APPROPRIATE TECHNOLOGIES FOR FARMERS IN SEMI-ARID WEST AFRICA

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APPROPRIATE TECHNOLOGIES FOR FARMERS IN SEMI-ARID WEST AFRICA

Editors: Herbert W. Ohm and Joseph G. Nagy

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*translated from French

FORWARD

Accelerating the rate of growth of a nation's economy is a matter of universal concern. Among the developing nations, it is of prime concern. In many such cases, agricultural development is the primary means of catalyzing general economic development and social progress. This appears to be true of West African nations as they struggle with semi-arid tropical environments, low resource productivity, rapid population growth and other endemic constraints to making agriculture the lead sector in national development.

The SAFGRAD/Purdue/Farming Systems Unit workshop on appropriate technologies for farmers in semi-arid West Africa was directed toward contributing to eventual amelioration of this concern. The workshop brought together leading African and expatriate scientists involved in systematic research on the technical, economic, social and policy constraints to agricultural development in the region. The scientific papers presented provide empirical information of explicit significance to increasing food production and farmer well-being. Workshop discussions, formal and informal, generated important insights relative to appropriate strategies for enhancing the role of scientific endeavors in accelerating agricultural development in the semi-arid regions of West Africa.

Purdue University is pleased to have had the opportunity during the past six years to collaborate, through SAFGRAD and USAID, with African and expatriate colleagues in farming systems research. It is grateful for the opportunity to have participated with FSSP, ICRISAT, IITA, IRAT, SAFGRAD and USAID in the organization and conduct of the workshop. It trusts that this volume of proceedings will be useful to all concerned with relaxing the constraints to accelerated agricultural development in West Africa.

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PREFACE

Research to increase agricultural production in the West Africa Semi-Arid Tropics (WASAT) has been greatly intensified at the national and international levels since the early 1970's. Because of the complexity of production constraints in the WASAT we have learned that production technologies which had proven effective in other areas of the world may not be appropriate in the WASAT. We have also learned that the farmer is an important part in the development of new technologies.

After nearly two decades of intensive agricultural research, at experiment stations and more recently on-farm, one can ask the questions: What technologies have been developed which are appropriate to the WASAT, and what are the promising research directions?

With these questions in mind, the research team of the Farming Systems Unit (FSU) of the Semi-Arid Food Grains Research and Development (SAFGRAD) project with encouragement from the national and international research community at Ouagadougou, provided leadership to oragnize a workshop. The workshop, Appropriate Technologies Semi-Arid West Africa, took place at Ouagadougou during 2 to 5 April, 1985.

The primary objective of the workshop was to assess agricultural technologies currently available in the region and focus on technology needs and new avenues of research. The workshop covered four main areas:

(1) soil and water management and soil fertility,
(2) plant improvement and crop associations,
(3) livestock and animal traction, and
(4) appropriate technologies and promising avenues of research.

The workshop was organized around a general summary paper in each area followed by case study papers. Each session was follwed by discussion groups and rapporteurs recorded the major highlights. The workshop ended with a general discussion after listening to the rapporteurs' summaries of each session. This volume includes the edited versions of the twenty-three papers presented at the workshop. We have added a general summary of the workshop papers and major points that were brought out in the discussions.

It was not possible during the 3 1/2 days of this workshop to deal with all the complex topics and issues of agricultural technology intervention in the WASAT. However, we believe that the topics covered and the papers that were presented add significantly to the information base in the WASAT. In particular, the general papers along with several of the case study papers can serve as a basis for future research direction in resolving some of the complex problems of the WASAT.

Workshops and workshop proceedings provide an important vehicle for researcher interaction and they provide an outlet for publication and dissemination of research findings. This is particularly true of regions like the WASAT where there are limited opportunities for publication of research results. This workshop was an opportunity for more than 60 scientists and agricultural administrators from national and international research institutions who are engaged in research in the WASAT to participate in an exchange of research information and extensive discussions of ideas.

We wish to acknowledge the members of the organizing committee (Drs. Taye Bezuneh, OUA/SAFGRAD; Peter Matlon, ICRISAT; Robert Nicou, IRAT; and Mario Rodriguez, IITA) for their generous and invaluable support. On behalf of the organizing committee, we express appreciation to workshop participants and to authors for their willingness to present papers to serve as a source of discussion. Thanks are extended to the chairpersons and rapporteurs for the plenary and discussion sessions who provided summaries from which information was taken for portions of the summary section of this volume. We express sincere appreciation to the U.S. Agency for International Development (USAID) for encouragement, funding support and co-operation throughout this activity from planning to publication of the proceedings. On behalf of African National participants we express sincere appreciation to the Farming Systems Support Project (FSSP) of the University of Florida for support of travel and subsistance costs. We sincerely appreciate the co-operation and logistical support of OUA/SAFGRAD Co-ordination Office. We acknowledge the staff of the Department of International Programs in Agriculture, Purdue University for logistical support throughout this workshop activity and for the publication of the workshop papers. We also acknowledge the organizational skills of Nell Diallo and Katy Ibrahim, who as a team contributed significantly to the success of the workshop.

Herbert W. Ohm and Joseph G. Nagy

SOIL TILLAGE AND WATER CONSERVATION IN SEMI-ARID WEST AFRICA

R. NICOU and C. CHARREAU[1]

The pedoclimatic conditions of the semi-arid West African zone are such that it is very difficult for annual crops to grow. The physical properties of the soil, in particular, impair crop root development.

In other respects, due to the extreme climatic irregularities, one of the first problems which the farmer needs to solve is that of providing water to his annual crops. As soils are very prone to degradation, infrequent but large and intense rains cause runoff and erosion. Thus, more than 50% of the rain water may be lost.

Agronomic research in many countries has, for a long time, striven to find solutions to these problems. It appeared that one of the means to succeed in so doing was to use good cropping techniques. Therefore, we are going to examine the major results obtained in soil tillage and water conservation in semi-arid West Africa.

MAJOR CLIMATE AND SOIL CHARACTERISTICS

The climate. The climate of the tropical zone of semi-arid West Africa is characterized by the strong contrast between a rainy season which lasts two to three months in the North and five to six months in the South between May and October; and a totally dry season.

Annual rainfall varies roughly between 200 and 1,300 mm; isohyets are irregularly parallel to the equator and rainfall shows a strong increase gradient from North to South. This gradient is more pronounced in western . negal than within the zone.

Because of the extreme irregularity of rainfall, the rainy season is often a succession of rainy periods and dry periods, the latter becoming more and more frequent northward. It is a fact that since 1966, a period of drought has prevailed all over this zone and that most isohyets have decreased by 200 mm (Dancette, 1977). The zone is under a very strong evaporative demand: annual potential evapotranspiration (PET) roughly ranges between 2200 mm in the North and 1600 mm in the South.

There are two other important characteristics in the physical properties of the soil:

(1) the absence of frost: temperatures rarely drop below 10. The phenomena of strong frost which are important in the northern countries are totally absent here;

(2) the very high intensity of rains and their erosive power. All calculation methods have demonstrated the very strong aggressivity of the climate throughout the zone. This aggressivity is the origin of the very strong hydric erosion that exists everywhere, especially in the South.

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1 Soil Physicist and Director of IRAT-CIRAD in Burkina Faso, Ouagadougou and Agro-Pedologist, Director of IRAT-CIRAD, Nogent du Marne, France.

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Other climatic factors are more favourable to crop production. In general, temperature is not a limiting factor for plant growth and solar radiation is high. The result is a high potential of production which stands in contrast with the present very low productivity.

The soils. Roughly speaking there are a number of soil units with respect to rainfed agriculture (Charreau, 1974). There are:

(1) sub-arid modal brown soils and red brown soils (CAMBORTHIDS) located between isohyets 200 and 500 mm. They develop mostly on aeolian sediments of the Quaternary and form a 200 km wide belt in the north of the zone,

(2) slightly leached tropical ferruginous soils (USTOPEPTS) which are mostly on the aeolian sediments under an annual rainfall ranging between 500 and 900 mm,

(3) leached ferruginous tropical soils (USTALFS). They are the most common in the zone. They are found on varied rock residus (granitogneiss, sandy and sandy-clayey rocks) and they have very differentiated profiles,

(4) poor and slightly unsaturated latosols (ALFIC EUTRUSTOX). They are not very common in the zone except in the south of Senegal and in the south-west of Burkina where they are associated with leached tropical ferruginous soils,

(5) vertisols and other complex associations with a montmorillonitic base. They are generally associated with materials of basic origin in Burkina,

(6) hydromorphic mineral soils (TROPAQUENTS, TROPAQUEPTS, etc.) are scattered in the zone. Some are used for rainfed agriculture but most of them form the major parts of the important alluvial plains of the main rivers; they are irrigated and temporarily flooded,

(7) lateritic cuirasses. The great extension of lateritic cuirasses (most of them being old) is one of the most common features of semi-arid West Africa. Most of them are located in the 500 and 900 mm isohyets.

Although the zone is characterized by a uniform rainy season and by a flat relief, the soils show variabilities with predictable consequences for cropping.

NEED FOR SOIL TILLAGE

In the traditional systems of semi-arid Africa, tillage by hand is the only practice. Soil preparation is generally very superficial. Animal traction was introduced at the beginning of the 20th Century and it developed differently according to the regions. Now it is used by farmers for seeding and weeding operations and very irregularly for soil preparation. By contrast, in another semi-arid region such as India, oxen traction tillage is the general rule.

The opinion of the agronomists on this matter vary. Some believe that deep tillage and especially ploughing has beneficial effects on soil an crops and should be generalized. Others consider that these effects are not important or regular enough to assure a good return for the costs that this practice entails for farmers. They also note that soil deep ploughing may have negative effects over a long period of time, such as

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increased erosion and accelerated burning of the organic matter. They recommend zero or minimum tillage.

To shed light on the subject under discussion, it is necessary to review first of all the role of the physical properties of the soil in semi-arid West Africa as a limiting factor of plant growth; then to review tillage as the most ancient technique and the most commonly used for soil preparation; and finally to review other soil tillage techniques and their effects on the soil and the crops (Charreau, 1972).

Soil physical properties in semi-arid Africa. The soils with clay content exceeding the 20% threshold and which are swelling minerals in the clayey fraction are generally considered by soil physicists as structurally active. The phenomena of swelling and shrinking in temperate region alternating with frost create or regenerate a fragmentary structure. The roots of plants, especially of grasses, are capable of improving the structure of the soil (Charreau, 1974).

Below this threshold and especially when the clayey fraction contains few or no swelling materials, the soil is structurally inert. Plant roots are not capable of improving the structure by themselves.

For structurally active soils, soil tillage may not be required or its frequency may be reduced. For inert soils, soil tillage might make it possible to compensate the inefficiency of natural factors and to create a structure.

It may be noted that the threshold of 20% clay content roughly corresponds to the limit between coarse loamy and fine soils in the USDA (18%) textural triangle.

From that point of view, the soils of the West African semi-arid zone fall into two catagories. Vertisols and comparable soils clearly belong to the category of structurally active soils. Some hydromorphic soils and latosols may also fall into this category, but these soils have a limited extension in this zone as compared to structurally inert soils.

The prevailing feature of tropical sub-arid and ferruginous soils is the poor clay content of superficial horizons. This results both from the sandy nature of the original material (aeolian drifts) for slightly leached tropical sub-arid or ferruginous soils and, from the pedogenesis for tropical ferruginous soils and latosols.

Whatever the causes may be, generally the upper horizons of these soils tend to be sandy-clayey. Furthermore, the clayey fraction is mainly made of amorphous iron kaolinite and hydroxides in ferruginous soils and latosols, whereas montmorillonite prevails in sub-arid soils but with a very low clay content (1 to 10%).

Given these textural and clayey characteristics, the main physical properties of the upper horizons of these soils may be listed as follows:

(1) very weak fragmentary structure (if any);
(2) rather low porosity, not more than 40% to 43%;
(3) very low structural porosity (porosity related to root penetration and to water circulation);

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(4) high propensity to compaction and to hardening during the dry season;
(5) infiltration capacity varying according to the soil and to the original materials; high in soils made of aeolian sediments, often limited in the other soils, with a propensity towards forming a superficial crust;
(6) rather low water reserve, depth of water storage may also be limited by concretions or by the lateritic cuirass;
(7) susceptibility to erosion ranging from weak to average: the Wischmeier index varies from 0.05 to 0.1 in the first years of cropping, from 0.2 to 0.30 after 3 or 4 years of cropping (Roose 1974), Wischmeier, 1959.

The physical properties of the soil, limiting factors of plant growth.
Many positive correlations (Charreau and Nicou, 1971; Nicou and Chopart, 1979) between total root weight or root density in g/dm3 and the yields of various crops (groundnut, sorghum, maize, rainfed rice) have been shown in the West African semi-arid zone (Fig. 1).

This seems to be a general rule for soils with sandy-clayey superficial horizons and can be explained by the fact that in these soils where water availability is limited and uncertain, and where the content of available mineral elements is poor, deep root establishment is essential for water and mineral nutrition.

In soils such as vertisols where water and mineral salts availability is high, the correlation between root establishment and crop yields may not exist.

Close relations between total porosity or apparent density and root density have been found in the sandy-clayey soils in various horizons and for different crops of Senegal (Fig. 2). Root weight or root densities rapidly decrease when density increases in accordance with a function which, most often, is linear and depends on the crop and the experimental conditions (Blondel, 1965; Nicou and Chopart, 1979).

In the vertisols or similar soils, the major limiting factor for plant growth is most often the insufficient infiltration and the water logging of the deep horizons, especially in the degraded vertisols.

The effects of the low porosity on root establishment may be explained mainly by two reasons:

(a) insufficient aeration of roots,
(b) mechanical resistance to root penetration into the soil.

The first explanation is not satisfactory for these soils because macroporosity is always high and the risks of temporary water logging are low in the upper horizons. On the contrary, the second reason is likely to be the most important one. The increase of porosity leads to a greater proportion of large pores through which roots can easily find their way.

Whatever the reasons may be, this low total porosity which results from an unadapted structure is often a limiting factor for plant root establishment and growth in these sandy-clayey soils of the dry tropical zone. The practices of soil development must increase porosity in order to obtain the best yields.

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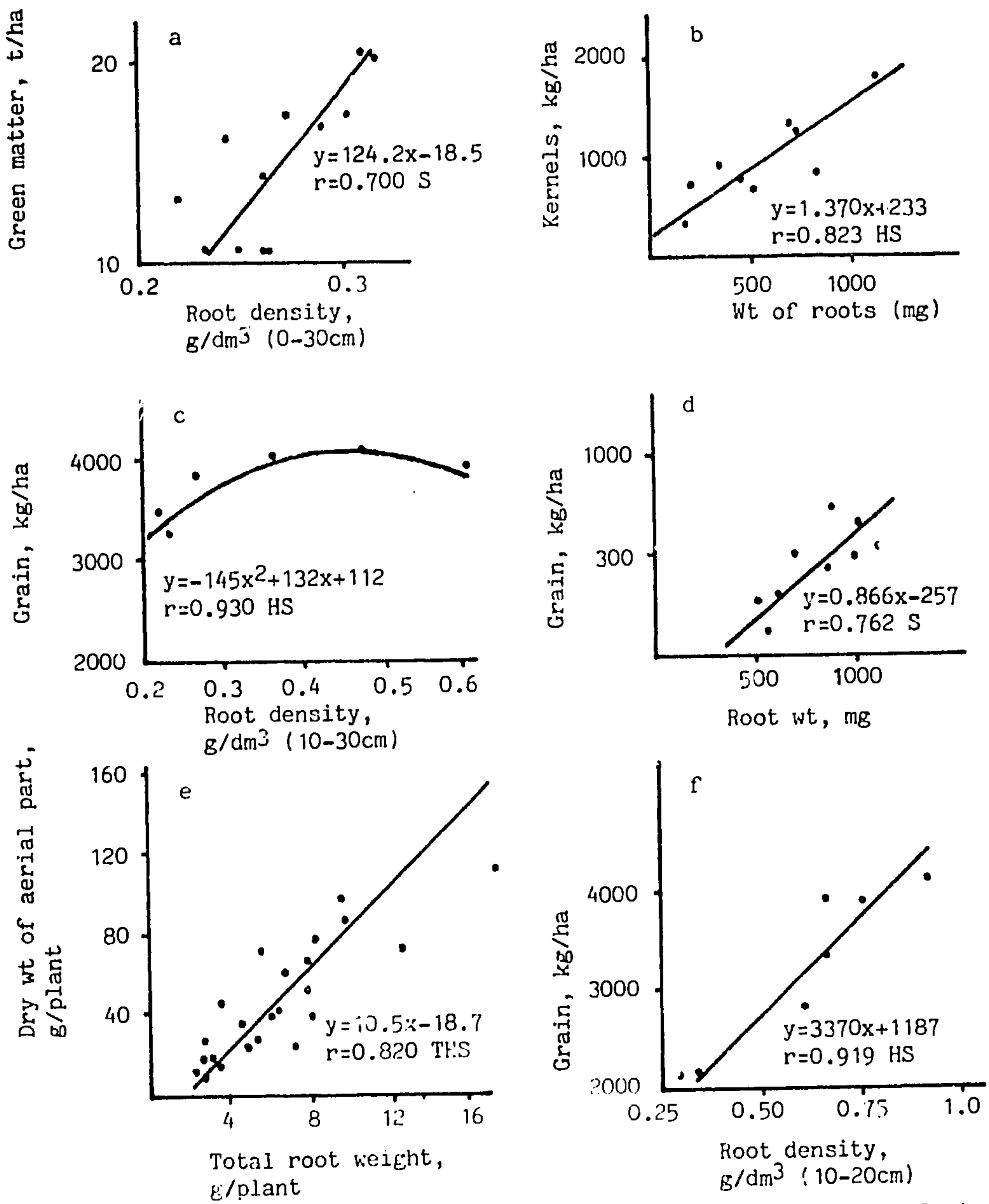

Fig. 1. Relations between root development and yield for different plant species in Sénégal. (a) Fallow, Bambey ; (b) Groundnuts, Bambey, 1964 ; (c) Sorghum, Nioro de Rip, 1967 ; (d) Sorghum, Bambey, 1964 ; (e) Rainfed rice, Séfa, 1970 ; (f) Maize, Séfa, 1969.

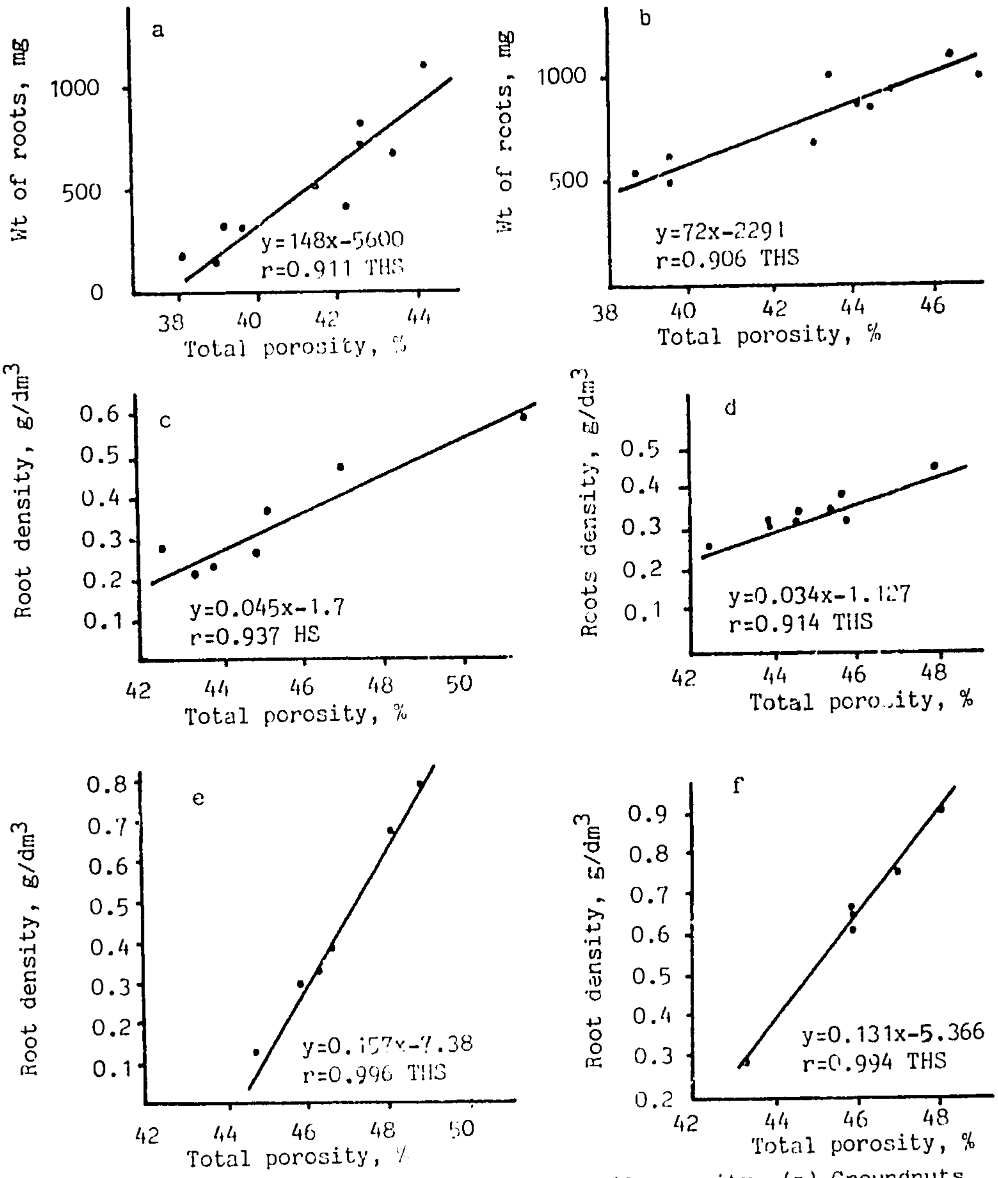

Fig. 2. Relations between root growth and soil porosity. (a) Groundnuts, Bambey ; (b) Sorghum, Bambey ; (c) Sorghum, Nioro de Rip (10-30 cm) ; (d) Maize, Sinthion-Malème (10-30 cm) ; (e) Rainfed rice, Sefa (10-30 cm); (f) Maize, Sefa (10-20 cm).

THE EFFECTS AND CONSTRAINTS OF TILLAGE

Tillage has many effects on the soils that have sandy-loamy and sandy-clayey surface horizons. The most important ones concern the structure of the soil, the hydric regime, the organic matter and microbial activity and consequently the yield of crops.

The structure of the soil. Tillage increases the total porosity of superficial horizons whatever the conditions of realization. It takes the earth, breaks it and turns it by dividing it more or less slenderly in accordance with its humidity and therefore with the intensity of the mass take-off. Thus it creates an artificial cleft which does not exist under natural conditions. Morphological observations of soil profiles after tillage show an important difference in the macrostructure between superficial horizons and deep-seated horizons.

In Table 1, we have gathered a few field measurements in a range of representative conditions (Nicou, 1977).

Table 1. Example of the effects of tillage on soil porosity.

Village	Type of soil	Total porosity: Control	Total porosity	Statistical Comparison
		—— % ——		
Bambey	Leached tropical ferruginous soil on sand-hills (DIOR)	38.9	43.4	++
		38.1	44.5	++
		40.8	[illegible]	++
		40.8	47.5	++
	Sandy-clayey soil (DEK)	39.2	46.0	++
		40.0	46.4	++
Nioro du Rip	Leached tropical ferruginous soil on sandy-clayey sandstone	43.4	47.2	+
		42.6	47.2	++
		41.9	47.5	++
		43.0	46.8	++
Sinthiou Malem	Leached tropical ferruginous soil on sandy-clayey sandstone	40.8	44.2	++
		43.4	47.5	++
Sefa	Leached ferruginous soil	43.4	51.3	++
		44.9	47.9	++

++ Highly significant difference
\+ Significant difference

Clod porosity also increases, especially where the organic matter has been incorporated. It has been shown that when tillage was well carried out in good conditions of soil moisture the changes of structural porosity affected not only the big clods but also the small aggregates of one to two cm of diameter (Nicou, 1974).

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This increase in total porosity that may appear to be limited (10 to 20%) has, nevertheless, very important consequences particularly on annual plant root development. We have seen that there exist relations between root density an global porosity, but it is the whole dynamics of root establishment which is favourably modified (Chopart, 1975):

(1) pace of progression of the root front,
(2) maximum depth and total length,
(3) deep root density,
(4) average distance between two roots.

A number of data assessed in figures appear in Table 2 as an example (Chopart and Nicou, 1976).

Table 2. Effects of tillage on some characteristics of crop root establishment

Characteristic	Control	Tillage
Pace of growth: rainfed rice root weight at 25-30 cm		
After 25 days, g	6	45
After 45 days, g	54	64
Characteristics of rainfed rice root establishment at 92 days		
Total length, m	36.2	96.2
Distance between main roots, cm	4,14	2.55
all roots, cm	0.66	0.48
Total weight, g	4.10	8.48
Diametral surface, cm^2	550	1676
Characteristics of sorghum root establishment at blossoming		
Total length, m	36.4	49.6
Distance between main roots, cm	12.8	10.1
all roots, cm	0.63	0.57
Diametral surface, cm^2	9.45	12.36
Indepth root weight by plant (mg)		
Millet 100 - 150 cm	532	1225
150 - 200 cm	91	308
Groundnut 50 - 110 cm	4010	5700
Sorghum 40 - 90 cm	2370	3910

The hydric regime of the soils. Tillage also affects the hydric regime of soils strongly. This is one of its most beneficial effects in semi-arid tropical zone. It is frequently observed that crops support dry periods better when they are planted after tillage.

Three mechanisms must be taken into consideration for this improvement of the hydric regime:

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(1) improvement of infiltration, tillage affects infiltration:
   (a) by increasing the porosity of surface horizons;
   (b) by creating obstacles to the partial or total circulation of water at soil surface, this obliges it to penetrate: cloddy superficial structure, modification of land pattern.

   This action has been checked under numerous circumstances, that is, (IRAT, 1982, 1983, 1984):
   (a) by hydric profiles at the beginning of the cycle (Fig. 3)
   (b) by measurements on runoff particularly with the help of erosion compartments (Southern Senegal, Center Burkina, Northern Nigeria).

   In that respect, the proper efficiency of tillage is mainly perceptible at the beginning of the cycle. Later on, it is the more important development of the vegetation cover that ensures better protection of the soil by intercepting the rains.

(2) Use of the stored water by the plant. This effect is linked to the development of the root system. Thanks to a more rapid and better utilization of the soil by the roots, the water reserve made available to the plant is more important (Table 3).

   Numerous monitorings of hydric profiles performed during periods drought have made it possible to find that plants cultivated on tillage explored the hydric reserves of the soil better (Charreau and Nicou, 1971).

Table 3. Differences of water stocks between control and tillage during millet cultivation in Bambey and rainfed rice cultivation in Sefa (Senegal).

Millet, Bambey			Rainfed Rice, Sefa			
Differences of water stocks, mm Control-tillage			Differences of water stocks, mm Control-tillage			
Depth in soil	1970	1973	Depth in soil	1968		1969
0 - 50 cm	- 1.5	+ 1.8	0-30 cm	+ 6.5	0-40	- 17
50 - 100	+ 9.1	+ 6.5	30-50	+ 10.3	40-80	+ 14.9
100 - 150	+ 9.2	+ 11.1	50-100	+ 15.2	80-200	+ 17
150 - 200	+ 17.5	+ 18.4				
0 - 200	+ 34.3	+ 37.8	0-100	+ 32	0-200	+ 14.9

   Whereas consumptions at surface are equivalent, in depth the plant consumes more on a tilled soil and uses the reserves better.

(3) Conservation of stored water. If performed after cropping, soil work makes it possible to reduce evaporation during the dry season, by breaking of the capillary front and suppression of all surface vegetation. If there is water left in the soil after harvest (short cycle cropping) and if the texture allows

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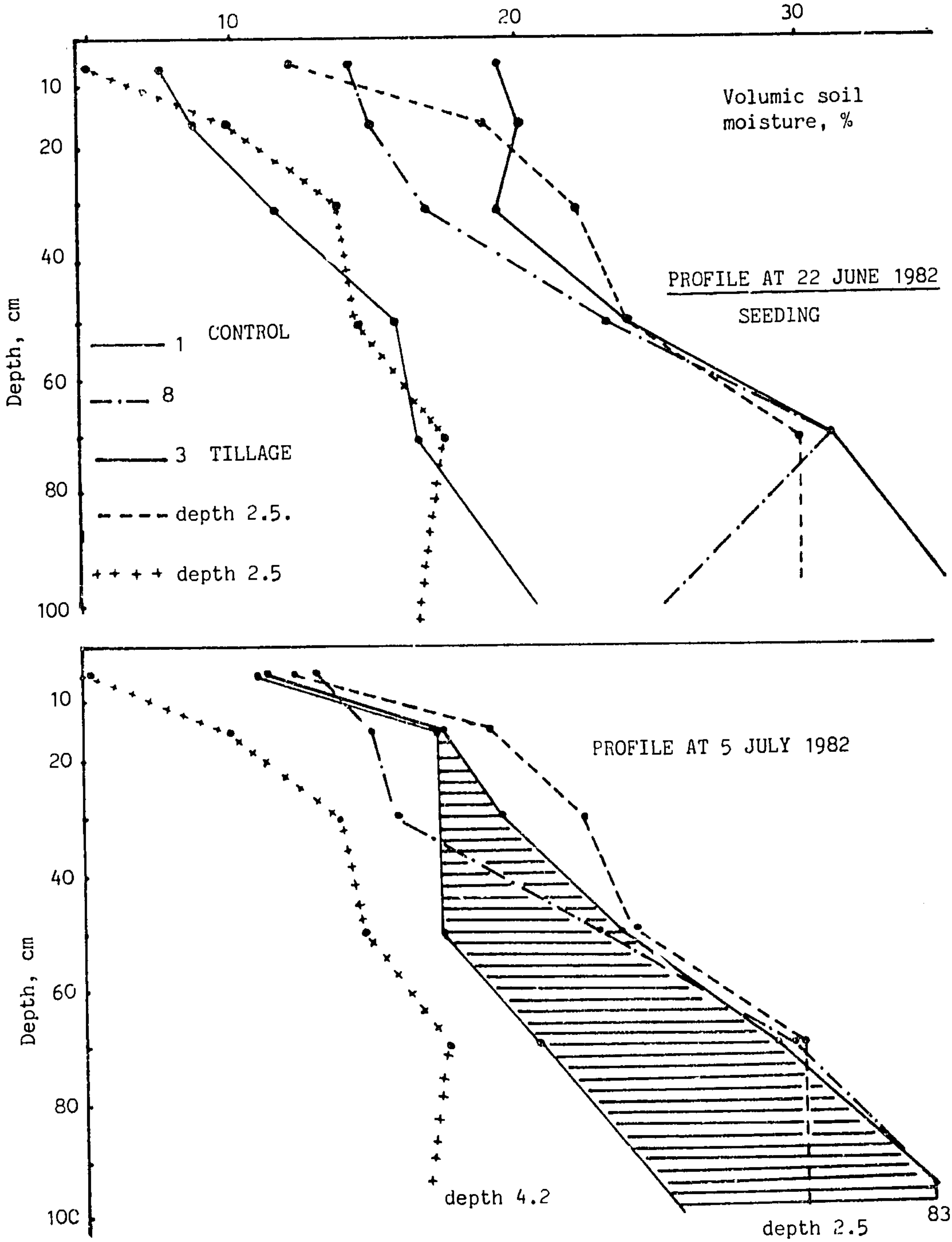

Fig. 3. Water conservation techniques hydric profiles at Gampela, Burkina Faso.

it, this water may thus be preserved during the dry season and be used at the beginning of the cycle of the following year (Dancette and Nicou, 1974).

Table 4. Variations of water stocks (mm) over 2 m during the dry season after different treatments.

Treatments	30 November 1972	29 June 1973
	mm	
Millet harvested, straw left on the spot, unweeded soil	34	3
Millet harvested, mulched, without weeds	71	30
Millet harvested, mulched, with weeds	5	2
Tillage at end of cycle, incorporation of straw into the soil early October	52	40
Tillage at end of cycle, incorporation of straw into the soil late October	57	53

The organic matter and microbial activity. As regards the organic matter, repeated tillage is reputed to accelerate the oxidation and mineralization of humus and to modify microbial activity and biochemical processes. In semi-arid West Africa, the decrease of humus rate is not evident. On the other hand, in the soils of Senegal it was demonstrated that tillage might increase nitrogen mineralization significantly during the rainy season (Ganry, 1977), which increases cereal yields.

