variance also shows that there was a highly significant ($P<.01$) interaction between treatments and fields, indicating that the response in weight change during this season was also dependent upon the condition of the pasture and not only on the stocking rate.

During the first green season (November-January) sheep on both stocking rates made substantial gains and the differences between the stocking rates were not significant. The rates of gain during the second green season (April-June) were only half those of the first green season, perhaps due to the animals having approached mature weights. During this period, the sheep on the higher stocking rate showed a slightly higher rate of gain, but the differences were again not significant. The analysis of variance shows that there were significant differences ($P<.01$) between fields within a stocking rate and that there was a significant interaction between treatments and fields. However, over the whole-year period the rates of gain between the two stocking rates were again not significant.

Weight changes of goats during the various seasons were very similar to those of sheep in terms of direction and magnitude. It is well known that goats tend to browse on shrubs rather than graze on grasses. This preference for browse allows them to have a nutritionally better diet, especially during the dry season when there are, in the pasture, a lot of deep rooted shrubs and trees that are not affected by seasonality. As it happened, however, in the experimental paddocks used, bush clearing was done so indiscriminately that very few browse species were left to enable goats to take advantage of their strategic feeding behaviour.

During the dry periods goats lost weight regardless of the stocking rate, at a time when sheep and steers either maintained their weights or gained. This indicates that the goats are disadvantaged when browse is scarce, even though grazing may be available.

Goats on the lower stocking rates had a higher rate of gain than those on the higher rate during the first green season, and the differences were highly significant ($P<.01$). On the other hand, during the second green season, the reverse was true; i.e. goats on the higher stocking rate had a higher rate of gain than those on the lower rate. Over the whole-year period, however, no statistically significant differences were observed in rates of weight gain between the two stocking rates, although the goats on the low rate had slightly higher rates of gain (36 g daily) than those on the higher rates (25 g daily).

Liveweight gains per hectare

The liveweight gains per hectare are estimated from the product of the animal days per hectare and the average daily gain per animal. For the two stocking rates studied, the following are the estimated gains per hectare for the 323 days under study.

Stock rate	Average daily gain/ animal (kg)		Animal days per hectare		Liveweight gain per hectare (kg)
1. 54 LU/ha					
(a) Steers	.189	×	(54 × 323)	=	32.96
(b) Sheep	.030	×	(54 × 323)	=	5.23
(c) Goats	.225	×	(54 × 323)	=	4.36
Total					42.55
2. 35 LU/ha					
(a) Steers	.161	×	(35 × 323)	=	18.20
(b) Sheep	.031	×	(54 × 323)	=	3.50
(c) Goats	.036	×	(54 × 323)	=	4.07
Total					25.77

These measurements reflect not only the net gains obtained per hectare but also the weights maintained on the hectare during the 323 days, even though the animals had gone through weight fluctuations. Sustained liveweight gains between 160 and 180 g per day for steers and 25–36 g per day for sheep and goats were achieved during the 323 days. However, for about 5 months of the year production was barely above maintenance and short periods of weight loss occurred.

The higher stocking rates resulted in both higher yields per animal and higher yields per hectare. Higher outputs per hectare at heavier stocking rates may be expected, but the output per head decreases under normal circumstances. This has been the most common relationship found by many workers (McMeekan and Walshe, 1963; Jones and Sandland, 1974; William and Gillard, 1971). These kinds of relationship were not found to be true in this study. While the cause of the absence of these relationships in our study may be traced back to the significant effect of pasture differences, the possibility cannot be ruled out that the carrying capacity of these natural pastures for short periods of time is very high. High production per individual animal depends on a high level of nutrient intake. If the quality and quantity of pasture is adequate, output per animal at high stocking rates may not decrease, which may in fact be the case in this study.

The point of maximum yield of animal product defines carrying capacity, and this is sometimes considered as the optimum stocking rate. But the optimum stocking rate is also that which allows grazing animals to produce at the most economical rate. Since the rates of gain in the two stocking rates were not significantly different, one may be tempted to conclude from this trial that the higher stocking rate is an economically better management system. However, the optimum rate will not be exactly the same from year to year because of variations in the weather. An increase in grazing pressure results in increased animal yield per unit of land only up to a point. The correct decision about stocking rates therefore can only be properly based on a much larger body of knowledge over a range of good and bad years.

Within the dryland environment, it would be expected that the variation in climate would have a greater effect on animal production per unit area than on production per animal, due to the seasonality of animal growth. Compensatory gains during the green season will offset losses made during the dry season. Therefore, whether to aim for maximum yield per animal or maximum yield per hectare depends upon pastureland availability, animal costs, and grazing-management costs. A high stocking rate requires higher investment in animals and management and may run the risk of a shortfall in feed supply, while cost of land is to be considered in connection with low stocking rates. Heavy stocking rates no doubt result in the deterioration of the pasture over the year, while low grazing pressures with rapid growth periods allow forage to develop and mature so that individual animal response may be reduced by low forage quality and reduced intake of digestible nutrients. Effective grazing-management systems in these seasonally marked dryland areas have little elasticity in animal numbers or in the capability of conserving surplus forage. But the possibility of short-duration intensive utilization of the natural pasture for high output per animal and per unit land area are clearly demonstrated.

As the pasture area used for these experiments is not exactly representative of the larger part of the Province, direct application of these results to other areas would not yield accurate predictions. As one stocking rate cannot be appropriate for the whole grazing year, so one rate cannot be appropriate for the whole region. The optimum stocking rate can only be an optimum range. And with good knowledge of the pasture/climate interrelationships across the Province, it may be possible to use the information in this study to make extrapolations. One may argue that even extrapolations may be dangerous on such limited evidence, but it may also be argued that limited evidence is better than none.

Grazing-management trial (1982/83)

Natural pastures in the dryland areas are normally grazed continuously, as they form the main source of feed for the livestock of small-scale farmers. Continuous grazing, especially in uncontrolled situations, results in seasonal overgrazing and undergrazing, since the number of livestock kept by small-scale farmers remains more or less constant. Alternations of rest periods with grazing periods increase the output of herbage dry matter, although not necessarily of nutrients available to the animal (Spedding, 1965).

Since digestibility of herbage falls with maturity, the mere accumulation of dry matter may be of only limited benefit to the animal under these circumstances. A desirable grazing-management system, especially where herbage production is markedly seasonal, would seem to be that which combines the efficient use of the herbage during the season of flush growth with a rest period that allows the herbage to grow further for use during the season of no growth. This would be some form of "deferred" rotation grazing. The assumed advantages of rotation grazing include the more efficient utilization of herbage, the provision of resting and seed-setting opportunities for the more desirable herbage species, and the consequent avoidance of undesirable changes induced by selective grazing (McKay, 1971).

The objective of this trial was therefore to compare the performance of animals grazed under continuous-grazing management with those grazed under a rotational system of management. It is well recognized that small-scale farmers cannot be expected to fence a number of paddocks to operate a complicated rotational grazing system. It seems possible, however, that farmers can demarcate their grazing lands as upland, lowland, etc. for periodic grazing purposes without having to fence them, if the advantages of rotational grazing are found to be clear. Therefore, the design of the trial, as dictated by the system within which its results are bound to operate, is a simple two-paddock rotational grazing system.

Tables VI and VII give the weight changes of sheep and goats at different seasons of the year under continuous and rotational grazing systems. The analysis does not include the dairy cows that were part of the treatment groups. This was because some cows finished their lactation very early in the trial while others continued even after the trial was stopped, although they were at the same stage of lactation at the start of the trial. As milk production was the main item of interest in measuring treatment effect, it was not possible to make valid comparisons since the response was confounded with the lactation length of the animals. For this reason, the cows were excluded from the analysis, although they were kept on the trial throughout, in order to maintain the grazing pressures prescribed for the treatments.

It will be observed in the two tables that there was great variation in weight gains between seasons. Grazing management, however, had very little influence on the weight changes of either sheep or goats. There were no statistically significant differences in rates of gain between continuous and roation grazing during any season of the year or over the whole grazing period.

Goats tended to have higher rates of gain during both dry seasons under the rotational system. With sheep, the reverse was true; i.e. they gained less during the dry season under the rotational system than under the continuous system. The differences in both cases were, however, not significant. The goats may have taken advantage of their ability to utilize whatever browse was present during the dry season. The analysis of variance indeed shows field-times-treatment interaction in the case of goats during the dry as well as the green season, indicating that the effect of the management system was not independent of the pasture differences. During both green seasons sheep made slightly higher gains with rotational grazing than with continuous grazing, although again the differences were not statistically significant. With goats there was no consistency in the effect of the grazing management on rates of gain during the green seasons.

Both sheep and goats made greater gains (50 to 100% more) during this grazing-management trial than the sheep and goats that were on the earlier stocking-rate trial of 1981/82. Sustained liveweight gains between 43 and 46 g per day were achieved by sheep and goats respectively during this trial, as opposed to 25 to 36 g achieved during the previous year. The outputs per animal and per hectare were similar for both continuous and rotational grazing managements.

It is recognized that long-term effects on pasture productivity, which in turn will influence animal productivity, cannot be determined from a one-year grazing-management trial. It is possible that the rotational paddocks have been more uniformly grazed, which might result in better managed and more productive paddocks for subsequent grazing. However, findings in this study are in agreement with work done on grazing systems in temperate areas (McMeekan and Walshe, 1963; Stobbs 1969), in which it was concluded that, with equal stocking rates, grazing methods show negligible differences in animal production.

TABLE VI—THE INFLUENCE OF GRAZING MANAGEMENT (CONTINUOUS VERSUS ROTATIONAL GRAZING) ON WEIGHT CHANGES OF SHEEP AT DIFFERENT SEASONS OF THE YEAR WHEN GRAZING NATURAL PASTURES AT THE NATIONAL DRYLAND FARMING RESEARCH STATION, KATUMANI

	Dry		Green		Dry		Green		Whole year	
Periods (seasons)	2/8/82—3/11/83		3/11/83—27/1/83		27/1/83—8/4/83		8/4/83—4/7/83		2/8/82—4/7/83	
Number of days	93	84	70	87	336					
Grazing management*	Continuous	Rotational	Continuous	Rotational	Continuous	Rotational	Continuous	Rotational	Continuous	Rotational
Number of animals	18	18	18	18	18	18	18	18	18	18
Initial average weight (kg)	17.2	17.2	18.8	18.4	23.7	24.4	27.8	27.2	17.2	17.2
Final average weight (kg)	18.8	18.4	23.7	24.4	27.8	27.2	32.2	32.2	32.7	32.2
Average daily gain (g)	17.3	13.7	57.5	71.6	56.7	41.1	55.9	56.8	46.2	44.7

Summary of the analysis of variance

Source	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)
Treatments	1	115.9(NS)	1	1776.6(NS)	1	2789.6(NS)	1	8.4(NS)	1	21.8(NS)
Fields	1	28.8(NS)	1	1779.4(NS)	1	165.9(NS)	1	73.9(NS)	1	327.6(NS)
Error	33	87.8	33	543.3	33	915.4	33	351	33	80.9
S. E. (Treatments)		2.2.		3.6		7.1		4.4		2.1

* = The stocking rate for both continuous and rotational grazing was similar and was adjusted to .54 LU/ha(1LU = 250 kg).
NS = Not significant

TABLE VII—THE INFLUENCE OF GRAZING MANAGEMENT (CONTINUOUS VERSUS ROTATIONAL GRAZING) ON WEIGHT CHANGES OF GOATS AT DIFFERENT SEASONS OF THE YEAR WHEN GRAZING NATURAL PASTURE AT THE NATIONAL DRYLAND FARMING RESEARCH STATION, KATUMANI

	Dry		Green		Dry		Green		Whole year	
Period (seasons)	2/8/82–3/11/82		3/11/82–27/1/83		27/1/83–8/4/83		8/4/83–4/7/83		2/8/83–4/7/83	
Number of days	93		84		7[illegible]		87		336	
Grazing management (*)	Continuous	Rotational	Continuous	Rotational	Continuous	Rotational	Continuous	Rotational	Continuous	Rotational
Number of animals	18	18	18	18	18	18	18	18	18	18
Initial average weight (kg)	15.7	15.7	17.3	17.4	22.5	22.7	26.5	26.5	15.7	15.7
Final average weight (kg)	17.3	17.4	22.5	22.7	26.5	26.5	30.6	30.0	30.0	
Average daily gain (g)	16.7	18.8	61.1	61.1	53.6	66.3	45.0	40.6	44.1	42.8

Summary of the analysis of variance

Source	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)	d.f.	MSS(F)
Treatments	1	39.3(NS)	1	.925(NS)	1	67.8(NS)	1	179.1(NS)	1	21.8(NS)
Fields	1	180.5(NS)		1776.6*	1	7744.0***	1	3763.8*	1	327.6(NS)
Error	33	78.9	33	238.7	33	519.9	33	508.8	33	80.9
S.E.		2.1		3.6		5.4		5.3		

* = The stocking rate for both continuous and rotational grazing was similar and was adjusted to .54 LU/ha(1LU = 250 kg).
* = 5%
** = 1%
*** = 1%
N.S. = Not significant

SUMMARY

The primary source of feed for livestock on small-scale farms in the dryland areas of Eastern Province is the natural pasture. Improvement in the management and utilization of this important feed resource should thus be an essential point of departure leading towards a positive and more productive livestock-feeding system. To effect this improvement, it is essential to establish the major factors that limit the productivity of pasture in order to specify the contributions it makes in the overall feeding plan.

Two trials, a stocking-rate trial and a grazing-management trial, were undertaken from 1981 to 1983 on the natural pasture lands of the Katumani Research Station. Although Katumani itself is not entirely representative of the grazing lands of the dryland areas as a whole, it was believed that relationships established between stocking rates, grazing management, and animal responses could serve as a good basis for making reasonable extrapolations to other areas of the Province. In order to carry out the experiments in the context of the prevailing farming system, the design of both the stocking-rate and grazing-management trials was kept simple and relevant; i.e. two fixed stocking rates that are assumed to be close to the optimum were used to define the response relationships between stocking rates and animal performances, and a simple two-paddock rotation-grazing system was compared with a continuous grazing system to study the effect of management on animal responses.

Herbage yield of the natural pasture was most closely correlated with high precipitation and was heaviest during May and June. Total animal dry-matter yields of 2,147 kg per hectare were obtained from clipping measurements. This is a reasonably high rate of dry-matter accumulation from natural pastures, and was the result of improvement made by bush clearing alone. Trends in nutritive values, especially crude protein, followed the same pattern as dry-matter yields and values of 9.0 and 10.0% were obtained during December and April.

Mean liveweight responses from steers, sheep and goats at different stocking rates showed pronounced seasonal variations. Over the whole-year grazing cycle, however, no significant differences were observed between animals grazing at the rate of .54 LU/ha and those grazing at the rate of .35 LU/ha. Compensatory gains during the green season offset the losses made during the dry season. Sustained liveweight gains of between 160 and 180 g per day for steers and 35 to 40 g per day for sheep were achieved during a year's cycle.

During the green seasons, however, rates of gain were as high as 90 g for sheep and goats and 250 g for steers, clearly showing the possibility of short-duration intensive utilization of the natural pasture.

The liveweight gains per hectare per year ranged from 25 to 43 kg at the optimum stocking rate.

Grazing management had very little influence on weight changes. There were no significant differences in rates of gain between continuous and rotation grazing during any seasons of the year or over the whole-year period.

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FEEDING OF DRAUGHT OXEN FOR IMPROVED AND MORE EFFICIENT POWER

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INTRODUCTION

The majority of small-scale farmers in the dryland areas of the Eastern Province of Kenya rely on animals as a source of power for land cultivation. Table I shows the percentage of farms owning plough and oxen and the average number of oxen owned in three farm-size classifications in three localities in the Province. It will be noticed that the cultivated areas do not increase with an increase in farm size. Regardless of the size of the holding, farmers in all localities keep, on the average, 2 to 3 oxen. Even when farmers have large holdings and are able to maintain more oxen, the area cultivated is still limited, suggesting that the problem is not the availability of land or oxen but lies with other factors related to draught-power availability.