Tillage may also have important effects on the symbiotic activity of rhizobiums. Groundnut yields may thus be increased by 50% in very sandy soils, due to increased nitrogen fixation, as has been measured in Senegal (Wey and Obato, 1984).

Crop yields. The modifications of the physical properties of the soil, due to tillage and particularly its effects on the hydric regime of the soils have very important consequences on the yield of the major plants cultivated. We have many data for French speaking semi-arid West Africa. In Table 5, we have shown the averages recorded in a large part of pre-extension field trials.

These are the effects of tillage only, without taking into consideration the incorporation of organic matters that may modify the percentages in relation to the nature of the organic matter.

Cereals are very sensitive to the effects of soil tillage which increase when one moves from millet to sorghum, then to maize and to rain-fed rice. In fact, this depends, to a large extent, on the hardiness of the species and on its adaptation to the aridity of the climate.

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Table 5. Effect of tillage on the yields of the major plants cultivated annually in semi-arid West Africa.

	Number of annual results	Yield		Gain of tillage
		Control	Tillage	
		kg/ha		%
Millet (grain)	38	1558	1894	+ 22
Sorghum (grain)	86	1691	2118	+ 25
Maize (grain)	31	1893	2791	+ 50
Rainfed rice (paddy)	20	1164	2367	+103
Cotton (cotton gr.)	28	1322	1550	+ 17
Groundnut (pods)	46	1259	1556	+ 24

We have also recorded residual effects of tillage; they may be relatively important and, most often they depend on rotation. Thanks to their clustered root establishment, cereals preserve the macrostructure created in the soil better whereas often after groundnut there is nothing left. This makes it possible to envisage tillage over periods of two or three years and therefore the distribution of the work over the whole field.

Finally, it must not be forgotten that tillage has a very marked effect on the growth of weeds. It has been demonstrated that a tillage correctly performed would make it possible to reduce the number of weedings significantly and, at any rate, to postpone the date of the first intervention; which is important for the crop calendar of the farm.

The difficulties and obstacles for tillage extension on-farm. The effects of tillage are not as marked everywhere because they depend on:

(1) the nature of the soil: we have said enough with respect to this subject and need not dwell on it,

(2) the climate and the vegetation.

In an environment of heavy rains, erosion control prevails. Furthermore, the presence of a long dry season is an obstacle to any efficient action of the mesofauna (earthworms):

(3) the plant cultivated,

(4) the cultural history of the plot.

On a recently cleared piece of land, it is often preferable not to upset the upper horizons whereas on a piece of land cultivated over a long period they must be tilled:

(5) the quality of the performance,

(6) the cultural manners of recovery: recoveries are often necessary when tillage is badly performed.

Tillage requires that the farmer should have an adequate force of traction (animal traction, motorization), that is, means of production.

In the case of ox traction, four to five days are required for tilling a hectare of land. The problem of crop calendar is especially serious at the beginning of the rainy season, when there is competition between soil preparation, seeding and weeding and when the state of health of the yokes of oxen is far from satisfactory after a long dry season.

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Tillage is often accused of increasing erosion. Numerous results show that this is not true, if tillage is correctly performed at a low pace as is the case with ox traction. Often, there is confusion between depth and intensity of soil work. In particular, the use of disk ploughs working at high speed on sloping soils must be condemned (Charreau, 1969). A means to prevent tillage from being erosive is to associate it to the organic matter.

Despite all the positive results obtained in trials, and the efforts of the extension services, it may be demonstrated that tillage is still relatively in little use among farmers of semi-arid West Africa. Even in some zones of western and southern Mali where it is used to a large extent, it is often used in an incorrect manner. This situation strongly contrasts with what exists in other semi-arid regions such as India, where tillage by animal traction has been largely and correctly used over centuries, despite the use of quite primitive instruments. It would be interesting to analyze the reasons for this opposition.

We have seen that in semi-arid West Africa there are numerous constraints to the adoption of tillage by the farmers. Among those constraints, the most significant one is the lack of the time required for performing this operation at the beginning of the cycle, due to the brevity of the rainy season and to the imperative need to seed early. The competition between cultural practices, seeding and weeding is particularly marked in the West where rains start suddenly. But inland, where a number of early rains of April and May may be used for tillage, this is not done without very clear reasons (Tradition prevails).

At the end of the dry season, the soils are too hard (taken as a whole) in order for work to be carried out with animal traction. After a short cycle cropping, the farmer may have a limited time to till at the end of the cycle. But here again, one is faced with a number of habits and practices, particularly that of taking a rest between the harvest of short cycle crops and that of long cycle crops.

All the drawbacks taken individually are not insurmountable, but their combinations explain the difficulties encountered in the introduction of this technique to the farmers of semi-arid West Africa.

OTHER TECHNIQUES OF SOIL TILLAGE

Soil tillage with tines or pseudo-tillage. Soil tillage with tines makes it possible to prepare the soil without turning it up. Its purpose in particular is to get rain water to penetrate without upsetting the surface of the soil. It may have different forms (Nicou, 1978):

(1) Shallow cultivation of dry land: performed with different types of tines; it makes it possible to split the soil (Canadian, pick-mattock, diamond point, etc.). Performed with animal traction, it is necessarily limited in width and depth by the force of traction and most often it is very localized and superficial.

The yield increases obtained are very irregular and depend, to a large extent, on the volume of soil really affected by the modifications of structure. Experimentally, the yield increases may range between 0 and 15%.

.../...

(2) Passage of tines on moist land: the tillage is deeper, faster and covers more surface. The use of parts known as "goose-feet" may be very efficient. But this work must be performed after the beginning of rains and therefore it competes with seeding. Yield increases have reached 23 % (whereas ploughing in the same conditions yielded + 39%)
(3) A chisel can only be used with a tractor. On a dry land, its depth of tillage is most often limited because of the hardness of the soils, but the surface cultivated may be important.
(4) Deep ploughing splits the soil more indepth, but the force of traction must be high. However, as the passages of tines are spaced by 1 m to 1.50 m, this reduces labour time. It is faster to use a deep-plough on a dry land than to plough 1 ha of moist soil with a tractor. Its efficiency depends a lot on the nature of the soil. If too sandy, splitting is inadequate and the modifications of structure tend to disappear rapidly. If clay content is inadequate, the effect may last at least two years.

An experiment conducted at Gampela (Burkina) over four years has led to very interesting results (Table 6). After Herblot, 1985.

Table 6. Effects of soil tillage with tines on cereal yields.

Treatment	Sorghum 1982	Groundnut 1983	Sorghum 1984
	kg/ha		
Control	950	1284	523
Chisel	1020	1186	652
Chisel/deep ploughing previous year	1200	1659	1050
Deep ploughing the current year	1390	1567	1841
Tillage with gang plough	1340	2000	1020

The efficiency of tillage with tines varies a lot:
(1) In terms of water economy, the deeper the tillage and the closer the passages the better the infiltration is. A deep ploughing that leaves big clods at soil surface may be very efficient at the beginning of the cycle. But a simple shallow cultivation remains very risky. The interest of these techniques is that as they are performed during the dry period they make it possible to store a more or less important part of the first rains.
(2) Action on root establishment is limited to the tilled area. If seed rows are found on the passage of the tines, there is a preferential penetration and an unquestionable efficiency. Between the tines, there is no visible effect, therefore, root penetration is very irregular.
(3) Tillage with tines alone does not play any role in evaporation control. But it may be efficiently combined with the mulch of crop residues.

Ridging and mounding. Ridging consists in making rectangular spaced embankments with a plough, a mounding body or a hand tilling instrument. The earth is taken from the space between two crop rows to an untilled part. The plants are seeded on top or on the side of the ridges that need to be banked up during the cropping cycle.

The principle of this technique is to trap rair water, to prevent runoff and to keep the maximum of this water at the disposal of the plant. In fact, this is possible only if:

(1) the ridges are made perpendicularly to the direction of the slope,
(2) the slope is gentle or low. If this is not the case, the water runs out faster carrying away the thin elements. This erosion is then facilitated by the fact that ridging work grinds the earth.

Furthermore, if the previous conditions are met, the water will be truly available to the plant only if the texture of the soil makes it possible and if the root establishment of the crop is adequate.

In the zones of West Africa where this technique is traditionnally used, tillage is performed by hand and, in general, seeding is delayed. Ridging is particularly useful for controlling weeds at the beginning of the cycle. This being so, contour ridging may effectively limit runoff.

However, it must be noted that in sandy soils, the ridges are gradually destroyed by rains. A layered structure which is unfavorable to crop root development may develop in the furrows in which the sedimentation occurs. This was particularly observed in the south of Senegal (Seguy, 1971).

Finally, it must be pointed out that when the soil is sandy or gravelly, that is leaching, the water does not remain in the body of the ridge. In case of seeding followed by a period of drought, the plant does not resist. But if it rains a lot at the beginning of the cycle, the system avoids water logging, which may be an advantage for some crops such as maize.

An experiment conducted over the last three years in Burkina (Table 7) in several different pedoclimatic situations makes it possible to compare flat ploughing and ridging (IRAT, 1982, 1983, 1984).

Table 7. Average yield of sorghum and maize.

	Number of annual results	Control	Flat ploughing	Ridging
		kg/ha		
Sorghum	20	730	1126	1090
Maize	5	1893	2791	2323

.../...

Generally, there is no significant difference between the two, as flat ploughing is superior in average. The interest of ridging is particularly marked when the slope becomes important. But its operation may be considerably improved by tying which will be discussed later on.

Mounding: it consists in taking the earth from the space between two rows to the plants being cultivated. The work may be performed by hand, by animal traction or even by motor traction. The seeding is performed on flat soil and it is only when the plant has reached a certain height that mounding can be carried out.

The purpose of the operation in terms of water preservation may be compared to that of ridging: to trap rain water and facilitate its infiltration. However, the result obtained may vary in relation to what happened before mounding and to what will happen after mounding.

If seeding was carried out after flat ploughing, one may expect to cumulate the effects of tillage and those of mounding. The same applies if there has been tillage with tines. This is important particularly concerning the development of the root system. However, mounding gives rise to a number of problems:

(1) To perform it, one must wait until the plant has grown enough. In regions with poor rainfall, when there is a period of drought at the beginning of the cycle, one must wait for a long time before getting the possibility of mounding. Therefore, the efficiency of the technique may then be questioned.
(2) When mounding, one may have to cut off a number of roots which are in the space between two rows. Some negative effects have been observed on millet.
(3) Seed lines must be perpendicular to the line of greater slope.

As in the case of ridging, the efficiency of mounding may be considerably improved by tying.

Tied ridges. The technique of tied ridges consists in making embankments with regular space between the ridges, in such a way as to prevent the runoff of water and to create basins for water microcatchment. This technique makes it possible to practically suppress runoff in the plot and, to put all the rain water that falls down at the disposal of the plant.

This technique which traditionally is in little use in West Africa is widely used in South America, it has recently been the subject of surveys by the IITA-SAFGRAD Agronmy Team on maize and cowpea in Burkina and, by the ICRISAT Team on millet and sorghum; its on-farm application has been initiated by the FSU/SAFGRAD Team. IFAT-CIRAD, under IBRAZ, has undertaken over the last three years a regionalized comparative study on all water conservation techniques which will make it possible to determine the most adapted techniques in relation to the pedoclimatic context. The efficiency of the tied ridge depends on numerous factors;

(1) distance between the ridges,
(2) date of ridging or of tied ridging,
(3) nature of the soil,
(4) position on the toposequence.

.../...

In a study carried out at the Kamboinsé station (Burkina), ICRISAT has compared different sizes of basins of microcatchment with or without complementary straw, for reducing evapotranspiration. For sorghum, a microcatchment basin of 0.50 m^2 was significantly better in terms of yields: this corresponds to a spacing of 1 metre between the ridges for seed rows spaced by 50 cm, (Zaongo, 1983).

Concerning the date of tying, several possibilities must be envisaged:

(1) Direct seeding at the outset on the tied ridges manually or mechanically. In that case one does without the effects of soil tillage such as tilling on crop root establishment.

(2) Flat seeding after preparation and tied mounding about three weeks or one month after seeding.

(3) Flat seeding, mounding at the beginning of plant growth and tying some time afterwards.

The efficiency of the tied ridge will then depend upon the distribution of rains with respect to the date of tying and also to the nature of the soil.

If the soil is too sandy, the device might not resist severe rains and it will be necessary to bank up regularly (hence additional work). It is, therefore preferable to perform tying rather late so that it can be efficient at the period of ear emergence or blossoming, a very stress sensitive period of plant growth.

If the soil is clayey enough and if the tied ridge is solid, it is preferable to make it early, but if one wishes to utilize all of the water of the profile by a deep root establishment, it is better to plough beforehand. The IITA-SAFGRAD experiment has shown that in that case, the device could be kept for two years without being banked up.

The regionalized IRAT trials of 1984 have shown that the best date for tying the ridges varies in relation to the site (IRAT, 1984).

Table 8. Effects of the ridge in relation to its date of construction on sorghum yield.

Location	Control	Ploughing + tied ridges 1 month	Ploughing + ridging, 1 month + tying, 2 months
		Kg/ha	
Sabouna	1	330	118
Kolbila	288	611	531
T O	876	1461	1219
Gampéla	109	1683	2594
Saria Haut	523	1410	1337
Saria Bas	259	1561	1790
Kassou	698	884	825

It must also be pointed out that when the soil is sandy or gravelly, the water may seep and not be used by the plant. Therefore, it is necessary to develop a deep root establishment.

The example of Saria Haut is a typical one in this respect (sorghum, kg/ha)

Control	523
Flat tillage	1083
Flat tillage + tied ridging at 1 month	1410
Direct tillage + tied ridging 1 month	959

Concerning toposequence, an important study is being conducted by IITA-SAFGRAD at Kamboinsé. Fig. 4 shows the results obtained in 1983. They reveal the effect of the position of the crop, along the toposequence, on the yield of maize. Tied ridging every other row or every row has increased yields on all positions except the bottom lands, (IITA-SAFGRAD, 1983).

Therefore, tied ridges appear as a very interesting water conservation technique that may be combined with other techniques (soil tillage, mulch).

However, if ridging may be done with animal traction and maintained in the same way, so far tying required considerable work from the farmer. The creation by SAFGRAD of an adapted tool gives rise to hopes in that respect.

It is a fact that mechanical weeding between the rows is no longer possible, everything must be done by hand. We believe that flat seeding (preferably after soil preparation) followed by tied ridging three weeks afterwards, will make it possible to solve the problem of weeds, as the effect of mounding is to limit the number of weedings. Thus only one manual intervention would suffice until harvest.

It must also be pointed out that another technique has been tested by IITA-SAFGRAD. It consists, after flat seeding, in digging small holes (about 40 cm long x 20 cm wide x 10 cm deep) at the same time as the first weeding. The holes are dug between the rows without mounding the plants. The system has had a very highly significant effect on the yields of maize in 1983 at Kamboinsé; 624 kg/ha without holes compared to 1272 kg/ha with holes. The average yield increase is higher than the opportunity cost of labour. If this is confirmed, this operation must be mechanized, (IITA-SAFGRAD, 1983).

<u>Mulching</u>. Mulching consists in leaving on the soil surface all or part of crop residues. The objectives of this technique are many (LAL, IITA, 1983):

(1) to protect the soil:
  (a) by limiting runoff and, limiting erosion as a consequence,
  (b) by reducing evaporation;

(2) to reduce soil tillage by avoiding to turn up the surface horizons;

(3) to enrich the soil with organic matters and increase the activity of the mesofauna (earthworms).

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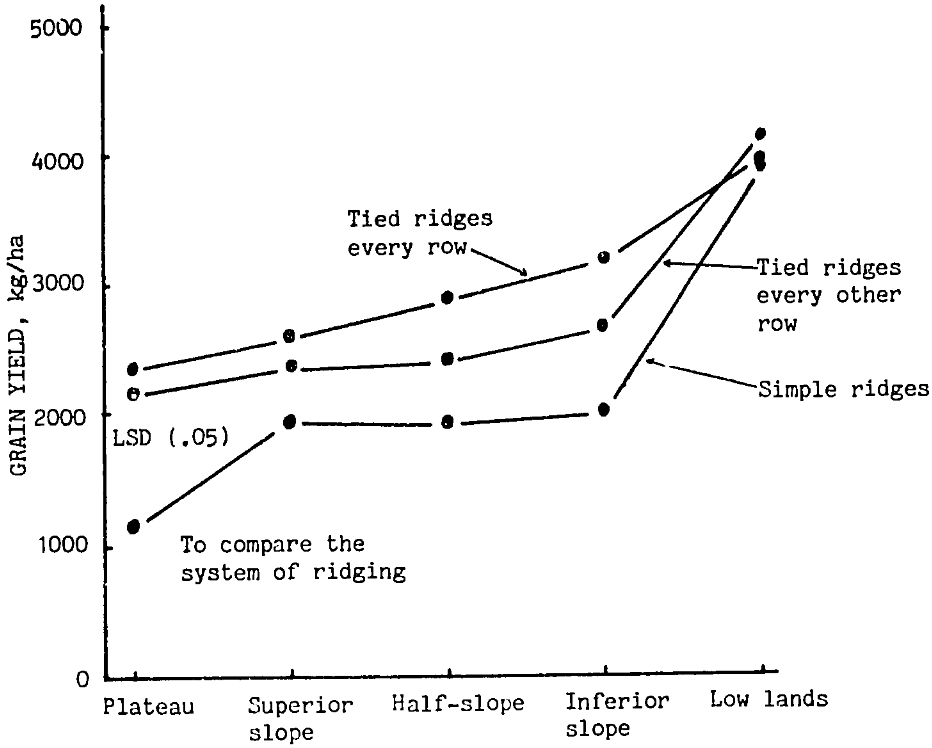

Fig. 4. Effect of the position of the crop along the toposequence and the tied ridges on maize grain yield at Kamboinsé, Burkina, 1983. Average of two seeding dates.

Many data have been produced particularly at IITA and more recently at ICRISAT. They show clearly that mulching reduces runoff and facilitates infiltration.

This is certainly the most spectacular effect of this technique. However, it must be noted that its efficiency depends on the quantity of straw present on the soil. If the harvest of the previous year has been poor, the quantity of straw will be poor and the protection will be reduced. In case of heavy rains, on a sloping soil, this straw may be carried away. Thus it was demonstrated in Senegal that a harvest of 1500 kg/ha of millet yielding 4 t/ha of straw is not enough to ensure adequate protection and that the tonnage must be doubled with contributions from outside. In general, the coverage is adequate in humid zones, whereas in the dry zones where the role of infiltration is primordial, it is difficult to produce the quantities required (Chopart, Nicou and Vachaud, 1976).

To be efficient in terms of moisture conservation and evaporation control mulching must be associated with weeding.

During the cropping cycle, it is somewhat efficient in reducing evaporation as compared to bare soil; it also makes it possible to store water, but it may favour deep seeping inasmuch as the root system of the plant is not adequately developed, which is the case in the absence of tillage on soils with mediocre porosity.

The drawback of mulching when used alone is that it does not allow for semi-deep plough with turning over. Therefore, the roots are at the surface, which make the plant even more sensitive to drought. In order to mitigate this drawback, one tries to associate it to techniques of soil tillage on the row but the results are far from being convincing.

Theoretically, one could think of taking the residues out of the field, tilling and then bringing the residus back. But this would require too much work and it is preferable under these conditions to make manure, compost or simply to incorporate the residues directly into the soil.

The presence of this layer of undecayed organic matter at the soil surface gives rise to other problems.

(1) the problem of weeding: one must resort to different herbicides, that is, to certain technologies,
(2) the problem of mechanical seeding which can be settled only by motor traction,
(3) finally, the farmer must have an adequate quantity of straw. But in the semi-arid West African zone, straws are used as animal feed, as fuel or as construction material. Therefore it is in the zones where the problems of hydric supply are the most crucial that this technique is less likely to be put in use. But it remains very interesting for zones recently cleared, in tropical humid environments on soils with good structure.

.../...

CONCLUSIONS

We have tried to recapitulate in one table (Table 9) the efficiency of different techniques on water conservation, for each of the following objectives:

(1) to improve infiltration,
(2) to facilitate the use of stored water,
(3) to preserve water.

We have assessed in a very simple manner how each technique would help meet those objectives:

- \- = no action,
- \+ = not very efficient,
- ++ = efficient,
- +++ = very efficient.

We have added a fourth column in which we highlight the problems raised by the application of the technique.

This has been done on the basis of experimental data at our disposal, with much objectivity. A rapid reading of this table makes it possible to determine the most efficient interventions and to think a priori of the most interesting combinations. However, the experimental results may moderate this trend by highlighting the importance of pedoclimatic conditons.

We can see that most soil tillage and water conservation techniques are relatively efficient in terms of rain water collection (reduction of runoff, increase of infiltration), but that they do not have the same effects on the use of this stored water by plants.

The essential difference, in terms of their efficiency, lies in their capacity to facilitate the development of the crop root system, particularly at the beginning of the cycle, and in their capacity to allow for the presence of a deep and extensive root system to ensure the hydric nutrition of the plant during dry periods.

But it must be noted that no technique is universal and that each of them must be adapted to the context. Indeed, it is observed that each of them depends on:

(1) the soil (texture, structure, depth, fertility),
(2) the climate (total rainfall, distribution),
(3) the vegetation, and
(4) past farming practices.

Finally, the socio-economic context plays a major role in the possibilities of application.

For example, it is illusory to talk of mulch in a country where all the residues are used or of deep ploughing when motorization is a luxury not very widely distributed.

Flat tillage requires minimal equipment and time available for work. Tied ridging requires an important effort from the farmer.

Therefore, a judicious choice must be made in relation to the situation which one is undergoing.

.../...

Table 9. Effects of different techniques and problems raised by their application.

	Shallow cultivation	Dry deep ploughing	Flat tillage	Tillage in ridges	Mounding: Without tillage	Mounding: With tillage	Tied ridges: Without tillage	Tied ridges: With tillage	Mulching
Improves infiltration, reduces runoff	+	++	++	++	++	++	+++	+++	+++
Facilitates the use of stored water by the plant	+	++	+++	+	-	++	+	++	-
Helps preserve infiltrated water	-	-	++	-	-	-	+	+	++
Problems raised by the application of the technique	- Force of traction	- Requires heavy motorization - Cost	- Animal traction equipment - Period of realization	To be done perpendicular to the slope - Problem of mechanical seeding - Labour time if done by hand	- Seed rows must be perpendicular to the slope Damage to toots - Mounding date dry zone - Labour time		Tying: Labour time for tying - Weeding		- Straw availability Weeding - Mechanical seeding

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SOIL PREPARATION IN THE SUDAN SAHELIAN ZONE: PROSPECTS AND CONSTRAINTS

P. DUGUE[1]

During the past 15 years, development authorities have embarked upon animal traction extension activities in the Yatenga Province, of Burkina Faso. This constituted one of the major themes for development activities among farmers. The number of equipped farms keeps increasing: in 1965 less than 8% of farms possessed animal traction materials whereas in 1973 equipped farms increased to 13%. Presently, the figure is in the neighborhood of 20% (it is over 30% in some villages). On the other land, Yatenga has considerable potential in draft oxen and this helps in the further spread of animal traction provided agricultural loan schemes are maintained. It is in this connection that the Yatenga Research/Development Program was initiated to develop a technical base for an increase in agricultural production (crops mainly).

For three consecutive years (1982-1984) the Yatenga experienced the lowest rainfall ever recorded (Ouahigouya 1921-1983). Consequently, the adaptation of cropping and producer systems to the drought became the priority theme for our activities. Besides variety related aspects (the introduction of early and drought resistant varieties, the development of water economy techniques was undertaken in collaboration with farmers from two villages. Soil preparation is one of the major elements of rain water conservation. In this connection, we shall base our findings on the utilization of ox traction equipment which are often found in this region.[2] First and foremost we will develop the agronomic aspects of soil preparation (study of the relationship between techniques-water-soil-plant), then we will discuss the degree of animal traction utilization by the farmers, with reference to case studies of some supervised farms during three agricultural seasons.

MATERIALS AND METHODS

The Yatenga Province, located in the North-Eastern part of Burkina Faso (Fig.1) includes some of the most degraded soils in the country. This degradation is explained by two major factors:

(1) a high population density ranging between 50 and 70 inhabitants/km^2 in the central part of Yatenga and around 25 inhabitants/km^2 at the peripheral areas of the province,

(2) considerable reduction in rainfall since 1970-71; this reduction has been marked since 1982 (Fig.2).

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2 The operation area presently consists of three villages: Sabouna, Ziga, Boukere.

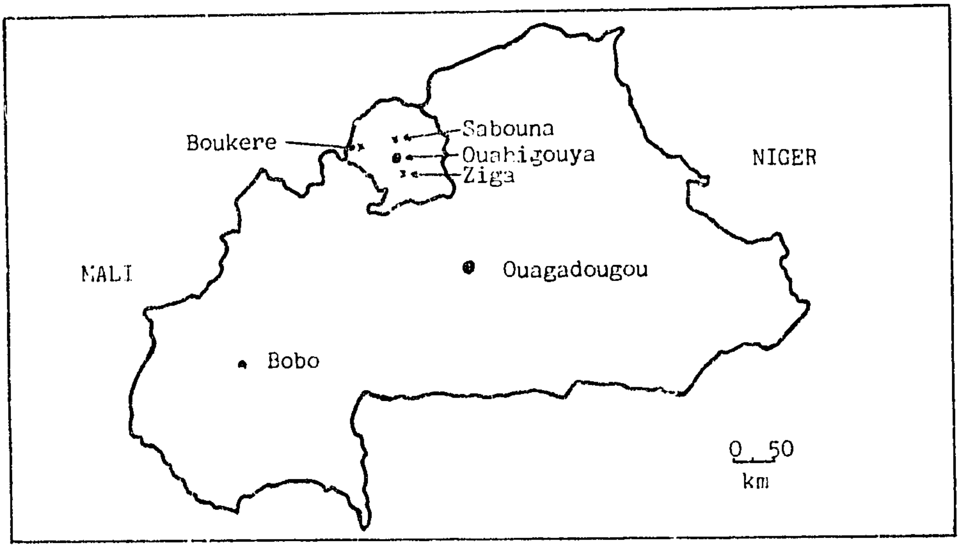

Fig.1. Location of the Yatenga on a map of Burkina Faso.

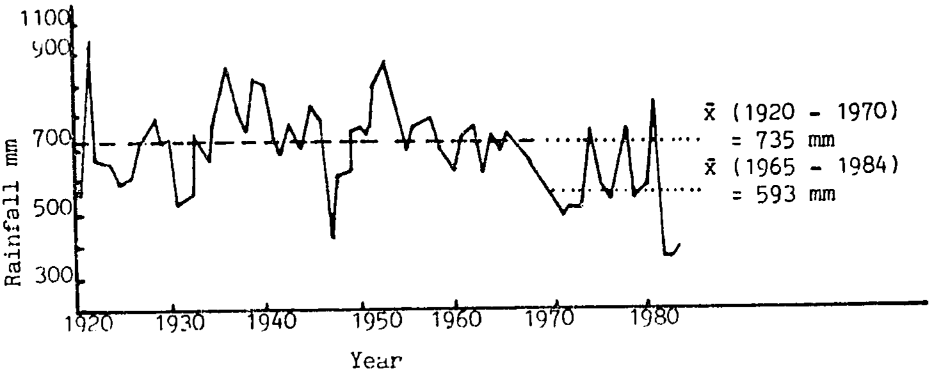

Fig.2. Annual rainfall, 1920 to 1984, Ouahigouya, Burkina Faso.

These two factors correlate with a total occupation of cultivable lands. Farmers became increasingly involved in extensive farming ("cultivate more so as to produce more"). Accordingly, chemical and physical soil fertility restoration practices disappeared. The poorest lands were farmed and erosion resulting from the wind, the run-off and degradation of natural vegetative cover reduced the cultivable land potential with each passing year.

Rainfall and plant production. The mean rainfall at Ouahigouya for the past 20 years is 593mm. Within our reference period (82-84), the 1982 rainfall was the best, so far as farming is concerned (Table 1). The season 1983was marked by two 10-day periods of drought in August causing a delay in flowering. Yield estimates for three major crops, millet (75% of cultivated land), sorghum (20%) groundnut (5%) demonstrate the interest in the cultivation of sorghum on lowlands (bas-fond). This made it possible to have more stable yield exceeding 1000 kg/ha, irrespective of the year.

Table 1. Rainfall recorded at Ziga and Sabouna within the past three years and estimates of yield at Sabouna.

	Rainfall		Yield at Sabouna		
Year	Ziga	Sabouna	On millet slopes	On sorghum low lands	Groundnut
	mm		kg/ha		
1982	400 (-32%)[1]	402 (-32%)	300-500	1000-2000	300-500
1983	457 (-23%)	410 (-31%)	150-300	1500-2000	100-300
1984	350 (-41%)	280 (-53%)	0-250	600-1200	0

[1]Variation in relationship with the mean 1965-1984

Animal traction and production systems. Animal traction was introduced in the Yatenga by Mossi farmers from the "Office du Niger" towards the end of the 1950s. Since 1965 there have been various extension operations promoted by either credit or cash payment sales of animal traction materials (plough, houe manga, multicultivator) in the Yatenga. The seed drill has never been advertized. Moreover, the province does not have any animal or operator training center. For purposes of demonstrating the interest of producers in these materials, we provide below figures on sales provided by the ORD (Regional Development Unit) in 1978/1979:

	Credit	Cash payment	Total
TOM 14 Plough	20	380	400
BM_2 M Plough	184	259	443
Houe Manga	148	252	400

The figures in Table 2, covering the Ziga and Sabouna areas were obtained from an "animal traction" survey carried out in 1982.

Table 2. Figures for farms using animal traction.

Item of information	Ziga	Sabouna
Size of sample surveyed	60	50
Animal traction, %	35	35
Farms with a plough, %	20[1]	35
Farms with a houe manga, %	25	15[2]

[1]At Ziga: Some farms had a plough and a hoe and others had only a houe manga.

[2]At Sabouna: Animal traction farms all had a plough, in effect the 15% houe manga corresponded to multicultivators (hoe+plough+ridger).

The introduction of animal traction at Ziga began as far back as 1965 with the sale of houe manga (donkey traction). At Sabouna, farmers purchased the first ploughs on a cash payment basis at the Ouahigouya market around 1970 (groundnut and cotton sales). Following the creation of village groupings (1972) various credit operations enabled the farmers to purchase equipment.

In almost all cases, farmers adopted animal traction (horses at times but rarely donkeys). At Ziga, a certain number of farmers preferred working the soil with the houe manga (faster). At Sabouna, the first hoes (weeding triangle) were obtained from the 1981 "multicultivator" credit[1] scheme. Before that time, farmers did not have ploughs.

In the two villages, soil tillage before sowing was a lot more developed than mechanical weeding. At Sabouna, the latter was introduced by the Research/Development Program in 1983 and 1984. At Ziga over half of the animal traction farmers weeded mechanically. Cereal ridging with ridgers was not practiced at Sabouna where there were 20 ridgers (there was only one at Ziga).

[1]Apicoma multicultivator: an equipment combining the plough, the three or four teeth weeding triangle and the ridger: Plough, very often the nine inch oxen model; houe manga, or five teeth, shallow cultivation and hoeing.

The 1982 figures are higher than those obtained in 1983. For the past two years, due to poor harvests, some farmers have been selling their materials and draft oxen. Others emigrated towards South Western Burkina Faso with their animal traction materials.

Types of soil and soil tillage. No discussion on soil preparation in the semi-arid zone can be objective unless it is based within the context of farming systems. In the Yatenga, it is necessary to stress the importance of the distribution of soil types per agricultural farm. At Sabouna, the soil toposequence is characterized by relatively steep slopes (> 1%) and a lateritic hard pan on the upper slope. The soils on the slopes are more or less degraded, gravelly soils, compacted soils, zones more conducive for sandy farming (Fig. 3).

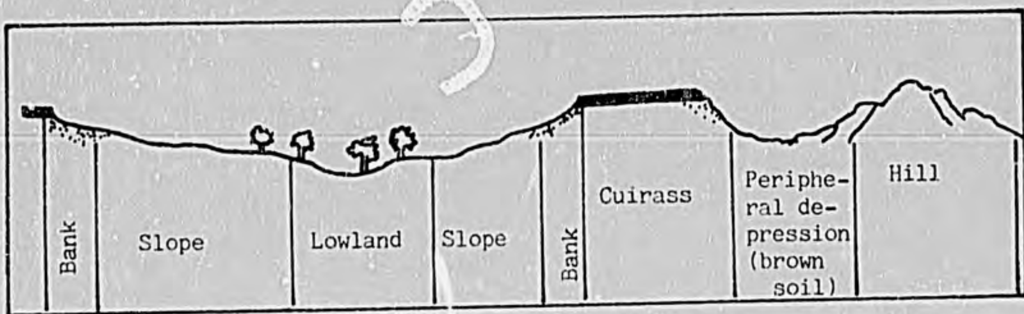

Fig. 3. Toposequence pattern at Sabouna.
Source: J.Y.Marchal, ORSTOM.

RESULTS AND DISCUSSION

From the point of view of chemical fertility and water characteristics in the rainy season, the best lands are located on the lowlands (bas fond).

It can be concluded from surveys conducted (for three years on 20 farms) that presently farmers do not work on lowlands and that light soils (sandy, non compact clayey-sandy or sandy-gravelly) are the most tilled or cultivated fields. Farmers rarely worked on compacted soil (Zippele "in Moré")due to the weak traction strength of the oxen and the poor water infiltration on such soil with destroyed scraping of arable sandy horizons by several tens of centimeters. The farmers there practice direct sowing (without much success) either with hoeing-weeding or with the "Zai" technique: before the rainy season, holes are dug at spots meant for future planting hills. The soil from these holes are mixed with manure.
This demands a lot of time before the rainy season. Mechanical tillage of the soil combined with plot management could help restore the fertility of these areas which have become wasteland.

Even though Yatenga is located in an area with climatic risks, no experiments in soil tillage have been conducted there. The GERES program which managed thousands of hectares between 1961 and 1964 did not undertake any studies of this kind (very little field materials were then available). However this project recommends raised ridges or banked-up bed cultivation, depending on the contours, to reinforce anti-erosion devices.

From 1982 to 1984, IRAT carried out two water economy trials at Ziga and Sabouna. The objective of the trial was to make an internal comparison of different techniques with a control that has not been tilled (direct) sowing is practiced on over 3/4 of the cultivated area). Treatments were chosen from observations of farmer practices and working day availability before sowings. Thus in 1982 we compared two ridged spacings at Sabouna. This was related to the fact that some farmers who had tested this technique in 1981 made ridges which were less spaced as compared to ridges of those conducting the experiment (0.60m between rows instead of 0.80m). We also tested repeated weeding after each heavy rainfall (that is five to six weedings for a plant cycle of 90 days), so as to break the soil crust and thereby reduce the run off.

During a meeting we had with the farmers, they recounted the difficulties they had in tilling large areas of land before July 10. Thereupon, we proposed a treatment that will postpone soil tillage (even though limited in this case) until after sowings. The sowing consisted of row cropping on soil that had not been tilled or cultivated.[1] A month after ear emergence, oxen were used to make ridgings which were manually tied (1m to 1.5m between ties).

At Ziga, the trial was carried out on a shallow soil that was sandy-gravelly on the surface and sandy up to 60cm. Beyond this, the hardpan was cropping out. The trial with local sorghum in 1983 failed, mainly because the soil suited millet. At Sabouna, the trial was sited on a sandy soil (0.30cm) covered with a brown entrophic horizon, more clayey and well structured.

We will discuss here, grain yield from different treatments. Various comments on water and crop profile were made. Moreover these comments have been published (cf list of references).

The difference between the control and various soil tillage treatments was more pronounced when the year was dry (zero yield on the control at Sabouna in 1984). In a year such as 1982 with 400mm of satisfactorily distributed rains, yield gains were around 30% in the case of flat tillage as compared to the control. This gain corresponded to that obtained under analogous climatic conditions for millet cultivation in Senegal. On the other hand, in 1983 and 1984, there were considerable disparities. On the two sites and for the two years, yield from the control did not exceed 150 kg/ha. Irrespective of the techniques used, the farmer largely lost his additional working hours.

Differences between the techniques. In 1982 tied ridging did not result in any benefit from the additional work involved; flat tillage offered the best yield. In 1983, a year with poor rainfall distribution in August, tied and ridged treatments exceeded flat tillage but this difference was not significant. In Ziga where stalk results were significant, flat tillage treatment (Table 4) and flat tillage with tied ridges exceeded the other treatments in terms of dry matter weight.

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[1]Scarification (in moist soil) reduces labor time by 50%.

Table 4. Results of water economy-soil tillage trials. Yatenga, 82-83-84.

Treatment	Sabouna millet 1982	Sabouna millet 1983	Ziga 83 Sorghum grain (straw)	Sabouna 1984 sorghum	Ziga 1984 millet
	kg/ha				
Direct sowing	1083	150	157(1324)	1	69
Flat tillage	1378	609	204(2538)	166	130
Ridging (0.80m)	1267	565	134(1803)	421	258
Ridging (0.60m)	1255	-	- -	-	-
Flat tillage, then ridging, then tied ridging (3 weeks after)	1314	725	- -	118	-
Direct sowing (or cultivation) then repeated hoeing (5 to 6 times)	1099	535	381(2248)	-	346
Flat cultivation and tied ridging	-	863	236(1730)	89	348
Flat tillage, then tied ridges	-	-	217(2931)	330	456

The trial at Sabouna in 1984 was almost completely destroyed by drought. At Ziga a positive effect of treatment involving mounding and ridging was noted with the local millet after sowing. Before sowing, these two treatments were ploughed or cultivated.

Due to problems posed by successive drought periods, this first experimentation phase can only enable us to draw partial conclusions for the time being:

(1) Any soil tillage techniques largely surpass the direct sowing control.

(2) In a normal year (it is estimated that 400mm of appropriately distributed rains suffice for a 90 days millet) flat tillage is equivalent to ridging treatments.

(3) The two "alternative" treatments (not tilled before sowing but ploughed from then on) are not rejected for purposes of pre-extension. These two treatments help to defer the labor peak period to the sowing period.

These results will be discussed in relationship with the present situation of farmers from the Yatenga. In 1981, voluntary farmers from Sabouna were proposed a land improvement technique package: ploughing + manure (5t/ha) + mineral manure (NPK or natural phosphate + urea) + conveniently timed weeding. This technique was maintained up to 1984. We developed soil working trials in the two areas in 1984 and partially in 1983.

Due to random response to mineral manuring in this semi-arid area, we intend intensifying the pre-extension of the already experimented water economy techniques from 1985 onwards.

Soil tillage x sorghum variety tests on lowlands; Sabouna, 1983-84. The objective of this test was to evaluate the effect of lowland cultivation with three sorghum varieties. It was noted that farmers did not work on this type of soil because they considered it too tedious for the traction and less atttractive from the point of view of yield.

The response given to tillage was high in respect to the two improved varieties which exhibited their genetic potentials in spite of low rainfalls (Table 5). Apart from beneficial effects of ploughing on the rooting system (it develops faster with ploughing on this type of clayey soil with a uniform structure) and water storage at the initial and final phases of the cycle, it is worthwhile noting that soil tillage also helps in checking weeds. Where farmers have their plots on the lowlands, weeding constitutes the major limiting factor to sorghum cultivation. Some of the farmers who paid visits to these trials in 1983, ploughed their lowland fields in 1984.

Soil tillage trials x sowing date; Sabouna, 1983. The objective of this trial carried out on farmers' fields was to compare three sowing dates and three soil preparations:

(1) direct sowing,
(2) farmer tillage,
(3) tillage with IRAT traction equipments.

Table 5. Results of sorghum trials on lowlands: mean yield of the four plots at Sabouna.

Variety	1983		1984	
	Ploughing	No ploughing	Ploughing	No ploughing
	kg/ha		kg/ha	
IRAT 204	2475	1296 + 86%	2404	1874 + 28%
IRAT 202	2220	1531 + 45%	2328	2047 + 14%
Local	1940	1516 + 45%	1234	1226 + -

The idea of this protocol emanated from the fact that farmers were waiting until the end of June or July before beginning to plough (this timing helped to eliminate the first weeds) certain fields (very often for groundnuts) while reserving the effect of the first rains for direct sowings. This conflicted with extension recommendations which specify that ploughing must go with the first rains.

Without ploughing, yield was very low irrespective of sowing date, around 1 qx/ha (Table 6). Flat tillage made it possible to obtain a production level around 3 to 4 qx/ha. Even if this level of yield is low, this difference of 2 qx/ha is significant if we consider the food situation of the farmer and his family. The ploughing made by the farmer gave lower yield than that of plot under IRAT management in two out of three cases.

Paradoxically, plots that were sown late produced the best yields. This is understandable in so far as millet is highly sensitive to photoperiodism. Furthermore there were several phases of the drought (second 10 days in August = 20mm, third 10 days in August = 80mm) affecting particularly the early sowings.

Table 6. Test results of millet sowing date x soil tillage.

Soil tillage	Sowing date	Yield
		kg/ha
Direct sowing	26 June	107
Farmer tillage	26 June	180
IRAT tillage	26 June	331
Direct sowing	4 July	90
Farmer tillage	4 July	261
IRAT tillage	4 July	371
Farmer tillage	11 July	412
IRAT tillage	11 July	361

Tied ridges test; Ziga-Sabouna, 1984. In the course of our contacts with producers from two villages we made the proposal to compare the following three soil tillage techniques:

(1) direct sowing,

(2) flat tillage before sowing,

(3) ridging, then ridge tying one month after ear emergence.

Due to the June-July drought, farmers could not perform these tests. Ridging required a soil-moistening rainfall of at least 20 to 25cm.

In 1984, farmers ploughed even though soil dampness ranged between 10 and 20cm depth. The test was resumed in August on plots where there was row cropping but where nc prior soil tillage had been effected, comparing flat weeding and tied ridges. A look at the effect of tied ridges on grain production shows that the yield obtained was low (Table 7). This proves that a month or a month and a half after sowing, it is difficult to "receover" the initial situation (i.e. in this case, direct sowing which does not favour crop vegetative growth) On the other hand, it was too late when farmers ridged (95mm of rains were recorded at Ziga after August 31 and 73mm at Sabouna), making it impossible to store large quantities of water for the end of the millet cycle. On some plots, the effect was either nil or negative (light sandy-gravelly soil). This technique involving additional work at the second weeding, must only be applied for certain soil types and areas with pronounced run-off.

Table 7. Results of tied earthing up trials on millet.

Treatment	Sabouna[1]			Ziga[2]		
	First earthing up date	Last earthing up date	Yield	First earthing up date	Last earthing up date	Yield
			kg/ha			kg/ha
Flat weeding	-	-	183[3]	-	-	198[4]
Tied earthing up	August 20	August 27	280	August 20	August 31	270

[1]Mean of 7 locations.
[2]Mean of 9 locations.
[3]Two weeded plots gave no yield.
[4]One weeded plot gave no yield.

Observation of crop profiles after tillage. A soil tillage technique must first of all be assessed at the level of crop profile. In 1984 we made several series of observations on plots tilled by farmers after June 28 rainfall (15 to 20 mm depending on Sabouna village soils). These observations are presented in the form of diagrams.

The profile (Fig. 4) is dry on July 2; no moistening front. The tillage was achieved on June 28 on a rather dry soil, hence the presence of quite hard thick clods on the tillage strips. The fine soil is located in the furrows.

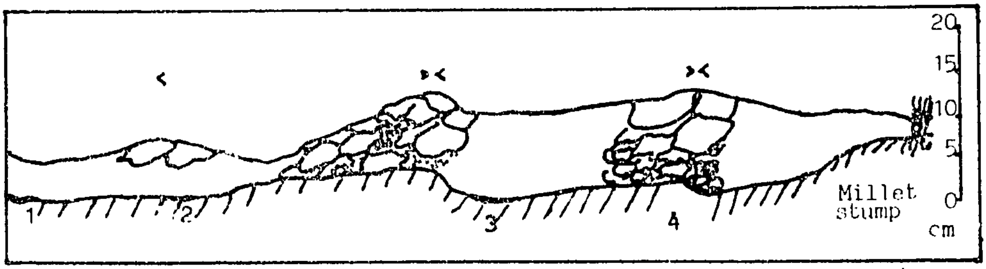

Fig. 4. Observation of crop profile after tillage (K. Salif - 1st observation).

Horizon tilled dry to wet (Fig. 5); the hardpan is wet; no thick clods; small crumbly clods. Tillage more regular, deeper (9 to 15 cm).

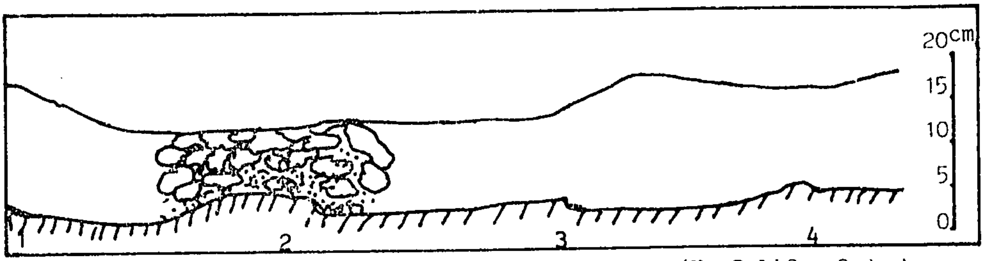

Fig. 5. Observation of crop profile after tillage (K. Salif - 2nd observation).

From these observations the poor quality of tillage effected by Sabouna farmers can be noted. This is mostly due to the spacing between passes of the plough. Farmers tried to plough the field too rapidly and carelessly which resulted in depth and profile irregularity. The plough is sometimes leaning and thus creates here and there poorly ploughed areas which are detrimental to rooting.

In Fig. 6, the farmer achieved very uneven and spaced tillage. The pass of the plough (too much leaning) can be clearly observed. The tilled horizon is dried up; the underlying horizon is wet up to 25 cm in depth.

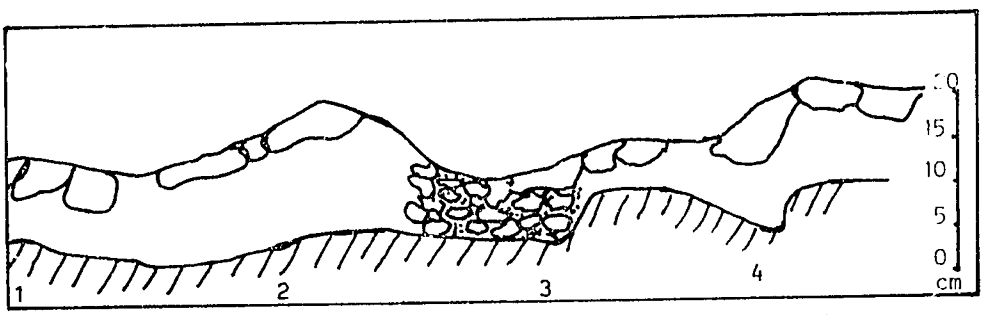

Fig. 6. Observation of crop profile after tillage (sandy soil).

In Fig. 7. the tillage was done on dry and compact soil; the profile is totaly dry. The worked horizon is composed of small crumbly clods. Highly superficial tillage equivalent to a scarification.

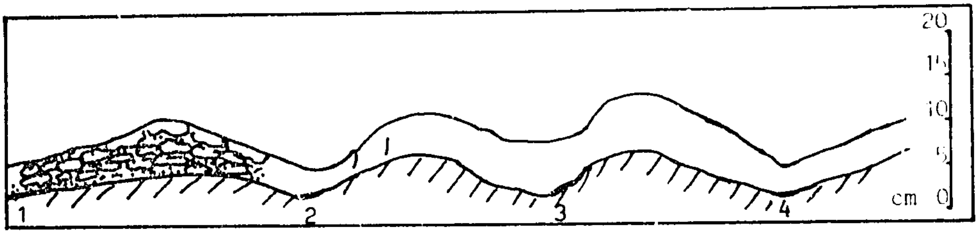

Fig. 7. Crop profile after tillage on degraded clayey (sandy soil).

Ideal tillage (Fig. 8) is difficult to achieve at such a date due to the low rainfall - depth ranging between 15 cm and 20 cm. - tight tillage strips - pass every 20 - 22 cm. Horizon composed of clods and fine soil.

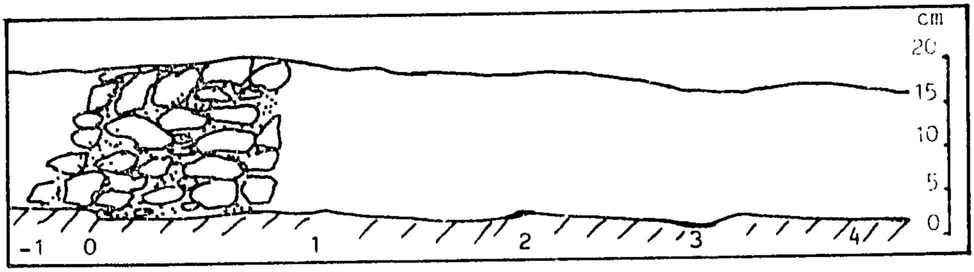

Fig. 8. Diagram of profile after "ideal" tillage.

Farming timetable: utilization of animal traction equipment on three farms in the Yatenga. We present below three cases studied since 1982 to determine the degree of animal traction utilization by the producers. We shall mainly refer to the 1983 farming season. 1984 may be considered as a very exceptional year and not in the least conducive for soil preparation before sowing.

It must be noted that these three farmers do not weed mechanically and do not practice row cropping. The number of active workers (Table 8) on the farms helps to synchronize tilling and sowing on all three farms (two to three persons are in charge of ploughing).

Table. 8. Equipment of the three farms surveyed, 1983.

Name of farmer	Basic equipment	Secondary equipment	Draft animal	Number of active workers
Abdoulaye	Complete multiculti-vator (ORD) credit 1981	No furrower	1 draft ox 1 donkey	6
Salif	Cattle plough (ORD credit 1979)	No furrower 1 plough	3 draft oxen	5
Mahama	2 ploughs 1973 (re-paid 1981, ORD credit)	No furrower	2 oxen (but not used ORD credit 1 horse	7

The importance of sorghum on these three farms is worth noting (Table 9) this is related to the type of soil cultivated. Groundnut undergoes considerable speculation by the farmers, Abdoulaye and Mahama. These three farms are characterized by hectarage ratio cultivated by number of workers exceeding the average which is around 0.8 ha/worker.

The distribution of soil types according to farms is very different (Table 10). However all these farms have fertile lands which are difficult to plough either lowlands or on piedmont (brown eutrophic soil of the depression). These soils are however tillable if the rains are sufficient at the beginning of the rainy season (these soils moisten more slowly than light soils). Gravelly soils are of minor significance and the farmer, Abdoulaye can not ever plough the hilly lands which are too sloping and stony. We can then estimate the size of tillable and easily tillable area for three farms (this corresponds to light soils).

Table 9. Crop rotation in 1983, including individual fields.

Farmer	Millet	Sorghum/ millet	Groundnut	Maize	Rice	Cotton	Sesame/ sorrel	Total	Per worker
	ha								
Abdoulaye	2	2.55	0.80	0.05	-	0.40	0.80	6	1
Salif	1.98	2.21	0.32	0.15	-	-	-	4.72	0.94
Mahama	5.05	1.65	1.30	0.15	0.12	-	-	8.35	1.19

Table 10. Distribution of soil types.

Farmer	Brown eutrophic or clayey sandy	Grav-elly	Sandy	Hilly low-land	Clayey low-land	Size of til-lable area	Size of easily tillable area
	%[1]					ha	
Abdou-laye	54	7	17	22	-	4,68 (78%)	3.57 (59%)
Salif	9	7	37	-	47	4,72 (100%)	2,50 (53%)
Mahama	-	7	73	-	20	8,35 (100%)	6,68 (80%)

1Percentage of total cultivated.

Soil preparation dates in 1982, 1983 and 1984. For each cropping season, rainfall days and days of tillage by farmer are graphically represented (Figs. 9, 10 and 11).

Days for soil, preparation. External ploughing corresponds to the hiring of services to another farmer or to a Fulani herder (case observed in 1984). It was in 1983 that farmers mostly ploughed (with the plough, no shallow cultivation with the hoe). The number of available working days in 1983 exceeded those of 1982 and 1984. Moreover, plots were directly sown in 1982 after the May early rains (from May 7 to May 30). As a result, the number of working days in 1984 was greater than or equal to the number of working days in 1982.

Date of soil preparation. Except in a few cases, farmers mostly ploughed in July and even at times in August and during the last 10 days in June. Farmers rarely utilized the early rains (those of May 1982 and May 1983) even on lowlands where the runoff provides some water. It is necessary however to draw attention to some ploughing trials on lowlands at the beginning of the rainy season; May 27, 1984, Mahama; June 11 1984, Salif; June 4 and 5, 1982, Salif. On the other hand, farmers may not hesitate to plough and sow late in the season, after July 15; in 1983 almost 40% of soil preparation days were after this date. The same thing happened in 1984 when rains occurred around late July, early August. In July, these farmers feel that sowing is only possible (millet or groundnut or early IRAT 204 type of sorghum) if the soil is tilled.

Groundnut maize and sesame fields are systematically ploughed (as well as individual fields) and sowed lately. In 1983, the farmer Salif, tilled fields on areas next to lowlands and then grew sorghum on these areas. This late tillage (July 3 to 6) was inevitable since he would not have sown earlier (with the May 26 or June 10 and 19 rains) in view of grasses that had grown on these plots by that time, he preferred to plough the lowland.

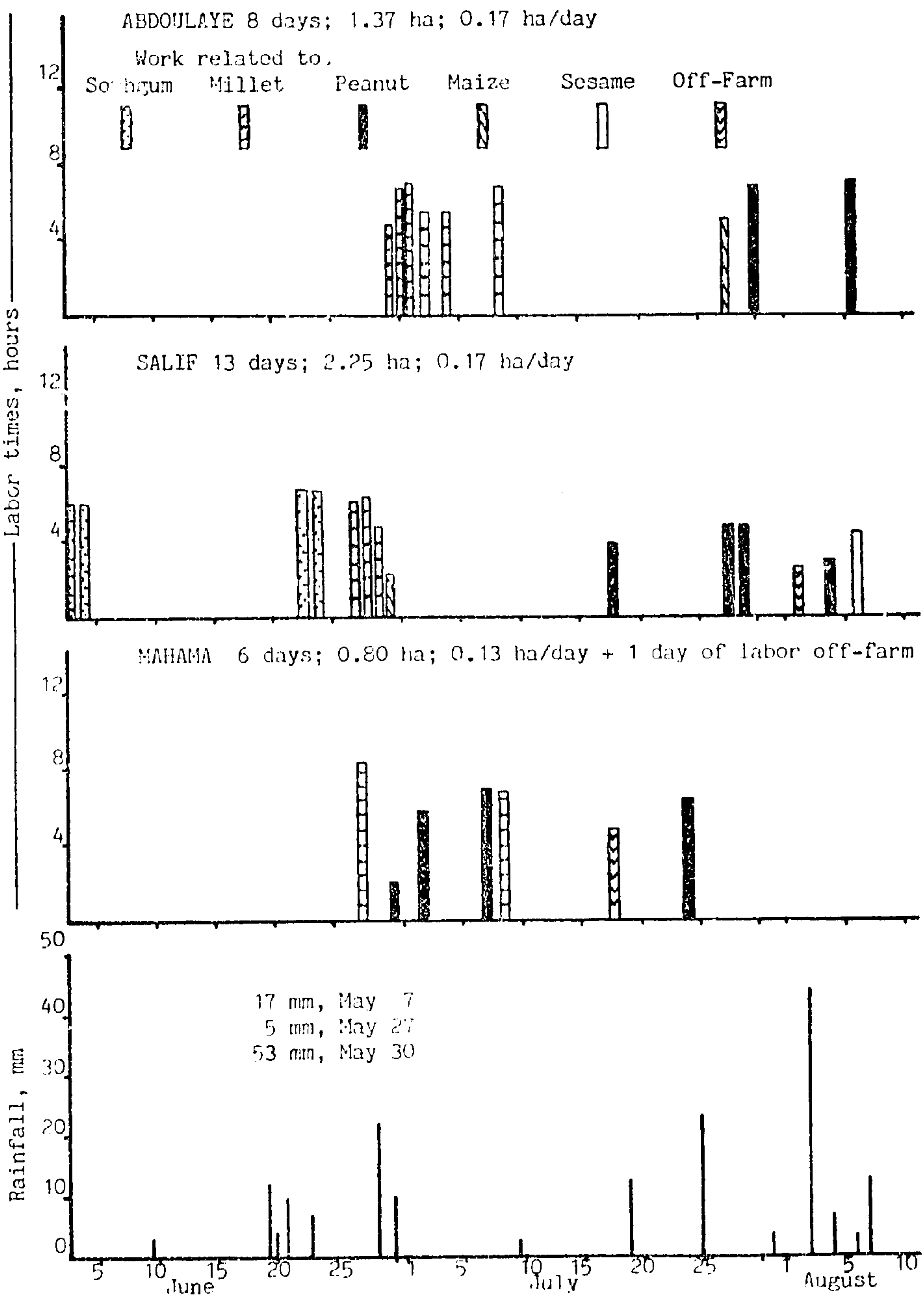

Fig. 9. Rainfall and number of days of fieldwork, 1982.

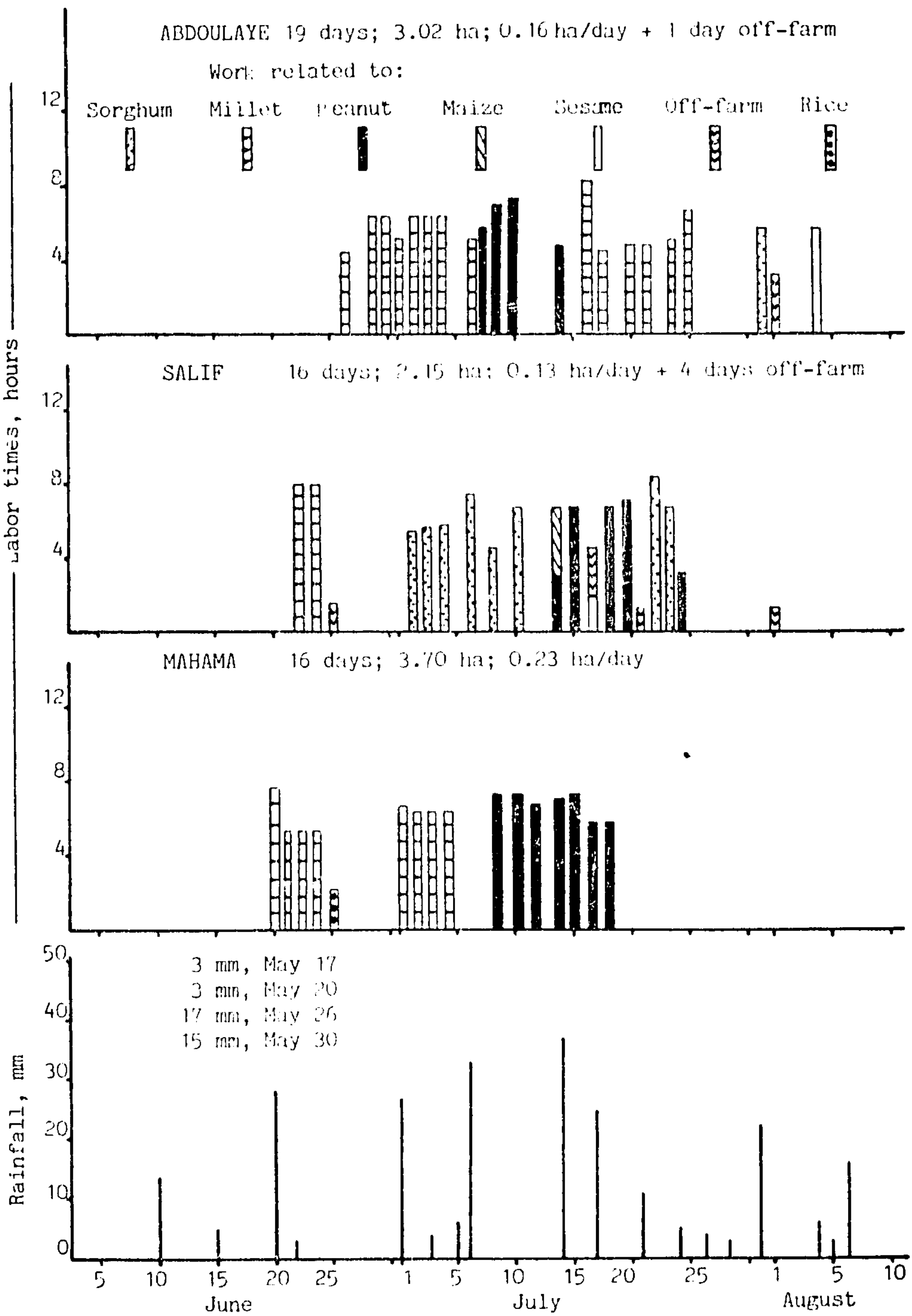

Fig. 10. Rainfall and number of days of fieldwork, 1983.

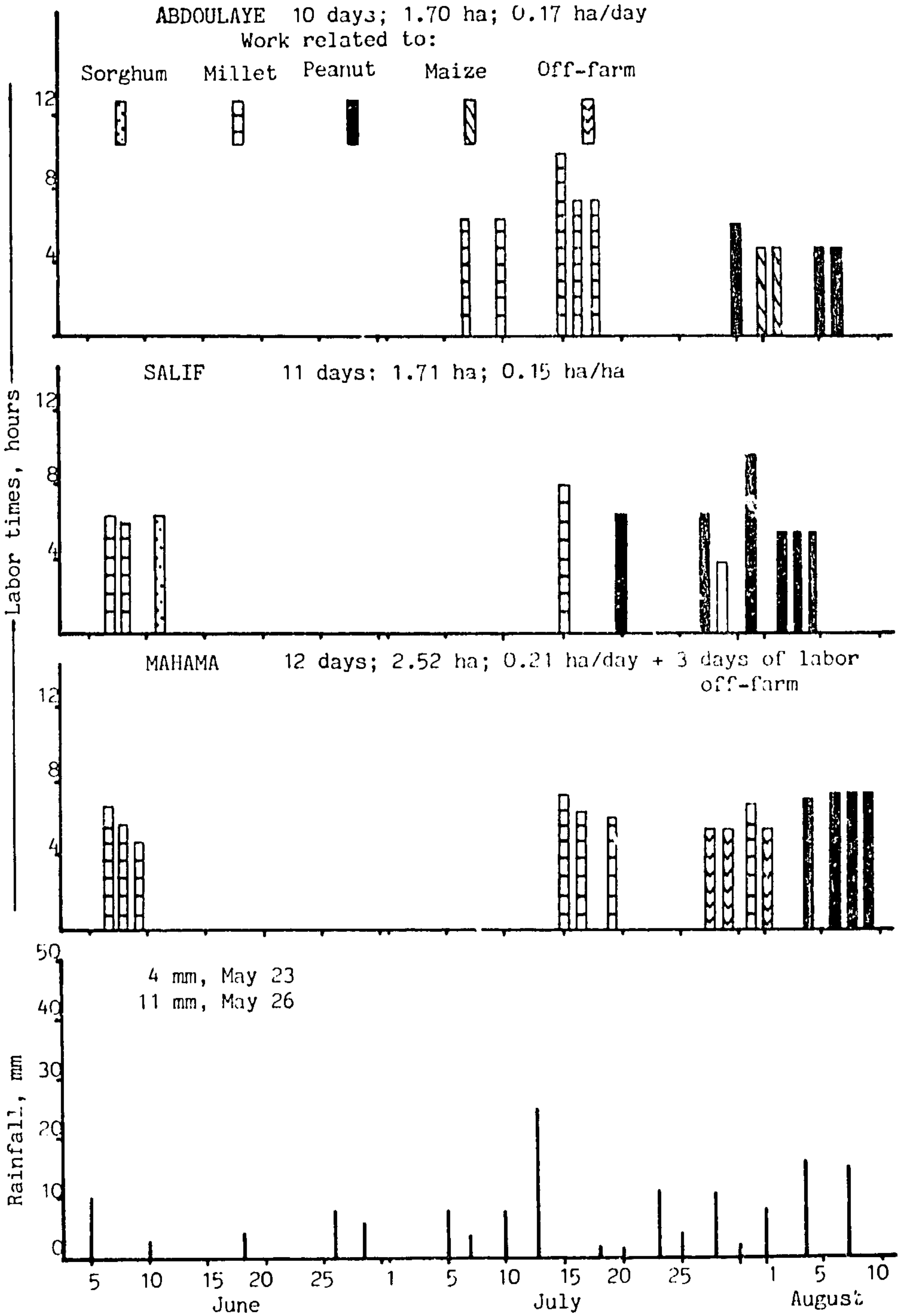

Fig. 11. Rainfall and number of days of fieldwork, 1984.

Table 11. Enumeration of ploughed areas according to crop, 1983.

Farmer	Crop					
	Millet	Sorghum	Groundnut	Maize	Rice	Sesame
	%					
Abdoulaye	61	8	20	5	--	6
Salif	28	44	23	5	--	-
Mahama	5	-	42	-	3	-

Tilled and tillable areas. Draft oxen are rarely capable of working at the beginning of the rainy season due to the scarcity of fodder (farmers do not have the necessary financial resources for purchasing concentrate, bran, cotton grains and cotton seed cake...).