Due to the short growing periods of the bimodal rainfall cycle, schedules for land preparation are rigid; tillage time is very limited and the amount of land a family can farm depends on how much they can till by the optimum planting dates. Ploughing and planting are generally late, since farmers have to wait until after the rains have softened the ground sufficiently to allow penetration by the plough. This is because oxen do not provide sufficient draught power to break the dry soil, since they are generally underfed at this time. Late planting reduces yields by about 6% per day after the first 20 mm of rain have fallen (Mbithi, 1972), but completing the basic land preparation before the rains start can make it possible to plant early and so take advantage of all the moisture available, to carry out thorough and efficient cultivation without being hurried, and to increase the area which can be effectively cultivated.

The effect of increased and efficient cultivation, apart from increased crop yields, is that more crop residues become available for animal feeding and more land can be cultivated, to the extent of including cultivated pasture and fodder crops in the cropping system. Thus, the development of improved and efficient draught power is a very important link in the interaction between crop cultivation and livestock production.

Early and efficient land preparation, however, requires that oxen are well fed and in good condition to be able to penetrate and break the dry soil with an appropriate implement. High daily rates of energy expenditure by oxen are required for efficient cultivation. It may also require the use of more, heavier, and stronger types of animal than the small-framed Kamba oxen at present being used by the small-scale farmer.

A series of studies on the performance of draught animals were made at the Katumani Station with the objectives of (a) determining the type of draught animals best suited to provide increased and efficient power and (b) developing appropriate feeding systems that will satisfy the needs for maintenance and work, based on feeds available on the farm during cultivation periods. The results of three completed experiments are reported here.

TABLE I—PERCENTAGE OF FARMS OWNING PLOUGH OXEN AND AVERAGE NUMBER OF OXEN OWNED

	Lower Machakos		Southern Kitui		Lower Embu	
Farm Size (ha)	%	Number	%	Number	%	Number
0–5	54	2.0	22	2.5	5	2
5–10	82	2.4	35	2.0	8	2
>10	93	3.0	34	3.0	17	2

1. FAO/National Dryland Farming Research Station, Katumani
2. National Dryland Farming Research Station, Katumani

EXPERIMENT No. 1

In this trial two types of draught animals and two feeding levels were used. The oxen were indigenous Kamba Zebu and Sahiwal/Friesian crosses. There were four teams of two animals each from each type of oxen, making a total of 8 teams and 16 animals.

Two teams from each type were fed at maintenance level and the other two teams at 1½ times maintenance level. The feed offered to all groups was the same, the only difference being in the level of feeding: grazing on natural pasture supplemented with a concentrate mixture. All teams were assigned to work on uniform land, doing similar and normal agricultural tasks (ploughing and weeding), and working to a similar rate and timetable.

Each team was assigned to an area of 2 ha of land on which it operated throughout the growing season. All teams were adequately trained well ahead of the start of the trials.

The oxen were grazed on natural pasture all day, except during times of cultivation. During these times they worked in the mornings from 8.30 till 12.30, and were grazed on natural pasture during the afternoon. The effective working time was 4 hours, which corresponds to present practice on small-scale farms.

In the evenings the oxen were offered the concentrate mixture, composed of grain, grain by-products, oil cake and minerals. The mixture contained 75% TDN and 16% DP. The group on maintenance level were offered 1.5 kg of this mixture per head per day and the group on 1½ times maintenance level were fed 3.3 kg of the mixture per head per day.

The performance of the oxen (in teams) at the time of ploughing was measured by draught pull (using a drawbar dynamometer), depth and width of cultivation, speed of operation, area cultivated per unit of time, and weight gain and losses during the study period. The implements used in cultivation were the mouldboard plough and ducksfoot cultivator developed at the station by another department.

Results

The cultivation performances of two groups of oxen on the two feeding levels are shown in Table II. The corresponding analysis of variance, comparing the differences between breeds and between feeding levels of each breed, are shown in Table III.

TABLE II—CULTIVATION PERFORMANCES OF TWO TYPES OF DRAUGHT OXEN ON TWO FEEDING LEVELS DURING A PERIOD OF 85 DAYS

	Treatments			
	Maintenance level*		1½ × Maintenance level**	
Item	Zebu	Friesian-Sahiwal cross	Zebu	Friesian-Sahiwal cross
Average body size (one pair)	626.000	774.000	556.000	862.000
Average depth of cultivation	10.750	13.750	11.400	12.300
Average speed (km/hr)	3.210	3.140	2.950	3.060
Average draught used (kg)	96.800 (15.5%)	88.500 (11.4%)	93.400 (16.8%)	84.00 (9.8%)
Tractive HP	1.170	1.020	1.020	0.960
Average weight loss/gain (kg)	+6.250	+24.000		
Average area cultivated ha/hr	0.072	0.073	0.069	0.076
ha/day	0.286	0.291	0.274	0.303

*Maintenance level = natural pasture plus 1.5 kg of the dairy meal (75% TDN and 16% DP) per head per day

**1½ times maintenance level = natural pasture plus 3.3 kg dairy meal/head/day

TABLE III—ANALYSIS OF VARIANCE DATA OF THE DRAUGHT PERFORMANCES AND THE INDIVIDUAL ACTIVITIES ANALYSED

Source or variation	d.f.	Draft		Speed		Depth		Width		Weight change	
		M.S.	F	M.S.	F.	M.S.	F.	M.S.	F.	M.S.	F.
Breeds	1	1.45	0.132 NS	0.068 NS	0.593 NS	3.51	1.84 NS	7.61	1.46 NS	712.53	7.00
Energy levels	1	36.14	0.48 NS	0.215	1.840 NS	14.38	6.55 NS	27.66	5.34 NS	324.59	3.19 NS
Standard error	5	16.94		0.115		1.90		5.19		101.72	

Analysis of the data shows that there were no statistical differences ($P>0.05$) observed between breeds or energy levels with regard to speed of operation or depth of cultivation. For dry-season ploughing, the depth of cultivation of all groups, which ranged from 10.75 to 13.75 cm, was found to be acceptable for planting crops and uprooting shallow-rooted grasses and weeds. The draught required to pull the mouldboard plough in these soils at a reasonable depth was therefore not greater than that produced by even the small Kamba Zebu animals.

Differences in pulling power between energy levels were also not significant. At both feeding levels, the Zebu oxen pulled more in relation to their body weight than the Sahiwal/Friesian crosses. The type of land worked was a regular agricultural soil for both types of oxen, and thus any variation in output was due to type of oxen and not to soil type. The Zebu team exerted force equivalent to 15.5% and 16.8% of their combined body weight at maintenance and twice-maintenance feeding levels respectively. The Sahiwal/Friesian crosses exerted force equivalent to 11.4% and 9.8% under maintenance and twice-maintenance levels of feeding respectively. It has been reported that a well trained and well fed pair of healthy oxen can exert a force equivalent to 10 to 14% of their combined body weights while travelling at a speed of 2.5 to 4 km per hour (Goe and McDowell, 1980; FAO, 1972). The tractive efforts measured in our studies are more or less similar to those reported by other workers, although the range is slightly wider.

The Sahiwal/Friesian crosses used a slightly reduced tractive effort, due to their larger body weight. This suggests that these animals can provide the same tractive effort for longer periods of time without becoming tired, while Zebu oxen may have greater difficulty in maintaining their strength with the same effort. For these reasons the Sahiwal/Friesians also cultivated a slightly larger area of land each day than did the Zebu oxen. But differences between feeding levels within breeds were not significant.

Differences observed between breeds with regard to weight changes (gains) during the operational period were significant ($P<0.05$). All animals on both feeding levels gained weight during the period, the Sahiwal/Friesian crosses gaining more than the Zebu breeds at both maintenance and twice-maintenance levels. It was estimated that the oxen would be able to consume natural pasture herbage at the rate of 1.5% of their body weight and that the herbage would

contain about 40% TDN. The supplementary concentrate mixture contained 75% TDN. Based on these assumptions, it was calculated that the oxen on maintenance level were getting 3.00 kg and 3.5 kg of TDN daily, for the Zebu and Sahiwal/Friesian breeds respectively. Similarly, the oxen on 1½-times maintenance level were getting 4.2 and 5.1 kg of TDN daily for the two breeds.

In view of the fact that all the oxen gained weight at both feeding levels, which was not intended, it is apparent that the energy consumed from the natural pasture grazing and concentrate mixture supplement was beyond that required for maintenance and work for both groups. Goe and McDowell (1980) reported that an ox weighing 350 kg and pulling 42 kg draught at a speed of 3.2 km/h would require 5.1 kg TDN for a 6-hour period of work, excluding maintenance needs. It is not to be expected that oxen can obtain these levels of TDN on small-scale farms during the period of land preparation, when feeding is largely limited to dry-season grazing on natural pastures and some amount of crop residues. The 65-day feeding period in this study included a 30-day period of cultivation before the rains and a 35-day period of planting and weeding after them. After the rains began, the digestible energy and protein content of the natural forage improved quickly and the oxen obviously obtained higher levels of TDN from natural pasture grazing than was originally estimated; hence they all made gains.

EXPERIMENT No. 2

An important factor that has to be considered in the feeding of draught oxen on small-scale farms is that the supplemental feeds available during cultivation periods are mainly crop residues. Grain and oil-cake mixtures are not only expensive but are also not readily available to the small-scale farmer. The purpose of using such a mixture in Experiment 1 was to assess the performance of the two types of oxen under a feeding system of known TDN levels. The aim of subsequent experiments was therefore the development of improved ways of using crop residues for draught-oxen feeding. Least-cost rations based on these feed resources would seem to be the only alternative for the small-scale farmer for feeding his draught oxen at ploughing times, as other feeds have been exhausted from the farm at that time.

In this experiment the diet of the oxen was supplemented with treated maize stover and a molasses-urea-mineral mixture. The stover was chemically treated with an alkali solution. Since crop residues, especially stovers and straws, are of low nutritive value, treatment with alkali solution has been used as a means of increasing the availability of energy from these feed sources (Jackson, 1980). The alkali treatment solubilizes the ligno-cellulose layers coating the cell walls of the stover so as to enable the enzymes of micro-organisms of the digestive tract to digest the nutrients made available.

Treatment was carried out by sprinkling the stover with a 5% urea solution, which was used as a source of the alkali, ammonia. One kilogram of urea mixed in 20 litres of water was adequate to wet 20 kilograms of stover. The material was then stored in cement bins for 20 days before being fed. The use of urea as a source of ammonia for alkali treatment, instead of sodium or calcium hydroxides, which are the alkalis commonly used, has the added advantage that it supplies non-protein nitrogen which can be used for ruminal synthesis of protein.

The molasses, urea, and mineral mixture fed as a supplement to the treated stover contained, by weight, 80% molasses, 14% urea, and 6% minerals. This is a commercial product sold in a semi-solid form at a cost of KSh. 1.60 ($US 0.12) per kg. It is available from some rural-town farm stores. Supplementation of the stover with these readily digestible energy and nitrogen sources increases the efficiency of utilization of the stover. In this respect, molasses not only improves the palatability of the stover, but also improves microbial activity in the rumen and in particular is used as a source of energy for the utilization of the urea. Although the mixture used in this experiment is also expensive, it is used in much smaller quantities than the concentrate mixture used in Experiment 1, so that it may be feasible for small-scale farmers to use it if benefits from improved draught performances are clearly demonstrated.

The mixture was fed at a level of 700 g per animal per day. At this level, the urea fed amounted to 98 g and, assuming a 10 kg total dry-matter intake per day from grazing and maize stover, the amount of urea fed was approximately 1%, which is the recommended amount of urea in the total ration. The mixture was fed at the same level to both types of oxen, although they were of different body sizes. The amount of supplement used was mainly designed to provide energy and nitrogen levels that would increase the efficiency of utilization of the stover. As the

treated stover was fed *ad libitum*, it was expected that the animals themselves would adjust their own intake levels.

Results

The cultivation performances of the two types of oxen under the feeding system described above are shown in Table IV. The Sahiwal/Friesian crosses cut the dry soil slightly deeper and cultivated a slightly larger area of land per day than did the Zebu oxen. They also used less tractive effort (10.9%) in relation to their body weight when compared to the Zebu oxen (16.5%), suggesting again that these animals can provide a sustained effort for a longer period of time. These differences between the two breeds were similar in magnitude and direction to those observed in Experiment 1, where the oxen were supplemented with a grain-concentrate mixture.

TABLE IV—CULTIVATION PERFORMANCE OF TWO TYPES OF OXEN SUPPLEMENTED WITH A DIET OF TREATED MAIZE STOVER AND MOLASSES, UREA, MINERAL MIXTURE DURING A PERIOD OF 70 DAYS (STOVER WAS FED *AD LIBITUM* AND SUPPLEMENTARY MIXTURE WAS FED AT 700 g PER ANIMAL PER DAY)

Item of interest	Type of oxen	
	Zebu	Friesian × Sahiwal Cross
Average body size (one pair) (kg)	618.000	916.000
Average depth of cultivation	12.300	13.500
Average speed used (kg)	2.750	3.000
Average draft used (kg)	102.000 (16.5%)*	100.000 (10.9%)
Tractive HP	1.130	1.140
Average weight gain/loss (kg)	+55.000	+[illegible].000
Average area cultivated ha/hr	0.081	0.088
ha/day	0.324	0.352

*Indicates percentage of body weight used for draft.

The heavier (916 kg) Sahiwal/Friesian team consumed more of the treated stover (6 kg per head per day) than the lighter (618 kg) Zebu pair, which consumed the treated stover at the rate of 4 kg per head per day. At an estimated TDN level of 55%, the treated stover + molasses, urea, and mineral mixture diet would provide the Sahiwal/Friesian oxen with 3.3 kg and the Zebu with 2.0 kg of TDN per day. The natural pasture grazing would provide an additional 2.75 kg and 1.85 kg of TDN respectively, from 4 hours of grazing each day. This brings the daily total feed equivalent to 6.05 kg and 4.05 kg of TDN to the Sahiwal/Friesian and Zebu breeds respectively. Both breeds made gains at the end of the cultivation and supplementation period, as seen in Table IV. The supplement was fed for a period of 70 days, which included 30 days before the rains began and 40 days afterwards. The gains made by both groups were substantial. Differences in weight gains between the two breeds were not significant. Here again, the energy consumed from grazing and supplementation was found to be in excess of the amounts required for maintenance and work.

EXPERIMENT No. 3

The feed requirement for work is difficult to quantify, since it varies according to such factors as the type of work the animal performs and the duration of the work, as well as the animal's weight, breed, and age. In the above two experiments, the feeding levels were above the requirements for maintenance and work, since the oxen gained weight in the course of the cultivation and feeding periods. There would be no advantage in feeding oxen to gain weight during cultivation periods, since the animals would only lose it again when supplementation ceased. In a system where animal feed is already in short supply, this factor can be of critical importance. The aim in feeding working oxen should therefore be to maintain their liveweight rather than allow it to fluctuate.

The design of this experiment was exactly the same as that of Experiment 2, except that the level of supplementation was reduced with the aim of reducing the cost of supplementation without affecting performance. The oxen were supplemented with urea-treated maize stover fed *ad libitum*, plus the molasses, urea, and mineral mixture at the rate of 200 g per animal per day. The period of supplementation was 30 days, which included a feeding period of 20 days prior to ploughing and 10 days of ploughing operations before the rains began. Each team of oxen ploughed an area of 2 hectares during the 10-day period.