The average area of land tilled per day does not exceed 0.23 hectares and in fact the average is around 0.17 ha/day. Post-tillage seedbed examinations have however shown that farmers do not properly space successive passes during ploughing. Farmers space successive plough passes widely apart to make a time saving of 30 to 50% as compared to correct tillage (20 cm spacing). Studies made on soil preparation at experimental stations indicate that a pair of oxen are capable of ploughing about 0.25 ha daily.

Here, we only take into consideration, estimates of tillable areas based on soil type (see Table 10). It is not possible for Mahama to till 6.68 ha per annum using a single traction (in view of the limited availability of working days, Table 12). Salif is the most regular, where between 75% and 90% of easily tillable areas are tilled (our argument follows these lines in view of the technical standard of the farmers and the condition of the draft animals.

Table 12. Tilled area, tillable and easily tillable area.

Farmer	Tillable area (A)[1]	Easily tillable area (B)	Tilled area 1982 Ha	1982 % of A	1982 % of B	1983 Ha	1983 % of A	1983 % of B	1984 Ha	1984 % of A	1984 % of B
Abdoulaye	4.62	3.57	1.37	29	38	3.02	64	84	1.70	36	43
Salif	4.[illegible]	2.50	2.25	48	90	2.15	45	86	1.71	36	68
Mahama	8.4[illegible]	6.68	0.80	10	12	3.70	44	53	[illegible]	30	37

[1]The cultivated land hardly varies from one year to the next. Fallowing is almost nil.

It therefore seems (except to a lesser degree for Salif) that farmers use tillage primarily as a catching up and weeding technique when the rainy season is belated. There is no systematic utilization (for example ploughing a field every two years) of animal traction. The 1982 results clearly show this.

Farmers using animal traction apply the following strategy:

(1) direct sowing in conjunction with the early rains (May, early June and even April on lowlands) even if this entails risks of having to make several resowings; in 1982 areas which had to be resowed were small and therefore available land to be ploughed was limited;

(2) late June, continuation of direct sowings and tillage of the most grassy plots;

(3) early-July, fields where sowings were unsuccessful were tilled and resowed ("catching up" technique);

(4) late July and early August, tillage and sowing of groundnut, sesame and maize-when the major crop (sorghum and millet); are well established in exceptionally dry years, lands on which millet could not survive are tilled and the millet resown.

Available and necessary working days. Rainfall distribution is the baseline data for calculating the number of days available for soil preparation (Table 13). Sowing must be terminated before July 10.

Table 13. Days available for soil preparation.

Year	Days available before July 10 (corresponding tilled hectares)	Days available before July 31	Maximum and Minimum Before July 10	Maximum and Minimum Before July 30
	day			
1982	8 (2ha)	11	8-5	11- 6
1983	13 (3ha)	20	11-9	19-16
1984	2 (0.5ha)	8	2-4	9-6

Available days before July 10 are very important and farmers attempt to sow as early as possible. Consequently, farmers have a tendency to till soils that are too dry during the period late June to early-July (especially in 1984). After July 15, the soil is generally quite wet, but after this date, it is inadvisable to sow except sesame (July 15- October 15, 90 days). In this case, it is impossible to plough all of the easily tillable areas before July 10 using a single traction. In 1983 (the most favorable year) Salif was able to till all of his land. Abdoulaye tilled 84% of easily tillable land while Mahama tilled only 45% It is therefore necessary to develop other strategies for purposes of better utilization of resources existing in the Yatenga.

CONCLUSION

Various remarks that have been made within the past three years (particularly dry years) in the Yatenga with respect to crop profile and farming systems, make it obvious that animal traction equipment potential (draft animals and equipment are underutilized. Even if farmers, researchers and development agents agree that soil tillage before sowing is important the practice is only used on limited areas where only late cropping is practiced. This is related to different constraints:

(1) The most important constraint is the poor condition of draft animals. The lack of village groupings and acricultural development organizations is a serious problem; this restricted the use and value of agricultural by-products, which could have been utilized for draft livestock.

(2) The second constraint is illiteracy among farmers. They hardly know how to use row cropping, the furrower, the cultivating yoke and the ridger (even though they have bought them).

These constraints (including of course the poor maintenance of equipment) largely limit the possibilities of preparing the soil before sowings, more so when the available number of days before July 10 is limited (about 8 to 10). It becomes necessary therefore to work with maximum efficiency now and anticipate the use of two pairs of draft animals per farm.

Experiments on different water economy techniques carried out by IRAT in the Yatenga also demonstrate that soil tillage activities could be postponed. Accordingly farmers must be initiated to tied ridging which must be done just after tillering (in our view, manual ridging does not seem to lend itself for extension at least on large areas). However, the risks involved in direct sowing in dry years are now known: rampant lateness of plants, more frequent resowings. These risks are all the more pronounced on soils with a destroyed surface structure and these soils are increasingly frequently cultivated.

From the development perspective, optimum utilisation of animal traction could be envisaged in the Yatenga (Bara, 1976) by combining anti-erosion management of plots and different soil tillage techniques: early tillage in the lowland areas, flat tillage before sowing in other areas, depending on the contours and shallow cultivation (wet), then tied ridges on areas that could not be tilled before sowing.

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WATER AND SOIL CONSERVATION BY FARMERS

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The agroforestry project of OXFAM[2] is located in the Yatenga province of Burkina Faso. There have been two phases:

(1) research, 1979-1982,
(2) extension, 1983-1986.

The objective of the research phase, with the participation of the farmers, was to develop water harvesting techniques capable of stabilizing the degradation of the environment while increasing the productivity of the soil. The extension phase aimed to spread the utilization of the techniques to a maximum number of farmers within and outside the region through short, intensive training sessions.

The degree of desertification of the Yatenga region is striking. Eleven percent of the region had become unproductive by 1973, and the trend continues (Marchal, 1983). Near Ouahigouya (administrative center for the region) the effects of erosion is spectacular. The relief, developed in long, low sloped, is subjected at each rainstorm to surface flow which, having removed the topsoil from the upper slopes, currently is eroding the mid slopes-and this more so due to their continuous cultivation-then finally seals the soils of the lower slopes (Marchal, 1979). Due to the high population density in the region (75-100 persons/km^2) desertification holds a dark future for many in the Yatenga.

The land degradation includes not only the loss of soil but also an increase in runoff and subsequently a reduction of infiltration, in a region where water is already the limiting factor of production (average anual rainfall is 680 mm). Two suppositions were made in view of the above situation:

(1) runoff water could be used more efficiently for productive purposes,
(2) the farmers should be interested in such possibilities.

In 1979 OXFAM provided funding to test these suppositions with an expatriate forester familiar with the region.

METHODS

The first participants in the project were members of eight village pre-cooperatives (groupements) suggested by a local forest service agent. During group meetings the participants and the project personnel discussed the environmental degradation and some possible actions.

Initially the project oriented its activities towards forestry with emphasis on the planting of local species of value to the villagers. It was suggested that the probability of tree survival would be increased with a rectangularly disposed network of earthen barriers called micro-catchments

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(Shanan and Tadmor, 1979). The barriers collected rainfall surface runoff, thereby enhancing the survival of the trees planted therein.

The microcatchments were constructed collectively by the members of each groupement on collectively owned fields. Several participants also tried one experiment on their own fields. Choice of sites was left to the discretion of the farmers, but while encouraging experimentation, the project personnel suggested that the more degraded areas may be of interest due to the abundant runoff available for collection.

An iterative process was used throughout the period of 1979 to 1982 whereby observations were solicited from the participants at the end of an activity or season. Intergroup visits to other farmers' fields increased the breadth of the observations. The farmers' observations were evaluated by the project through direct measure (e.g. percent tree survival) or subjectively. Any innovations or orientations were then suggested for testing in the following season or session. Through this process the original rectangular network of microcatchments was changed to an open 'v' form to reduce the labor input necessary, and local rice was sown in some of the water catchment plots where the water and soil characteristics seemed suitable to the farmer. Sorghum was accidentally sown in some plots along with the trees. At the end of the first season the farmers were especially encouraged by the success of the cereal crops and in subsequent years action was oriented more towards cereal crops. At the end of three years three definable aspects were apparent in the farmers' orientations :

(1) agricultural production dominated the participants' interest more than planting trees,
(2) the number of private fields with barriers outnumbered collective fields,
(3) the individual trials reflected an appreciation for techniques and construction methods of local origins but which had fallen into disuse.

Two aspects of the initial orientation remained in the farmers' trials :

(1) the treatment of degraded soils and abandoned fields,
(2) the capture and exploitation of runoff water.

The innovations noted in some of the individual farmers' trials were primarily the placing of barriers across waterways. These barriers were made with bundles of stalks or branches fixed to the ground with stakes or low walls of rock or rock/earth. The most efficient in terms of water retention and labor input were those barriers which followed the contour lines.

Two instruments introduced by the project in 1982 presented the possibility of determining contour lines to the farmers. A 'triangle' made of wood with a plumb line, was not appropriate because of the wind and low slopes. After a year of trials in the hands of farmers the 'water tube' appeared practical and precise.

At the end of 1982, the spontaneous adoption of the trials by over 100 farmers, the spectacular reclamation of several degraded fields[1] and the feasibility of the water tubes convinced the project personnel that it was proper to initiate an extension phase.

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1 The farmers in the village of Kao treated an abandoned terrain with no 'A' horizon and produced 1200 kg/ha of paddy rice and sorghum in 1981.

The approach used in the extension phase resembled that defined during the first phase:

(1) training was given directly to farmers; the extension agents of the Regional Development Organization who wanted to participate were trained along with the farmers,

(2) intergroup visits were used to facilitate observations and the exchange of ideas between inovative farmers,

(3) the empirical nature of the activity was underlined: farmers must adapt the techniques to each situation.

Training of farmers (and extension agents) concerned principally the use of the water tube to determine the contours. After each two or three day training session each groupement was given a water tube and the members were invited to try the techniques on their private fields (results from collective fields were often discouraging or unrepresentative).

RESULTS

By 1984 training in the use of the water tube had reached over 500 farmers in more than 100 villages of the Yatenga. A survey of 313 fields treated by farmers using the water tube was performed to characterize the application and techniques. Typically the farmers constructed barriers of 10 to 50 centimeters high and 10 to 100 meters long or longer, placed along the contour lines as determined with the water tube. The barriers were constructed on individual fields rather than on a large scale such as the watershed. Barriers were mostly of permeable design, permitting runoff water to pass either through or over each barrier. Construction materials used for the barriers were rock, stalks or branches tied in bundles, or live vegetation (grass, Euphorbia spp., etc). Barriers constructed with only earth were rare. Rocks were greatly the preferred material and farmers would transport rocks with donkey carts from distances up to 4 km.

Spacing between barriers was chosen by each farmer and varied from 10 to 50 m for slopes of 0.5% to 2-3%. If because of shortage of labor (the principal constraint) a farmer was unable to construct barriers at a proper spacing; he would construct a few barriers at large spacings across the entire field during the first year and add other barriers between the existing ones during following years.

Fields chosen for treatment were bush fields in 70% of those surveyed. In the most degraded zone of the Yatenga around Ouahigouya, 45% of the fields were on abandoned land--barren, crusted soils. Barriers were oriented to permit the capture of sheet flow originating from the degraded surfaces upslope from these sites. Indeed, for one third of all fields surveyed, farmers made a point of diverting waterways into the fields.

The majority of treated fields received no other soil treatment (58%). Only nine percent were plowed with animal traction, while 33% were treated with "zai" (water pockets) which represent an efficient traditional method of water harvesting and management of organic matter (e.g. manure). Manure was applied to 60% of the treated fields, and those who used "zai" always associated manure with the pockets. Less than 2% of all fields received chemical fertilizer. Soil types associated with the treated fields surveyed typically were those found on the mid-to upper-slopes of the soil catena, with the exception of sandy soils.

Economic analysis. Certain costs and benefits associated with the treatment of fields were evaluated from the point of view of the farmer and the project.

Project costs per hectare (Table 1) include all real annual expenses of the project,, less salaries of governmental personnel, without depreciation of capital expenses (vehicles). It is intended to give an appreciation for the evolution of costs rather than exact costs for any given year.

Table 1. Evolution of project costs.

Year	Annual cost	Surface area treated/yr	Cost/ha
	CFA	ha	CFA
1981	5,400,000	7	771,400
1982	5,400,000	62	87,100
1983	13,600,000	150	90,700
1984	13,345,000	327	40,800
1985	10,400,000[1]	600[2]	17,300

[1]Annual budget for 1985.
[2]Projected.

Average grain harvests of sorghum and millet measured on 100 m^2 plots placed in treated and untreated fields from 1981 to 1984 are presented in Table 2. The choice of untreated (control) fields presented a problem in those cases where the treated field was on an abandoned site: a control field on the same soil would produce nothing. In those cases the control fields had the advantage of being situated on soils superior to the treated fields.

All yields reflected a decrease in rainfall from 1981 to 1984, but the difference between yields of control plots and treated plots became increasingly significant as indicated by the Z-test. In 1984 the average yield per hectare on treated fields was 290 kg as compared with 155 kg on control fields: an average increase of 135 kg/ha.

Table 2. Evolution of yearly rainfall and cereal yields, sorghum and millet.

Year	Annual rainfall	Control Plots Number	Control Plots Yield	Treated plots Number	Treated plots Yield	Z
	mm		kg/100 m^2		kg/100 m^2	
1981	692	3	5.10	14	8.57	-
1982	421	45	4.42	47	4.95	1.26
1983	413	37	2.95	63	4.18	3.01
1984	383	72	1.53	74	2.92	3.89

[1]Average of 3, 7, 5 and 6 villages in respectively 1981, 1982, 1983 and 1984.

The quantity of food necessary to supply the labor required to construct the barriers was estimated from cereal banks placed in 53 villages in 1984 as a means of promoting mutual aid between farmers. For more than 20 tons of cereal distributed the rate of consumption was on the order of 90 kg of cereal per hectare treated. It appears therefore that the labor cost, when measured in cereal, may be repaid with increased harvests during the first season.

There is reason to believe that the increase in yields between treated and untreated plots from 1981 to 1984 was also due to soil improvements as well as improved water management. Besides the observation of soil deposits and organic matter, the pH of two degraded sites treated with barriers and organic matter was measured. After one year the untreated soils had a pH of 4.7 and 4.8 while the treated soils had a pH of 6.6 and 5.7 respectively.

DISCUSSION

Farmer Participation. The key to effective farmer participation was to find and encourage their innovative spirit. This spirit is by no means monopolized by the influential members of the society. To the contrary, some of the first farmers to experiment with the techniques in their fields were accused by non-participants of being crazy. Once discovered, this spirit was easier to encourage. Discussions in private as well as in groups, visits to other villages, the engagement of "experienced" farmers in the training of new farmers: these served to open the communication between technicians and farmers and between farmers themselves. This is important because no member of the society wants to feel like an outsider. He must be shown that he is not alone in trying to innovate.

Initially, the role of trees was emphasized in the farming system, but through the active participation of the farmers this orientation was modified as well as the techniques themselves. This is attributed to the immediate impact noted with the cereal crops, in contrast to results obtained with tree planting. Not only did the trees take much longer to achieve economic usefulness, but the problem of protecting them from animal browsing confronted the existing farming system: There could be no control of animals' access to fields (site of the tree planting) except by decision making of a political nature at a level well beyond that of the individual farmer. As such farmer's participation served to orient the project towards the most urgent needs while taking into consideration the constraints imposed by the farmers' environment. This does not mean that the need to improve the physical environment and farming methods by planting/protecting trees was ignored by the farmer, only that the possibility of doing so did not exist at the time.

Techniques. Farmers participating in the project undertook the construction of barriers in their fields for one or several of the following reasons:

(1) to exploit runoff water (water harvesting),
(2) to control the expansion of degraded land or better yet to reclaim it,
(3) to control the loss of manure and organic matter from their fields.

The choice of sites, placement of barriers, and construction materials and methods demonstrated the importance of these goals.

The advantage of water harvesting on certain fields was demonstrated by successful sowing of crops up to one month in advance for other fields as well as better drought resistance throughout the growing season. Early sowing also helped to avoid a labor bottleneck. The use of permeable barriers, stable under submersion, allowed the exploitation of areas exposed to heavy sheet flow of water while increasing infiltration both upslope and downslope from each barrier. The treatment of degraded soils and bush fields permitted the reclamation of lost land and the protection of manure in places it would otherwise be impossible to use. Fields down slope from treated fields also received some protection from heavy sheet flow.

The techniques were practiced by the farmers themselves with available materials. The techniques were easily transmitted and assimilated; a group of 15 to 30 farmers were trained in two days.

The principal constraints to constructing the barriers are related to the labor requirements: availability of rocks (preferred material), labor, and food. Forms of group participation during construction of barriers helped to overcome these constraints while providing a medium for the spontaneous training of other farmers. Those with the means used donkey carts to gather rocks, several have used a dump truck, while most use their heads, baskets and bicycles.

CONCLUSIONS

The agroforestry project was able to motivate and train hundreds of farmers to undertake practices to control the degradation of their land and improve agricultural production with their own means while adjusting to local constraints.

Although the project may be considered a success, the techniques described herein are only a starting point. The need for other complementary techniques, such as agroforestry, remains. But the rational management of the entire rural environment remains intractable, and so, survival too.

The participation of farmers in the conception of a formula for managing their environment can not stop at the individual's level, but rather must include all who use and share the use of a common land. The farmers' participation must become a political reality, a change in the milieu.

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COMPLEMENTARY EFFECTS OF TIED RIDGING AND FERTILIZATION WITH CULTIVATION BY HAND AND DONKEY AND OX TRACTION

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Burkinabe farmers, like most farmers in the West Africa Semi-Arid Tropics (WASAT) are largely subsistence farmers (FSU/SAFGRAD, 1982). In a country where rainfall is limited and unpredictable (Matlon, 1983), farmers are risk averse and work on a limited and fragile soil resource base (Charreau, 1977 and Pichot et al., 1981). Amelioration of the soil base is imperative if it is to support more intensive crop production. Risk is an obstacle to more intensive crop production, particularly when cash inputs are required. Technologies should maximize the use of non-purchased inputs, still using minimal applications of purchased inputs. Technologies should be designed to minimize risk associated with the use of cash inputs. Promising technologies include :

(1) construction of tied ridges resulting in catchment basins to reduce rainfall runoff and thereby increase the amount of water available to the plants, and
(2) fertilization.

Results from experiment station trials have shown that tied ridges can result in significant cereal yield increases compared to flat cultivation or simple ridging (Rodriguez, 1982, 1983; ICRISAT, 1981; IRAT, 1982), but the amount of crop yield response has been variable. Cereal crop yield response in farmer-managed trials has generally been less (FSU/SAFGRAD, 1982; Lang et al., 1983; Rodriguez, 1982) than in experiment station trials.

The variable response from tied ridging is undoubtedly due to several interacting factors, including level of soil fertility, amount and frequency of rainfall, moisture stress at seeding, whether tied ridges are constructed at or prior to seeding, position of crop area along the toposequence, soil type, quality of the tied ridges, and crop growth stage when tied ridges are constructed. Crop yield response to tied ridging is generally greater when soil fertility is less limiting (Rodriguez, 1982 and 1983; FSU/SAFGRAD, 1983 and 1984).

Significant cereal yield responses to fertilization with NPK have been demonstrated (synthesis by Matlon, 1983 of trials by IRAT in Burkina Faso during 1978 to 1982) with financial rates of return of 450, 330 and 37 percent for maize, sorghum and millet, respectively. Farmer-managed trials have shown fertilization to be highly risky in semi-arid conditions. Fertilization of sorghum with 100 kg/ha of 14-23-15 in the 900 mm rainfall zone in Burkina Faso resulted in a 2:1 benefit: cost ratio. Millet fertilized with 100 kg/ha of 14-23-15 in the 500 mm rainfall zone resulted in negative returns (ICRISAT, 1982). In the 900 and 800 mm zones, the proportion of fields where incremental yields did not cover subsidized fertilizer costs were 44 and 70 percent respectively. (ICRISAT, 1982 by Matlon, 1983). In farmer-managed trials by FSU/SAFGRAD, the percentage of farmers who would have lost cash from fertilization

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of sorghum with 100 kg/ha of 14-23-15 plus 50 kg/ha urea ranged from 17% to 58%. The percentage of farmers who would have lost cash by fertilization of millet with 100 kg/ha volta phosphate plus 50 kg/ha urea ranged from 80% to 86% (Lang et al., 1983).

The potential benefits of animal traction include expansion of area cultivated, reduction of labor constraints, and increased yields. The relevance of animal traction to this study is the deeper cultivation of the soil during weeding which enables farmers to construct more effecive tied ridges than with manual cultivation.

The objective of this study is to determine economic returns from investments in tied ridging and minimal fertilization of sorghum, maize and millet under farmer-managed conditions. Data presented here, from trials in 1984, are generally supportive of, but more extensive and conclusive than, data from previous years (FSU/SAFGRAD, 1982; Lang et al, 1983).

MATERIALS AND METHODS

Agronomic and socio-economic research was conducted in five villages (Nedogo, Bangasse, Poedogo, Diapangou and Dissankuy) which represent a wide range of agroclimatic zones and agricultural productivity. In each village a census was taken to identify all households (Lang et al., 1983). From this census a random sample of 30 households was selected. This sample was used as the base for socio-economic surveys which were designed to identify production constraints and to understand the farmers' decision-making environment. A questionnaire was also conducted to find out the extent of adoption of certain technologies. Farmers were asked to comment on the benefits and problems with the new technologies.

Three experiments were conducted on fields of up to 25 randomly chosen farmers in each of one to five villages. The number of treatments for each experiment was five or less. Each treatment was randomly assigned to a parcel of the farmer's field. Parcel size ranged from 0.05 to 0.12 ha, depending upon the size of the farmer's field. The one parcel of each treatment in each farmer's field was considered as an observation. The farmers managed and carried out the experiments and were responsible for all labor inputs. Prior to seeding, FSU field staff stationed in each village delineated each parcel with colored stakes and measured the area of all parcels. FSU field staff frequently visited the farmers to ensure that seeding, application of fertilizer, construction of tied ridges and other tasks were effected correctly and on time. Labour inputs by the farm families were recorded each week by FSU staff on a farmer-recall basis. Prior to harvest, FSU staff evaluated all parcels for general conditons of the crop. Farmers harvested all parcels. FSU staff weighed the harvest from all parcels.

The economic analysis required labor data, prices of grains and fertilizers, and agronomic data. The labor data requirements were the number of hours of labor it took to construct tied ridges and apply fertilizer. For tied ridges, the values of 100, 75 and 75 hours of labor per hectare were used for manual labor, donkey traction, and ox traction, respectively. Because tied ridges are constructed in combi-

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nation with a weeding operation, these figures express the additional time necessary to tie the ridges above that required for the weeding operation. Fertilizer application required 40, 20 or 75 additional hours of labor per hectare when applied, respectively, in the seed rows, or in pockets at 10 to 15 cm from the seed pockets. The labor hour figures are all expressed on a man-hour equivalent basis weighted as follows; one male hour ($\geq$ 15 years) = 1, one female hour ($\geq$ 15 years) = 0.75 and one child hour ($<$ 15 years) = 0.5. The labor data, which was gathered on a farmer recall basis, showed a large variation and with the help of the field staff, the data was carefully screened to arrive at the figures. A 40 CFA/hr opportunity cost for farmers' labor is used in comparing the economic return/hr of the additional labor required to construct tied ridges and/or apply fertilizer.[1] This figure represents a best estimate of the opportunity cost based on field staff observations. Grain prices are the official OFNACER prices in the fall of 1984. The prices are 92 CFA/kg for sorghum, millet and maize. The fertilizer prices are the the official prices (subsidized) in the spring of 1984. The prices are 78 CFA kg for 14-23-15, 88 CFA/kg for urea and 25 CFA/kg for volta phosphate.

Total rainfall during the 1984 growing season was considerably below long-term seasonal average rainfall at all villages. Total rainfall (mm) was 514, 452, 633, 675 and 458 at respectivelly Bangasse, Nedogo, Poedogo, Dissankuy and Diapangou. At Bangasse the rains began early in the season and continued regularly until 15 August. Absence of rainfall from mid-September caused severe drought stress in most cereal fields during flowering and grain fill. At Nedogo rainfall was limited, but occurred regularly and was adequate for fair crop growth. At Poedogo, lack of rainfall delayed seeding of most cereal fields until early July. Beginning mid-July, rainfall was excellent and continued until mi-October. At Dissankuy, lack of rainfall delayed seeding. Throughout the season several large but infrequent rains occurred resulting in several periods of drought stress. At Diapangou, rainfall was limited and infrequent until early July. Rains were small but frequent during September and October.

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[1] Most of the agricultural labor is provided by family members throughout the agricultural season. Although some farmers are able to hire labor in peak periods because of economic or social status, little labor is available for hire at these times. The 40 CFA/hr. opportunity cost is he average of the wagd rates paid for hired labor during the peak labor periods of seeding, first weeding and second weeding. Imperfections in the labor market account for the fact that the wage rates do not substantially change from period to period. However, the marginal product of labor can be four to five times the average wage rate in critical labor shortage periods (Norman et al., 1981; Roth and Sanders, 1984).

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Experiment I. The experiment was conducted at Nedogo with manual traction and donkey traction, at Bangasse with manual traction, at Dissankuy with ox traction and at Diapangou with manual, donkey and ox traction. The four treatments were the following: traditional management practices including flat cultivation and no fertilization, the control (C); construction of tied ridges (TR) one month after seeding and no fertilization; flat cultivation and 100 kg/ha of cotton fertilizer, 14-23-15, applied in a band at 10-15 cm from the rows of sorghum two weeks after seeding plus 50 kg/ha of urea, applied in pockets at 10-15 cm from the seed pockets one month after seeding (F); and construction of tied ridges as described above, plus fertilization as described above. Locally grown varieties of sorghum were utilized.

The experiment was conducted at Dissankuy for the first time in 1984. At Nedogo, Bangasse and Diapangou the experiment was conducted in 1983, and in 1984; treatments were assigned to the same parcels as in 1983. At Bangasse and Dissankuy, the experimental design was a randomized complete block. Farmer's fields were replications. At Nedogo and Diapangou, the experimental design was a split-plot with whole-plots (types of traction) arranged in a completely randomized design. Treatments were the subplots.

Experiment II. The experiment was conducted at Nedogo with donkey traction, Bangasse and Poedogo with manual traction, Dissankuy with ox traction. Local varieties of maize were utilized. The two treatments were the following: traditional management practices including flat cultivation, the control (C) and construction of tied ridges (TR) one month after seeding. It was planned that half of the farmers at Poedogo and Dissankuy (villages at which mulch was most available) were to apply mulch at 5 t/ha to one of the two parcels after construction of tied ridges. It was reasoned that farmers would have access to sufficient mulch for one-half of their compound maize field which is usually very small in area. However, only four farmers at Poedogo and two farmers at Dissankuy had access to sufficient mulch. We abandoned the application of mulch, although these six farmers did apply the mulch. Compound fields, on which maize is usually grown, are relatively well fertilized with manures and organic wastes, and rainfall is usually the most limiting constraint.

The experiment was conducted at Poedogo and Dissankuy for the first time in 1984. At Nedogo, Bangasse and Diapangou the experiment was conducted in 1983, and in 1984. In 1984, treatments were assigned to the same parcels as they were in 1983 to capitalize on residual soil water which might be present as a result of tied ridges in 1983. At Nedogo, Bangasse, Poedogo and Dissankuy the experimental design was a randomized complete block. Farmers' fields were rep ications. At Diapangou, the experimental design was a plit-plot with whole units (types of traction) arranged in a completely randomized design and treatments were the subunits. The statistical significance of differences between maize yield means of the two treatments (flat cultivation and tied ridges) was determined by the t-test on pairs of observations. A pair of observations, the yield for maize with flat cultivation and the yield for maize with tied ridges, was obtained from each farmer's field.

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Experiment III. The experiment was conducted for the third year in 1984 at Nedogo and Bangasse with manual traction only. Local varieties of millet were utilized. The five treatments were the following: traditional management practices including flat cultivation (without tied ridges) and no fertilization, the control (C); construction of tied ridges (TR) one month after seeding; F, consisting of 100 kg/ha of volta phosphate (VP1) applied in the seed pocket plus 50 kg/ha urea applied in pockets at 10-15 cm from the seed pockets two weeks after seeding, and construction of tied ridges one month after seeding; 2 F, consisting of 200 kg/ha of VP1 and 50 kg/ha urea applied together in a pocket at 10-15 cm from seed pockets two weeks after seeding; and F, consisting of 100 kg/ha VP1 plus 50 kg/ha urea, but without tied ridges.

In 1984, treatments were assigned to the same parcels as in 1982 and 1983 to capitalize on the availability of phosphorus from VP1 applied in previous years. At Nedogo and Bangasse, the experimental design was a randomized complete block. Farmers' fields were replications.

Adoption of technologies. A survey was conducted in November, 1984 by interviewing the FSU farmer cooperators of the farmer-managed trials. The farmers within the farmer-managed trial group also comprise the farmers that FSU collects socio-economic data from. The socio-economic data made it possible to analyze some of the key variables that may distinguish adoptors from non-adoptors.

RESULTS AND DISCUSSION

Experiment I. The relative responses of sorghum to the four treatments was consistent across the four villages: Nedogo, Bangasse, Dissankuy and Diapangou (Table 1). Treatments consisting of tied ridges to reduce surface runoff of rainfall, or fertilization to ameliorate the low soil fertility resulted in increased levels of sorghum yield. However, the greatest yield response was consistently achieved with the combination of tied ridges and fertilization.

Yields of sorghum were generally higher with animal traction than with manual traction. However, at Nedogo, the difference was significant only for the combination of tied ridges and fertilization. At Diapangou, sorghum yields with ox traction were not superior to those with donkey traction. It is possible that t[illegible] deeper cultivation during weeding with ox traction, compared to donkey [illegible]tion, accentuated the severe drought conditions in 1984, especially [illegible]dy soils with low organic matter.

The economic analysis shows [illegible] for the mean yield increases at all locations, the return/hr for labor inputs to construct tied ridges and/or to apply fertilizer is above the 40 CFA/hr opportunity cost of labor. The combination of tied ridging and fertilization resulted in the largest net returns at all locations. Net returns were larger for fertilization alone than for tied ridging alone at Bangassé and for the three types of traction at Diapangou. Also, the return per hour of additional labor for the combination of tied ridging and fertilization were largest at Bangassé and for the two types of animal traction at Diapangou. With respect to risk, tied ridging alone carries no risk of losing cash. However, the fertilization alone treatment is moderately risky and some farmers at each

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Table 1. Economic analysis of farmer managed trials of sorghum with fertilizer and tied ridges, 1984.

	Treatments 1/ C	TR	F	TR,F	4/ S.E	4/ CV	Number of Farmers
	Nedogo, Manual Traction						
Grain Yield, kg/ha	157	416	431	652	75.1	42	11
Yield Gain Above Control, kg/ha	-	259	274	495			
Gain in Net Revenue, CFA 2/	-	23828	13275	33607			
Return/hr. of Additional Labor, CFA 3/	-	238	140	172			
% Farmers Who Would Have Lost Cash	-	0	27	9			
	Nedogo, Donkey Traction						
Grain Yield, kg/ha	173	425	355	773	63.4	44	18
Yield Gain Above Control, kg/ha	-	252	182	600			
Gain in Net Revenue, CFA	-	23184	4811	43267			
Return/hr. of Additional Labor, CFA	-	309	51	255			
% Farmers Who Would Have Lost Cash	-	0	50	0			
	Bangasse, Manual Traction						
Grain Yield, kg/ha	293	456	616	944	145.0	62	12
Yield Gain Above Control, kg/ha	-	163	323	651			
Gain in Net Revenue, CFA	-	14396	17783	47959			
Return/hr. of Additional Labor, CFA	-	150	187	246			
% Farmers Who Would Have Lost Cash	-	0	8	17			
	Dissankuy, Ox Traction						
Grain Yield, kg/ha	447	588	681	855	35.1	19	25
Yield Gain Above Control, kg/ha	-	141	234	408			
Gain in Net Revenue, CFA	-	12972	9595	25603			
Return/hr. of Additional Labor, CFA	-	173	101	151			
% Farmers Who Would Have Lost Cash	-	0	28	0			
	Diapangou, Manual Traction						
Grain Yield, kg/ha	335	571	729	1006	48.4	23	19
Yield Gain Above Control, kg/ha	-	236	394	671			
Gain in Net Revenue, CFA	-	21712	24315	49799			
Return/hr. of Additional Labor, CFA	-	217	256	255			
% Farmers Who Would Have Lost Cash	-	0	26	0			
	Diapangou, Donkey Traction						
Grain Yield, kg/ha	498	688	849	1133	45.6	18	19
Yield Gain Above Control, kg/ha	-	190	351	635			
Gain in Net Revenue, CFA	-	17480	20359	46487			
Return/hr. of Additional Labor, CFA	-	233	214	273			
% Farmers Who Would Have Lost Cash	-	0	21	0			
	Diapangou, Ox Traction						
Grain Yield, kg/ha	466	704	839	1177	46.8	18	19
Yield Gain Above Control, kg/ha	-	238	373	711			
Gain in Net Revenue, CFA	-	21896	22383	53479			
Return/hr. of Additional Labor, CFA	-	292	236	315			
% Farmers Who Would Have Lost Cash	-	0	5	0			

1/ C = control (no tied ridges or fertilizer); TR = tied ridges constructed one month after seeding;
/ F = 100 kg/ha 14-23-15 two weeks after seeding plus 50 kg/ha urea one month after seeding.