Results

The cultivation performance of the two types of oxen under the feeding system described above are shown on Table V. No differences were observed between the two breeds in depth of cultivation or speed of operation. The depth of ploughing for both groups was deeper during this trial than in the two earlier trials. This was deliberately enforced on the oxen to see if other performances would be affected, but neither the speed of operation, nor the area covered per day were affected by the deeper ploughing.

The Sahiwal/Friesians still used much less tractive effort (8.3%) in relation to their body weight when compared to the Zebus (12.1%). They again cultivated a slightly larger area of land (0.436 ha) per day than the Zebu breeds (0.396), though the differences observed were not large.

TABLE V—CULTIVATION PERFORMANCE OF TWO TYPES OF OXEN SUPPLEMENTED WITH A DIET OF TREATED MAIZE STOVER AND MOLASSES, UREA, MINERAL MIXTURE DURING A PERIOD OF 70 DAYS (STOVER WAS FED *AD LIBITUM* AND SUPPLEMENTARY MIXTURE WAS FED AT 200 g PER ANIMAL PER DAY DURING PERIOD OF 30 DAYS)

Item of interest	Type of oxen	
	Zebu	Friesian × Sahiwal Cross
Average body size (one pair) (kg)	803.000	1360.000
Average depth of cultivation	15.8000	15.700
Average speed (km/hr)	3.200	3.400
Average draft used (kg)	97.000 (12.1%)*	113.000 (8.3%)
Tractive HP	1.150	1.400
Average weight gain/loss (kg)	−4.500	−15.000
Average area cultivated ha/hr	0.099	0.109
ha/day	0.396	0.426

*Indicates percentage of body weight used for draught.

Large differences were observed in the weight changes between the two breeds. At the end of the ploughing period, the Sahiwal/Friesian crosses had lost considerably more weight (−15 kg) than the Zebus (−4 kg). Although the average dry-matter intakes of treated stover were similar to those of Experiment 2, i.e. 6 kg and 4 kg per animal per day for the Sahiwal/Friesian and Zebu breeds respectively, the fact that the supplementary molasses, urea, and mineral mixture was reduced from 700 g to 200 g per animal per day must certainly have affected the efficiency of utilization of the treated stover and thus reduced the TDN available from the diet, consequently causing weight losses in the oxen during the time of cultivation. The fact that the Zebus lost less weight than the Sahiwal/Friesians may indicate that they utilized the treated stover more efficiently, even though they used more tractive effort (12.1% as against 8.3%) in relation to their body weight. In any case, as output in terms of energy used is inevitably linked with the energy available from feed, it is obvious that the oxen in this trial were underfed. However, since the changes in liveweight were recorded at the end of the ploughing period in this experiment, whereas they were recorded at the end of the weeding period in the two previous experiments, it is most probable that the gains made by the oxen in the earlier experiments were made after

ploughing operations had been completed and when the animals had begun to gain access to lush green growth from natural-pasture grazing in addition to the supplemental feeding. Although both groups lost weight, their performances in depth of cultivation, speed of operation, and area of land cultivated per day were not less than their performances in the two previous experiments, when they were supposedly overfed. It follows, therefore, that for short periods of work it may be adequate to keep oxen in fit working condition by appropriate feeding prior to cultivation periods, even if they tend to lose weight during the cultivation itself. There is certainly no advantage in supplementing oxen after the ploughing period has ended, as the energy requirement for subsequent operations, such as planting and weeding, can be met from grazing new regrowth of natural pasture land.

SUMMARY

The development of improved and efficient animal draught power is a very important link in the interaction between crop cultivation and livestock production in small-farm systems. Timely completion of basic land preparation before the rains start is very critical in these dryland areas. At present, ploughing and planting are generally carried out after the rains have started, since draught oxen are too weak to break the dry soil before the rains begin. Feed sources are scarce and feed quality very poor, and oxen are underfed at the time of land preparation. Late planting reduces crop yields by about 6% per day after the first 20 mm of rain have fallen. It is therefore important to develop appropriate feeding systems that will satisfy the need for maintenance and efficient draught power production for work. From increased and efficient cultivation, apart from increased crop yields, more crop residues become available for animal feeding and more land can be cultivated, to the extent of including cultivated pasture and fodder crops in the cropping system.

A series of studies were made on the performances of draught animals with the objective of determining the type of animal and the feeding system best suited to provide increased and efficient power on small-scale farms.

Two types of experimental animals, indigenous Zebu and Sahiwal/Friesian crossbreds, were used. They were grazed on natural pasture and supplemented with either a grain and oil-cake concentrate mixture or with treated maize stover plus varying levels of a molasses, urea, and mineral mixture. Animal performance at the time of cultivation was measured by draught pull, depth of cultivation, speed of operation, area cultivated per unit of time, and weight gains and losses during the study period. The implements used in cultivation were those that are being developed at the station.

No statistical differences were observed between breeds or energy levels with regard to speed of operation and depth of cultivation when the two types of oxen were fed at maintenance and at 1½-times maintenance level. The Sahiwal/Friesians exerted less force at the two levels of feeding than did the Zebu oxen. The crossbreds ploughed slightly deeper and worked at a slightly faster speed than the Zebus. These performances were observed when the oxen were on a diet of natural pasture grazing supplemented with a grain and oil-cake concentrate mixture. When the supplementary feed was changed to a diet of treated maize stover plus molasses, urea, and mineral mixture calculated to provide adequate energy for maintenance and work, the cultivation performances of the two types of oxen were similar in magnitude and direction to those observed when the oxen were supplemented with the grain concentrate mixture. These feeding regimes were started at least 30 days prior to cultivation and were continued for 40 days to complete planting and weeding operations. As weeding operations were carried out after the rains when the oxen had access to good quality forage from natural pasture grazing, the supplementary feeding was found to be in excess of the energy requirements for the operations carried out and therefore all the oxen made liveweight gains at the end of the cultivation and feeding period. With reduced levels of supplementation and shortened periods of feeding the oxen lost weight, but their cultivation performance in terms of depth of cultivation, speed of operation, and area of land cultivated per day was not less than that observed at the time when they were fed higher levels of energy.

These results indicate that, given the implements used at present, there would be no advantage in using crossbred oxen over indigenous breeds. Properly and adequately supplemented, indigenous oxen perform as well as the bigger and stronger crossbred animals. As a direct function of their larger body weights, the crossbreds require more feed than the Zebu oxen and also require more care and attention. These facts do not justify their use as draught animals under the

feeding systems described, unless draught requirements are changed because of the development of new and improved implements.

Both breeds of oxen performed reasonably well in terms of depth of cultivation, speed of operation, and area of land ploughed per day when they were on natural pasture grazing and were offered a supplementary diet of treated maize stover fed *ad libitum* plus a small amount of a molasses, urea, and mineral mixture. Soil conditions apparently did not dictate greater tractive effort than could be provided by the oxen when they were at these energy levels.

The use of these small levels of supplements for feeding draught oxen for short periods of time prior to cultivation would seem to be warranted when one assesses the economic consequences of early ploughing and planting and the consequent increase in productivity per hectare, as well as the possibility of increasing the area cultivated per unit of time.

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UTILIZATION OF MAIZE AND SORGHUM STOVER BY SHEEP AND GOATS AFTER FEED-QUALITY IMPROVEMENT BY VARIOUS TREATMENTS AND SUPPLEMENTS

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INTRODUCTION

Crop residues and farm by-products are the most readily available livestock feeds and sometimes the only feeds available during the dry seasons in dryland areas. Although maize stover is the most abundant residue, others, like sorghum stover, millet stover, pigeonpea stover, cowpea leaves, cassava leaves, and groundnut vines and haulms can also be found in various quantities. The majority are bulky and poor-quality cellulosic roughages with high fibre, low protein, poor mineral composition and low digestibility. Weathering from improper post-harvest storage causes major losses of nutrients and the quality further deteriorates. Because of the difficulties arising from these factors, only a small part of the thousands of tons of these residues available is used as feed and, where and when used, the efficiency of utilization is very low.

Although these feedstuffs have at the present time some importance in the feeding of farm animals, their production and utilization are likely to increase further in the future, since (1) crop production is likely to increase following increases in acreages and technical inputs, and (2) acreages of grazing lands and lands under fallow are likely to be reduced. The development of suitable methods that improve the utilization of these feeds should therefore be given high priority in animal-feeding-and-management research programmes especially with regard to the finding of solutions to problems of dry-season animal feeding on small-scale farms.

Being deficient in several nutrients and containing a number of factors that limit optimum utilization, these feed resources are of little value when fed as they exist. Lignin is the principal factor, giving them a low nutritive value. Lignification is promoted by high environmental temperatures and the short photo-periods characteristic of the tropics (Deinum, 1976). The development by plant breeders of stiff-stalked and insect-resistant varieties of maize and sorghum may also contribute to the increased lignin content. A low-lignin mutant would therefore be of great use in the improved utilization of these residues by livestock.

Improvement of the nutritive value of these feedstuffs can be achieved through (a) treatment methods that increase the availability of nutrients, and (b) supplementation methods that add deficient nutrients or correct nutrient imbalances. It has been established by numerous research workers (Jackson, 1978) that processing of poor-quality roughages by physical and chemical means can considerably increase the availability of nutrients from these feeds. In his review, Jackson reported that 10 to 20% increments in digestibility and more than 100% increments in voluntary intake can be achieved by processing. Physical treatments such as chopping do not increase digestibility but have the advantage of reducing wastages by preventing selection by the animal. It may also increase the amount consumed. Chemical treatment is based on solubilizing the lignocellulose layers coating the cell walls so as to enable enzymes of micro-organisms of the digestive tract to digest the nutrients made available. Gramineaceous lignin appears to be constituted of polymerized substituted phenyl propionic acids esterified to xylan lignocelluloses (Harkin, 1973). Treatment with alkali saponifies this linkage. The lignin content is not reduced but digestibility is increased substantially. Sodium hydroxide is the most fully investigated and widespread chemical treatment applied to poor-quality roughages. The techniques of chemical processing of low-quality roughages to improve their quality have been practised in Europe and North America for a long time. These involved alkali treatment with large volumes of solution (soaking) as well as treatment under high temperatures and pressure cooking. Obviously, such high-powered technologies have no applicability to small-scale farms. They will have to be modified and made simple and inexpensive to fit the socio-economic status of the small-scale farmer.

With respect to supplementation, it is re-

cognized that conventional energy and protein feeds such as grains and oil cake are not only unavailable but are also too expensive for the small-scale farmer. It is therefore necessary to consider cheaper, preferably home-grown, supplements, e.g. fodder shrubs such as *Leucaena leucocephala* and pigeonpea stover. These feedstuffs, being high in nitrogen and energy, are used in small quantities, and should greatly improve the efficiency of utilization of poor-quality roughages.

The objectives of the experiments undertaken were:

1. to determine the effect of farm-level alkali treatment of maize and sorghum stover upon chemical composition, *in vitro* dry-matter digestibility, and voluntary intake;
2. to determine the effect of supplementing maize and sorghum stovers with molasses, urea, minerals or the fodder plant *Leucaena leucocephala* and pigeonpea stover upon the performance of sheep and goats;
3. to determine the cost/benefit relationships of treating and supplementing stovers with weight changes in sheep and goats fed with these materials.

MATERIALS AND METHODS

1. Maize and sorghum stover were used without distinction in all trials.
2. The stover was chopped by a hand chopper to lengths of 2–3 cm.
3. Simple farm-level equipment, e.g. buckets, garden sprinklers and hay forks, were used in the preparation of the treated stover.
4. The alkali employed in the treatment was NaOH. The optimum NaOH treatment rate of 5% (as recommended by other workers, e.g. Jackson, 1978) was adopted in consideration of costs and ease of handling.
5. The chopped stover, spread on a cement floor, was sprinkled with NaOH solution so that it was uniformly wetted. This was achieved by mixing 1 kg of NaOH in 20 litres of water, which would be adequate for wetting 20 kg of stover. The material was continuously turned over by hay fork while being sprinkled. The material was left on the floor for 24 to 36 hours before it was fed. A fresh batch was prepared daily.
6. The supplements used were molasses, urea, and mineral mixture, the fodder plant *Leucaena leucocephala*, and residue from pigeonpea crops. The molasses, urea, and mineral mixture was reconstituted with water and sprinkled on the stover. The *Leucaena* and the pigeonpea residue were chopped and sprinkled on.
7. Growing sheep and goats (both male and female) were used in all these trials.

RESULTS AND DISCUSSION

Effect of 5% NaOH Treatment on Chemical Composition

Plant cell wall, measured by NDF, is the most fundamental feed characteristic determining feeding value. This fraction is only partially available, depending upon the degree of lignification. Table I shows that treatment decreased this component by 14.6 percentage units, thus bringing the level of cell solubles of the treated stovers from 14.2% to 28%. The amount of cell solubles of a feed determines the proportion of completely available nutrients. The cellular contents comprise the bulk of the protein, starch, sugars, lipids, organic acids, and soluble ash.

TABLE I—EFFECT OF NaOH (5%) TREATMENT UPON CHEMICAL COMPOSITION AND *IN VITRO* DRY-MATTER DIGESTIBILITY OF MAIZE STOVERS

Composition (%)	Untreated stover	Treated stover
NDF	85.80	71.20
ADF	51.00	49.40
ADL	5.60	5.60
CP	3.19	3.86
IVDMD	35.90	44.50

Treatment thus increased the soluble and easily digestible portions of the stover. The acid detergent fibre (ADF) consists of cellulose, lignin, silica, and other acid-insoluble minerals. In Table II it is shown that alkali treatment resulted in only a slight decrease of ADF. The hemicellulose content decreased considerably, from 34.8 to 21.8%, indicating an extensive degradation of this fraction by alkali treatment, rendering it more readily available for digestion.

As expected, lignin, which is essentially indigestible and also the principal factor limiting the availability of the cellulosic fraction, was not affected by alkali treatment. The crude-protein composition remained virtually the same after treatment.

Effect of 5% NaOH Treatment on Digestibility

The most reliable technique for assessing the effectiveness of any treatment method is to determine the difference in *in vitro* digestibility between treated and untreated stover, since such values are not influenced by animal factors. The 5% NaOH treatment increased *in vitro* dry-matter digestibility to 8.5%, as shown in Table I. This degree of improvement was expected. According to Jackson (1978), roughages treated with 4–5 kg NaOH/100 kg have rarely been found to have increased digestibility by more than 10 percentage units, whereas when higher levels of NaOH were used (7–9%) digestibility increased by as much as 17%. But straw treated with 8 kg NaOH/100 kg dry matter should be fed mixed with other ingredients in the diet and not separately, as it is somewhat unpalatable.

TABLE II—EFFECT OF NaOH (%) TREATMENT ON INTAKE OF MAIZE STOVER BY SHEEP AND GOATS (JULY/OCTOBER 1981)

	Average DM intakes (g/animal/day			
	Chopped maize stover as the only source of feed		Chopped maize stover plus natural pasture grazing	
Animals	Untreated	Treated	Untreated	Treated
Sheep and goats (48)	650[a]	674[a]	470[a]	715[b]

a, b. Means with different superscripts were different at the P 0.5 level.

Digestibility predictions of such low-quality roughages cannot be directly determined as the coefficients obtained do not accurately reflect the nutritive value these feeds have when properly supplemented. Crude protein is the major factor limiting intake and digestibility of low-quality roughages when fed alone (Campling *et al.*, 1962). As seen in Table I, the crude-protein levels of both the untreated and treated stover were very low; i.e. 3.2 and 3.9% respectively. Supplementation of such feeds with non-protein nitrogen (NPN) should improve intake and digestibility beyond what was achieved by treatment alone.

Effect of 5% NaOH Treatment on Intake

Dry-matter intake values of treated and untreated stover using sheep and goats are given in Table II. When stover was the only feed offered, sheep and goats consumed 650 and 674 g dry matter per day for untreated and treated stover respectively, showing no significant difference in intake due to treatment. The measurement of voluntary intake in such a situation is rather difficult and unrealistic, as a number of factors, e.g. levels of energy and protein and the condition of the animal, affect intake levels. In this particular trial, deaths occurred in both the untreated and treated groups when stover was the only feed made available. This was because intake levels and the nutrients derived from these levels were not adequate to maintain sheep and goats weighing on the average 28 kg. However, intakes were significantly improved (from 470 and 715 g per day of untreated and treated stover respectively) when levels of energy and protein in the diet were increased through additional grazing.

Effect of 5% NaOH Treatment and Supplementation of Maize and Sorghum on Animal Performance

In the earlier part of the study on voluntary intake, when stover was the only source of feed made available to sheep and goats during a 127-day feeding period, all animals lost weight considerably, and some even died, on both treated and untreated stover diets. In the following series of studies we compared the performance of grazing sheep and goats when supplemented with various forms of stover during the dry and wet seasons.

Gains made during the dry season (Table III) by grazing sheep and goats were small when supplemented with both treated and untreated stover, although these gains were significantly higher (P 0.05) than the control group, which were on grazing alone. However, there were no significant differences between weight gains with untreated and treated stover. Similarly, there were no significant differences between weight gains of animals when a limited amount of molasses, urea, and mineral mixture was added to the diet. As the control group had a highly significant weight loss during the experimental period, the gains made by the groups fed various forms of stover supplements indicate the value of even untreated but chopped stover as a dry-season supplement. We will note that feed costs per kg of gains made were very high in all cases. When we consider net gains made we can see that treatment of stover by 5% NaOH is a very expensive proposition, at the present prices of NaOH.

TABLE III—THE EFFECT ON NaOH (5%) TREATMENT AND CONCENTRATE SUPPLEMENTATION OF MAIZE AND SORGHUM STOVER WHEN FED TO GRAZING SHEEP AND GOATS DURING THE DRY SEASON

	Treatments				
Item of interest	Grazing alone	Untreated stover	NaOH-Treated stover	Untreated molasses, urea, and mineral mixture (200 g/animal/day)	NaOH-treated stover + molasses, urea and mineral mixture (200 g/animal/day)
No. of animals	16.0	16.0	16.00	16.00	16.00
No. of days on trials	90.0	90.0	90.00	90.00	90.00
Initial average wt (kg)	24.0	24.0	23.90	23.40	24.20
Final average wt (kg)	18.0	25.7	25.50	25.30	26.20
Average daily gain (g)	22.0[a]	19.0[ab]	18.00[ab]	21.00[ab]	22.00[a]
Average DM-intake/day (g)	—	271.0	420.00	516.00	730.00
Daily feed cost (KSh.)	—	—	0.51	0.36	0.92
Feed cost/kg gain (KSh.)	—	—	28.33	17.14	441.82

a, b. Means with different subscripts were different at the P 0.05 level.

Diets based solely on low-quality roughages and non-protein nitrogen (NPN) and minerals barely provide maintenance requirements for ruminants (Coombe and Tribe, 1962). These results have led to the conclusion that low-quality roughages are unsatisfactory energy sources for protein synthesis from NPN in the rumen. The inferiority of low roughages as sub-

strates for NPN utilization is due to a slow rate of digestion in the rumen. Hence, the utilization of diets based on low-quality roughages plus NPN should be expected to improve with alkali treatment, since treatment increases the rate of digestion of the total dry matter in the rumen. This phenomenon was not found to be true in our studies.

A study was conducted with another group of sheep and goats during the wet season (Table IV). Amounts gained during the wet season were considerably higher than in the dry season, for obvious reasons. Analysis of variance shows that there were significant (P 0.05%) differences between treatments. Slightly higher weight gains were made by sheep and goats when supplemented with treated rather than untreated stover. However, when the molasses, urea, and mineral mixture was added to these two forms of stover, the animals on untreated stover gained slightly more than those on treated stover, showing that treatment does not in fact pay.

TABLE IV—PERFORMANCE OF SHEEP AND GOATS WHEN FED VARIOUS SUPPLEMENTS WHILE GRAZING NATURAL PASTURE DURING THE WET SEASON

Item of interest	Grazing alone	Treatments			
		NaOH-treated stover + molasses, urea mineral mixture	NaOH-treated stover + molasses, urea mineral mixture	NaOH-treated stover + *Leucaena**	Untreated stover + *Leucaena**
No of animals	8.0	8.0	8.0	8.0	8.0
No. of days	112.0	112.0	112.0	112.0	112.0
Initial average wt (kg)	35.9	35.0	35.2	35.6	34.6
Final average wt (kg)	32.1	39.4	40.4	40.4	38.6
Average daily gain (g)	−34.0[a]**	39.0[b]	46.0[b]	43.0[b]	38.0[b]
Average DM-intake/day (g)	—	210.0	290.0	250.0	350.0

**Leucaena leucocephala* was fed as green chop and mixed with chopped stover at 20% of the dry matter offered.
a, b. Means having different subscripts were different at the P 0.05 Level.

The Effect of Different Levels of Leucaena *Supplementation on the Performance of Sheep and Goats*

In an attempt to find other, less costly protein and energy supplements that can be used with maize and sorghum stover, the leguminous plant *Leucaena leucocephala* was mixed with treated and untreated stover and fed to grazing sheep and goats. The performances of animals fed these and other supplements are shown in Table V.

One known disadvantage in the feeding of *Leucaena* to sheep and goats is its high content of the non-protein amino acid mimosine, which results in toxicity in animals at high intake levels. However, it has been observed that ruminants in some countries, e.g. Hawaii, Mexico, and the Philippines, can take high levels of *Leucaena* without deleterious effects. It is suggested that these animals may possess certain micro-organisms capable of breaking down the Mimosine to avoid its toxic effect. As this fodder showed good promise as a supplement to poor-quality roughages, it was thought important to know the level at which *Leucaena* can be fed to sheep and goats without danger of toxicity.

Leucaena was fed at two levels, i.e. 30 and 50% of the daily dry-matter intake. There were 12 growing shoats in each group, composed of 6 sheep and 6 goats. The *Leucaena* was chopped and mixed with chopped Bana grass and this mixture constituted the diet for the animals for a

TABLE V—PERFORMANCE OF SHEEP AND GOATS SUPPLEMENTED WITH DIFFERENT LEVELS OF *LEUCAENA LEUCOCEPHALA*

	Treatments			
	30% *Leucaena*		50% *Leucaena*	
Item of interest	Sheep	Goats	Sheep	Goats
No of animals	6.0	6.0	6.0	6.0
No. of days	48.0	48.0	48.0	48.0
Initial average wt. (kg)	15.70	17.0	15.6	16.7
Final average wt (kg)	16.00	14.3	17.0	14.6
Average daily/gains/ loss (g)	11.07	−95*	46.8	−76.4
Average DM-intake/ day (g)	453.00	474.0	456.0	416.0
Leucaena	126.00	132.0	212.0	196.0
Bana grass	327.00	242.0	235.0	218.0

*One goat in this group had severe diarrhoea for 8 days.

period of 48 days. The results of this trial are given in Table VI.

The trial was conducted during the dry season and weight gains in general were low. In average daily gains made by the different treatments there were no significant differences (P 0.05) observed between animals supplemented with treated stover, treated stover plus molasses-urea-mineral mixture, treated stover plus *Leucaena*, and untreated stover plus *Leucaena*. This indicates that *Leucaena*, a much cheaper and home-grown supplement, when fed at 20% of the dry matter intake, can effectively replace the molasses, urea, and mineral mixtures fed at 200 g per animals per day. The daily weight-gain differences between these treatments also shows that it is uneconomical to treat stovers when *Leucaena* is available.

It will be observed that at both 30% and 50% *Leucaena* levels goats lost weight, while sheep made gains, gaining significantly more at the 50% level than at 30%. The sheep were a mixture of Red Masai (indigenous) and Dorper (exotic) breeds, while the goats were a mixture of Galla (indigenous) and Small East African breeds. Apart from the goats losing weight and one goat from the group on 30% *Leucaena* developing a severe case of diarrhoea, there was no other observable toxic effect. There were no differences between the dry-matter intakes of the groups and all groups were fed *ad libitum*. With only one such trial, involving a small number of animals and a short period of time, it is doubtful whether we can at this time conclude that sheep can handle high intake levels of *Leucaena* better than goats. Additional studies along the same lines are being undertaken in order to draw definite conclusions.

Effect of 5% Urea Treatment and Supplementation of Maize Stover with Pigeonpea Residue on Animal Performance

In view of our findings that cost benefit relationships did not warrant the use of NaOH for treating low-quality roughages, it was thought that urea may offer a better alternative, due to the fact that it is cheaper and readily available to the farmer as fertilizer. It is also easier to handle.

Jackson (1978) and Sunstol *et al.* (1978) have shown that ammonia can be a good alternative to sodium hydroxide in the treatment of low-quality roughages. The use of ammonia for alkali treatment has the added advantage that it supplies non-protein nitrogen which can be used for ruminal synthesis of protein. Urea is used as a source of ammonia.

In this trial, urea at a concentration of 5% of stover weight was dissolved in water and the solution was sprinkled on the chopped stover.

The wet material was put in small bins covered with a plastic sheet and weighed down to prevent the ammonia from evaporating. The material was stored for 20 days to complete the treatment process before it was fed to the animals. Ammonia is a slow-reacting alkali requiring processing times of several days (Waiss *et al.*, 1972). But a short treatment time was necessarty since farmers do not have large storage capacity and must make small amounts at a time. The stover turned dark in colour and had the distinct smell of ammonia even after the material dried out, indicating that treatment was effective.

Table VI shows the performances of sheep and goats when fed urea-treated and -untreated maize stover mixed with pigeonpea residue while grazing natural pasture during the dry season. Intakes of growing sheep and goats on treated stover plus pigeonpea residue averaged 200 g/animal/day, while similar animals on untreated stover plus pigeonpea residue averaged 200 g/animal/day. The weight gains made reflected these differences in intake levels. The animals on treated stover plus pigeonpea residue gained 71 g/day while those on untreated stover plus pigeonpea residue gained 77 g/day. Improvements in intake with urea treatment were similar to those obtained previously with NaOH-treated stover. These findings are in conformity with those of other workers (Garrett *et al.*, 1974; Martyn or, 1972).

TABLE VI—PERFORMANCE OF SHEEP AND GOATS WHEN FED UREA-TREATED AND -UNTREATED MAIZE STOVER MIXED WITH PIGEONPEA RESIDUE WHILE GRAZING NATURAL PASTURE DURING THE DRY SEASON

Item of interest	Treatments	
	Urea-treated maize stover + pigeonpea residue*	Untreated maize stover + pigeonpea residue
No. of animals	8.00	8.00
No. of days	88.00	88.00
Initial average wt. (kg)	17.52	17.93
Final average wt. (kg)	22 50	24.20
Average daily gain/animal (g)	77.00	57.00
Average DM-intake/day (g)	229.00	200.00

*Urea treatment was at 5% level and the material was fed after being treated for 20 days in an airtight bin. Pigeonpea residue was fed as green chop and mixed with the chopped stover at 50% of the dry matter offered.

Pigeonpea residue is found to be a valuable feed for supplementing maize stover. Although not as high as *Leucaena* in protein content and dry-matter yield, the advantage that pigeonpea has over *Leucaena* is that it stays green throughout the dry season. When *Leucaena* stops growing and becomes dry during the latter part of the dry season pigeonpea is still green, and in fact is removed only because farmers have to prepare the land for the next planting season. Average daily gains made by sheep and goats fed maize stover supplemented with pigeonpea residue (Table VI) were higher than those made by sheep and goats fed maize stover supplemented with *Leucaena*, while both groups were on natural pasture grazing during the dry season. These results could of course have been affected by differences in pasture quality in different years and the weights of the experimental animals. The results indicate, however, that diets of even untreated stover supplemented with pigeonpea residue, which is found on almost all farms, will not only prevent weight losses but also result in modest gains in growing sheep and goats during the dry season.

SUMMARY

The most readily available livestock feeds in the dryland areas are crop residues. Although maize stover is the most abundant residue, others like sorghum stover, millet stover, pigeonpea leaves and stems, cassava leaves, etc. are found in various quantities. The majority are

poor-quality cellulosic roughages with high fibre and low protein, poor mineral composition, and low digestibility, which make them of little value when fed as they exist.

The treatment of maize and sorghum stover by sprinkling the chopped material with a 5% solution of NaOH reduced the fibre fraction by about 15% and rendered the soluble fraction more readily available. *In vitro* dry-matter digestibilities increased by an average of 8.5% and voluntary intakes were also substantially improved, by about 60% when stover was treated with 5% NaOH.

Gains made by grazing sheep and goats were small when supplemented with either treated or untreated stover during the dry season, although these gains were significantly higher than the control group on grazing alone. In general, however, no significant differences were observed between weight gains of sheep and goats fed treated or untreated stover when stover alone was the supplement. When the energy and protein levels of the stover were improved by the addition of urea, molasses, and minerals, animals on the treated stover gained better, although differences were still not significant when compared with those fed untreated stover. Cost/benefit relationships indicate that the improvements brought about by 5% alkali treatment do not warrant the expenditure at the current price of NaOH. Although supplementation of the stovers with molasses, urea, and minerals offers a more reasonable economic return than the treatment of stover with NaOH, its applicability in small-farm systems is still questionable because it is not easily available to the farmer.

Supplementation with home-grown proteinaceous plants such as *Leucaena leucocephala* or pigeonpea stover offered the most economic benefit. Animals supplemented with untreated maize stover mixed with *Leucaena* performed just as well as those supplemented with treated maize stover plus molasses, urea, and minerals. Grazing sheep and goats, supplemented with maize stover mixed with pigeonpea stover at a one-to-one ratio, on the dry-matter basis, gained 57 g daily when the stover was untreated and 71 g daily when it was treated.

The outstanding features of *Leucaena leucocephala* are its ability to withstand drought and repeated defoliation, its high production of forage, high palatability, and very high crude-protein content. The ability of the pigeonpea residue to remain green with high protein content throughout the whole dry season makes these feed resources ideal supplements to add deficient nutrients to correct nutrient imbalances in the feeding of poor-quality roughages to livestock on the small farms of dryland areas.

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A REVIEW OF PASTURE-RESEARCH WORK AT KATUMANI, KENYA (ABSTRACT)

P. F. Wandera [1]

In early work carried out by Sands and his colleagues, varieties of *Cenchrus ciliaris, Chloris gayana* and *Panicum maximum* were identified among the pasture grasses as being most suitable for the area. During initial adaptation trials some varieties of *Pennisetum purpureum* (local, from Ghana, and from Cameroon) appeared suitable for areas receiving about 700 mm of rainfall, while recent work produced the variety Bana. Legumes that survived in better years were *Dolichos argentius, Phaseolus atropurpureus, Clitoria tenatea, Glycine javanica,* and *Stylosanthes gracilis.*

For the establishment of pasture grasses a coarse seedbed is required, to trap most of the incident rainfall and to shield the grass seedlings from sun and wind. Present work shows that ploughing after the first showers reduces weed infestation. Because of the poor water-holding capacity of the local soils the aiding of water penetration and retention is essential for successful pasture and fodder establishment. When water is limiting, fertilizer should be used sparingly.

On dry-season feeding, Rossiter envisaged a potential system of wet-season exploitation, based on pasture grasses such as Guinea grass for the first 4 weeks of the season, followed by a cut of fodder grass for the succeeding four weeks, then grazing of pasture for 2—3 more weeks, and finally the use of cut fodder regrowth.

However, seasonal productivity must be considered, especially in the March-April "long rains", since the dry season that follows, covering 4—5 months, is the most critical in animal production. Fodder shrubs have been studied as dry-season supplementary feeds together with crop residues.