2/ Net revenue = yield gain x grain price (92 CFA/kg) minus fertilizer cost; (78 CFA/kg for 14-23-15, and 66 CFA/kg for urea), Includes interest charge for six months at rate of 15%.

3/ Net revenue/additional labor of tied ridging and fertilizer application. Manual, Donkey, and Ox traction require 100, 75, and 75 hours of additional labor/ha for tied ridging respectively. Fertilizer application requires 95 additional hours/ha.

4/ S.E. = the standard error of the difference between two treatment means. CV% = coeficient of variation.

location would have lost cash. The use of tied ridging in combination with fertilization, substantially reduces the farmers' risk of losing cash as opposed to the fertilization alone treatment. When tied ridges and fertilizer are combined, only 9% of the farmers at Nedogo with manual traction and 17% of the farmers at Bangassé with manual traction would have lost cash. Only at these two locations is the tied ridging-fertilization combination a greater risk than tied ridges alone. However, the low-risk tied ridging options results in substantially reduced net returns when compared with the tied ridging-fertilization combination.

Experiment II. Because of drought conditions which were particularly damaging to maize in 1984, several farmers in each village failed to construct the tied ridges and these fields were abandoned. This resulted in a limited number of observations for treatments. Although the number of observations was less than desired, the results show that at all villages, representing a wide range of yield levels, maize with tied ridges produced greater yields than maize without tied ridges (Table 2). At Diapangou the experiment was conducted with manual traction and with ox traction. With both types of traction, yields of maize with tied ridges were significantly greater than yields of maize without tied ridges. Maize with ox traction produced significantly greater yields than maize with manual traction.

The economic analysis shows that in all trials, the mean yield increase from constructing tied ridges compared to that of flat cultivation results in labor returns/hr which are much greater than the 40 CFA/hr opportunity cost is moderately high at the Nedogo, Poedogo and Diapangou (manual traction) locations. Assuming farm labor can earn 40 CFA/hr in other employment opportunities, some farmers would have been better off doing so at all locations with the exception of ox traction at Diapangou. The results, however, do emphasize the value of water conservation by the construction of tied ridges on the fertile compound fields where maize is grown.

Experiment III. Grain yields of millet for the treatments (tied ridges in combination with fertilization or fertilization alone) tended to be greater than yields of millet without tied ridges or fertilization at Nedogo and Bangasse (Table 3). However, yield differences from that of the control were significant only for the combination of tied ridges and fertilization at Bangasse and for treatments consisting of tied ridges and/or fertilization at Nedogo. Responses from treatments involving fertilization were generally greater in 1984 than in 1983 (Lang, et al., 1983) or 1982 (FSU/SAFGRAD, 1982).

Tied ridges without fertilizer resulted in a significant yield increase compared to the control at Nedogo. This treatment requires no cash inputs, but this practice cannot solve the problem of soil fertility improvement over years. Tied ridges in combination with fertilization resulted in the greatest yield of millet in 1984, which is consistent with our results in 1982 and 1983.

The mean yield increases at Nedogo and Bangasse for the two treatments which involve tied ridging (TR) and tied ridging plus fertilization (TR, F) are adequate to cover the opportunity cost of labor. When ferti-

.../...

Table 2. Economic analysis of farmer managed trials of maize with tied ridges, 1984.

	Treatments 1/ C	Treatments 1/ TR	6/ CV	Number of Farmers
	Nedogo, Donkey Traction			
Grain Yield, kg/ha	869	1305**** 5/	26	19
Yield Gain Above Control, kg/ha	-	436		
Gain in Net Revenue, CFA 2/	-	40112		
Return/hr. of Additional Labor, CFA 3/	-	535		
% Farmers Not Covering Labor Opp. Cost 4/		21		
	Bangasse, Manual Traction			
Grain Yield, kg/ha	341	466****	62	12
Yield Gain Above Control, kg/ha	-	125		
Gain in Net Revenue, CFA	-	11500		
Return/hr. of Additional Labor, CFA	-	115		
% Farmers Not Covering Labor Opp. Cost		8		
	Poedogo Manual Traction			
Grain Yield, kg/ha	1339	1953*	43	8
Yield Gain Above Control, kg/ha	-	614		
Gain in Net Revenue, CFA	-	56488		
Return/hr. of Additional Labor, CFA	-	565		
% Farmers Not Covering Labor Opp. Cost		25		
	Dissankuy, Ox Traction			
Grain Yield, kg/ha	564	725****	16	14
Yield Gain Above Control, kg/ha	-	161		
Gain in Net Revenue, CFA	-	14812		
Return/hr. of Additional Labor, CFA	-	197		
% Farmers Not Covering Labor Opp. Cost		6		
	Diapangou, Manual Traction			
Grain Yield,kg/ha	445	724**	69	7
Yield Gain Above Control, kg/ha	-	279		
Gain in Net Revenue, CFA	-	25668		
Return/hr. of Additional Labor, CFA	-	257		
% Farmers Not Covering Labor Opp. Cost		29		
	Diapangou, Animal Traction			
Grain Yield, kg/ha	976	1700***	46	7
Yield Gain Above Control, kg/ha	-	724		
Gain in Net Revenue, CFA	-	66608		
Return/hr. of Additional Labor, CFA	-	888		
% Farmers Not Covering Labor Opp. Cost		0		

1/ C = control (no tied ridges or fertilizer); TR = tied ridges constructed one month after seeding.

2/ Net revenue = yield gain x grain price (92 CFA/kg)

3/ Net revenue/additional labor of tied ridging. Manual, Donkey, and Ox traction require 100, 75, and 75 hours of additional labor/ha for tied ridging respectively.

4/ A 40 CFA/hr. opportunity cost of labor is used.

5/ *,**,***, and **** indicate a level of significance of 0.2, 0.05, 0.02, and 0.01 respectively for differences between treatments C and TR as determined by the T-Test for paired observations.

6/ CV% = coeficient of variation

Table 3. Economic analysis of farmer managed trials of millet with volta phosphate and tied ridges, 1984.

	Treatments 1/					4/	4/	Number of
	C	TR	TR,F	2F	F	S.E.	CV	Farmers
	Nedogo, Manual Traction							
Grain Yield, kg/ha	107	238	349	228	195	28.0	32	11
Yield Gain Above Control, kg/ha	-	131	242	121	88			
Gain in Net Revenue, CFA 2/	-	12052	16029	2209	1861			
Return/hr. of Additional Labor, CFA 3/	-	121	75	29	16			
% Farmers Who Would Have Lost Cash	-	0	0	55	55			
	Bangasse, Manual Traction							
Grain Yield, kg/ha	220	283	469	251	273	40.3	39	17
Yield Gain Above Control, kg/ha	-	63	249	31	53			
Gain in Net Revenue, CFA	-	5796	16673	-6071	-1360			
Return/hr. of Additional Labor, CFA	-	58	78	-	-			
% Farmers Who Would Have Lost Cash	-	0	6	59	59			

1/ C = control (no tied ridges or fertilizer); TR = tied ridges constructed one month after seeding; F = 100 kg/ha volta phosphate applied in the seed pocket and 50 kg/ha urea applied in pockets 10-15cm from seed pockets two weeks after seeding ; 2F = 200 kg/ha volta phosphate and 50 kg/ha urea applied together in a pocket 10-15cm from seed pocket two weeks after seeding.

2/ Net revenue = yield gain x grain price (92 CFA/kg) minus fertilizer cost; (25 CFA/kg for Volta Phosphate and 66 CFA/kg for urea), Includes interest charge for six months at rate of 15%.

3/ Net revenue/additional labor of tied ridging and fertilizer application. Manual traction requires 100 hours of additional labor/ha for tied ridging. Fertilizer application requires 115 additional hours/ha for F and 75 additional hours/ha for 2F.

4/ S.E. = the standard error of the difference between two treatment means. CV% = coeficient of variation.

lizer is used alone at both locations, mean yield increases are not sufficient to cover the opportunity cost of labor. At both locations, the combination of tied ridging and fertilization provided the largest net returns, emphasizing the gains which can be made by combining soil fertility and water conservation. It is important to note that millet response to improved soil-water management would likely be greater in the presence of a more soluble source of phosphorus.

In the economic analysis, net returns are calculated without considering the carry-over effect of fertilizer from one year to the next. The amount of fertilizer carry-over varies with rainfall and the type of fertilizer. There is considerably more carry-over of volta phosphate than either 14-23-15 or urea.

Assuming that 25 percent of the value of 14-23-15 and urea and 75 percent of the value of volta phosphate is carried over each year with an opportunity cost of 15 percent, the economic relationships among the treatment, made in the paper still hold.

Adoption of technologies. The FSU program is research-oriented and not specifically designed for an extension role. Although FSU research involves direct interaction and feedback from the farmer cooperators, any adoption by farmers of the technologies that FSU works with is not sollicited by FSU but is a welcome externality of the program. The FSU farmer-managed and researcher-managed trials, however, do provide a demonstration effect and add to the programs provided by the local extension services. When asked who introduced them to tied ridges, 95 percent of the farmers said FSU. Across all villages with the exception of Dissankuy, a similar question of fertilizer brought the response that 50 percent of the farmers were introduced to fertilizer by FSU and 50 percent by the local extension service (Ohm, et al., 1984).

Data are presented on a number of farmers basis (Table 4) and on a hectarage basis (Table 5). A demonstration effect was evident in that some farmers adopted the tied ridging, fertilization and new variety technologies in the FSU villages. A positive relationship between adoption and the number of years FSU worked in the villages was evident for tied ridges. The adoption rates may, however, have been hampered by the poor 1983 and 1984 agricultural seasons. The primary reason for not adopting tied ridging more extensively was lack of sufficient labor. The farmers said that financial conditions of not having the cash or not being able to obtain credit was the primary reason for not utilizing more fertilizer. Farmers were generally hesitant about trying new varieties until they could give them a good appraisal.

In summarizing the characteristics of adoptors and non-adoptors, the main characteristic of tied ridge adoptors is that they have larger than average size land holdings. Other characteristics are a larger than average cash crop area and a higher management level. All three characteristics showed up most noticeably in Nedogo and Bangasse. The main characteristic of new variety adoptors was farm size and the other characteristics were cash crop area and management level all exhibiting a positive relationship. The Poedogo fertilizer case indicated that younger farmers used fertilizer. Other characteristics included farm size and management level.

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Table 4. Percent of farmers adopting tied ridges (TR), fertilizer and new varieties by village, 1984.

Village	Years[1]	Number of Farmers	Percent of Farmers Adopting		
			TR	Fertilizer	Varieties
Nedogo	5	69	25	10	10
Bangasse	3	53	23	0	0
Poedogo	2	27	4	33	41
Dissankuy	2	60	2	97[2]	0
Diapangou	3	61	25	8	8

[1] Number of years FSU in villages; 1984 was the first year for farmer-managed trials at Nedogo and Dissankuy.

[2] The figures relate only to land sown to cotton. Small amounts of fertilizers are used on cereals.

Table 5. Average hectares of technology adoption, 1984.

Technology	Village				
	Nedogo	Bangasse	Poedogo	Dissankuy	Diapangou
	ha				
Tied Ridges	.32	.03	.11	.03	.18
Fertilizer	.46	0	3	3	.34
Varieties	.33	0	.12	0	.04

The characteristic that consistently showed the strongest relationship to adoption in all cases was farm size. Farmers controlling larger land areas are associated with adopting the technologies. Perrin and Winkelmann (1976) found similar results with respect to farm size for new varieties in countries where variety introductions were recent. Underlying the size effect are the factors of economies of size in the transaction costs of evaluating and acquiring new technologies, differences in prices for inputs and products, and difference in land productivity (Perrin and Winkelmann, 1976). Given that farmers with large sized farms may be the first adoptors of technology as is suggested by this preliminary analysis, questions concerning future income distribution should be pursued.

SUMMARY

Three farmer-managed experiments were conducted on fields of up to 25 randomly chosen farmers in each of one to five villages with manual cultivation and/or cultivation with donkey and/or ox traction. Treatments for the experiment with sorghum were a control, construction of tied ridges one month after seeding, fertilization with 100 kg/ha 14-23-15 plus 50 kg/ha urea and the combination of tied riging and fertilization. Treatments for the experiment with maize grown on compound fields were a control and tied ridging. The third experiment, with millet, involved five

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treatments: a control tied ridging, fertilization with 100 kg/ha volta phosphate (VP1) plus 50 kg/ha urea, 200 kg/ha VP1 plus 50 kg/ha urea and the combination of tied ridging and 100 kg/ha VP1 plus 50 kg/ha urea. The economic analysis accounted for labor inputs, prices of grains and fertilizers and agronomic data.

Construction of tied ridges can result in significant increases of cereal crop grain yields throughout the Central Plateau even on areas with very gentle slopes. This is because the water infiltration rates are low for most of the soils, partially due to low organic matter, and with flat cultivation, much of the limited rainfall is lost due to surface runoff. Although tied ridges constructed prior to planting can result in greater yields than tied ridges constructed later in the season, it is usually impractical to construct them prior to first or second weeding. Because seeding is done manually, availability of labor is a serious constraint and because seeding must be effected as soon as possible after rains which may be infrequent during May and June, there is no time or available labor to construct tied ridges or till the soil prior to seeding.

An alternative is to construct tied ridges as soon as possible after plant emergence. For most farmers this is during second weeding when plants are tall enough and when labor is slightly more available than earlier in the season. With presntly available equipment (daba or weeding equipment including the butteur and houe-manga) construction of tied ridges even when weeding with animal traction involves substantial manual labor. Because of the large amount of labor required, tied ridges may not be generally accepted although several of the FSU/SAFGRAD cooperator-farmers do practice tied ridging on areas other than those of FSU farmer-managed trials.

A promising alternative is the use of a mechanical tied ridger which attaches to a butteur to construct tied ridges during weeding and which would require no additional manual labor. A low-cost, easy-to-operate mechanical tied ridger has been developed and on-farm research must now be conducted to determine its effectiveness and farmer reactions.

Fertilization with minimal amounts of cotton fertilizer (100 kg/ha) plus 50 kg/ha urea can result in significant yield increases. However, sorghum yield response to fertilization without tied ridging is variable and involves the risk of losing the cash cost of the fertilizer. In addition, the problems of fertilizer purchases and availability of fertilizers must be dealt with. Experimentation to determine benefits from possible accumulation of nutrients in successive years of fertilization with minimal amounts of fertilizers should be continued. In a very dry season it is probable that not all of the applied nutrients even at minimal rates of application, will be removed by crop growth. The inconsistent responses to fertilization with VP1, UV5 and urea compared to the more consistent responses from cotton fertilizer (Ohm et al., 1984) suggests that more research is needed to characterize soils for concentrations of a broad range of nutrient elements essential for crop growth.

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[1] Jeff Wright, U.S. Peace Corps Volunteer, IITA Kamboinse, Burkina Faso.

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FOOD CROP FERTILIZATION AND SOIL FERTILITY: THE IRAT EXPERIENCE

Christian PIERI[1]

The improvement and maintenance of the fertility of cultivated African soils in the sub-saharan region north of the equator, has become a major problem.

In effect, it has been noted that the rate of population growth on the sub-continent is becoming one of the highest in the world and that agricultural lands are getting impoverished following the upsetting of the delicate balance between the rate of land occupation (by man and herds), the natural fertility of soils and food production. The persistent drought plaguing this part of the world since 1972 dramatizes the situation considering especially that forecasts for food requirements in the year 2000 indicate that food production in Africa needs to be greatly increased if Africans are to be adequately fed by that time. This increase concurrently necessitates an extension of cultivated areas of land, an increase in farming intensity (number of farming cycles per annum) and most importantly, an improvement in the productivity of soils, which alone must represent 51% of the total increase (Table 1).

To meet this challenge, solutions must urgently be found to the problems of improving the generally low natural fertility of African soils. These solutions depend on technical factors and conditions, as well as the often neglected social, economic and political data for each country.

For over the past 20 years, CIRAD and IRAT have jointly endeavoured to offer their contribution in finding the solution to this complex problem in collaboration with several national research bodies (ISRA in Senegal, IER in Mali, IDESSA in the Ivory Coast, IBRAZ in Burkina Faso, INRAN in Niger, IRA in Cameroon and the agronomic research bodies in Togo and Benin), development units (SAED, SODEVA, CMDT, CIDT, SODECOTON...) and national extension services. Since 1974, there has also been an increasing collaboration with agricultural scientists (Senegal Experimental Units) directly involved in the research-development process that has been ushered in.

This experience acquired over a long period of time has rightly proved that there can be no lasting and proper achievements, without a close collaboration between all the rural development agents; agriculturists, extension officers, trainers, researchers, national rural development officials, etc.

However, as recently emphasised by the UNEP in a document, it is clear that: "the only condition for progress and improvement in the standard of living is the institution of a valid agrotechnical base for an increase in production".

This paper aims at outlining the synthesis of francophone agronomic research contributions, and at formulating plans for agrotechnical bases aiming at improving and maintaining the fertility of cultivated sub-saharan soils, by stressing the major role that fertilization could play in stepping

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Table 1. Contribution to increases in production, (90 developing countries, 1975-2000).[1]

Region	Contribution to increase		
	Extension of cultivated areas of land	Farming intensity	Increase in yield/ha
	%		
90 countries	26	14	60
Africa	27	22	51
Asia	10	14	76
Latin America	55	14	31
Middle East	6	25	69

1 Source: FAO, 1981.

up the productivity of soil by specifying the technical conditions for an efficient use of mineral and organic manuring in the physical, economic and human environment of this part of the world.

THE POTENTIAL ROLE OF FERTILIZATION TO INCREASE YIELD AND MAINTAIN SOIL FERTILITY

Dimension of the problem. Fertilization plays an essential role in improving crop yields. Particularly in the case of annual pluvial crops in the sub-sahara, this intensification practice must be conceived as part of farming and production systems fulfilling three major objectives:

(1) to guarantee food self-sufficiency and to satisfy the basic needs of farming households,
(2) to maintain the fertility of the soil at an optimal level, and
(3) to reduce all types of risks borne by farmers especially climatic and economic risks.

This means that while looking for the conditions required for an optimal efficiency in manuring, it is necessary to bear in mind that the techniques developed must suit the conditions of farmers who have very little economic resources, and who represent more than 2/3 of the farming population on the sub-continent (Bird, 1981).

Potential role of fertilizers for increasing crop yields. IRAT in 1975 demonstrated in a synthesis of agronomic research trials carried out from 1969 to 1974 that there was a considerable potential for increasing the yields of major African and Madagascar food crops.

Following the prior detection of the defects in some major soil minerals (Chaminade, 1965) coupled on one hand, with the development of a restorative manuring process that helps in rectifying these defects and a maintenance manuring adapted to the crops on the other hand, it was demonstrated experimentally that the following yields could be obtained:

Maize	100q/ha	Madagascar, Ivory Coast
Sorghum	40q/ha	Northern Cameroon
Millet	30q/ha	Senegal

Irrigated rice	90q/ha	Madagascar, Ivory Coast
Pluvial rice	70q/ha	Western Cameroon

The major role of fertilization in raising yields to a high level has been demonstrated throughout the area under study and particularly in the case of desaturated ferralitic soils in the humid tropics (Roche, 1974) endowed with good physical properties but chemically poor.

In the semi-arid tropics, the effects of fertilization were much greater when fertilization was linked with soil tillage techniques which improve the poor physical and water quality of crop profiles (Charreau and Nicou, 1971).

This is how cropping systems with gradual intensity were developed associating manuring with soil tillage (Tourte, 1971). In this way the most intensive systems seem to be only ones capable of yielding high added monetary values helping to maintain the productivity of soils (Tables 2 and 3).

Table 2. Effects of intensification systems on yields from a groundnut-millet-groundnut sequence in Senegal (Tourte, 1971).

Crop	Yield[1]		
	0	T1	TL
	kg/ha		
Groundnut	950	1090	1140
Millet	430	700	1020
Groundnut	960	1170	1070

1 0 = Control : without fertilizers, T1 = 150 kg/ha 6:10:10 on groundnut, 14:7:7 on millet-manual soil tillage, TL = 500 kg/ha natural phosphate and NSK complements for each crop-tillage with the plough.

Fertilization and maintenance of soil fertility. It is known that the itinerant cropping systems, studied particularly by Greenland (1970), are certainly unproductive but they help maintain the natural fertility (low) of soils relatively well. Such systems which tend to minimize risks and efforts (Norman and Binswanger, 1982) have a more and more limited future in view of the pressure on the land.

Accordingly, it was shown that seven years of fallowing would be necessary for farmlands that have been exhausted by successive millet and groundnut cultivation in Senegal to recover their initial level of natural fertility (Charreau, 1972).

However, fallowing is becoming rare (lands under fallow in the Senegal groundnut basin now represent less than 2% of cultivable areas of land). This is why in francophone West Africa, agronomists have become anxious about the maintenance of soil fertility within the framework of a fixed agriculture since the 1960s.

Table 3. Maize yield at nine intensification stages at Bouake, Ivory Coast; 1967 to 1978.

Fertilization	Surface harrowing	Ploughing with oxen, 12 cm depth	Deep ploughing with the tractor (30 cm) + incorporation of residus
		kg/ha	
Without fertilizer	368	483	459
40-40-60[1]	1809	1670	2330
80-80-120[2]	2726	2690	3089

1 Manuring replaced with 15t/ha manure every three years + 20-40-40.

2 Manuring replaced with 15t/ha manure every three years + 40-80-80.

Experimental designs of long duration were set up to keep track of the trends in the fertility of soils under continuous cropping, without fertilizer with mineral manuring and with mineral and organic manuring. A list of these major designs (and related written documents) is provided in the annex. It is worthwhile noting that many of these designs came into existence over ten years ago and that the Saria designs (Burkina Faso) were developed over 25 years ago.

Moreover, studies on fertility trends have been carried out under actual conditions of agricultural production such as those of Sibard (1972) and Morel and Quantin (1972), which help in establishing a distinct relationship between the dynamics of fertility on experimental plots and farmers' fields.

Lessons drawn from these studies are summarized below:

(1) By applying fertilizer, continuous cropping is potentially possible under the climatic and pedologic conditions pertaining in West Africa: this is proved by results from Senegal, Mali, Niger, Burkina Faso, Northern Cameroon and Central and Western Ivory Coast.

(2) Crop rotation and especially cereal - legume alternation (Fig.1) help to increase the soil fertility.

(3) As already explained, owing to its effects of improving the conditions of water supply to crops in the more arid zones, soil tillage (ploughing) does not only increase the value of manuring (Table 3) but in some cases, it also helps in continuously improving the productivity of lands when mineral fertilizers and harvest residues are provided, in spite of the yearly rainfall uncertainties (Fig. 2).

(4) In any case, in the semi-arid zones, a rapid evolution is observed in fertilizer requirements especially nitrogen. These requirements increase from year to year.

(5) After an initial period of continuous cropping spreading over two (Senegal, Burkina Faso) to five years (the case of Gagnoa in the Ivory Coast), a fall in yield and a decreasing efficiency of fertilizers are observed in the case of farming systems using only

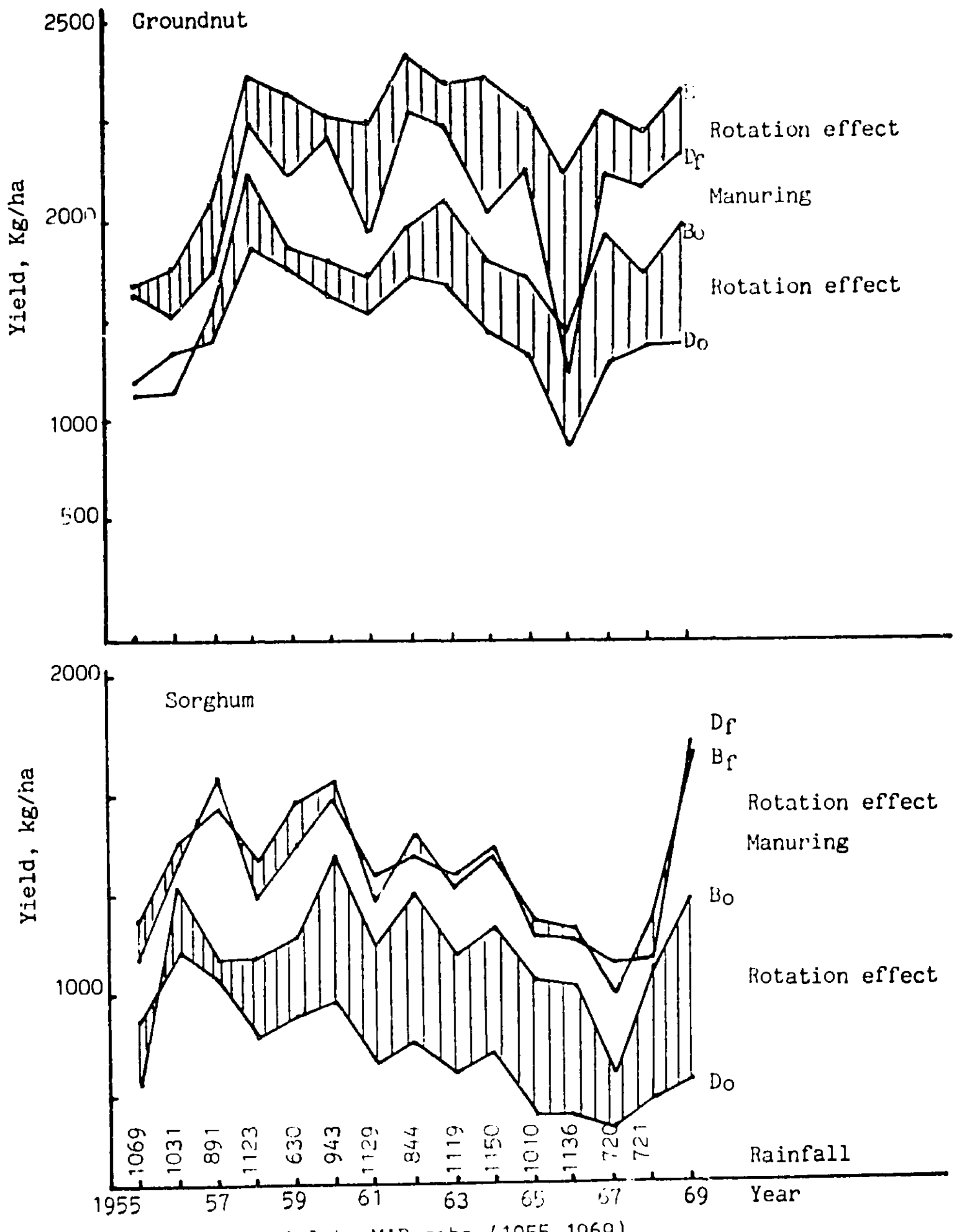

Fig. 1. Rotation trial by M'Pesoba (1955-1969).

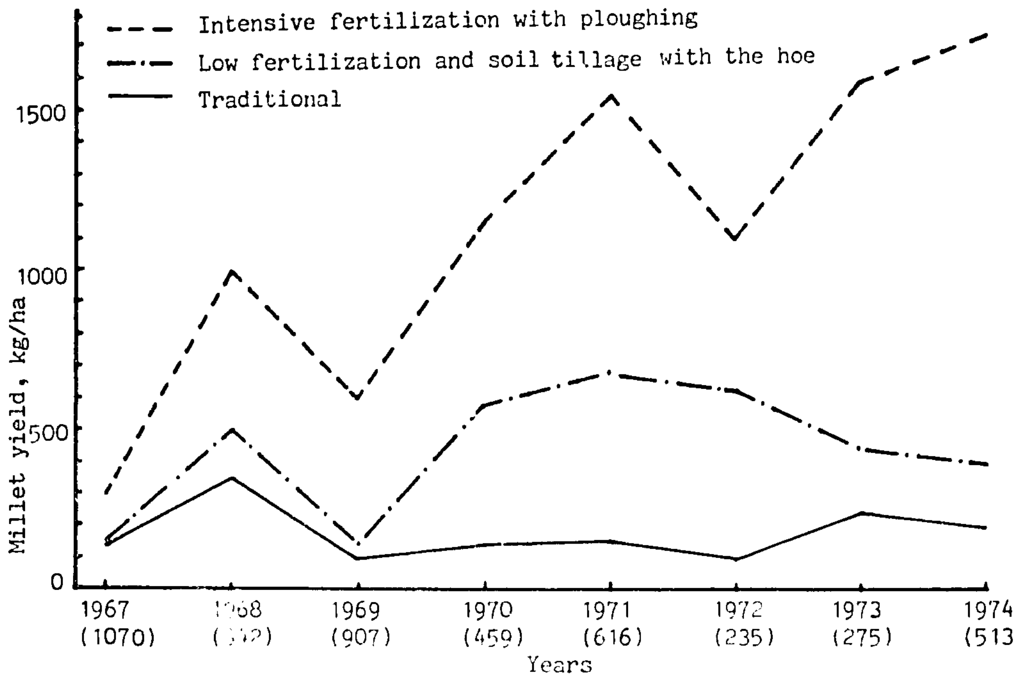

Fig. 2. Changes in productivity resulting from fertilization and ploughing (G. Pocthier).

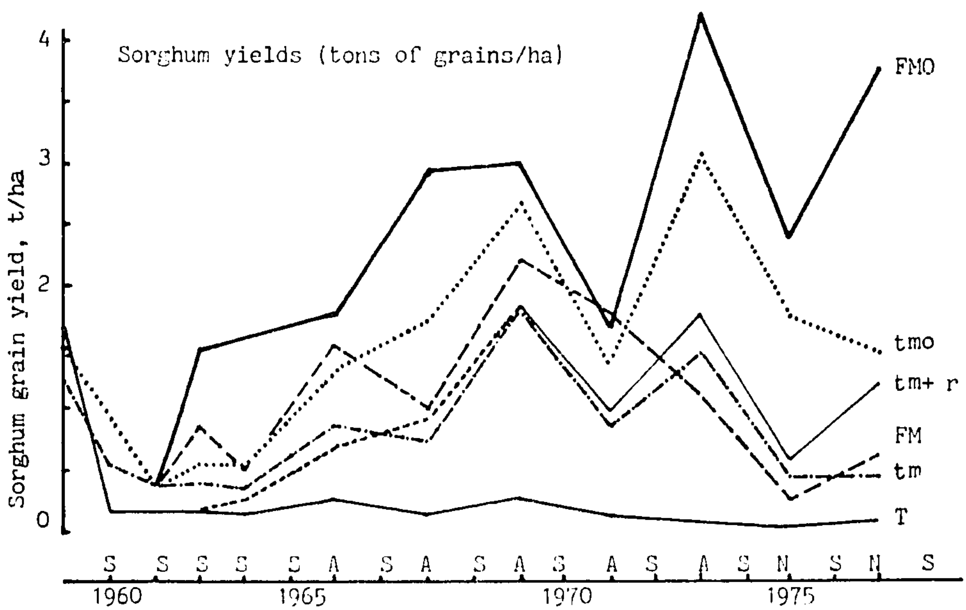

Fig. 3. Fertility maintenance trial-Saria Sorghum-Legumes alternation.