In the intercropping system of *Leucaena leucocephala* and maize, there has been a significant (12%) reduction of maize grain yields. However, the DM yield of *Leucaena* and maize stover under such a system has provided a 0.67: 1.0 mixing ratio of the feeds. The effect of such a level of supplementation on animal production is at present under study at Katumani.

1. National Dryland Farming Institute, Katumani

CLIMATE, GROWTH AND ANIMAL PRODUCTION IN A RANGE AREA OF KENYA (ABSTRACT)

H. L. Potter[1]

The paper reports on attempts to develop a predictive model relating primary (plant) and secondary (animal) productivity to climate and soil parameters in a range area. The results indicate the importance of a "threshold" amount of water required to initiate growth of the sward after drought, the role of herbage selection in animal performance, and the differences between the effects of defoliation by machine and by the grazing animal.

Growth rates of 350–400 g per head per day on a year-round basis are routinely obtainable with beef steers on unimproved semi-arid rangeland without any supplementary feeding, provided that an appropriate stocking rate is used.

1. Animal Production Research Department, Kenya Agricultural Research Institute, Muguga

TECHNICAL SESSION 6: REPORT ON DISCUSSION

Chairman (Mr J. D. Wachira): Eight-five per cent of Kenyan land receives less than 750 mm of rain per year and most of this zone is regarded as rangeland. Improvement in the management and utilization of the natural pasture and crop residues coupled with specified human and livestock population densities are a prerequisite to increased livestock productivity, which is a major source of income in arid and semi-arid areas.

Dr. R. K. Jones: Some of you may be aware of the exciting work by ILCA in northern Nigeria, where legumes are being grown in "fodder banks" which are grazed in the dry season. Work is now being directed at quantifying the value of the legumes to subsequent crops grown on the area. There are mutual benefits in integrating the cropping and livestock enterprises. I understand that the cropping and livestock enterprises are segregated in the Machakos–Kitui area. Why is this so, and does it always have to be that way?

Mr F. P. Wandera: The unit farms in Machakos and Kitui have both crop and livestock enterprises integrated. Farmers grow crops and keep livestock.

Mr A. M. Marimi: Different seed rates or spacing lead to different seedling densities, which in turn imply different rates of dry-matter accumulation for animal feed. Do you consider that farmers could manipulate these density parameters to obtain adequate early feed? If so, would such an advantage warrant the additional cost?

Mr Wandera: The seed rates normally recommended are the optimum for DM production and seedling competition for nutrients and space. The manipulation of rates is advantageous for different seed-bed preparations to enable easiest establishment. But experiments to establish the advantage of incurring additional cost in terms of supplementary water and nutrient application have not been done in the semi-arid areas.

Mr J. K. Mavua: Taking into account the physical impact on soil of grazing animals and the impact of rain on such soil, would you still recommend this high rate of stocking—2 ha/head?

Mr H. L. Potter: Ten years of grazing at 2 ha/head shows no physical damage to the sward or soil or bush encroachment, so that for the site in question the level of 2 ha/head is not excessive.

Mr I. K. Ojwang: Don't you think it would be beneficial if a research programme were carried out to determine the maximum stocking rate during the wet seasons and the optimum stocking rate during the dry season? This would also require close liaison with extension officers and improving the marketing system so that farmers are advised to sell surplus animals during the dry season to prevent degradation of vegetation and soil.

Mr Potter: Such work is required, of course, and has in fact been planned. However, the lack of information about the whole subject when the programme reported was planned meant that year-round set stocking was used as the baseline system, for initial examination. The sale of excess stock during the dry season to reduce degradation requires careful consideration. Timing of sales may have to take into consideration the seasonality of requirements for cash for farm or family, as well as the factors of forage availability, soil conditions, animal condition, etc. The best time for sale may, in fact, be in the early rainy season, to allow greater accumulation of forage and ground cover—selling in the dry season may be too late because degradation may already be in progress.

Mr Marimi: Mature grass swards (probably lodged) hold considerable water from incident rainfall so that rainwater which reaches the soil is ultimately available. Under those circumstances determination of Ea/Eo ratios as high as 1.3–1.6 have been reported. Of course these high rates last as long as the sward is wet. Don't you think Ea/Eo ratios of this magnitude would significantly affect the accuracy of your prediction models?

Mr Potter: Yes, and also the long period of dormancy of the sward in the dry season will affect the crop factor, even though the sward is perennial. The results to date do indicate, however, that rainfall alone may be adequate as an indication of water availability, rather than the very much more complex water-balance-derived evapotranspiration estimate.

Dr Wachira: It is important that we recognize the role of livestock as generators of income through increased production of meat, milk, eggs, and other animal products, rather than as a source of draught power and manure for crop production *per se*.

TECHNICAL SESSION 7

FARMING SYSTEMS AND THEIR MANAGEMENT

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FARMING-SYSTEM RESEARCH: THE KATUMANI APPROACH (ASBTRACT)

J. K. Mavua[1]

A farming system can be defined conceptually as any set of agricultural elements or components which are interrelated and interact among themselves. A farming system is influenced by the physical, biological, and socio-economic environments within which it operates. At the centre of these interactions and interrelations is the farmer.

The primary aim of agricultural research is to increase and sustain the productivity of the farming system in the context of the entire range of private and societal goals, given the constraints and potentials of the existing farming system.

The farming-system approach to agricultural research is an approach which seeks to integrate all research disciplines in the process of identifying, delineating, and describing existing farming systems, problems, constraints, and priorities of the farmer, and his goals and objectives, in order to formulate relevant research programmes which are geared to generating appropriate technologies which when tested on the farmer's fields under his own conditions are found to be relevant and acceptable to him and to solve his farming problems.

The approach operates on the premise that effective agricultural research begins and ends with the farmer. Three phases are identified:

1. identification, delineation, and description (dignosis);
2. formulation and generation of technology;
3. testing, evaluation, and feedback under farmers' conditions, and derivation of farmer recommendations.

The multi-disciplinary and integrated nature of the approach is noted as crucial and critical to its success. It is farmer-based, comprehensive, problem-solving, dynamic and socio-economically responsive. The approach entails mainly applied and adaptive research which is on-farm based under farmers' conditions.

The approach makes agricultural research farmer orientated and generates technologies that are relevant and appropriate to the farmer and his farming conditions.

1. National Dryland Farming Research Station, Katumani

FARMING SYSTEMS OF SEMI-ARID EASTERN KENYA: A COMPARISON

Mwita Rukandema[1]

INTRODUCTION

This paper is based on three farm-management studies in three different Locations in the semi-arid parts of Kenya's Eastern Province. The three completed studies are part of a larger farm-management research programme which aims at providing detailed descriptions of identified, and quite distinct, farming systems existing in the drier parts of the Province.

The primary objective of these studies is to provide detailed background information for the biological and other scientists at the National Dryland Farming Research Station (NDFRS), Katumani, so that they may better tailor their research programmes to finding solutions to identified problems facing small farmers in the target area. Secondary objectives include: provision of benchmark data for future gauging of the impact of research/development programmes; provision of planning data for future investment programmes; and highlighting policy areas in need of government action.

METHODS

Following an exhaustive review of the current literature (non-existent for the most part) on prevailing farming systems in semi-arid eastern Kenya, a rapid but carefully planned presurvey was undertaken which, on the basis of a set of criteria,[1] led to a preliminary classification of the target area into fairly distinct farming-system types. This process was then followed by the formal study, selecting at least two research sites (Sublocations) within each farming-system type so as to capture whatever intrasystem variation might exist. The three completed studies were conducted in the following areas:

District	*Location*	*Sublocation*
Machakos[2]	Mwala	1. Myanyani 2. Kyawango
Lower Embu	Evurore	1. Kathera 2. Kamarandi
Southern Kitui	Mutomo	1. Kawelu 2. Kibiuni

Sampling frames for farmers in Machakos and Embu were compiled from land registers obtained from the respective District Land Offices, as farms in the selected research sites had been government demarcated, surveyed and registered. In contrast, the sampling frame for Kitui had to be generated from farm household enumeration, because farms in the District are not yet surveyed. Stratified farm random samples were drawn as shown in Table 1.

Farm stratification and sampling were simpler and more precise in Machakos and lower Embu, where sizes of individual farms were known. In Kitui, on the other hand, farm-size estimation was made visually with the help of farmers at the time of household enumeration. It is therefore quite certain that substantial errors exist which will tend to obscure interclass differences.

With these points in mind, certain features may be noted from Table 1. Kathera Sublocation in Embu District is characterized by a preponderance of very small farms. Seventy per cent of the farms there are of 2 hectares of less. This is in sharp contrast with the situation in Machakos, Kamarandi and southern Kitui, where, respectively, 23 per cent, 21 per cent and (probably) less than 20 per cent of the farms are of 2 hectares or less. Two further adverse factors in Kathera are its very rough terrain and widespread rockiness, both of which render the prospect of

1. For example: crops and cropping patterns; production technology; livestock types and ownership patterns; live stock-management systems; land-tenure systems; etc.
2. In Machakos, the two sublocations were so similar that they were treated as one research site.

TABLE I—FARM SAMPLES IN THE THREE STUDY AREAS

(a) Machakos District

Farm size group (ha)	No. farms	%	Sample
0.1 – 2.0	160	23	25
2.1 – 5.0	180	26	25
5.1 – 10.0	180	26	25
10.1 +	172	25	25
Total	692	100	100

(b) Lower Embu

	Kathera			Kamarandi		
Farm size group (ha)	No. farms	%	Sample	No. farms	%	Sample
0.1 – 1.0	392	35	50	37	7	10
1.1 – 2.0	389	35	50	76	14	20
2.1 – 3.0	154	14	20	77	15	22
3.1 +	173	16	25	340	64	93
Total	1108	100	145	530	100	145

(c) Southern Kitui

	Kawelu			Kibiuni		
Farm size group (ha)	No. farms	%	Sample	No. farms	%	Sample
Less than 4	79	19	20	152	24	25
4 – 8	124	30	30	172	27	25
More than 8	212	51	50	312	49	50
Total	415	100	100	636	100	100

mechanizing (or "oxenizing") agriculture practically impossible. Clearly, Kathera will require special consideration in technology development and policy design.

Farm resources

1. *Land availability*

Table II gives average farm sizes in each farm-size class for Machakos and Lower Embu.[3]

Broadly speaking, farms in Machakos are still relatively larger than those in lower Embu.

Note that already nearly 50 per cent of the farms in Machakos average 1.30–3.24 hectares in size, and the trend is definitely towards even smaller farms because of the rapidly rising rural population. Thus, in a few years' time, the situation in Machakos is likely to be very similar to that existing today in lower Embu. The table gives further emphasis to the special small-farm problem in Kathera, where the sampled 145 farms averaged only 2.10 hectares each.

In Kitui, on the basis of the information that Kawelu Sublocation is 35 km² in size and Kibiuni 240 km² (1979 Kenya Population Census), and applying the number of households we enumerated in each area during the presurvey (Table I), gross land-holding per household was estimated at 8.43 hectares in Kawelu and 37.7 hectares in Kibiuni.

Land quality

Samples of farmers in the three study areas were asked to name land- and soil-related factors which they believed limited the productivity of

3. It was not possible to calculate sizes for Kitui.

TABLE II—AVERAGE SIZES OF SURVEYED FARMS

Farm-size class (ha)	Mean	Standard deviation
(a) Machakos		
0.1 – 2.0	1.30	0.50
2.1 – 5.0	3.24	0.89
5.1 – 10.0	7.54	1.73
10.1 +	17.80	6.23
All farms	7.47	7.27

(b) Lower Embu

	Kathera		Kamarandi	
	Mean	S.D.	Mean	S.D.
0.1 – 1.0	0.78	0.23	0.70	0.24
1.1 – 2.0	1.57	0.29	1.76	0.35
2.1 – 3.0	2.52	0.26	2.88	0.51
3.1 +	5.20	1.90	11.74	7.53
All farms	2.10	1.91	8.65	7.64

their farms. Their responses are shown in Table III.

Most of these factors are of course interrelated; for example, soil erosion leads to soil infertility, cultivation of steep slopes leads to soil erosion, soil erosion exposes otherwise subsurface stones and rocks, and so on. Nevertheless, the factor mentioned by a consistently high percentage of farmers in all the areas is soil erosion. This is followed by soil infertility and sand/rocks/stones. Steep slopes are a special problem in lower Embu, particularly in Kathera. These responses tally very well with our own observations on the state of farmlands in these areas. There should be little doubt that soil conservation programmes ought to be given a high priority in semi-arid eastern Kenya.

2. *Farm labour*

Farm family composition by age and sex in the three study areas is shown in Table IV.

Taking the age group 16–60 years as the eco-

TABLE III—FACTORS LIMITING LAND PRODUCTIVITY IN SEMI-ARID EASTERN KENYA

	% Farmers mentioning				
	Machakos	Embu		Kitui	
Factor		Kathera	Kamarandi	Kawelu	Kibiuni
Soil erosion	61	53	54	70	66
General infertility	41	38	75	47	53
Sand/rocks/stones	52	50	24	35	23
Steep slopes	—	74	52	—	—
Waterlogging	12	—	—	—	3
Other	1	—	—	2	1

Table IV—FARM HOUSEHOLD COMPOSITION IN SEMI-ARID EASTERN KENYA

	0–10 yrs		11–15 yrs		16–60 yrs		Over 60 yrs		Total	
	M	F	M	F	M	F	M	F	M	F
Machakos	175	160	58	58	164	199	29	31	426	448
M + F	335		116		363		60		874	
% Total	38.3		13.3		41.5		6.9		100	
Mean household size									8.74	
Embu										
Kathera	164	176	96	60	186	213	31	19	377	468
M + F	340		156		399		50		945	
% Total	36.1		16.5		42.2		5.2		100	
Mean household size									6.5	
Kamarandi	157	150	94	73	176	228	30	23	457	474
M + F	307		167		404		53		931	
% Total	32.9		17.9		43.4		5.8		100	
Mean household size									6.4	
Kitui										
Kawelu	118	154	36	55	150	190	4	8	308	407
M + F	272		91		340		12		715	
% Total	38.0		12.7		47.5		1.8		100	
Mean household size									7.15	
Kibiuni	95	140	71	52	151	209	29	24	344	425
M + F	233		123		360		53		769	
% Total	30.3		16.0		46.8		6.9		100	
Mean household size									7.69	

nomically most active, it will be noted that it constitutes between 41.5 and 47.5 per cent of the farm population. Even though youths (11–15 years) and even children (0–10 years) may help in farm work, especially in livestock herding and bird scaring, their contribution to farm production is basically small not only because of their age but also because a majority attend school. Thus, all the three study areas exhibit rather high dependency ratios. A further aspect to note is the male/female ratio in different age groups. This is summarized below:

	0–10 yrs	11–15 yrs	16–60 yrs	60+ yrs
Machakos	1.90	1.00	0.82	0.93
Embu: Kathera	0.93	1.60	0.87	1.63
Kamarandi	1.05	1.30	0.77	1.30
Kitui: Kawelu	0.77	0.65	0.79	0.50
Kibiuni	0.66	1.36	0.72	1.21

The male/female ratio is consistently lowest in the age group 16–60 years, the economically most active group, reflecting, most likely, a higher rate of male out-migration in search of wage employment to augment farm incomes. It means that the rural labour force is dominated by

women. Closely related to this point is the percentage of farms which were being managed by women. This was found to be as follows:

	% Farms managed by women
Machakos	47
Embu: Kathera	23
Kamarandi	28
Kitui: Kawelu	45
Kibiuni	41

Thus almost one-quarter to one-half of the farms in semi-arid eastern Kenya are managed by women. This fact should always be borne in mind when designing agricultural extension programmes, especially farmer training courses, which tend to favour male farmers.

Farmer education

In the main, farmers in semi-arid eastern Kenya have had little or no formal education, as indicated in Table V.

TABLE V—FARMER EDUCATION IN SEMI-ARID EASTERN KENYA

	Number with some schooling	%	Number without schooling	%	Average yrs schooling
Machakos	45	45	55	55	5.1
Embu: Kathera	78	54	67	46	3.0
Kamarandi	74	51	71	49	4.0
Kitui: Kawelu	30	30	70	70	5.1
Kibiuni	44	44	56	56	3.5

Quite significant numbers have no formal education, and even those who went to school received only very limited exposure. Kitui farmers are the least exposed to formal schooling, followed by Machakos farmers. These statistics have important implications for effective agricultural extension and research approaches.

Hired labour

In all the three study areas, the main source of farm labour is the farm family itself. On average, only 10—20 per cent of the sample farmers reported hiring paid labour, mainly for weeding.

3. *Farming implements*

Probably the greatest variation in the farming systems of semi-arid eastern Kenya occurs in the possession and use of farming implements. Table VI indicates possession of common farm implements in the three areas studied.

Starting with the ox-plough, it is noted that the majority of Machakos farmers, 78 per cent, possess this important implement. At the other extreme are the Embu farmers, whose use of the plough is virtually nil; they rely overwhelmingly on simple hand tools. Somewhere in between are Kitui farmers, one-third of whom possess the implement. Thus, on the basis of this implement alone one could characterize the three farming systems as: an oxenized system (Machakos), a semi-oxenized system (southern Kitui), and a hand-tool system (lower Embu). Non-use of the plough in lower Embu is explained partly by an adverse physical environment (Kathera) and partly perhaps by sociocultural factors. The ox-cart, a potentially very important farm implement, is owned by only 26 per cent of farmers in Machakos and is practically non-existent in the other two areas. Possession of sprayers and wheelbarrows is negligible in all the three areas, despite, as will be shown later, farmers' serious concern about crop pests and farmyard-manure transportation.

4. *Livestock*

Cattle, goats, sheep, chickens and to a much lesser extent, donkeys are the livestock commonly found on farms. The extent of ownership is indicated in Table VII.

Goats are the most widely kept animals, followed by cattle and sheep, Cattle ownership is more widespread in Machakos than in the other

TABLE VI—POSSESSION OF VARIOUS FARMING IMPLEMENTS

	% Farmers possessing				
	Machakos	Kitui		Embu	
Implement		Kawelu	Kibiuni	Kathera	Kamarandi
Ox-plough	78	34	32	0	16
Ox-cart	26	2	2	0	0
Wheelbarrow	7	13	8	1	0
Sprayer	10	0	2	0	4
At least one hoe[1]	96	97	100	59	71
At least one digging panga[2]	—	—	—	70	74

1, 2. A hoe is a wide-bladed metal implement fixed to a wooden handle at right angles, whereas a digging *panga* is a pointed piece of metal fixed to a wooden handle at 180 degress. The digging panga here is different from the ordinary cutting panga (machete).

TABLE VII—LIVESTOCK OWNERSHIP IN SEMI-ARID EASTERN KENYA

	% Farmers owning				
	Machakos	Embu		Kitui	
Livestock type		Kathera	Kamarandi	Kawelu	Kibiuni
Cattle	80	54	63	54	41
Goats	82	74	68	71	65
Sheep	49	21	43	53	47
Donkeys	—	—	—	19	28

two areas. The donkey emerges as an important means of transport (water and produce haulage) in Kitui. Thus, typically, farms in semi-arid eastern Kenya are mixed farms, raising both crops and livestock. However, as will be shown later, the degree of complementarity between these two farm subsectors varies significantly.

Average herds/flocks per farm household are shown in Table VIII. Average herd and flock sizes are largest in Kitui, followed by Machakos, with lower Embu taking the third position. This variation is most likely due to differences in grazing-land availability in the three areas.

The main purposes of keeping livestock in these areas, as has been reported elsewhere (Rukandema *et al.*, 1981, 1983a, 1983b), are cash (whenever the need arises) and milk (especially from cattle and to a lesser extent from goats).

Use of farm resources

1. *Land use*

Crop and livestock production are the two primary uses of farmland in all the three areas, while secondary uses include production of fuel wood and building materials. The amount of farm land put under crops per season is shown in Table IX.

The basic determinants of cultivated hectarage per farm family are land availability and source of farm power (animal or human). These two factors are particularly limiting in lower Embu. In

TABLE VIII—HERD AND FLOCK SIZES IN SEMI-ARID EASTERN KENYA

	Average number per owning household				
	Machakos	Embu		Kitui	
Livestock type		Kathera	Kamarandi	Kawelu	Kibiuni
Cattle	7	4	4	11	12
Goats	10	8	9	11	10
Sheep	3	1	2	7	4

TABLE IX—CULTIVATED HECTARAGES PER SEASON IN THE THREE STUDY AREAS

	Machakos	Embu		Kitui	
Farm-size class[1]		Kathera	Kamarandi	Kawelu	Kibiuni
1	1.02	0.48	0.55	1.96	1.85
2	1.62	0.77	1.04	3.22	2.47
3	1.92	0.91	1.18	3.38	3.13
4	3.24	0.88	1.36	—	—
All farms	1.05	0.76	1.01	2.85	2.48

1. See Table I for class specifications.

Kathera the hand-tool technology interacts with small farms to limit cultivated areas to under 1 hectare. In Kamarandi, where farms are relatively larger, especially in the fourth farms class, the hand-tool technology sets the ceiling for cultivated areas at around 1 hectare. The situation is quite different in Machakos, where farms are still relatively larger and where the use of ox-ploughs is widespread. In the first three farm classes cultivated hectarage is limited by the need to leave a portion of the farm for livestock grazing. In the fourth class, where farms average nearly 18 hectares (Table II), the main limiting factor to expanded crop hectarage is the amount of labour available for weeding, as this operation is mainly done by hand. As for Kitui, recalling the rough method used for classifying farms, the picture is broadly similar to that of Machakos. Relatively large farms and limited use of the plough result in an overall cultivated area of about 2.5–3 hectares. The conclusion to be drawn from these comparisons is that if land is not limiting, a hand-tool technology limits the cultivated area per family to about 1 hectare, while the use of animal draft power, mainly for land preparation, raises the cultivated hectarage to about 3 hectares, at which point labour for weeding becomes limiting.

Crops

The range of crops, grown almost entirely in various mixtures, is shown for the three study areas in Table X.

The very range of crops and the relative importance of drought-sensitive crops such as beans in a particular farming system are a reflection of relatively favourable climatic conditions. On this basis, Machakos ranks first, followed by Kawelu, Kibiuni, Kathera, and lastly Kamarandi. The universal presence of maize to the same degree in all systems (except in Kamarandi) is due to a relatively recent shift in consumer tastes in favour of this crop rather than to its environmental adaptability. In fact, its failure rate is very high in all the systems studied. However, note that while sorghum and bulrush millet have largely disappeared from Machakos (very important crops early in this century), they are

TABLE X—CROPS OF SEMI-ARID EASTERN KENYA

	% Farmers growing				
	Machakos	Embu		Kitui	
Crop		Kathera	Kamarandi	Kawelu	Kibiuni
Maize	100	90	23	100	100
Sorghum	11	56	92	84	87
Bulrush millet	1	70	94	32	84
Finger millet	22	4	—	28	10
Beans	64	31	1	62	39
Cowpeas	91	83	85	100	100
Pigeonpeas	100	39	2	97	98
Green grams	5	85	85	69	66
Cotton	75	34	6	25	12
Cassava	74	30	1	80	42
Sweet potatoes	37	24	—	47	13
Irish potatoes	2	—	—	—	—
Sunflower	9	—	—	8	3
Bananas	3	35	—	2	8
Pawpaws	24	14	3	29	66
Mangoes	33	14	3	17	57
Gourds	63	68	24	99	71
Citrus	—	—	—	3	—
Lablab beans	2	—	—	12	4
Castor	1	—	—	68	86
Tomatoes	7	—	—	15	—
Tobacco	2	—	—	—	—

important cereals in lower Embu and Kitui.

With regard to pulses, the most important seems to be the cowpea, which is grown by almost every farmer in all the three areas. The other pulses exhibit marked variations across the different farming systems. Pigeonpeas are very important in Machakos and Kitui but relatively unimportant in lower Embu. Similarly, beans are quite important in Machakos and Kitui (Kawelu) but much less so in lower Embu and lower Kitui (Kibiuni). Green grams, which are important cash earners in Embu and Kitui, are virtually not grown in Machakos.

The remainder of the food crops in Table X are minor crops in the sense that they either occupy tiny plots, usually around the homestead, or else are found scattered randomly among the major crops. Note the various fruit trees which, though low yielders at present, suggest a potential for horticulural development.

Livestock grazing

Farmland not under crops is generally given over to livestock grazing. However, there is an important variation in grazing practices between Machakos on the one hand and Embu and Kitui on the other. In Machakos, 81 per cent of livestock owners reported that they graze their animals exclusively on their own farms, having no access to neighbours' farms or other areas. In contrast, communal grazing is the normal practice in lower Embu and Kitui; livestock owners have unrestricted access to one another's grazing land. The implication of these two grazing systems is that animal/pasture improvement programmes will stand a better chance of success in Machakos than in the other areas, where farmers have no control over their grazing land.

Crop and livestock interactions

In an ideal mixed-farming system, livestock and crops are highly interdependent for their mutual benefit and for maximum farm production. Although this ideal situation does not exist in any of the farming systems studied, there are varying degrees of complementarity in the

systems. Table XI summarizes the extent of crop/livestock complementarity in semi-arid eastern Kenya.

The degree of complementarity is highest in Machakos and lowest in lower Embu, with southern Kitui occupying an intermediate position. Put another way, livestock and crops are managed almost separately in lower Embu, semi-separately in southern Kitui, and quite closely in Machakos. The limited use of animal manure is due largely to an absence of carts, lack of knowledge of its usefulness, and limited quantities of the input in some parts (Rukandema *et al.*, 1983 a and b).

TABLE XI—COMPLEMENTARITY BETWEEN CROPS AND LIVESTOCK IN SEMI-ARID EASTERN KENYA

	% Farmers reporting				
	Machakos	Embu		Kitui	
		Kathera	Kamarandi	Kawelu	Kibiuni
Owning ploughs/oxen	78	0	16	34	32
Applying manure	68	14	6	25	13
Feeding crop residues	92	18	3	10	10

2. *Labour Use*

Crop production

The main crop-production operations which demand significant amounts of labour in the study areas are land preparation and planting, weeding, bird scaring (Embu and Kitui) and harvesting. The relative labour requirements of these operations in a given season are summarized in Table XII.

In Machakos and southern Kitui, the operation requiring the most labour is weeding. But in the sorghum/millet-dominated system of lower Embu, bird scaring becomes the most labour-consuming task. This activity is important also in southern Kitui, where sorghum and millet are grown on a significant scale, but it is absent in Machakos, where these cereals are not produced (Table X). Weeding is still quite labour-demanding in the sorghum/millet-dominated lower Embu system, taking the second place after bird

TABLE XII—RELATIVE LABOUR REQUIREMENTS OF VARIOUS CROP PRODUCTION OPERATIONS

	Per cent of total labour inputs				
	Machakos	Embu		Kitui	
Operation		Kathera	Kamarandi	Kawelu	Kibiuni
Land prep./planting	23.6	18.9	16.3	15.3	12.0
Weeding	48.8	20.5	20.3	42.9	32.1
Bird scaring	—	48.6	50.1	18.7	26.7
Harvesting	20.9	12.0	13.3	23.1	29.2
Other (e.g. manuring)	6.7	—	—	—	—
Total	100.0	100.0	100.0	100.0	100.0

scaring. Differences in labour requirements for land preparation and planting are basically a function of local practice as well as of the nature of soils. In the hand-tool system of lower Embu and the semi-oxenized system of southern Kitui, land preparation is done lightly (mainly trash clearing), followed by broadcasting of seed which is then covered superficially using hand-tools. In Machakos, however, land preparation and planting entail deep ploughing of fields with an ox-plough and placing the seed in the furrow behind the plough. The seed is then covered by the plough on the return run. Widespread soil capping makes ox-ploughing quite arduous, a situation which is largely avoided by shallow iand preparation in the hand-tool farming systems. Harvesting labour is a function of crops grown and their yield levels, the latter in turn depending mainly on the nature of the season when the data were collected.

An important aspect which needs emphasizing, particularly in the sorghum/millet-dominated systems, relates to the degree of competition for family labour between different farming operations. It may easily be falsely assumed that land preparation, planting, weeding, bird scaring and harvesting are performed at different times in a season and that therefore they do not compete for the available family labour. That land preparation, planting and weeding do overlap in peasant agriculture because of the common practice of staggering these operations over time is now a well documented fact. In addition, where birds are an important hazard to crop production, bird scaring imposes an extra strain on the available family labour. Bird scaring requires undivided attention daily from dawn to dusk, right from the time when the affected crop reaches a certain maturity stage to its harvest, a period which may stretch over three months or more. But during this time other crops (or the same crop on different plots) need to be weeded or even harvested. An absence of even only a few minutes can lead to severe crop loss to birds. Clearly, in bird-prone cropping systems competition for family labour assumes greater intensity, resulting in a loss in potential production. It is also worth noting that bird scaring takes place largely during the months when schools in Kenya are in session (January/February; May/June/July), and when children are therefore not available to help.

Animal production

Since significant numbers of farm households in all the study areas keep animals, livestock labour requirements, especially for herding and watering, are an added and relatively fixed demand on the available family labour resources. During the dry season, animals in some locations must be driven tens of kilometres to watering places.

3. *Use of modern purchased inputs*

The extent to which farmers in the various farming systems use purchased, yield-increasing modern inputs is indicated in Table XIII.

In lower Embu and southern Kitui, the use of purchased *production* inputs is minimal. Machakos farmers are on a slightly higher level, with 8 per cent using chemical fertilizers, 31 per cent purchasing Katumani maize seed seasonally, and nearly 15 per cent applying field pesticides. On

TABLE XIII—USE OF MODERN PURCHASED INPUTS IN SEMI-ARID EASTERN KENYA

	% Farmers using				
	Machakos	Embu		Kitui	
Inputs		Kathera	Kamarandi	Kawelu	Kibiuni
Chemical fertilizers	8	2	1.4	0	0
Katumani maize seed[a]	31	2.8	4.1	7	1
Field pesticides[b]	14.7	0	0	0	0
Storage pesticides	21.3	44.4	20.5	13	10.5

a. Those buying Katumani Composite B maize seed seasonally.
b. Those applying pesticides on food crops only, i.e. ignoring cotton.

the other hand, slightly higher percentages of farmers in all the study areas apply storage pesticides.

The overall picture is that of traditional farming systems dependent on family labour and land, with a minimum of improved technology. Reasons given by farmers for not using various purchased inputs are reported elsewhere (Rukandema *et al.*, 1983 a and b).

Farming hazards

As is generally well known, the greatest farming hazard in semi-arid eastern Kenya is limited, unreliable and erratic rainfall, which leads to highly variable farm-production levels. The second most important farming hazard, perhaps generally less appreciated, is the pest problem. This includes insects, birds, rodents and wild animals, probably in that order of importance. Farmers' views about the seriousness of the insect attacks on their major food crops are indicated in Table XIV.

With respect to field insect pests, and excepting millet, a large majority of farmers in each study area are of the view that insect pests pose a serious problem for their major food crops. The same holds true for storage pests, although the picture here varies somewhat. The low figures for Kitui could be a reflection of, more than anything else, low production levels which do not last long in stores. Given this high level of concern about the problem, what do farmers do to minimize its effects? Their responses are shown in Table XV.