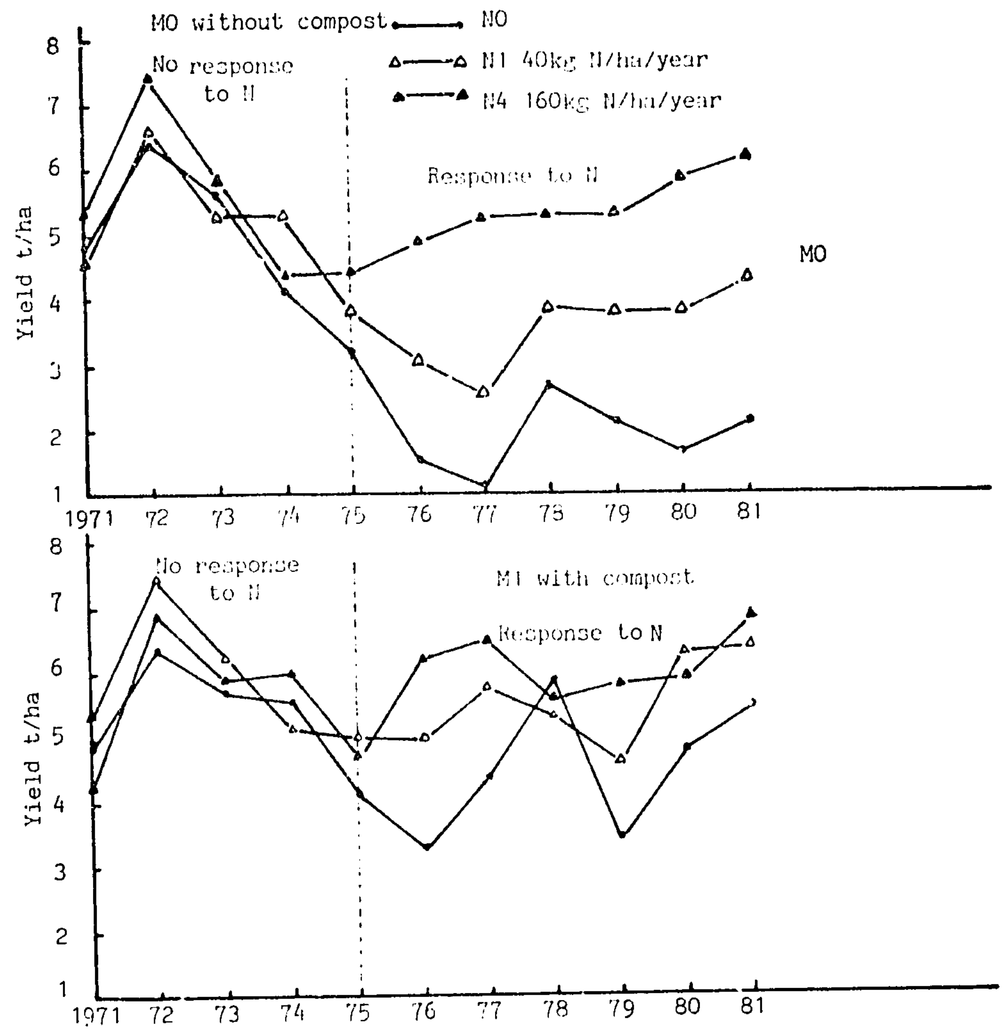

Fig. 4. Evolution of maize yields under continuous cropping at Gagnoa.

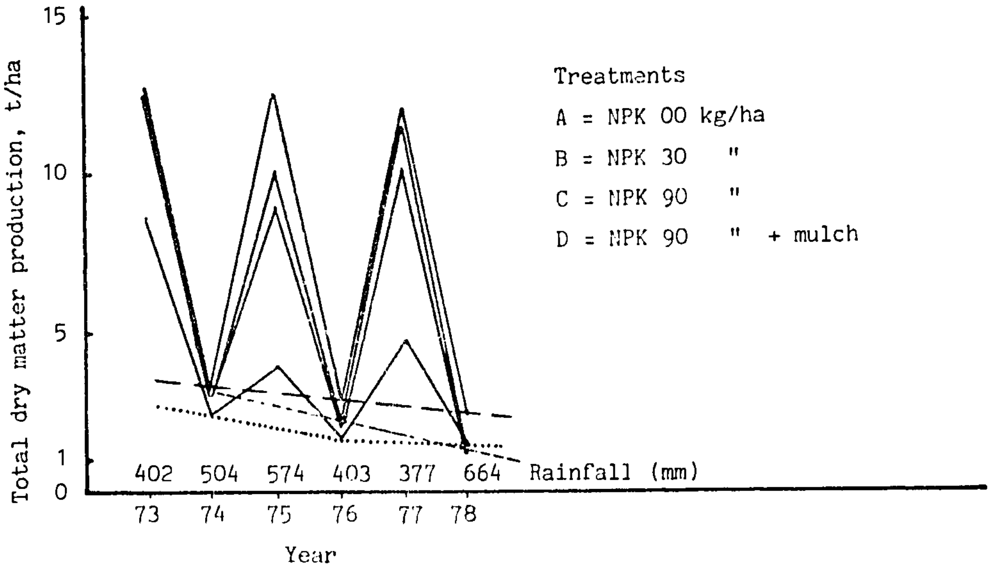

Fig. 5. Evaluation of the total production of dry plant material produced from 1973 to 1978 at Bambey.

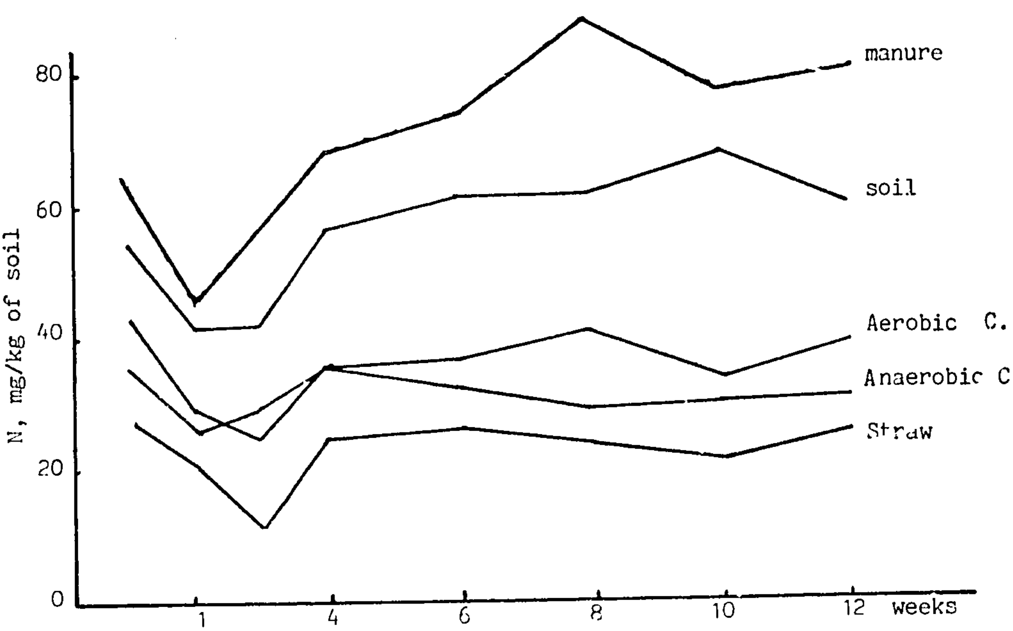

Fig. 6. Evaluation of nitrogen content in soil extracted by a 0.5N of K_2SO_4 solution during an incubation using as well, various organic soil amendments added at a rate of 350mg/100g of soil and 50mg/kg of N. (Sedogo, 1981).

mineral fertilizers (Figs. 3 and 4): under the conditions of the semi-arid environments, mineral manuring alone, even if abundant, can not help raise and maintain the productivity of continuously cultivated lands at a high level.

(6) The effects of organic matter additions are diverse, depending on their nature (green fertilizers, strawy residues, compost, manure) and the environment:

  (a) Marquette has demonstrated that in order to restore the productivity level of Togolese barren lands (desaturated ferrallitic soils, wet tropical climate with two rainy seasons), it suffices to incorporate into the soil, green fertilizers of the cultivated legumes for a period of 12 months or to restore the composted residues of the harvested maize.

  (b) Velly and Lorgueval (1976) observed that the incorporation of maize stalks on the High Plateau in Madagascar (very desaturated ferrallitic soils, wet tropical climate) is very effective in maintaining yields and even increasing the organic matter content of soils.

  (c) With regards to the semi-arid tropics, the numerous works carried out by Ganry (1977-1984) and quoted in the bibliography, as well as those of Chabalier (1976), Gigou (1982), Pichot (1981) and Pieri (1982) tend to prove that as a condition for maintaining crop yields and the productivity of lands, already transformed organic products such a compost and manure (Fig. 5) should be restored.

The establishment of mineral balance for these different cropping systems, and the study of the evolution in the chemical properties of soils on which these long-term experiments have been conducted help in obtaining a better understanding of the essential role that organic restoration can play in the maintenance of fertility in West African soils.

Mineral balance and evolution of the chemical characteristics of soils. A recent document has been published on this subject for the semi-arid climatic zone (Pieri, 1983).

For example, Tables 4 and 5 corresponding to the calculation of the mineral balance established after 17 years of cropping in Senegal, indicate the following basic points:

(1) With annual N P K manuring, and restoration of cereal straw, the presence of N P K manuring, the apparent nitrogen balance (N fertilizer + fixation + N residues - N exported by the harvest) is negative.

(2) The apparent balance and the balance established from the evolution of mineral stocks in the soils (0 to 30 cm) are at a striking disagreement: in effect, the nitrogen deficiency in the soil far exceeds the picture given by the apparent balance; the highly deficient calcium balance is similarly reflected in the apparent balance.

(3) For purposes of making a sound diagnosis of the fertility trends, it is indeed necessary to take into consideration most of the terms used in these balances. Such factors as the soil internal flows of organic matter mineralization and the flow of mineral elements in a form available from reserves, leaching, losses of nitrogen gas, atmospheric contributions are all to be taken into

Table 4. Mineral balance estimated from 17 years of quadriennal crop rotation in Senegal (Pieri, 1982); Cameroon (Gigou, 1982), and Ivory Coast (Chabalier, 1983).

Terms, Balance	N		P_2O_5		K_2O		CaO	
	Control	E	Control	E	Control	E	Control	E
	kg/ha							
E[1]	-746	-1731	-178	-379	-411	-1095	-273	-480
F+Nf+O[2]	+252	+ 956	0	+438	0	+1353	+346	+571
Balance	-494	- 775	-178	+59	-412	+258	+96	+91

1 E = mineral exports from the crops to the harvest.

2 F = fertilizers, Nf: quantity of N fixed by the groundnut (60% total N), O: restoration of organic residues, Control: without fertilizers, E: disseminated NPK manuring + restoration of cereal straw.

Table 5. Variation of soil mineral stocks in total N, absorbent P_2O_5 and exchangeable K and Ca, after 17 years of farming in Senegal (Sarr, 198?).

	N		P_2O_5		K_2O		CaO	
	Control[1]	E[2]	Control	E	Control	E	Control	E
	kg/ha							
"Soil" Balance	-1320	-1200	+10	+55	+12	+44	-571	-1438

1 Control = without fertilizer.

2 E = with fertilizer (Cf Table 4).

consideration in establishing the balance. It would be wrong to limit these balances to a comparison of mineral exports with crops/addition of fertilizing elements.

We may briefly recall the impact of under-estimation of losses through leaching and erosion and an over-estimation of the effects of biological N_2 fixation:

(1) Losses through leaching. Tables 6 and 7 referring to the semi-arid tropics and humid tropics give an estimate of these losses.

Contrary to popular beliefs, the losses in the semi-arid areas are not minor due to the very irregugular rainfall distribution especially at the beginning of the cropping cycle on very sandy soils.

It is interesting to note that with traditional cereals, (millet and sorghum), water and mineral element losses are minor as compared to crops which are less deep-rooted. There is also a close relationship between nitrogen losses and Ca and Mg in the semi-arid area.

Table 6. Mineral losses through leaching under cropping in Senegal (Pieri, 1982), Cameroon (Gigou, 1982) and Ivory Coast (Chabalier, 1983).

Place (Country)	Rainfall (year)	Crop	Drainage	Mineral losses N	CaO	MgO	K_2O	P_2O_5
	mm		mm	kg/ha/annum				
Bambey (Senegal)	507 (1981)	Millet	9.5	0.3	0.8	0.4	0.3	TR
		Groundnut	100.5	25.1	54.1	13.6	5.2	TR
Maroua (Cameroon)	705 (1975)	Sorghum	2	TR	0.1	0.1	TR	TR
	683 (1977)	Cotton	83	2.1	43.7	12.3	1.7	TR
Bouake (Ivory Coast)	633 (1981)	Maize	210	6.1	36.4	26.2	2.4	TR
	532 (1981)	Cotton	260	7.1	18.0	6.6	2.0	TR

Table 7. Mineral losses through leaching under fertilized cropping at Ampangabe (Arrivets, 1981).

Rainfall (Year)	Crop (Yield)	Drainage mm (% rainfall)	Mineral losses N	K_2O	CaO	MgO
mm	g/ha		kg/ha			
1106 (78-79)	Groundnut (30)	457 (41.3)	43.0	20.4	36.4	38.2
1297 (79-80)	Maize (46)	393 (30.3)	39.0	14.4	43.4	28.5
	Groundnut (-)	420 (32.4)	51.0	15.6	51.8	41.5
	Wheat (12)	490 (37.8)	37.0	12.0	28.0	44.8
1209 (79-80)	Maize[1] (59)	379 (31.3)	18.3	8.4	26.6	30.5
	Bare Soil[1]	717 (59.3)	102.7	58.4	109.2	102.4

1 Equal fertilization: Nov. 72, 2t/ha dolomite, 1t/ha Hyper Reno, 0,5t/ha KCL; Nov. 79 140N, 30 P_2O_5, 60 K_2O.

(2) Losses through erosion. For the same reasons (irregularity) in rainfall) erosion can not be neglected in the West African semi-arid area.

Roose (1980) indeed remarked that in West Africa, the rains are erosive because they are three to 60 times more aggressive than in the temperate regions. The resulting average losses of mineral elements are within the following limits:

C = 80 to 1900 kg/ha/annum
N = 15 to 80 "
P = 3 to 30 "
K = 10 to 55 "
Ca= 15 to 70 "
Mg= 10 to 35 "

Table 8 gives some indications with respect to the average losses (between 1958 and 1963) of elements measured under different crops in Madagascar.

Since the annual losses of soil do not follow any normal distribution pattern (it is rather log normal), nutrient losses were estimated by taking into account the geometric mean of the losses of soil.

However, these mean values conceal a largely diversified situation. Thus, during the flat tillage of maize in 1962-63, soil losses reached 67.8t/ha and consequently the mineral losses, measured in the solid portion (soil deposited in the tank) and the liquid portion (suspension) were the following:

	"Solid" erosion	"Liquid" erosion
Organic matter	2915 kg/ha	146 kg/ha
N	173 "	- "
P_2O_5	16 "	1 "
CaO	30 "	39 "
MgO	7 "	4 "
K_2O	4 "	9 "

Mineral and organic losses through erosion and run-off are therefore likely to feature very strongly in the mineral balance of cropping systems developed in the humid savanna zone.

The most harmful "solid" erosion is the major cause of organic matter losses from the soils. It also causes significant losses of nitrogen and phosphorous. The run-off waters in particular, are the cause of losses Ca, Mg and K cations.

(3) Symbiotic fixation. The quantity of nitrogen that is fixed by a given legume in a given place largely varies with the environmental conditions. In the arid and semi-arid areas, this quantity largely depends on the amount of water available to the crop.

For different legumes cultivated in Senegal, Ganry and Wey (quoted in Wetselaar and Ganry, 1982) have given the following values of absorbed percentage nitrogen obtained from symbiotic fixation (Nf):

(a) 20 to 70% for the same groundnut variety,
(b) 0 to 58% for the same soya cultivar.

According to the authors, these percentages are mainly influenced by the drought periods, the presence or absence of mineral nitrogen in the soils and/or the efficiency of the <u>Rhizobium</u> strains.

Table 8. Average run-off values of losses in land and mineral elements under different crop rotations (Manisana Ambatobe-Madagascar, 1958-1963).

Types of losses	Content	Maize + ("Pois mascatte")		Groundnut		Grassland	
		Flat	Ridges	Flat	Ridges	1st year	2nd year
Run-off		% pmm					
Mean, 1955-1963		11.5	7.5	11.8	11.1	14.7	0.7
Extreme values		5.5-17.1	6.2-11.3	3.6-16.0	7.4-17.5	7.6-19.4	0-1.2
Geometric mean		10.5	7.2	9.7	10.7	14.1	0.2
Erosion		t/ha/annum					
Mean, 1958-1963		19.1	3.9	12.5	4.1	16.1	0.1
Extreme values		1.0-67.8	2.6-5.0	1.4-26.4	2.0-5.6	1.9-33.8	0.1
Geometric mean		8.4	3.8	8.9	3.9	11.4	0.1
Solid mineral losses (Mean 1958-1963)	Content	kg/ha/annum					
MO	4.9 ± 0.7%	412	186	436	191	559	5
N	2.42 ± 0.58%	20	9	22	9	28	0.2
P_2O_5	0.526 ± 0.215%	4	2	5	2	6	TR
CaO	1.262 ± 0.715%	11	5	11	5	14	0.1
MgO	0.176 ± 0.071%	1	1	2	1	2	TR
K_2O	0.086 ± 0.030%	0.7	0.3	0.8	0.3	1	TR

In the interesting case of groundnut (Table 9), it is observed that insufficient rainfall can lead to a moderate decrease in yield (12%) whereas the Nf quantity is reduced by almost 70%: groundnut then draws 75% of its nitrogen requirements from the nitrogen and organic reserves consequently contributing to impoverishing the soil.

Accordingly, the following conclusion can be drawn: instead of always improving the N balance of the soil, some legumes can on the contrary contribute to the nitrogen losses of these soils (Wetselaar and Ganry, 1982).

(4) Conclusion. This brief account of results obtained by agronomists in francophone Africa (and Madagascar) clearly demonstrate that fertilization is a potent means for increasing crop yields within the farmework of a stabilized agriculture.

However, this intensification of crops without stand-by lands (long period of fallowing) poses particular acute problems in semi-arid Africa as indicated by Pichot et al. (1981).

"Binary mineral fertilizers (NP) or the ternaries (N P K) generate yield increases for some years but deprive the soil of bases and cause an acidification which is detrimental to crops. This situation relating to the nitrate fertilizer addition results in the development of potassium deficiencies and aluminium toxicities which can have a pronounced effect on the establishment of seedlings.

Table 9. Effects of rainfall on the efficiency of N_2 symbiotic fixation by legumes (Canry and Wey, 1982).

Rainfall	Crop	Yield (mobilized quantity of N)	Percentage of nitrogen in the aerial parts obtained from: Fixation	Soil	Fertilizers
		kg/ha	%		
Satisfactory[1]	Soya	2315 (189N)	55	40	5
	Groundnut	1420 (74N)	66	32	2
Poor[2]	Soya	835 (68N)	58	38	4
	Groundnut	1126 (59N)	21	75	4

1 Rainfall ensuring a good water supply to the plant.

2 Insufficient and poor rainfall distribution.

Organic matter additions to the soil: the applications of green manure and cropping residues or manure additions help to mitigate or eliminate these detrimental effects of mineral manuring. However, sorghum residue supplied to the soil every other year does not constitute a sufficient and lasting means for avoiding acidification and base deficiencies. Depending on the applied doses, manuring is the only means corresponding on the farm, to a real transfer of fertility making it possible to maintain soil productivity".

It can be concluded that the development of integrated systems of agricultural intensification and of fertility maintenance on soils cultivated by farmers supposes that within the agronomic and economic context of West Africa, steps are taken to develop techniques permitting an efficient recycling of organic residues produced in agricultural farms, the highest possible biological fixation of atmospheric N_2 and an optimum utilization of expensive mineral fertilizers. The adaptation of these techniques must be based on the cropping systems and the diversified agroclimatic context of the sub-saharan zone.

PROBLEMS CONNECTED WITH THE PRACTICE OF RECYCLING CROP RESIDUES

The practice of recycling crop residues poses three series of problems:

(1) Irrespective of the advantages in the experimental results obtained through recycling, are crop residues still existing on present agricultural farms, available for purposes of fertility improvement and maintenance?

(2) The treatment of the soil with organic residues having a high C/N cannot lead to immediate depressive effects on crops (allelopathy, nitrogen deficiency, loss of N-fertilizers).

(3) What are the modes of organic recycling that can presently be recommended for tropical West Africa?

Availability of organic residues on agricultural farms. In tropical agrosystems the exportable part of the plant is variable depending on the farmer's production system and the domestic needs of his family. Cereal residues are often put to use outside the field; in feeding animals, in constructing dwelling places and in cooking. It is also clear that residues obtained from legumes are now considered by farmers as an essential part of the harvest, particularly in the soudano-sahelian regions (rainfall, 1000 mm).

Surveys conducted in various Senegalese regions (Allard et al., 1983) has under real conditions, made it possible to evaluate the quantities of residue produced and those that are likely to be recycled for agronomic purposes (Table 10). So it is clear that the available quantities of residues are very limited particularly in areas where the problem of domestic energy is acute. Similar remarks have been made on the Mossi plateau (Sedogo, 1981) in Burkina Faso. The scarcity of fuelwood sources increases the collection of millet and sorghum residues and their use for fuel.

In areas with more rainfall, domestic use of residues is lower and the possibilities of agronomic use remain considerable. Accordingly a first verification is required: the availability of organic residues is often very limited and particularly critical in the animal rearing areas of the semi-arid regions in Africa.

Effect of organic residue incorporation on crop nutrition. Some studies were carried out in Senegal to determine plant toxicity attributable to phenolic compounds contained in millet residue (Ganry et al., 1978) or in the totality of sorghum cropping residues (Burgos-Leon et al., 1980). These phenomena do not however seem to play a major role except in the case of incorporations made immediately before sowings. In effect, the biodegradation of phenolic compounds in residues require about three rainy weeks.

Other experiments made it possible to detect nitrogen deficiencies in crops particularly in the absence of nitrogen fertilizers (Gigou and Dubernard, 1978 and Gigou, 1980) and solely in the case of a massive straw addition. When the quantities correspond to the normal harvesting quantity (3 to 5 t/ha) with a repeated incorporation, only modest and positive effects are generally observed on yield. Moreover, the incorporation of straws into soils have large effects on potassium balance (Pieri, 1982) or on soil acidity.

Studies carried out in Burkina Faso indicate that composting of sorghum residues supresses the "nitrogen deficiency" effect (Table 11).

Manure seems to combine all the advantages: positive effect on potassium nutrition, suppression of aluminium toxicity, and most of all, a very positive effect on nitrogen supply as is made evident by Sedogo in his measurement of nitrogen mineralization on different organic residues (Fig. 6).

Several studies have been conducted on the effect of organic recycling on the coefficient of utilization of nitrogenous mineral fertilizers and on the contribution of these fertilizers to the nitrogen of cereal fertilizers (Table 12).

Table 10. Availability of plant residues in central Senegal (J.F. Allard et al., 1983).

Zone	Crop	Residue	Collection	Utilization	Availability
		t/ha	%		t/ha
Northern groundnut Basin	Groundnut	0.7-1.0	100	Animals	nil
	Millet	1.0-2.0	50-100	Domestic + Animals	nil
	Fallow	0.4-3.0	50-100	Domestic + Animals	nil
Groundnut sub basin	Groundnut	0.7-1.7	100	Animals + Sale	nil
	Millet	1.7-3.0	10-15	Domestic	1.0-2.5
	Fallow	0.4-3.0	10-15	Domestic	0.2-2.5

Table 11. Effect of different organic residues on sorghum yield at Saria, Burkina (Sedogo, 1981).

Treatment	Sorghum yield	
	Without nitrogen	60 kg/ha N
	kg/ha	
Without organic treatment	1831	2796
10t/ha of sorghum straw	1652	3427
10t/ha of manure	2409	3591
10t/ha of aerobic compost	2505	3688
10t/ha of anaerobic compost	2304	3601

It is absolutely necessary therefore, to stress that organic residues did not reduce the efficiency of nitrogen fertilizers whose nitrogenous grains contribution[1] is about 35% on the average.

Methods for recycling organic residues. How can cropping residues then be managed?

Besides the traditional practice (but ineffective for nitrogen-saving) of burning in the mountainous volcanic areas, there remain four possibilities:

(1) mulching,
(2) incorporation,
(3) aerobic or anaerobic composting, and
(4) transformation by animals.

1 Contribution = $\frac{\text{(Fertilizer N) in the grains \%}}{\text{Total N in the grains}}$.

Table 12. Effects of organic residues on the coefficient of utilization of N fertilizers.

Crop (Location)	Manuring Manuring	Grain yield	Coefficient of utilization of N fertilizers 1st addition	2nd addition
	kg/ha			
Maize (Bouake)	100N	4800	27	34
	100N+ 5t/ha straw	5150	27	33
	120N	1900	13	28
Millet (Bambey)	120N+ 10t/ha compost	2200	11	28
Sorghum (Maroua)	50N	2870	40	43

1 Coefficient of utilization = $\frac{\text{(N fertilizer) in the grains \%}}{\text{Applied dose of (N fertilizer)}}$.

Research on soil fertility carried out by IRAT exclusively involved the last three solutions:

(1) The practice of straw incorporation. Ploughing or pseudo ploughing at the beginning of cycle. Several experiments conducted in Senegal and Ivory Coast on this subject, shed light on the considerable difficulties that are involved in incorporating all the residues, in a non-motorized cropping system. This solution therefore does not seem to be feasible to be recommended for non mechanized animal traction agriculture.

(2) Composting. This solution considered for a long time as unrealistic has the advantage of being carried out in various places: on the plot itself, within compounds or group of compounds. It can provide a product that is more easy to incorporate into the soil than residues can be. Energy can even be provided.

The transformation of cropping residues into compost is possible through the semi-aerobic channel: Composting in a heap or pit or again through the anaerobic channel by methanogenic fermentation producing BIOGAZ.

These different possibilities have mainly been studied jointly with ORSTOM in Senegal and with CIEH in Burkina Faso. A prototype of a "continuous digestor" "was developed by IRAT and the biogaz has since the past four years enabled Lossa (Niger) to provide the necessary energy for a pilot irrigated farm (Forest, 1980). From the point of view of soil fertility however, the results obtained at Gagnoa (Ivory Coast) and Bambey (Senegal) indicate that composting cannot be the panacea. Especially with very sandy soils in Senegal, results obtained prove that under continuous cropping, the improvement of organic matter content in the soil can only be envisaged if the cropping techniques associate organic soil amendment and fertilization. Comparison has also been made between several cropping residues (millet and sorghum stalks and groundnut shells) be they composted or not. The treatment of the soil with raw organic residues at a dose of 10t/ha or with compost at 8t/ha does not really enrich the soil except in the case of composted groundnut shells.

This result seems to be of particular interest in a country like Senegal where groundnut plays a major economic role.

It can be concluded that even if we ignore for the time being, the monetary value of compost production through a systematic and less expensive production of biogaz and energy, we must not underestimate the advantages that this "technological package" could offer for the wet tropical area where cattle rearing is insignificant or nil but where biomass potential and availability is high. This "biomass channel" also seems to be particularly appropriate for agricultural farm units at the fringes of a permanent water supply point (Niger valley, Senegal valley, pools and ponds in the coastal part of Benin, Togo, etc...) without following this channel, let us not lose sight of the fact that this simple heap of straw which gets composted on the spot is a feasible practice which is often used by some African farmers (the bamileke in Cameroon who also practice burning).

(3) Manure. The development of animal traction in certain African regions significantly modified the relationships for utilizing the plant residues which are present on the farm after harvesting. Traditionally, plant residues were consumed by nomadic herds during the dry season; at times, this utilization paved the way for the establishment of contracts between farmers and herders.

This is because the effects of animal excreta on soil fertility are well known, particularly in the sudano-sahelian area. The development of sedentary animal rearing paved the way for competition between farmers and animal herders. Thereupon, appropriation of residue developed whereby the residue is carefully gathered and deposited in the form of stacks near homes. In enclosures where the sedentary herds are kept, animal excreta keep accumulating mixing with the soil with a variable composition and quite limited agronomic value (Table 13).

One of the activities known to be capable of improving manure quality is the construction of manure stables for purposes of retrieving a less earthy manure, mixed with plant refuse.

Studies have also been carried out on the best methods of manure utilization (Ganry and Guiraud, 1978). It seems then that incorporation is very useful in checking nitrogen losses to the atmosphere and in limiting the mineralization of organic matter. Considering that the use of manure can be utilized and its production improved it remains the only solution available for the agricultural semi-arid regions and the animal-rearing sudano-sahelian zone for purposes of achieving a lasting increase in soil fertility.

Conclusion. Irrespective of experimental proofs with their multiple attraction and even the necessity for recycling organic residues, there are several limitations involved with the systematization of this practice in African small-scale farming.

Table 13. Average mineral content of manure sampled in the Tananarive, Mahisy, Ambohimandratrino, Bevalala regions (Madagascar, 1958, 1962, 1965).

Element	Dry matter content		
	Average	C.V.	Extreme values
	%		
N	0.68	32.6	0.43 - 0.96
P_2O_5	0.26	37.1	0.16 - 0.38
K_2O	0.59	42.8	0.36 - 0.84
CaO	0.12	61.9	0.06 - 0.23
MgO	1.48	100.9	0.64 3.71

In the semi-arid areas, the biomass produced in low quantity is used in multiple ways impeding its rational use, in the medium term, within a policy framework of fertility maintenance which is vital for the fate of agriculture in these zones. Improvement of production and manure utilization appears to be the only solution.

In more humid areas, there seems to be more possibilities but it will be necessary to develop residue recycling "channels" which beside their fertility maintenance ability will immediately provide farmers with the additional effort (equipment, for transportation, watering, incorporation), being requested from them. The channel, "biogas + small scale irrigation", is an interesting example. Here the compost produced directly on the plot makes it a simple practice which can certainly be disseminated, and which is already being applied by some farmers (Cameroon).

POSSIBLE IMPROVEMENT IN THE EFFICIENCY OF SYMBIOTIC FIXATION BY LEGUMES[1]

The practical difficulties involved with an effective recycling of crop residues on agricultural farms make it necessary to attach much importance to the improvement of the nitrogen balance of soils by making use of legumes. Comments made above indicate that the positive role that these nitrogen fixation species can play is not totally guaranteed and that it would be necessary to develop cropping systems which will help draw near to the "potential fixation".

For a given fixation system, this optimal activity is always reduced, in effect, by different factors; these factors could be related to bacteria, to the plant, or to environmental conditions, in which the symbiosis functions.

Three different actions that can be envisaged to be undertaken are briefly discussed below.

<u>Action on bacteria</u>. Under certain conditions, the nearly complete absence of adapted fixation bacteria in the soil makes it possible to take an action in the form of inoculation.

1 This chapter recounts the essential aspects of an article presented to CNEARC by H. Saint Macary.

A typical case is soya in Senegal on a large number of soils in the sudano-sahelian zone. As indicated in Tables 14 and 15, inoculation helps to improve emergence, the nitrogen content in the plant and yield from this crop.

In recent years, IRAT has jointly studied with ISRA (Senegal), particular problems relating to the practice of inoculation: choice and evaluation of strains, preparation of inoculum in an appropriate fermenter (Wey, 1983; Montange and Bernard, 1984), development of inoculation techniques (Wey and Saint Macary, 1982; Wey, 1983). It was demonstrated that inoculation of soya seeds in Senegal was not advisable and that the soil inoculation was preferable (Table 16). This operation can be carried out by using a spraying seed-drill, a prototype of which was developed in this respect.

In the case of other fixation systems, and especially in the case of groundnut, it has been proved that inoculation had no effect; Ganry, Wey and NDiaye, 1976 (Fig. 7).

Action on plant. Even though the choice of the variety that makes it possible to obtain a maximum efficiency in symbiosis remains a very promising research approach, it is often difficult to implement concrete action in this domain. Gary (1984) however emphasizes the importance in the farming practice of choosing soya varieties which:

(1) on one hand economize on nitrogen, i.e. varieties for which the quantities of mineral N derived from the soil and from fertilizers, necessary for obtaining 100 kg plant N, are the lowest possible.

$$\text{Coefficient } e = \frac{\text{absorbed mineral N}}{\text{total plant N}}$$

(2) on the other hand helps maintain the N stock in the soil, considering that the quantity of N contained in leaves (and normally returned to the soil during harvesting) is at least equal to the quantity of soil N used:

$$\text{Coefficient } m = \text{leaf N} - \text{sol N} > 0$$

Table 17 demonstrates a typical application of this double criterion, on four varieties in Senegal and compared with Jupiter. The later variety has proved to be among those that mostly exhaust the nitrogen fertility of the soil.

Action on the environment. Very often in practice, from the experience of IRAT, actions on the environment have the greatest impact on improvement in the efficiency of symbiotic fixation and legume yields which face no inoculation problems.

(1) Water stress control. The effect of water stress on fixation has already been emphasized above and illustrated in Fig. 8 (Ganry, 1982). It will be demonstrated later that any farming practices that help to improve the water supply of legumes especially at the young stages, are of considerable importance.