TABLE XIV—FARMERS' VIEWS ON THE INSECT PEST PROBLEM

	% Farmers reporting problem to be serious				
	Machakos	Embu		Kitui	
Crop		Kathera	Kamarandi	Kawelu	Kibiuni
a. *Field insects*					
Maize	64	90	91	79	79
Sorghum	NA	84	74	73	69
Millet	NA	47	62	42	26
Cowpeas	74	88	85	96	97
Pigeonpeas	68	100	NA	85	85
b. *Storage insects*					
Maize	57	95	85	82	67
Sorghum	NA	91	90	72	67
Millet	NA	32	57	26	37
Cowpeas	38	97	89	42	27
Pigeonpeas	59	100	NA	61	51

NA = not applicable.

The contrast between the two sections of the table is quite remarkable. With the slight exception of Machakos, farmers in these areas do not protect their crops at all against field insect pests. In contrast, significant numbers do attempt to protect harvested crops, using either purchased chemicals or ashes. Asked why they do not protect their crops against insects in the field, farmers responded as shown in Table XVI. Clearly, the most important reason is lack of information on how to deal with the pest problem. However, although the responses suggest that lack of cash and non-availability of chemicals are minor factors at present, these would certainly become very important once the information constraint had been removed.

TABLE XV—FARMERS' ACTION TO MINIMIZE INSECT PEST DAMAGE

	% Farmers carrying out action				
	Machakos	Embu		Kitui	
Action		Kathera	Kamarandi	Kawelu	Kibiuni
a. *Field insects*					
Do nothing	80.3	100	100	100	100
Apply pesticides	14.7	0	0	0	0
Apply ash	5	0	0	0	0
b. *Storage insects*					
Do nothing	14.4	38.8	51.8	60.3	65.5
Apply pesticides	21.3	44.4	20.5	13	10.5
Apply ash	64.3	16.8	27.7	26.7	24

TABLE XVI—FARMERS' REASONS FOR NOT PROTECTING THEIR FOOD CROPS IN FIELDS

	% Farmers reporting				
	Machakos	Embu		Kitui	
Reason		Kathera	Kamarandi	Kawelu	Kibiuni
No knowledge of what to do	91	98	99	75	90
Lack of cash	3.7	1	1	10	5
Chemicals not available	0	0	0	3	0
Damage little	4	0	0	12	15
Other	1.3	1	0	0	0
	100	100	100	100	100

THE FARM/HOUSEHOLD ECONOMY

1. *The food economy*

As a general rule, farm households in semi-arid eastern Kenya do not produce enough food to carry them through the year. At one time or another during the year, they must enter the market to buy some of the foods they themselves produce. The low levels of production are a function of low per-hectare yields and limited cropped hectarage. Table XVII shows some of the food crops commonly purchased by farm families during any given year.

By far the most commonly purchased commodity is maize, reflecting its high ranking by consumers (as elsewhere in Kenya) as well as its high rate of failure in semi-arid eastern Kenya. Beans come second, most likely for the same reasons, followed in the third place by cowpeas. Of more significance, however, is the *timing* of purchases during the year. Table XVIII shows monthly food buying by farm families in the study areas.

Food shortages appear to be most serious during the period September-January in all areas. This is the so-called "hungry period" It should be noted that the short-rains crops are planted during October-November and harvested during January-February, while the long-rains

TABLE XVII—FOOD PURCHASES BY FARM FAMILIES

	% Farmers families purchasing				
	Machakos	Embu		Kitui	
Commodity		Kathera	Kamarandi	Kawelu	Kibiuni
Maize	100	96.7	66.4	81	62
Beans	39	61.7	37.8	20	2
Cowpeas	39	61.4	26.9	27	12
Pigeonpeas	24	—	—	27	11
Sorghum	—	2.5	6.7	33	—
Millet	—	1.7	31.1	18	6
Other	15	4.2	1.7	—	—

TABLE XVIII—MONTHLY FOOD PURCHASING PATTERNS IN SEMI-ARID EASTERN KENYA

	% Farm families reporting buying food				
	Machakos	Embu		Kitui	
Month		Kathera	Kamarandi	Kawelu	Kibiuni
January	23	46	28	23	28
February	15	17	19	1	9
March	8	8	18	3	4
April	8	3	18	5	3
May	21	2	17	3	1
June	13	5	13	—	3
July	14	9	8	3	5
August	20	12	17	55	12
September	33	47	67	29	28
October	36	29	70	40	62
November	42	52	69	45	69
December	44	66	51	43	63

crops are planted during March-April and harvested during July-August. Thus the hungry period coincides with a very busy agricultural season when land preparation, planting and weeding are being performed. In other words, some of the most energy-demanding tasks are performed when energy levels are lowest, people are more prone to sickness and other health hazards, and some family members must of necessity take time off to look for food to augment the low family food resources. There can be little doubt that seasonal food shortages are an important constraint on increased agricultural production in semi-arid eastern Kenya.

2. *The farm economy*

In interpreting and comparing farm incomes in the three farming systems studied, cognizance must be taken of the different seasons when the various surveys were carried out, as well as of the real and general error problem, which is very common in estimating farm incomes, more particularly in a semi-subsistence agriculture. Partly for this reason and partly for ease of presentation, income estimates presented in Table XIX are averages for the areas studied and no attempt is made to compare different farm-size classes.

TABLE XIX—LEVELS, STRUCTURE AND SOURCES OF ANNUAL FARM AND FAMILY INCOMES IN SEMI-ARID EASTERN KENYA

	Machakos	Embu		Kitui	
Income component		Kathera	Kamarandi	Kawelu	Kibiuni
Mean gross farm income (KSh.)	2,940	1,810	1,505	2,640	2,535
% Crops	70	61	35	77	87
% Livestock	30	39	45	23	13
% Subsistence	71	78	76	88	85
Mean off-farm income	2,368	704	676	3,261	2,308
Mean family income	5,308	2,514	2,181	5,901	4,843
Per capita	590	419	363	843	605

Although admittedly these estimates may contain large error margins, the overall picture they reveal is one of very poor farm families. This is particuarly indicated by the per capita incomes, which range between KSh. 363 and 843 ($US 27—62). In relative terms, lower Embu seems to be at the bottom of the scale. Finally, and not surprisingly, farming in semi-arid eastern Kenya is typically subsistence in nature, with more than 70 per cent of farm output retained for domestic consumption.

SUMMARY AND CONCLUSION

The major objective of this paper was to attempt to decribe as fully as possible the various farming systems found in the semi-arid parts of Kenya's Eastern Province. The data presented were derived from three farm-management surveys conducted in lowland Machakos, lower Embu and southern Kitui.

It has been shown that there is a high degree of variability in the quantity of resources, especially land and capital, available to farm families. The common denominator in respect of farm resources is that they are of poor quality and, consequently, low productivity. Farms are typically mixed farms, but only nominally, as crops and livestock tend to be managed separately. But here also there is a significant degree of variation across the three systems, with Machakos showing the highest degree of complementarity and lower Embu the lowest. Livestock grazing systems also vary, being communal in lower Embu and Kitui, but individualized in Machakos.

While sorghum and millet have virtually disappeared from the Machakos farming system, they are extremely important crops in the other two systems. As a consequence of the presence of these crops, birds are a big problem to farmers in these two areas, and a high proportion of farmers' time is spent guarding the crops. Another important farming hazard, besides the well known unreliable rainfall, is the prevalence of insect pests. However, despite the fact that most farmers are concerned about crop losses to insects, very little is done to protect crops, especially in fields, basically because people lack information on how to deal with the problem.

The application of yield-increasing, purchased inputs in all the systems is minimal to nil, with labour and land being the dominant production inputs.

Farm production in all the three systems is subsistence oriented, while in general all the agrarian economies are characterized by low production and productivity, seasonal food shortages, and extremely low living standards.

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THE ECONOMICS OF FERTILIZER USE IN KATUMANI MAIZE PRODUCTION: AN APPLICATION OF RESPONSE-FUNCTION ANALYSIS (ABSTRACT)

J. K. Mavua[1]

Production of any crop depends upon the level of utilization of all productive agents. The productivity of each agent depends on the level of utilization of other productive agents, some of which cannot be varied at will in the field.

It is now recognized by both agronomists and economists that recommendations to farmers should be based on data and principles drawn from both sciences and taking into account the farmers' goals and farming situations. Agronomic data must fit farmers' agronomic conditions and the economic evaluation be consistent with their goals.

Machakos District is an area of low-to-medium potential, with 500–800 mm of rainfall annually, divided between two seasons. Only short-period-maturing drought-resistant or tolerant crops can be grown to utilize each season's rainfall. The area is subject to frequent droughts and hence famine due to crop failure. Maize development at Katumani has been an effort to alleviate this problem.

This study explored the economic response of Katumani maize to the application of the current fertilizer recommendation of 150 kg/ha of 20:20:0 compound fertilizer. The main aim was to illustrate the methodology of applying economic criteria to experimental data in order to draw conclusions that are relevant to forming advice for farmers.

An experiment using five treatment levels was carried out in the long rains of 1978 at Katumani and Kampi ya Mawe and the results were subjected to response function analysis, that is, using a production function of quadratic form. A revenue function was used to estimate different profit-maximizing inputs of fertilizer for different prices of maize and fertilizer. The effect of labour input associated with fertilizer use was also analysed.

A modified value function incorporating the labour function was used to arrive at the optimum input level of fertilizer.

The results of the economic analysis indicate how sensitive input recommendations are to changes in input and output prices. Advice to farmers should not only be adjusted to variations in agro-ecological conditions but also to changes in market conditions.

The results show clearly that the identification of an economic optimum for input use is quite different from the identification of a yield maximum input level. The analysis indicates the need to take into account farmers' circumstances when arriving at various recommendations for them.

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ON-FARM RESEARCH AT KATUMANI: THE PRE-EXTENSION TRIALS EXPERIENCE (WITH SPECIAL REFERENCE TO SEMI-ARID AREAS OF EASTERN PROVINCE OF KENYA)

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PRE-EXTENSION TRIALS

Definition

Pre-extension trials is a term adopted a Katumani to refer to trials conducted on a farmer's field with the farmer as the main experimenter, in order to test the performance, feasibility and acceptance of improved technology, before it is released to other farmers.

Objectives

The main objective of the pre-extension trials reported on here was to test the improved technology on a large scale and over wider agro-ecological zones and under farmers' actual conditions in order to generate information on its performance, adoption rate, and associated problems requiring further research work.

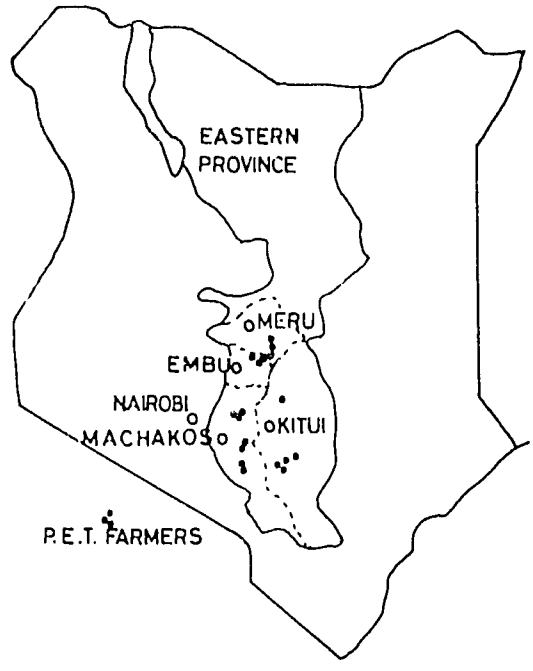
The second objective was to assess the actual yield levels of the crops grown in the target area, under both traditional and improved technology, in order to be able to define the relative advantages.

It was also assumed that, by working together with the extension agents, it would be possible to bridge the gap that exists between researchers and extension workers. To help towards this objective, technical assistants covering the pre-extension farmers were trained in aspects of research at Katumani, while research scientists have focused more on the farmers' problems by visiting them.

METHODOLOGY

Selection of sites and farmers

Sites for pre-extension farmers were selected in the four districts covered by the project, namely Machakos, Kitui, and the lower parts of Embu and Meru. These sites are shown in Map 1. At the start of the pre-extension trials 24 farmers were selected, 8 each in Machakos and Kitui, and 4 each in Embu and Meru. After the first season, 8 farmers were dropped because they were either not willing to participate or had other more absorbing off-farm activities which conflicted with the pre-extension trials.



MAP 1. Location of pre-extension trials

1, 2. FAO Agronomists, Dryland Farming Research and Development Project
3. Farming Systems Agronomist, National Dryland Farming Research Station, Katumani

The criteria adopted for selecting the farmers were as follows:

—the person selected should be a full-time, average farmer;
—he should have both crops and livestock;
—he should be willing to participate in this research activity by providing labour and other inputs, be able to accept and implement advice given, and be willing and able to collect simple data and share his experience with other farmers;
—his farm should be located near a road for easy access to enable frequent visits to be made by both research and extension workers.

These criteria were based on the findings of farm surveys and pre-surveys conducted in Machakos District (Rukandema *et al.*, 1981). In Machakos District the farmers were selected from among those included in farm surveys and are representative of different farmer clusters. In the other Districts, where results of farm surveys were not available, farmers were selected on advice given by the extension agents.

Some of the farmers initially chosen proved unable to fit in with the laid-down criteria and they were therefore dropped and replaced with others, when farm survey information became available. At present there are 18 participating farmers, 7 in Machakos, 5 in Kitui, 3 in Embu, and 3 in Meru.

The recommended technology

The recommended technology is of a dynamic kind; it has been modified and improved, as new findings and feedback from farmers became available, to suit different farm practices and individual farmers' requirements.

The current recommended farm practices are as follows:

—early land preparation (immediately after harvesting);
—dry or early planting;
—use of good-quality seed of improved varieties;
—mechanized weeding using improved ox-drawn implements;
—control of pests in field and store (including seed dressing);
—improvement of soil fertility by use of farmyard manure or 20 kg N and 20 kg P_2O_5/ha;
—soil- and water-conservation measures;
—intercrop maize with pulses when appropriate;
—selection of crops and adjustment of plant populations according to soil fertility and rainfall (maize—about 40,000 plants/ha in pure stand; beans—about 100,000 plants/ha in pure stand);
—introduction of fodder (Bana and Bajra grass) and improvement of natural pasture.[1]

However, as will appear in Table IV (rate of adoption), use of farmyard manure as well as fertilizer and chemical pest control have been implemented by only a few of the co-operating farmers. This was due to shortage of labour and lack of transport in the case of farmyard manure, and to lack of cash in the case of chemicals and fertilizers.

The roles of farmers, researchers and extension agents

In this type of trial, the farmer is the main experimenter and is responsible for the timely execution of the farm operations, providing labour and other inputs, and bearing all possible risks. He is free to decide whether to confine the improved technology to only one field or to adopt it in the whole farm. A small quantity of seed of new varieties not yet available on the market is the only input given. Researchers, on the other hand, are supposed to advise the farmers on improved technology and visit the farmers as often as possible, but particularly during germination, crop-establishment and grain-filling stages. The extension agents are supposed to convey the recommendations and make sure that they are followed. They are supposed to report back on specific problems, and on the impact of the technology on neighbouring farmers.

Data collected

The size of pre-extension trials is usually about 0.5 ha. Yield is assessed from random sample plots of 100 m². The main observations made are:

—rainfall in mm;
—planting date;
—germination percentage;
—plant population after emergence and before harvest;
—pest and disease incidence;
—labour requirements.

Besides these, data are collected on other qualitative parameters like method of land preparation, sowing, weed competition, and major limitations of the technology.

1. The livestock component will not be discussed here, since it has already been presented in a previous paper.

RESULTS

Rainfall data

Rainfall data recorded in the different PET sites indicate great variability among seasons (Table I). The long rains of 1981 and short rains of 1982, with 492 mm of rain on 26 days and 524 mm on 26 days respectively, were largely above average, while the short rains of 1981 and long rains of 1983 with 239 mm on 15 days and 192 mm on 8 days respectively were much below. According to our experience an average season is regarded as one receiving an amount ranging between 250 and 400 mm on 15 to 20 rainy days. Above 400 mm and below 250 mm are regarded as good and poor seasons respectively.