(2) Acidity control. Even if differences in efficiencies have been observed in fixation systems under low pH conditions, it does not seem that the bacteria are directly affected by the low pH.

Table 14. Effect of inoculation, using different Rhizobium strains on soya yields, Senegal.

Effect	Strains[1]			
	Control	USDA 138	local A	local B
Dry weight of nodules, mg/plant	236	1971	1730	633
Yield, kg/ha	685	1583	1087	682
Total grain nitrogen, kg/ha	38.1	105.9	62.1	37.2

1 The plants were inoculated by soil application.

In a recent experiment (Fig. 9) soybean plants were first made to grow in a nutritive medium at pH 6 for 0, 1, 8, 12, 16 ... days, and then subsequently maintained at pH 4. It was observed that nodulation is normal when the favorable period (pH = 6) is equal to or exceeds 10 to 12 days; production (and efficiency) however, is only affected when the favorable period is less than two days (Samson, 1984).

Thus the nodule formation phase is certainly very sensitive to acidity, but there is the possibility of recovery because efficiency does not seem to be altered by acidity.

In this way, the conditions for a localized soil amendment on the farm or for the coating of seeds are reproduced for purposes of maintaining a favorable physico-chemical environment within a brief period (De Marie, 1968). This technique which is just a bit onerous would be as effective as a massive application of soil amendment with the view to increase the pH of the soil to a level normally considered to be satisfactory (pH 5.5).

These two techniques are presently being compared in Madagascar in a soya -maize cropping system, because lime requirements might not be appreciated from the behavior of soya cultivation only but also take into consideration the exigencies involved with maize (sensitivity to Al and Mg requirements).

(3) Farming practices. Table 18 and Fig. 10 illustrate the considerable impact of soil preparation and manuring techniques on groundnut yields and symbiotic N_2 fixation = ploughing and addition of associated manure, with or without lime, has proved to be very effective in improving both the root growth and the efficiency of symbiotic groundnut fixation which enjoys more favorable water and mineral conditions.

It is worthwhile noting however that intensification and enhancement of the vegetative development of plants make the latter more sensitive to water stress. Since fixation is one of the first activities of the entire fixation system to be affected, much care must be taken under semi-arid climate conditions.

Table 15. Comparison of Rhizobium strains on soya.

Characters	Non-inoculated	G3 strain	Local strains[1] SA	SB	OP	Mixture of strains	C.V.%	F Test[2]
Number of shoots/ha	356,000	373,000	369,000	379,000	372,000	359,000	5.1	NS
Percentage emergence	79.1	83.0	82.0	84.4	82.8	80.0	-	-
Nitrogen rate in the leaves on the 60th day[3]	2.41a	4.23b	3.22a	2.61a	3.01a	2.80a	10.8	H S
Fresh weight of nodules, mg/plant	236	1971	1730	633	615	363	59	-
Grain yield, kg/ha	685a	1583c	1087b	682a	685a	704a	23	H S
Nitrogen in grain, %	5.58	6.69b	5.71a	5.44a	5.61a	5.55a	6.8	H S
Nitrogen exported by grains, kg/ha	38.1	105.9	62.1	37.2	38.4	39.1	-	-
Number of nodules per plant on 60th day	2.5	41.4	16.6	12.1	10.2	6.5	73.0	-

1 Liquid inoculation of soil.

2 Results with the same letter are not significantly different at the level of P = 0.01 (H.S.) and P = 0.05 (S).

3 Figures followed by the same letter are not statistically different.

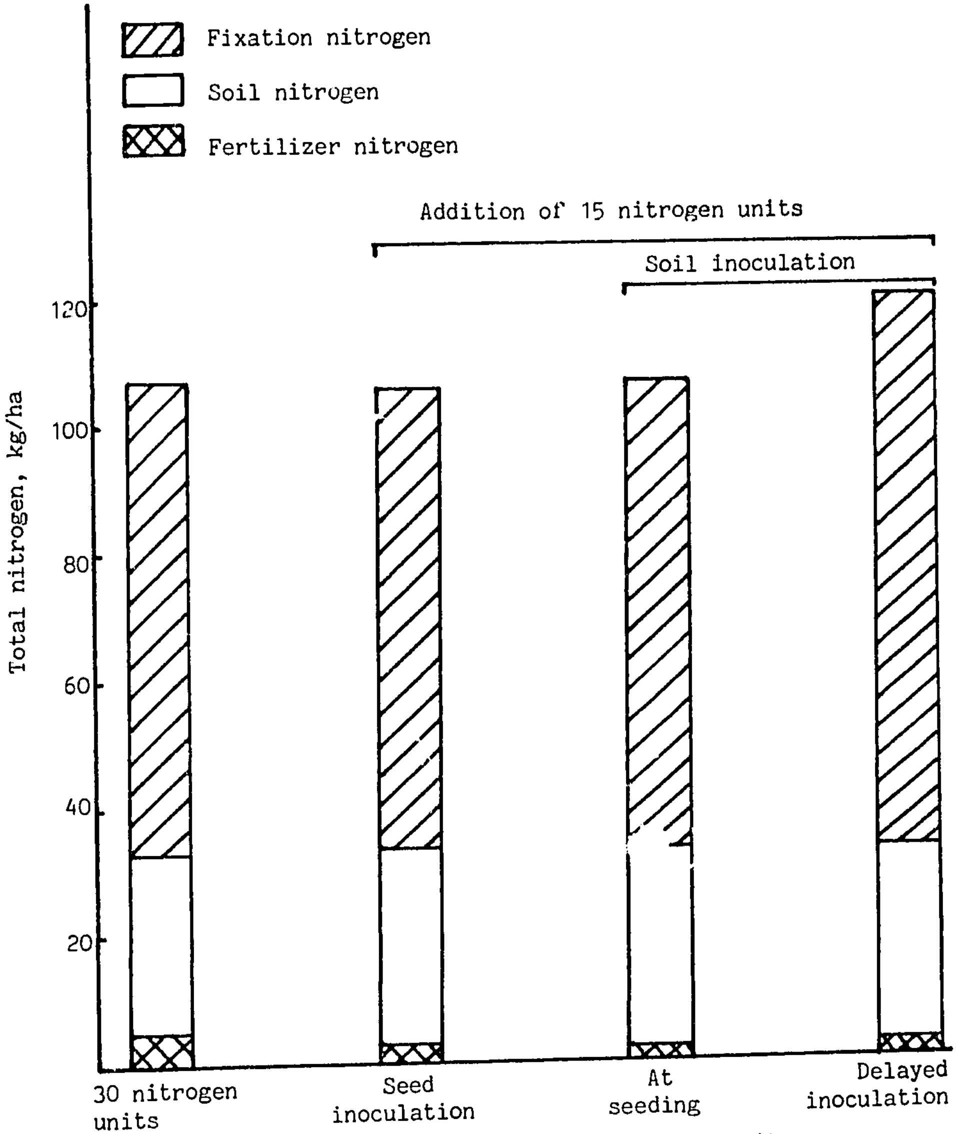

Fig. 7. Effect of groundnut inoculation on sources of nitrogenous nutrition, Bambey 1975.

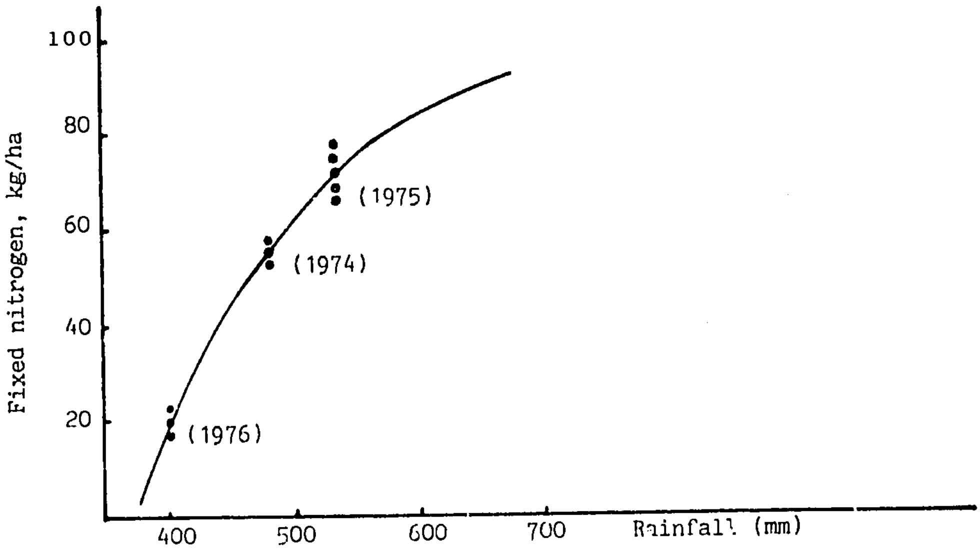

Fig. 8. Relationship between rainfaill and the quantity of nitrogen fixed by groundnut, Senegal.

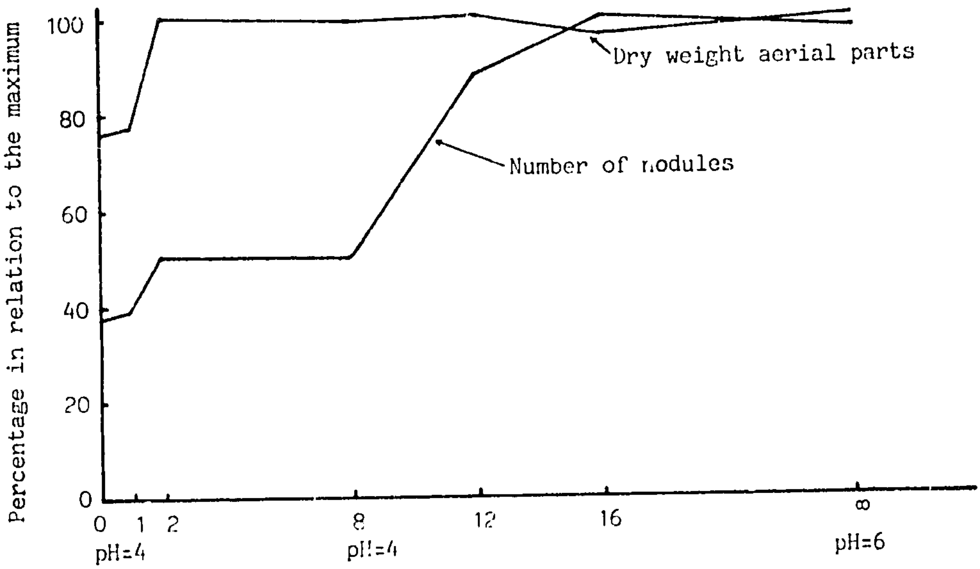

Fig. 9. Influence of pH at the beginning of cropping on the formation of nodules and plant production. At the beginning of cropping the plants were placed at a pH of 6.5 and after some time at pH 4.

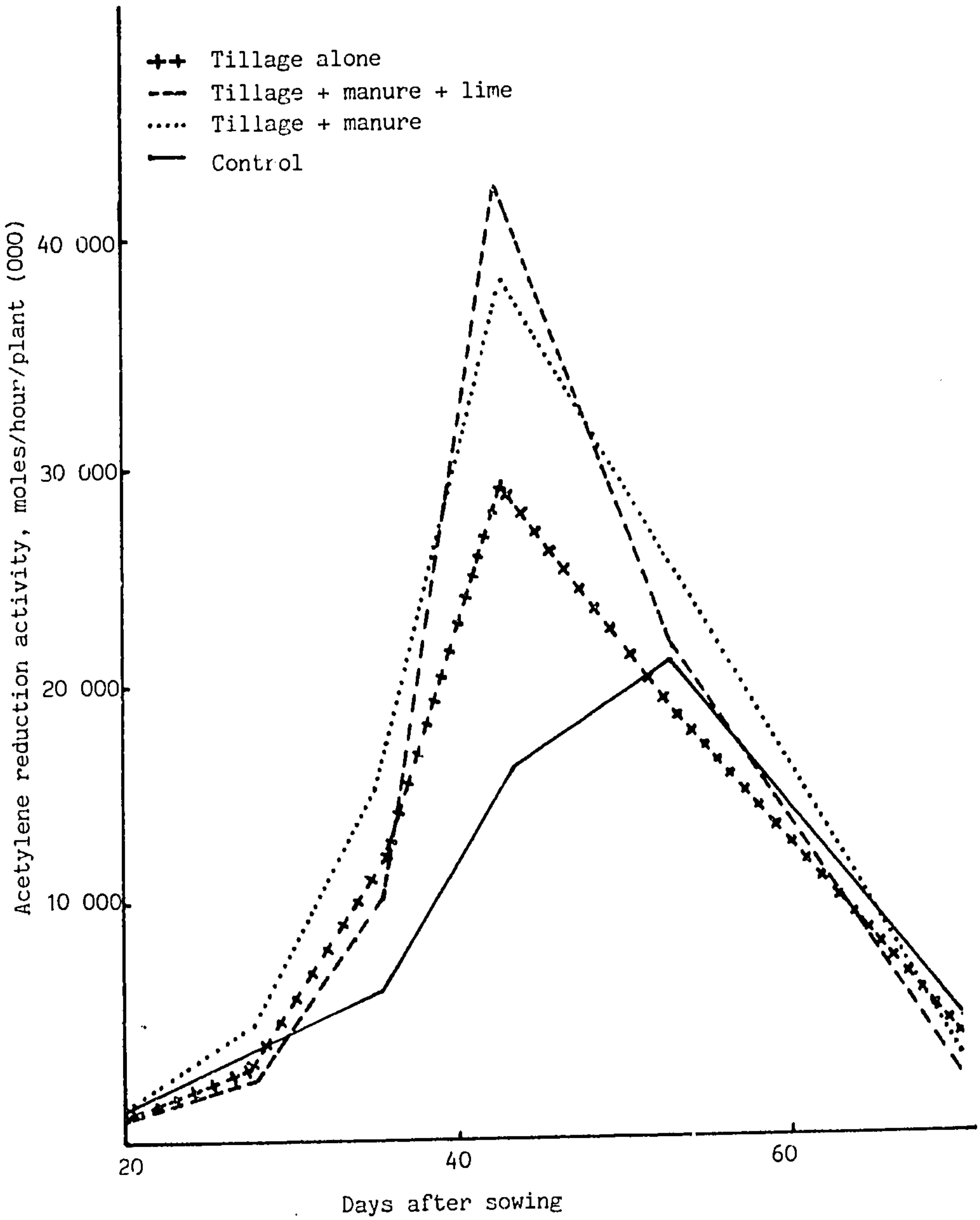

Fig. 10. Effects of farming techniques on groundnut nitrogen fixation, Senegal, 1974.

Table 16. Effect of inoculation method on soya yields in Senegal.

Method	Year	Control	Inoculated
		kg/ha	
Inoculation of grains	1972	993	983
	1973	2016	2541
Inoculation of soil	1975	685	1583
	1978	826	1528

Table 17. Choice of varieties economizing on nitrogen and enhancing the maintenance of soil N fertility (Ganry, 1984).

Varieties	e%	m
44/A/73	24.4	- 0.7
4/73	26.9	- 5.6
22/72	19.5	+ 6.6
26/72	14.4	+ 7.1
Jupiter	25.0	- 6.1

Table 18. Effect of cropping techniques on yield of groundnut. The Thilmakha trial, Senegal.

	Cropping techniques					
Trial, character	Control	Ploughing	Ploughing + manure	Lime	Ploughing + lime	Ploughing + manure + lime
	kg/ha					
Mean 1972-75						
Pods	815	950	1177	910	1024	1178
Hay	794	1031	1486	913	987	1455
Year 1981						
Pods	355	413	669	652	725	816
Hay	429	487	1162	802	833	1367

Conclusion. It is being recommended for this region that cropping systems must resort to legumes. Grain legumes and even fodder and green manure legumes are sources of "gratuitous" nitrogen that are of particular interest to small-scale farming in Africa.

However, in several cases, owing either to the insufficient availability of adequate efficient bacteria or to the unsuitable conditions of the physical environment (water stress, acidity, mineral deficiency), the efficiency of nitrogen fixation can be highly reduced and the nitrogen balance of the cereal-legume rotation will show shortages (Table 19).

Table 19. Nitrogen balance of the millet-groundnut cropping system under semi-arid conditions, Senegal (Ganry, 1982).

Gains	kg/ha	Losses	kg/ha
Atmospheric contribution	Tr	Net exportation by millet	- 33
Fertilizer on millet	+80	Net exportation by groundnut	-109
Fertilizer on groundnut	+15	Denitrification and volatilization:	
		Soil - N (two years)	- 50
Symbiotic N_2 fixation	+82	Organic residues - N (two years)	- 8
		Fertilizer - N (two years)	- 28
Net balance	-71	Leaching (two years)	- 20

Suitable farming practices helping to compensate for the constraints imposed by an unfavorable environment (lack of water, acidity) often constitute the most significant actions that can be taken to improve the efficiency of symbiotic N_2 fixation by legumes. Here also, as it was the case when fodder legumes were introduced into a stabilized agricultural and animal production system, considerable research and extension efforts are yet to be made.

OPTIMIZATION OF MINERAL FERTILIZER UTILIZATION

Even for purposes of improving the mineral nutrition of crops agricultural productivity of soils cannot be envisaged to be increased for a long period of time, even in the case of an efficient recycling of cropping residues, without resorting to mineral fertilizer.

The following three objectives must always be set as targets in matters of optimizing the use of mineral fertilizers in the sub-saharan region:

(1) to correct the mineral deficiencies which tend to limit the potential fertility of soils,
(2) to supplement the mineral "supply" of soils so as to meet the demand of intensified croppings,
(3) to limit (at least not to increase) the risk borne by farmers using mineral fertilizer especially climatic (worsening of the effect of water stress in a situation of erratic rainfall) and economic risks (lack of profit).

Correction of mineral deficiencies of soils. In Africa as in Madagascar, the most frequent case observed is phosphate deficiency.

Several studies have been carried out on this subject (Pichot, Truong and Beunard, 1979) and on the methods for correcting these deficiences.

In West Africa the correction of this deficiency necessitates the application of mild doses of phosphorous (40 to 70 kg/ha P_2O_5). However, the case of desaturated ferrallitic soils having a high capacity for absorbing phosphate ions is of particular interest because it seems that the real impact of the "fixation" phenomenon has often been exaggerated. This impact which has been perfectly demonstrated in the laboratory (Fardeau, 1976) seems in practice, to be less constraining than was imagined. Moreover, it appears that massive corrective manuring which was recommended to be applied in a single year (in the form of land investment with the cost borne by the national or international community and not the farmer who cannot bear this cost) can be gradually applied in practice.

This was specially studied in Madagascar where the effects on production and soils with a high initial P Manuring (360 kg/ha P_2O_5) were compared with moderate annual applications (45 to 90 kg/ha P_2O_5) of phosphate. The following were the major conclusions:

(1) With an annual addition of 45 kg/ha of P_2O_5, 80% of production obtained after application of strong corrective manuring was obtained in the fourth year of application.

(2) In spite of the apparent "retrogradation" of P fertilizer, indicated by the normal chemical analysis, its residual effects are clearly felt on the crops. This available portion of the P fertilizer applied is all the more greater as the additions were graduated i.e. the proportion of annual P additions as compared to the initial dose (corrective manuring) is higher.

(3) The Hyper Reno type of natural phosphate in a pulvarized form, has the same efficiency as a triple superphosphate under the conditions of this experiment conducted at Ampangabe.

(4) In a nutshell, a massive corrective manuring applied only once, is that which makes it possible to obtain the highest monetary P manuring enhancing a gradual development of production constitutes a very attractive means since it reduces financial risks and waste (disturbing erosion) which are always high (Arrivets et al., to be published).

<u>Fertilization adapted to suit crop requirements</u>. Several research studies have been conducted in this area, with agronomists studying doses, forms, application methods and mineral balances most adapted to each crop (IRAT, 1975). Emphasis was given to techniques helping to reduce losses through leaching under cropping by dwelling partly on the improvement of the overall water balance and partly on the reduction of soluble drainage element contents (Pieri, 1983).

From the foregoing analysis it is recommended that the addition of some fertilizers be split, particularly nitrogenous on cereals (Ganry, 1982) and even potassium in the humid tropics. Velly (1972) quotes several experimental results relating to the advantage of K fertilizer split applications under intensive cropping conditions. Thus at Ampangabe, an addition of 90 kg/ha of K_2O at seeding resulted in 3709 kg/ha of maize grains, two applications resulted in 4134 kg/ha and three applications resulted in 4630 kg/ha.

Moreover, IRAT, attaches much importance to all techniques favoring crop development and particularly the exploration of the soil by a dense and deep root system (cf, Nicou, Chopart). It must be stressed that the cultivated species have different abilities for developing a vigorous rooting, especially in the savanna areas subjected to temporary hazards of drought.

Especially among small-scale farmers, this can justify the use of intercropping systems, with traditional types of cereals such as sorghum or West African millet constituting, in comparison with cotton or groundnut cropping, real water and mineral element "traps".

Fertilization and risk limitation. For farmers with limited financial resources who generally have a very limited access (cash crops) to credit, it is important that the use of mineral elements does not increase the risk relating to the irregular rainfall and the generally unfavorable price ratio between crop production and fertilizer.

Fertilization and climatic risk. The considerable potential of fertilizer in raising production has been highlighted (Tables 2 and 3). However, the mean values of yield often conceal a very large interannual variability in production because of the climatic conditions of that year.

Recent research carried out at research stations seems to prove that fertilization is a factor of production helping to minimize these climatic effects (water stress, high temperature) which are commonly known. In this way, Forest and Kalms (1982) in their studies on the influence of water regimes on pluvial rice production (1984) dropped the hint that by virtue of fertilization (30-30-40), this cropping makes a far better utilization of available water during the critical period from the end of tillering to the panicle initiation stage. These authors argue, on the other hand, that it seems unjustifiable to use a more intensive and therefore more costly manuring, in view of climatic and therefore economic risks.

This effect of manuring exists provided that the latter is balanced. Thus in intensive millet cultivation (with deep ploughing and control of weeds), the addition of K to a phosphoro-nitrogenous manuring helps in reducing by half, the inter-annual variability in yields which, in the absence of manuring, is of the same order in size as that of rainfall (Pieri, 1982) (Table 20).

In the two cases cited, the authors explain this effect of minimization of water and temperature stress by the role of manuring (associated with a suitable preparation of the soil which is not generally the rule on farmers' fields) on accelerated crop growth and particularly, root growth which consequently has access to a greater volume of soil and therefore to a more abundant useful water reserve.

In the case of millet, it appears that K fertilizers essentially influence the vigor with which crop development begins (accelerated rate of growth in the first fifteen days) and exert only a slight influence on potassium nutrition through the cropping cycle.

Reduction of fertilizer cost: case of natural phosphates. In francophone Africa, it is observed that the most widely used fertilizers are generally very concentrated (urea, complex formula based on DAP and KCI) on account of the very significant cost of transport, this cost being particularly high in land-locked countries where there is neither a coastal border non local production.

The availability of several natural phosphate deposits in this part of the world of course led to the IRAT recommendation for a direct use of these potential fertilizers (Pichot et al., 1979). Experimentally, this indicates

Table 20. Mean effect of potassium manuring on millet grain yield in the absence of straw restoration (1973 to 1977).

Statistic	Useful rainfall	Control	NPK, kg/ha 0	30	60	90
	mm	kg/ha				
Mean (1973-1977)	452	1278	2246	2489	2513	2515
Standard gap	83.8	265	261	188	118	67
C.V. (%)	18.5	20.7	11.9	7.6	4.7	2.7

(Tourte, 1964) that manuring plans through crop rotations based on successive use of simple fertilizers (phosphated manuring as a basis, nitrogenous manuring on cereal, potassium manuring on groundnut, etc.) can thus be recommended and not rotations based on complex NPK formulae adapted to each crop.

It is true however that these phosphates are not always directly assimilable and can hardly be compared with more soluble forms which are more easy to be handled by farmers in view of their granulated form.

IFDC has renewed interest for partially acidified phosphates which European fertilizer producers have gradually withdrawn from the market.

Table 21 shows some experimental results obtained in Togo and Burkina Faso with phosphates originating from these countries and partially tackled by two fertilizer producing firms (Siveng and Timac, 1981).

Undisputably, this partial acidification procedure significantly increases the efficiency of natural phosphates but the economic benefits to the farmer (reduction in cost of fertilizers) and to the country (reduction in imports) are yet to be appreciated. It must be added that the procedure supposes in a nutshell, that one can have access to sulphuric acid at a low cost price.

Moreover, concurrently with this industrial procedure a partial solubilization has also been tried through the composting procedure, and for the time being, the experimental results have shown to be variable (Burkina Faso) and at times very encouraging (Senegal) (Ganry, 1978).

GENERAL CONCLUSION

A review of research carried out as part of francophone agronomic research in Africa and Madagascar demonstrate that solid agrotechnical bases exist, making it possible to involve the countries concerned in agricultural intensification. The latter must necessarily be applied to satisfy increasing food demand in these countries.

Certainly, fertilization is a prime technique for increasing agricultural productivity in this part of the world but in order to obtain a greater and lasting production it is indispensible to combine the effects of mineral fertilizers, the recycling of organic residues and biologic nitrogen fixation, and also to optimize the use of local mineral resources such as natural phosphates.

Table 21. Comparison of different forms of phosphate fertilizers.

Treatments	Cotton seed (47 trials)		Maize (21 trials)		Sorghum grain	
	kg/ha	Index, %	kg/ha	Index, %	kg/ha	Index, %
	Togo					
Control, without fertilizer	777	53	444	51	-	-
NPK (raw phosphate)	1133	77	745	85	-	-
NPK (phosphate acidified at 61%)	1260	86	817	93	-	-
NPK (soluble phosphate)	1484	100	875	100	-	-
	Burkina					
Control, NK	-	-	-	-	848	69
NPK (raw phosphate)	-	-	-	-	929	76
NPK (phosphate acidified at 29%)	-	-	-	-	1128	92
NPK (soluble phosphate)	-	-	-	-	1217	100

Organic maintenance of tropical soils, as well as the practice of liming of which the immediate impact on yield is not always visible, even though inevitable, raises serious application problems since they depend on a long-term fertility maintenance strategy.

Experiences from the last ten to twenty years unfortunately prove that on the whole, technical systems of food production intensification were very badly handled by farmers who very often chose to retain certain techniques helping to stretch the extensive traditional systems up to a land saturation.

This crisis situation to be dealt with makes it possible to hope for a reversal in trends but it must also be stressed that it only depends on farmers.

Agricultural intensification which must be based on reliable agrotechnical bases, must also be accepted by all national and international rural development agents and decision makers. Do present pricing policies and even land legislations of most of these countries permit such a revolution?

If we limit ourselves to crop fertilization and soil fertility in several countries, particularly those of the semi-arid regions, would it not also be necessary to:

(1) start restructuring the rural landscape in order to enable agroforestry to enjoy its merited status,
(2) regulate common pasture land and the use and value of crop residues through a sedentary live stock system,
(3) solve the problems of providing circulation means, and cropping season credit for non-cash crops,

(4) establish a proper balance between the price of inputs and purchasing and selling prices of agricultural commodities. The task to be undertaken is as immense as this vast continent.

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ANNEX

REFERENCE STUDIES ON LONG-TERM FERTILITY TRENDS

(1) Long Duration Trials:

(a) in the dry tropics:
- . Saria trial in Burkina Faso since 1960 (Pichot et al., 1981; Sedogo, 1981)
- . Nioro Du Rip trial in Senegal from 1963 to 1979 (Sarr, 1981)
- . M'Pesoba trial in Mali from 1955 to 1970 (Pieri, 1974)
- . Bambey trial in Sengal from 1973 to 1978 (Pieri, 1982
- . N'Tarla trial in Niger from 19.. to 1973 (Pichot et al., 1974

(B) in the humid tropics:
- . Gagnoa trial in the Ivory Coast from 1971 to 1981 (Chabalier, 1977; Akomian, 1982)
- . Boukoko trial in the Central African Republic from 1965 to 1970 (Pichot, 1971)
- . Ampangabe trial from 1965 to 1971 (Velly and Longueval, 1976)
- . Davie trial from 1976 to 1981 (Marquette: to be published)

(2) Diagnosis in Farmers' Fields:

(a) in the dry region:

- A study on the evolution of soils under traditional cropping in Upper Casamance (Siband, 1972)
- Problems of cotton cultivation in eastern Senegal (Ange, 1984)

(b) in the humids tropics:

- Ten years of motorized cropping on a catchment basin in central Ivory Coast: production and fertility trends (Le Buanec, 1972)
- Comments on the long term fertility trends of soils cultivated at Grimari, Central African Republic (Morel and Quantin, 1972).

AGRONOMIC AND ECONOMIC EVALUATION OF ALTERNATIVE PHOSPHATE FERTILIZER SOURCES IN NIGER

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Phosphorus plays an important role in food production in the semi-arid environments of sub-Saharan Africa. It is recognized that in developing countries fertilizers have so far accounted for more than 50% of the increase in crop yield.

Fertilizer consumption in Africa is very low and represents about 3% of the world's consumption. For example, Africa uses 20 kg/ha of fertilizer nutrients compared with Asia where the average is 68 kg/ha. Almost three-fifths of the fertilizer consumed in Africa is used by Egypt and South Africa. In Niger fertilizer consumption in 1982/83 was 3,563 mt, and the fertilizer nutrient consumption was 1 kg/ha.

Since 1982 the International Fertilizer Development Center (IFDC) in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has carried out a systematic research program on nitrogen and phosphorus fertilizer sources and their management in semi-arid sub-Saharan Africa.

The objectives of the phosphorus component of the research program are as follows:

(1) to evaluate the potential of indigenous phosphate rocks for direct application,

(2) to investigate the production, at minimum cost, of alternative phosphate fertilizers such as partially acidulated phosphate rock (PAPR) and to test the agronomic effectiveness of these materials,

(3) to develop management practices for a more efficient use of phosphorus fertilizers.

The objective of this paper is to compare information obtained from agronomic and economic evaluation of alternative phosphate fertilizer sources at experiment station trials with that from on-farm researcher-managed trials.

Several investigators have shown that lack of P constitutes a major constraint to food production in tropical Africa (Milne, 1968 ; Pichot and Roche, 1972).

The sandy soils of sub-humid and semi-arid West Africa are low in P buffering capacity (Juo and Fox, 1977; Mokwunye 1977; Bationo, 1982), and crop responses have been obtained with small P application of the order of 4-10 kg P/ha (Kang and Osiname, 1979). Responses to P are more spectacular in the semi-arid zone of tropical Africa (Hauck, 1966). Jones and Wild (1975) have reported that P deficiency occurs widely in the savanna zone. The low organic matter content in the sandy soils of semi-arid Africa contributes to the phosphate problem. Several investigators have indicated that in soils rich in organic matter, the release of organic P plays a vital role in plant nutrition (Nye and Greenland, 1960; Acquaye and Oteng, 1972; Agboola and Oko, 1976).

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The cost of transportation in a landlocked country like Niger makes it necessary to use high-analysis fertilizers. However, these high-analysis fertilizers contain little or no sulfur. Several workers have reported sulfur response in a number of crops (Greenwood, 1951; Watson, 1964; Braud, 1970; Osiname and Kang, 1975; Kang and Osiname, 1976; Enwezor, 1976; Fox et al., 1977). Kang et al., (1981) found that total sulfur in soil decreases in the the following order: forest > derived savanna > Guinea savanna. Thus sulfur deficiency is expected to be even more acute in soils from the semi-arid ecosystems.

For most countries of Sahelian Africa, it may be more economical to use phosphate rock (PR) for direct application. But the effectiveness of PR depends on its chemical and mineralogical composition, soil factors, and the crops to be grown (Khasawneh and Doll, 1978; Lehr and McClellan, 1972; Chien and Hammond, 1978).

Several experiments have been carried out to evaluate agronomic effectiveness of West African indigenous phosphate rocks for direct application (Nabos et al., 1974; Jenny, 1973; Boyer, 1970; Juo and Kang, 1978; Jones, 1973; Mokwunye, 1979; Thibout et al., 1980; Bationo; 1982). The results suggest that the agronomic effectiveness is low. Truong et al., (1978) compared several PR sources (Anecho in Togo, Arli and Kodjari in Burkina Faso, Tahoua in Niger, Taiba in Senegal, and Tilemsi in Mali) and found that only Tahoua and Tilemsi PR were suitable for direct application.