Yield assessment

The yield is assessed as explained above. There is great variation between the different seasons and farmers' conditions. The average yields achieved are shown in Table I. Table II shows the results from Machakos District and is used to give an indication of the expected yields of maize when intercropped with a pulse in a good, average, or poor season. In Table III the results obtained from the traditional technology are shown. The average yield increase due to the improved technology in Machakos is 40% for maize and 59% for pulses.

This yield increase obtained by farmers using the recommended technology, mainly based on simple husbandry changes and the adoption of the improved varieties, has been confirmed also for Kitui, Embu and Meru Districts (Bakhtri *et al.*, 1982–1983); however, wide variations still occur among farmers, mainly due to the different management levels.

Identification of problems

The very erratic and low rainfall, together with the general low level of organic matter and fertility of the soils, are the main problems that limit crop production in the area. The commonest problems observed as affecting production in farmers' fields have been grouped into four different categories; the percentage indicates the number of times the problem has been ranked as the most limiting factor, based on visual observation, for each farmer over four seasons.

—*Poor crop husbandry* (31%) includes improper practices like late or poor land preparation, late planting, wrong planting technique and/or seed rate, and poor weed control. These common problems are due to farmers' lack of knowledge and in some cases to the absence of effective extension services, particularly in areas with poor communication facilities. Moreover, farmers generally lack good tools and good-quality seed of improved varieties.

—*Soil problems leading to low field germination* (30%). The plant population in farmers' fields has been found to be usually much lower than that recommended (38,000 for maize pure stand; over 100,000 for beans pure stand). Very commonly this is due to poor soil structure; surface sealing and capping after dry-spells and waterlogging during heavy rains are common problems in soils which have been cropped for several seasons without the addition of organic matter. There is compaction and poor porosity, and consequently poor rooting and plant establishment. The use of farmyard manure together with the addition of more crop residues to the soil and proper tillage and soil management practices can improve the soil structure and the field germination rate.

—*Pest damage* (24%). This is a widespread problem which greatly reduces yields. Pest control is usually not practised because farmers lack knowledge of control measures, chemicals are not always available at village level, and there is a general lack of sprayers. Moreover, most chemicals require the use of water, which is often very scarce. The most prevalent pests in the field have been the following: pod-sucking bugs (*Acanthomia tomentosicollis*), pod borers (*Maruca testulalis* and *Heliothis armigera*), apion (*Apion soleatum*) and thrips (*Taemiothrips*) on cowpeas, pigeonpeas, and to a lesser extent on beans; aphids on cowpeas, and stalk borer (*Busseola fusca*) on maize. The use of DDT dust is known to the majority of the farmers. Chafer grubs (*Schizonycha* spp.) and cutworms (*Agrotis ipsilon*) are the main soil pests; although site specific, they are of serious concern for maize, sorghum and beans. Termites are a major problem in all crops. They attack standing plants in the field as well as crop harvest and crop residues. Rodents and birds can also cause severe losses (Kabir 1983).

—*Intensive soil erosion in cropped land* (15%). Due to lack of proper methods of soil and water conservation, soils are becoming shallow, rocky in some areas, and depleted of organic matter and nutrients. When terraces cannot be dug due to shortage of labour or lack of cash, other methods of soil and water management like ridging (using ox-drawn implements)

TABLE I—AVERAGE YIELDS (KG/HA) OF PRE-EXTENSION TRIAL PLOTS (ALL YIELDS REFER TO INTERCROP SITUATIONS)

	Long rains 1981	Short rains 1981/1982	Long rains 1982	Short rains 1982/1983	Long rains 1983	Average four seasons	
Rainfall	570 mm/ 27 days	245 mm/ 16 days	352 mm/ 16 days	517 mm/ 27 days	169 mm/ 7 days		M = maize (Katumani Composite B) P= pulses (cowpea, beans, green gram, pigeonpeas) S= sorghum var. IS 76
Machakos (7 farmers)	M 1,397 P 631	M (C)= 383 P 177	M 879 P 492	M 1,412 P 562	Crop failure for all seasonal crops. Pigeon peas and some cotton have been harvested.	M 1,016 P 466	
Rainfall	495 mm/ 27 days	229 mm/ 17 days	240 mm/ 16 days	410 mm/ 26 days	150 mm/ 7 days		
Kitui (5 farmers)	M 1,800 P 400	M 714 P 387	M 1,168 P 524	M 1,000 P 338	Crop failure for all seasonal crops. Pigeon peas have been harvested.	M 170 P 412	
Rainfall	501 mm/ 23 days (Ishiara)	243 mm/ 13 days	470 mm/ 20 days	644 mm/ 24 days	257 mm/ 10 days		MLT= Bulrush Millet Serere Composite II
Embu & Meru (6 farmers)	S 1,312 MLT 659	S 281 MLT 153	S 143 MLT 471 P 298	S pure stand MLT 152 pure stand 1,883	Crop failure for seasonal crops. Only cotton and pigeon peas have been harvested.	S 653 MLT 633	

TABLE II—EXPECTED CROP YIELDS UNDER IMPROVED TECHNOLOGY (kg/ha)*

	Good season (>400 mm)	Average season (250–400 mm)	Poor season (<250 mm)
Maize	1,370	880	390
Beans	808	456	106
Cowpeas	788	468	148
Pigeonpeas	615	438	167

*Average from PET results in lower parts of Machakos District only; yields refer to intercropping arrangement, i.e. maize plus one pulse. Only farmyard manure has been used to improve soil fertility.

TABLE III—PRESENT YIELD LEVEL (kg/ha)*

	Traditional technology		
	Good season	Average season	Poor season
Maize	977	627.5	278
Beans	319	180	42
Cowpeas	329	364	115
Pigeonpeas	438	312	186

*These are averages from different surveys in Machakos District before the pre-extension trial programme started. Intercropping arrangement as in Table II.

TABLE IV—RATE OF ADOPTION OF THE RECOMMENDED TECHNOLOGY

Component	Adoption on PET plot (%)	Adoption on the whole farm (%)
Early land preparation (immediately after harvest)	39	—
Early planting	78	50
Recommended interrow spacing	100	72
Right plant population	100	70
Use of manure	72	28
Use of fertilizer	22	11
Use of improved varieties	100	100
Field pest control	17	17
Weeding with animals	55	55
Using sweeps	15	15

following the contours, strip cropping, and grass strips should be developed.

Distribution of farmers according to different cropping systems and levels of technology

Three different cropping systems have been identified in the project area, mainly dependent on altitude and rainfall.

—A maize/bean system is predominant above 1,300 m altitude; this system is common in the upper Machakos and Kitui Districts, around Ishiara township, etc. Two co-operating farmers are well represented by this system;
—A maize/pigeonpea/cowpea system is found in areas between 900 and 1,300 m in altitude, in the lower Machakos and Kitui Districts. These are potentially sorghum-growing areas, but because of bird damage, availability of early-maturing Katumani maize, and change in food habits, farmers prefer growing maize, which is at present the dominant cereal. Pigeonpeas and cowpeas are the dominant pulses; beans are also grown, although the risk of failure is greater. Thirteen of the pre-extension trial farms are found in this group.
—A sorghum/bulrush millet system is practised in areas below 900 m, in lower Embu, lower Meru, and southern Mutomo. Cowpeas and green gram are the most common pulses. Three co-operating farmers are mainly sorghum/millet growers.

The co-operating farmers use different levels of technology. Four of them are advanced farmers who usually apply fertilizer or manure to food crops, weed using animals, and practise crop rotation on pure-stand fields. Three farmers are growing all crops in a haphazard mixture, using only hand labour and to some extent practising shifting cultivation within the farm (field rotation). The rest of the co-operating farmers are between these two categories; they use ox-ploughs for planting in rows and intercrop cereals with pulses; they weed mainly by hand and rarely apply manure, due to lack of transport.

Rate of adoption of the recommended technology

A farmer will adopt a new technology if it contributes to the achievement of his goals, mainly if it:

—provides a substantial yield increase;
—improves labour productivity;
—is easy and cheap to implement.

Our measure of the rate of adoption by farmers is based mainly on the extent of implementation within the same farm of the different components of the technology tested in the pre-extension plot. It was observed that farmers adopted components of the technology selectively, accepting those that met their goals, rather than the full package. This may be due to the fact that the technology has been assembled to suit a relatively large group of farmers representing different management levels and ecological zones in the project area, rather than aiming only at one local target group of farmers (Collinson 1983). Table IV shows the rate of adoption of some components of the recommended package.

Feedback and refinement of recommendations

Unsolved technical problems and recommendations rejected for any reason or which require refinement are incorporated as priorities in the research programmes. As a result of the pre-extension trials some programmes have been influenced or modified to focus on farmers' priorities. The following are a few examples of the feedback provided by the PET programme which has contributed to the refinement of the recommended technology.

—The multipurpose implement, which was found to be too heavy for the small-size oxen commonly found in the area, has been modified into a similar but lighter one. Unfortunately, 500 units of the heavy version were manufactured before being properly tested by the

farmers and are at present unsold.

—Pest damage to pulses having proved a major limiting factor, and farmers not being prepared to apply chemical pest-control measures, plant-improvement research work is currently emphasizing the identification of pest-tolerant varieties, mainly of pigeonpea and cowpeas.

—The agronomy programme is focusing on crop arrangement, intercropping, and manure application in order to find solutions which suit the real situations of the farmers. It also aims to suggest viable alternatives to the use of chemical fertilizers, which are still out of the reach of the majority of the small-scale subsistence farmers of the semi-arid areas.

—More attention has been devoted to the development of an ox-drawn ridger which can help in soil and water conservation and contribute to better crop establishment in difficult soils.

CONCLUSION

The pre-extension trials conducted for five consecutive seasons in the project target area have been a very efficient tool for gaining a deeper understanding of farmers' present practices, problems, and priorities. The eighteen farmers currently participating in the PET programme are representative of the project target area; they are found in different ecozones, and they represent various management levels.

Although the improved and appropriate technology was not actually available at the time when these trials were started, it appears that the strategy adopted at Katumani—to start working straight in the farmers' fields—has been beneficial. The following things have been achieved:

—Good relationships have been established with the participating farmers, which is important for the implementation of the whole-farm approach.

—Yield levels achieved by both the traditional and improved technology have been assessed. This forms the basis for modelling a future development strategy.

—The commonest problems and constraints have been identified, and this will facilitate the formulation of the appropriate technology. Impact points or components of the improved technology that have substantial effect on crop production have also been identified.

The nature of the trial, with the large size of the plots, clusters of farmers, and replicated seasons, warrants reliance on the data and information obtained; these data can be used confidently in planning future work. The assumption that the improved technology, if successfully implemented by the farmers in the pre-extension trial plot, may later on be adopted on the whole farm and also on neighbouring farms has been confirmed. For example, 50 per cent of the farmers were actually growing the improved varieties on the whole farm after the third season. These farmers have also reported that they have been giving or selling small quantities of improved-variety seeds to neighbouring farmers, who have also started adopting the same technology. Finally, this work on pre-extension trials has brought the research scientists and extension agents closer, thus bridging the gap that has always existed between the two. The close working link between the two will help in the formulation of an appropriate, sound, and acceptable technology for the semi-arid areas of Kenya.

SUMMARY

On-farm trials conducted for five consecutive seasons from 1980 to 1983 are introduced in the context of farming systems research at the Katumani National Dryland Farming Research Station.

Pre-extension trials started during the short rains of 1980 with 24 farmers selected within the project target area, which covers Machakos, Kitui and the lower areas of Embu and Meru Districts; at present seven farmers in Machakos, five in Kitui and three each in Embu and Meru are participating in the programme.

The objectives of the trials, the methodology used, and the technology tested are briefly discussed in the paper.

The main results include:

—yield assessment for the improved technology;
—identification of farmers' problems;
—distribution of farmers according to different cropping systems and level of technology;
—rate of adoption of the recommended technology;
—feedback and refinement of recommendations.

The positive outcome of the trials carried out by the farming systems group at Katumani is summarized in the conclusion. Three major achievements are identified:

—good working relationships have been established with the participating farmers, which

is important in view of the implementation of the next phase, the "whole-farm approach";
—reliable information has been produced on yield levels, farmers' problems, and impact points;
—a strategy to reduce the distance between research and farmers has been set up through better links with the extension service; this will help in the formulation of an appropriate, sound, and acceptable technology for the semi-arid areas of Kenya.

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TECHNICAL SESSION 7: REPORT ON DISCUSSION

Chairman (Dr M. P. Collinson: A recent notion in agricultural research is the farming-systems approach, which seeks to integrate all research disciplines. Through this approach an existing farming system is identified, delineated, and described, taking into account farmers' problems, constraints, priorities, and goals. Work at Katumani has endeavoured to generate appropriate technology and relevant research programmes for the farming community in the dry areas.

Mr J. M. Muasya: When the speaker listed the problems which farmer respondents mentioned, it was noted that the time spent drawing water was omitted. Could he comment on it?

Dr M. Rukandema: Yes, this problem was not envisaged outright.

Mr W. Makokha: Could you either give me a brief on what formula to use to arrive at the optimum quantities of various inputs—for example, pesticides in cotton, fertilizer in maize, beans, coffee, etc.—or give me a chart showing the approximate quantities of the same for various crops at the rate 20/2 per man day?

Mr J. Mavua: I had worked on maize response to fertilizer application and the labour used in planting, weeding, fertilizer application, and harvesting but formulae for the other crops can be worked out using the same function if the data are available.

Mr P. A. Omanga: Your tables showed how to predict the rate of fertilizer from the prices of fertilizer/kg and maize/kg. Since maize is the end product and its prices vary with production at the end of the season, how can you make predictions from it? Which maize prices were you using in your predictions?

Mr Mavua: The tables show a range of maize and fertilizer prices and all that is needed is to cross-check in the table in the appropriate columns.

Mr Makoha: Since you used data that reflect a true situation and a formula that is recommended for analysis of these data, don't you think this system of analysis is confusing and needs to be cautiously applied as it is likely to lead to recommendations that contradict other established recommendations?

Mr Mavua: This analysis was to illustrate how economic criteria can be superimposed on agronomic data to derive farmer recommendations, but one season's data are totally inadequate to make any recommendations. Incidentally, nothing is established, everything is subject to change.

Dr B. N. Majisu: Dowker observed in 1963* that farmers in the now Eastern Province tended to increase the acreages under sorghum/millets after experiencing a series of bad seasons when maize crop failed. Was this phenomenon observed during your surveys?

Dr. Rukandema: Although this did not come out in the surveys, it is true. This used to happen in Machakos when sorghum/millets were grown by many farmers. At present they are not, except in Meru, Kitui, and Lower Embu.

Dr F. H. C. Scott: Commenting on Dr Majisu's point: farmers have increased their interest in sorghum after the previous bad rains once a late onset of these rains is observed. Their cropping pattern is therefore seen to be open to adjustment in relation to recent rain-season performance and expectations of the next rains.

Dr P. Anandajayasikeram: At the time the concept of FSR was introduced only a few researchers had any experience in the methodology. But the majority of them used the terminology and lumped everything under FSR. This created confusion for national practioners. Now they are trying to sort out the confusion—FSR/R, FSR/E, etc. At this stage you are promoting another concept—FSD. What do you think this will do to the understanding gained by the national practioners and the implementation of the national programme?

Dr H. Kunert (FAO): FSD is not a methodology, it is an approach. While a few years ago emphasis was laid on integrated rural development, emphasis is now laid on farming-systems development through special programmes by USAID, FAO, and International Research.

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*Dowker, B. D. (1963). Sorghum and millet in Machakos District. *E. Afr. Agric. For. J.* 52—57.