The effectiveness of African PR is due to their low reactivity, which results in their inability to supply P in soil solution for crops. Partial acidulation (PA) is one way to increase solubility of PR. The term PA50 indicates that 50% of sulfuric acid required to produce single superphosphate is used to make the product. The work on PAPR to date has been characterized by conflicting results. McLean and Wheeler, 1964; McLean et al., 1965; McLean and Balam, 1967; McLean and Logan, 1970; Misra and Panda, 1969; Lutz, 1971; and Ashby et al., 1966, found that PAPR at various acidulation levels was equal to and sometimes better than concentrated superphosphate (CSP), whereas Terman et al., 1964, and Terman and Allen, 1977 and Allen, 1977, found that PAPR was inferior to CSP. Mokwunye and Chien (1980) reported that when an equal amount of water-soluble P in the form of PAPR or CSP was added to two Alfisols from Nigeria and an Oxisol from Colombia, the amount of water-extractable P was higher in soil treated with PAPR.

Work done on farmers' fields by McIntire (1983) suggested that fertilizer use under farmers' traditional practices was profitable in Niger.

MATERIALS AND METHODS

Field trials for agronomic evaluation of alternative phosphate fertilizer sources. In 1982 different P fertilizer sources were tested at the research station at Sadore, and in 1983 and 1984 the most promising fertilizers that had emerged from on-station research were evaluated in experiments set up and managed by the researcher on a farmer's field at Gobery.

Some selected chemical and physical properties of the soils at Sadore and Gobery are presented in Table 1. Table 2 gives additional information on rainfall, cropping system, origin of PR used, and crop variety used.

Table 1. Selected chemical and physical properties of soils of Niger.

Soil characteristics	Sadore	Gobery
Soil classification USDA	Alfisol	Alfisol
Organic matter, %	0.29	0.30
Total nitrogen, %	0.02	0.02
Soil pH, water 1:1	5.6	5.2
Available P, Bray P-1	3.4	2.6
CEC, meq/100 g	1	1
Base saturation, %	60	55
Sand, %	92	95
Clay, %	6	2

Table 2. Rainfall, cropping system, type of rock and crop used at each experiment site.

	Sadore	Gobery
Total annual rainfall	mm	
1982	370	-
1983	598	392
1984	-	260
Cropping system	Millet sole crop	Millet sole crop
Origin of PR	Niger Parc-W rock	Niger Parc-W rock
Crop variety	CIVT	CIVT

On-station research (Sadore 1982). The fertilizer sources were:
(1) Parc-W phosphate rock (PR),
(2) Parc-W phosphate rock partially acidulated at 25% (PA25),
(3) Parc-W phosphate rock partially acidulated at 50% (PA50),
(4) Triple superphosphate (TSP), and
(5) Single superphosphate (SSP).

P rates were 10, 20, 30 and 40 kg P_2O_5/ha, and all plots received 30 kg N/ha as urea at 21 days after planting and 30 kg K_2O/ha as KCL. The K and P applications were broadcast and incorporated with a tractor before planting. A randomized complete block design with eight replications was used for the experiment, and millet was planted at a spacing of 1 x 1 m. The chemical properties of Parc-W PR and Parc-W PAPR are presented in Tables 3 and 4, respectively.

To compare the different P sources, the relative agronomic effectiveness (RAE) was calculated. RAE is defined as :

$$\frac{\text{Yield with P} - \text{Yield of Control Treatment}}{\text{Yield with SSP} - \text{Yield of Control Treatment}} \times 100$$

On-farm rechearch (Gobery 1983, 1984). At Gobery during 1983, PA50 was compared with SSP. Rates were 20 and 40 kg P_2O_5/ha. Nitrogen was applied as prilled urea, broadcast and incorporated (U), or as urea supergranule (UG) placed on the millet hill, at the rate of 30 kg N/ha. Potassium was applied

Table 3. Chemical analysis of Parc-W phosphate rock.

Soil element	Wt, %
Total P_2O_5	28.5
CS P_2O_5[1]	2.6
CaO	40.0
F	3.4
Al_2O_3	1.5
Fe_2O_3	1.0
MgO	0.13
Na_2O	0.13
K_2O	0.04
CI	0.005
SiO_2	23.0
CO_2	1.2

1 Measured in neutral ammonium citrate solution.

Table 4. Chemical analysis of partially acidulated Parc-W phosphate rock, wt %

Level of acidulation[1]	Type of material	Total P_2O_5	WS[2] P_2O_5	CS[3] P_2O_5
25	Granular[4]	23.8	5.4	2.8
40	ROP[5]	21.6	9.2	2.1
50	Granular[4]	20.2	9.9	1.9

1 Indicates percentage of sulfuric acid required to produce SSP.

2 WS = Water soluble.

3 Soluble in neutral ammonium citrate solution.

4 Analysis reported on minus 6- plus 14-mesh (Tyler).

5 ROP indicates semigranular, run-of-pile material.

as KCI at 30 kg K_2O/ha. The P and K were applied before planting and incorporated by hand with a hoe. The N was split, one-half at 21 days after planting and one-half at 45 days after planting.

At Gobery in 1984, PA40, SSP, TSP, and PR were compared. Rates were 30, 60, and 90 kg P_2O_5/ha. Potassium was applied as KCl at 30 kg K_2O/ha and N as urea at 30 kg N/ha. The phosphorus and potassium were applied before planting and incorporated with a hoe. The nitrogen was split, one-half at 21 days after planting and one-half at 45 days after planting. In both years a randomized complete block design with eight replications was used, and millet planting distance was 1 x 1 m.

Statistical procedures. Analysis of variance was conducted to determine the statistical significance of different treatments on crop yields. The following general model, consistent with the completely randomized block design, was used for this purpose:

$$Y_{ijk} = \mu + R_i + X_j + Z_k + (XZ)_{jk} + e_{ijk}$$

where the observed crop yield Y_{ijk} is equal to the true mean μ plus the effects of the ith replicate R_i, the jth fertilizer rate X_j, the kth phosphorus source Z_k, the interaction effect of the jth fertilizer rate and phosphorus source $(XZ)_{jk}$ and the error term e_{ijk}.

The effects of different P sources on crop yields were compared and evaluated by using orthogonal contrasts and by estimating the following P response function models using ordinary least squares:

$$Y = B_o + \sum_{k=1}^{m} B_k F_k + \sum_{k=1}^{m} \theta_k F_k^2 + e$$

$$Y = \gamma_o + \sum_{k=1}^{m} \gamma_k \ln F_k + e$$

Where : Y = crop yields in kg/ha;
F_k = rates of P_2O_5 applied using the kth P source in kg/ha;
B, Θ, and γ = parameters of the response functions;
e = random errors with normal properties.

Economic evaluation. The adoption of new fertilizers by farmers depends in great part upon the relative profitability of these fertilizers with respect to the profitability of fertilizer products already available in the market. Fertilizer technologies that can significantly increase economic returns to farmers have a high probability of being adopted by farmers. Moreover, these technologies will economically increase the productivity of fixed and limiting factors of production, expand agricultural production, and promote agricultural and economic development in a region or country.

The economic evaluation of PR and partially acidulated products was carried out by calculating and then comparing the economic benefits of these fertilizers with those of SSP. SSP is the most commonly used source of P in Niger. The economic benefits were calculated by subtracting the cost of fertilizer from the value of the increments in crop yields associated with the use for fertilizer. Cost estimates for the partially acidulated products were used for this purpose. In terms of cost per unit of P_2O_5, the PA50 and PA40 were considered to be 20% and 25% less expensive than SSP, respectively. These cost estimates are based on general production cost studies conducted at IFDC. Actual cost, however, will depend on the type of rock and the cost of ground PR and sulfuric acid.

RESULTS AND DISCUSSION

Agronomic effectiveness. Fig. 1 depicts response of millet yield to sources and rates of P at Sadore (research station) in 1982. There was a significant response to both P sources and P rates. It was observed that the response to various sources of P was in the following order: TSP > PA50 > SSP > PA25 > PR.

The relative agronomic effectiveness (RAE) of the various P fertilizer sources at the optimum rates of 30 kg P_2O_5/ha was found to be 26%, 78% and 110% for PR, PA25, and PA50, respectively. The result depicted in Fig. 1 clearly suggests that PA50 was agronomically as good as SSP. Therefore, PA50 was selected for further testing under farmers' conditions at Gobery in 1983. The trials, however, were managed by the researcher rather than the farmer.

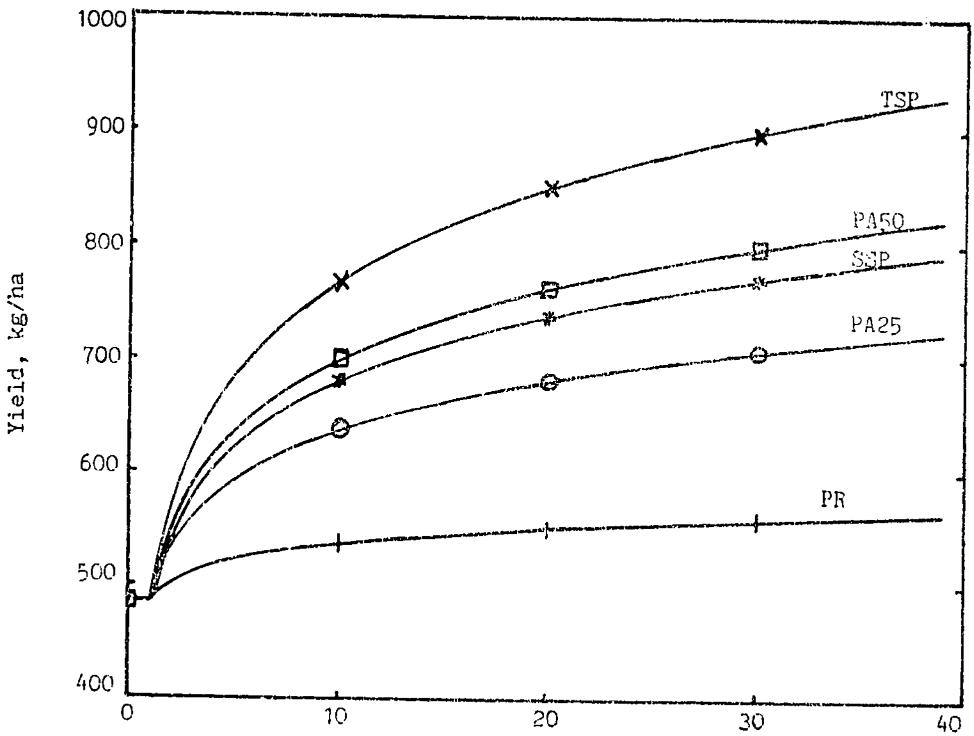

Fig. 1. Effect of phosphorus rate and source on millet grain yield in Sadore, 1982.

The millet yield response functions for the various P sources and rates at Gobery in 1983 are shown in Fig. 2. It was observed in other experiments at Sadore (not reported) on N management that prilled urea (U) performed better than urea supergranules (UG). When these two types of N were included in the P trial at Gobery, the following results were noted.

PA50 combined with prilled urea was as good as SSP with prilled urea, and both were significantly superior to the sources where urea supergranules were applied. The RAE of these treatments using SSP with urea or with urea supergranules is presented in Table 5. It demonstrates conclusively that PA50, in the presence of prilled urea, is a viable alternative to SSP.

Further tests involving SSP and PA50 were conducted at Gobery in 1984. Response to sulfur had been observed in a demonstration trial at Gobery in 1983. Therefore, TSP and PR were included in the 1984 trial to study both the effect of a lack of sulfur and higher rates of P applications. Fig. 3 shows the response to the different sources and rates of P applications with the two types of N sources. The RAE of the various P sources at 30 kg P_2O_5/ha was 41%, 97%, and 97% for PR, PA50, and TSP, respectively. Grain yield of millet was lower in 1984 than in 1983. The decrease in yield was the result of the low rainfall obtained in 1984 (Table 2).

At 30 kg P_2O_5/ha there was no significant difference between SSP and TSP. This indicates that the lack of S in TSP did not result in significant yield decrease in 1984 in contrast to what was observed in 1983. The nonsignificant effect of S in 1984 could be attributed to the lower rainfall recorded.

Economic evaluation. Results obtained at Gobery in 1983 and 1984 are presented in Tables 6 and 7. Results for 1983 show that the net economic benefits of using PA50 were not significantly lower than those obtained using SSP. In 1984 a similar conclusion was obtained by comparing the net economic benefits of PA40 with those of SSP; the difference between the net benefits of these two fertilizers was not statistically significant. These results indicate that PA50 and PA40 could be economically competitive sources of P if supplied at a price equal to about 80% and 75% of the price of SSP, respectively. The direct application of PR was significantly less profitable than the use of partially acidulated products and SSP.

SUMMARY AND CONCLUSIONS

In research conducted at both the research station and the farmers' fields under the management of the researcher, P application resulted in a significant increase in grain yield of millet indicating that soil at these sites was P deficient. Partial acidulation of phosphate rock greatly improved the initial agronomic effectiveness. It was also observed that PA50 was, in general, as good as the superphosphates.

The economic evaluation of P sources and rates from results of non-farm research and on the basis of subsidized prices of fertilizer showed that all sources of P were profitable. PA40 and PA50 were found to be as profitable as SSP, but PR was substantially less profitable than the partially acidulated products and SSP. These results indicate that PA40 and PA50 could be economically competitive sources of P if supplied at a price equal to about 80% and 75% of the price of SSP, respectively.

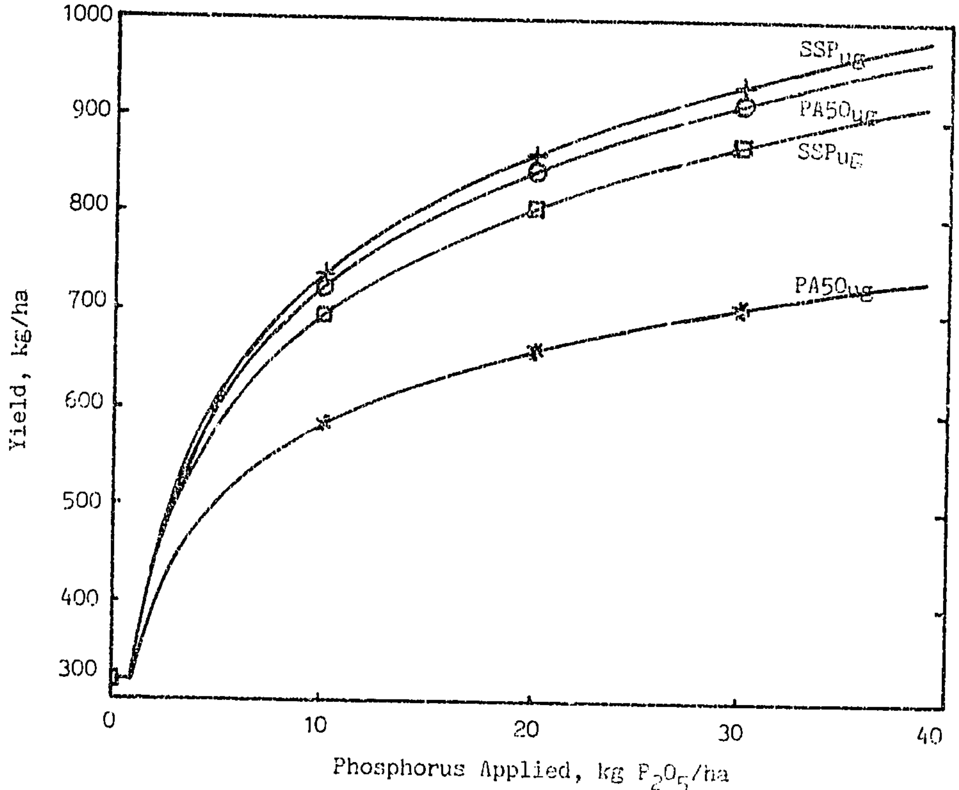

Fig. 2. Effect of phosphorus source and rate on millet grain yield in Gobery, 1983.

Table 5. Relative agronomic effectiveness (RAE)[1] of P fertilizer sources at 30 kg P_2O_5/ha, Sadore 1983.

	SSP + U	PA50 + U	PA[illegible] + UG	SSP + UG
	%			
SSP + U	100	97	63	89.5
SSP + UG	117	109	70	100

1 $RAE = \frac{\text{(Yield With P - Yield With Control)}}{\text{(Yield With SSP - Yield With Control)}} \times 100.$

Table 6. Economic evaluation of P fertilizer sources at Gobery, 1983.

Economic factors	PA50	SSP
Prices of fertilizer, FCFA/kg P_2O_5	177[1]	222
Prices of millet, FCFA/kg	100	100
P rate, kg P_2O_5/ha	30	30
Yield increment, kg/ha	597	616
Gross benefit, FCFA/ha	59,700	61,600
Cost of fertilizer applied, FCFA/ha	5,310	6,600
Net benefit, FCFA/ha	54,390	54,940
Benefit: cost ratio	11.2	9.2

1 The cost of PA50 P_2O_5 is assumed to be 20% less than that of SSP P_2O_5.

Table 7. Economic evaluation of P fertilizer sources at Gobery, 1984.

Economic factors	PR	PA40	SSP
Prices of fertilizer, FCFA/kg P_2O_5[1]	55	166	222
Prices of millet, FCFA/kg	100	100	100
P rate, kg P_2O_5/ha	30	30	30
Yield increment, kg/ha	153	359	374
Gross benef.t, FCFA/ha	15,300	35,200	37,400
Cost of fertilizers applied, FCFA/ha	1,650	4,980	6,660
Net benefit, FCFA/ha	13,650	30,[illegible]	30,740
Benefit: cost ratio	9.27	7.1	5.62

1 The cost of P_2O_5 supplied by PR and PA40 is assumed to be 75% and 25% less, respectively, than the cost of SSP P_2O_5.

It is gratifying to report here that the governments of both Niger and Burkina Faso have begun to consider the technology of partial acidulation as a basis for local P industry. Also, there is obviously a need for more work to be done on farmers' fields with the farmers actually managing all operations in order to confirm these observations.

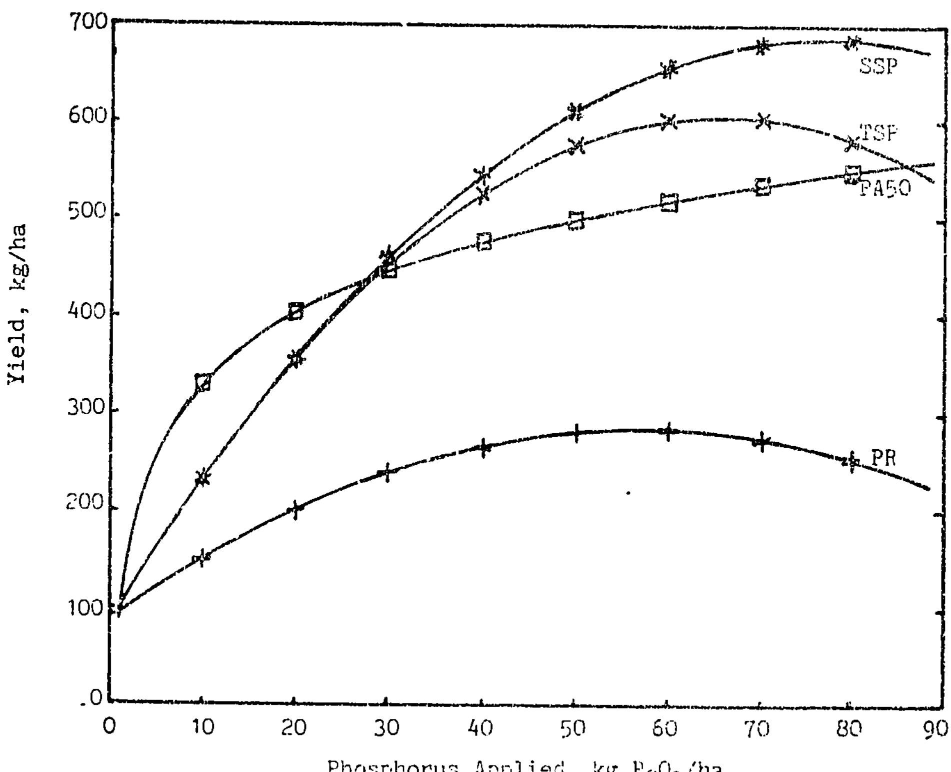

Fig. 3. Effect of different sources and Rates of phosphorus on millet grain yield in Gobery, 1983.

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PROSPECTS AND PROBLEMS OF USING SOIL TESTING FOR ADOPTION OF FERTILIZER USE IN EKITI-AKOKO AGRICULTURAL DEVELOPMENT PROJECT AREA

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The soil testing program for determining the available nutrients to estimate the fertilizer needs for crops is probably one of the most widely used, but least understood, tools of modern agriculture. Some people think it has the magical powers for predicting the exact amount of any and all nutrients necessary for plant growth. Others believe it is nothing but a hoax designed to sell fertilizers. The true value of soil testing lies somewhere between these two extremes. The recommendations based on soil analysis will frequently be a little higher or lower than the actual optimum. Occasionally, the recommendation will miss the optimum by a wide margin. However, soil testing, even with these shortcomings, is still the most practical method for determining the fertility status of a field and the most practical means of estimating fertilizer needs.

In temperate-zone agriculture, fertilizer use has revolutionized agriculture, but this has not been possible in the African sub-region, partly due to lack of a soil testing program. In the humid tropics, there is a common misconception that building soil analytical laboratories for soil sampl analysis is synonymous with a soil testing program. The extension aspect of a soil testing program should consist of four phases:

(1) soil sampling,
(2) analysis,
(3) interpretation, and
(4) fertilizer recommendation.

The chance of obtaining a good fertilizer recommendation from a given soil analysis depends on a number of factors. They include:

(1) how well the analysed sample represents the entire field,
(2) how well the extractant (soil test used) correlates with the nutrient uptake by the crop,
(3) how accurately the soil analysis is done,
(4) how well the person interpreting the soil analytical values understands the relationship between test values and plant response to that particular type of soil, and
(5) how well the person making the recommendations understands:
   (a) the reactions of the fertilizer with the soil which determine the most efficient method of application and the rate of application required for a specified increase in yield under optimum conditions, and
   (b) the economic factors involved.

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Every factor requires information from many investigations in the field, greenhouse and laboratory. Therefore, it can be said that the soil testing program is only as good as the research on which it is based. The objective of this paper is to report the application of these steps for making meaningful and economical fertilizer recommendations for farmers in the Ekiti-Akoko Agricultural Development Project, Ondo State.

Project features. The Ekiti-Akoko Agricultural Development Project (EAADP), in Ondo State, Nigeria is a World Bank assisted agricultural development project. It was set up as an agency for integrated rural development with two major objectives:

(1) increasing annual food production and overall farm productivity, and

(2) providing and strengthening social and farm support services.

The project which is situated between lat 7°15' - 8°15'N and long. 5°16' - 6°E, and covers an area of 4,950 km^2 (about 25% of Ondo State). The climate is tropical, humid and hot, with two distinct seasons: a long rainy season (March - October) separated into two growing seasons by a dry July - August spell, allowing growth of two short-cycle crops; and a clearly marked dry season. Annual rainfall varies from 1,120 to 2,000 mm and the duration decreases towards the savannah, which makes the second season crop unreliable. The temperature varies between 21° to 32°C, the low values being associated with the arid, cold harmattan winds. Vegetation varies from typical rainforest in most of Ekiti-central and east, and parts of Akoko south; derived savannah in Ekiti north and Akoko south; and southern Guinea savanna in Akoko north and Ekiti north. Underlying rocks are crystalline basement complex formations consisting of gneisses, magmatites, schists, quartzites and younger granitic formations. They make up the inselberg landscape in the north-west and central-south of the project area. The terrain is undulating, with dotted, residual hills. Soils are ferruginous tropical soils (D'Hoore, 1964) belonging to the soil series within the two soil Associations (Smyth and Montgomery, 1962), which are Alfisols. There are also a considerable number of areas with Ultisols, Entisols and Inceptisols; lisohyperthermic, having Ustic and Udic moisture regimes. Earlier work on soil samples from the area show that the clay consists of kaolinite and sesquioxides, low nutrient status and buffering capacity, and a low P fixation.

Although fertilizer use is not entirely new to the project area, efforts by ministries of agriculture met with little success, with the exception of tree cash crops. Although farmers want to use fertilizer to alleviate soil fertility problems, there is scepticism because fertilizers can, in fact, ruin the soil and reduce the yield when the nutrient dynamics and soil characteristics are not clearly understood. Many unproved 'side-effects' of fertilization are common among farmers: yams turning black on cooking, not pounding well, and having poor storability; cassava giving low starch and gari yield; loss of taste in fresh maize; unfilled groundnut pods and empty glumes in rice. These beliefs indicate a loss of faith and prevent farmers from using fertilizers. This does not even take into account the extra labour required for application. These fears were justified however, because of the blanket fertilizer recommendation (Table 1) given to the area as part of what used to be Western State and is now subdivided into five different states.

Table 1. Fertilizer recommendation for some arable crops as applicable to Ekiti-Akoko Agricultural Development Project.

Nutrient/ha	Material/ha	Recommendation
Cassava		
60 kg N	Urea, 135 kg (2 1/2 bags) or CAN, 230 kg (4 1/2 bags)	South-Western Nigeria
30 kg P_2O_5	or SA, 300 kg (6 bags) SSP, 170 kg (3 + bags)	(a) 60 kg/ha N + 30 kg/ha P_2O_5 + 30 kg/ha K_2O (b) 200 kg/ha of 15-15-15 + 20 kg/ha N
30 kg K_2O	KLC, 50 kg (1 bag) or K_2SO_4, 60 kg (a bag) Compound fertilizer, 200 200 kg (1 bag)	
Maize		
50 kg N	Urea, 110 kg (2 bags) or CAN, 195 kg (4 bags) or SA, 250 kg (5 bags)	For newly opened land 50 kg/ha N + 25 kg/ha P_2O_5 + 25 kg/ha K_2O
25 kg P_2O_5	SSP, 170 kg (3 1/2 bags)	Under continuous cropping
	or TSP, 55 kg (1 bag)	100 kg/ha N + 50 kg/ha P_2O_5
25 kg K_2O	KCl, 40 kg (1 bag) or K_2SO_4, 50 kg (1 bag)	+ 50 kg/ha K_2O or 300 kg/ha of 15-15-15
15-15-15	Compd 300 kg (6 bags)	
Rice		
15-15-15	Compd 100 kg (2 bags) Urea 45 kg (1 bag) or SA 100 kg (2 bags)	For 5 Western States 100 kg/ha of 15-15-15 + 20 kg/ha N

There were three problems that needed urgent solutions to facilitate the use of soil testing program in Ekiti-Akoko:

(1) There was no soil fertility characterisation of the project area, therefore a soil fertility survey of the area was initiated to identify the nutrients limiting yield that need to be determined in the soil analytical phase.

(2) Soil sampling is the weakest part of the soil testing program and the largest source of error, because of the magnitude of extrapolation of result. A 5 g sample from a composite of a 25 ha field (0-15 cm) represents one-billionth of the total soil volume for which the analysis is made. Representativeness is a function of:
(a) soil microvariability,
(b) number of samples taken, and
(c) the way the sample is taken.

In Nigeria, research on methods of soil sampling on farms for a soil testing program is limited. Moreover, the extension workers in the project area have no experience with soil sampling for soil analysis. Furthermore, the fertility status varies both vertically and horizontally over short distances due to undulating topography. Variabilities also arise from differences in parent materials, cropping history, vegetation cover, drainage and management practices (such as size and shape of ridges and mounds). Ridges and mounds for planting yams, cassava or cocoyams in height, and diameter from 30 to 150 cm. The biggest mounds for yams are found in the hydromorphic soils.

Farms animals also deficate unchecked, especially when the Fulanis graze their herds. This causes variation in soil fertility patterns. Since the majority of farmers had not previously been using fertilizer for food crops however, there is no variability in fertility patterns due to different methods of fertilizer application.

(3) Due to the poor financial position of the farmers in the project area, they cannot finance an expensive soil testing program. Therefore, the use of extractants which can extract a single nutrient at one shaking is very expensive. A multipurpose extractant for P, K, Mg, Cu and Zn which had been found to be deficient in our survey, was developed.

The research into the analytical method designed to assist the interpretation and fertilizer recommendation was implemented in five steps:

(1) choice of extractant, bearing in mind that:
   (a) the extracting solution and the procedure used should extract the total amount (or a proportionate part) of the available form or forms of a nutrient from soil with variable properties,
   (b) the amount of the nutrient in the extract should be measured with reasonable accuracy and speed,
   (c) the amounts extracted should be correlated with the growth and the response of each crop to that nutrient under various conditions:
(2) correlation of the extractant with uptake in the greenhouse;
(3) field correlation using strip cropping and setting nutrient critical levels using the Cate and Nelson model;
(4) using nutrient fixation and recovery curves to determine the amount of nutrient required to raise soil nutrient level by 1 ppm;
(5) field calibration, using 4 above to calculate the amount of fertilizer required, and using replicated trials.

MATERIALS AND METHODS

A total of 410 composite surface soil (0-15 cm) samples from demonstration plots located in the 25 zones of the EAADP representing all the soil classes commonly cultivated in the project area were collected. Each site differed widely in cropping history. The soils were Alfisols and associated Entisols derived from undifferentiated basement complex rocks. The soil samples were air-dried and sieved.

Soil analysis. The pH was determined by a 1:2.5 soil distilled water mixture, the organic matter by dichromate oxidation, and the particle size analysis by the hydrometer method. Exchangeable cations were extracted with 1.0^N NH_4OAc pH (7.0), K, Ca, Na and extracts were read with flame photometry, while total acidity was determined by titrating 1.0^N KC1 extracts with 0.01^N NaOH. Effective CEC was taken as the sum of total exchangeable cations and total acidity. Other nutrients were extracted with 0.005^N DPTA using 15 minutes stirring time in a 1:10 soil solution ratio.

Evaluation of extractants. Thirty samples were taken from the project area. The soil samples were analysed for P, K, Mg, Mn, Cu, Fe and Zn with Bray's P1 + 0.05^N AHDF; Bray's P1 + 0.01^M EDTA 0.05^N AHDF + 0.05^MD1/2TA; $0.5^M NaHCO_3$ + 0.01^MEDTA; and 0.05^M $NaHCO_3$ + 0.005^M DPTA, using 15 min stirring time in a 1:10 soil solution ratio. The minus-one technique was used for each nutrient using maize (TZPB) grown for 28 days. Four hundred ml of air-dried samples were measured into half-litre plastic cups. The following nutrients per litre were added in solution form: 100 mg N as NH_4NO_3, 80 mg K as KCl, 100 mg Mg as $MgSO_4.7H_2O$, 100 mg Zn as $ZnCl_2$, 7.5 mg Fe as Fe SO_4. $5H_2O$ and 2.0 mg Cu as $CuSO_4.5H_2O$ and 20 mgP as orthophosphoric acid. The nutrient being considered is omitted. Maize was established at 5 plants per cup and watered daily with NH_4NO_3 (ug/10 l). At 28 days, plant tops were harvested, oven dried at 80°C for 24 hours and weighed. Plant tops were milled and a 0.5 g sample was digested with 35 ml of mixture of concentrated HNO_3, H_2SO_4 and $HClO_4$ acids ("5 : 5:5 V/V). The digest was analysed for the relevant nutrient. Uptake was determined as the product of % nutrient in sample and dry matter yield.

Laboratory studies. A fixation experiment involving 30 soils selected for variability in colour and chemical properties was conducted to determine changes in the extractant Bray's P1 + 0.005^M DPTA (selected after the evaluation of extractants)test values resulting from nutrient addition with increasing time of incubation.

A 2.5 ml portion of soil was incubated with 2.5 ml of solution containing various concentrations of P,K, Mg, Zn, Cu, Fe and Mn for 42 days. Samples were extracted with 25 ml of Brays P1 + 0.005^M DPTA solution and nutrients were determined at day 1, 7 and 42. From the recovery curves, amounts of each of the nutrients added to raise the soil nutrient level by 1 mg/ml soil were calculated as a rate at day 42, divided by the difference between the nutrient extracted at that rate and control. For example, at each rate of P addition, extractable P decreased with time, and at 42 days, rate of increase was somewhat slow, suggesting equilibrium conditions, the mean fertilizer factor was then calculated. Similar calculations were made for other nutrients, which showed that the soils have varying capacities for immobilising added nutrients.

Field correlation. There were 30 locations. These locations covered all the different soil groups being cropped in the area. The land was cleared and traditional hoes were used in tillage operations.

The experimental design used was "strip cropping". This was a simple un-replicated plot designed to compare the yield and performance of a row of maize which is supplied with an adequate amount of fertilizers with an adjacent row in which one or more fertilizer elements were left out. Each plot size was 21 x 36 meters with 30 rows of maize. Twenty four rows of maize were treated while the remaining six rows (three on both ends of each plot) served as guard rows. Maize variety (TZPB) was planted on the flat land with jab planters designed at Agronomy Department of the University of Ibadan at a spacing of 30 cm within and 90 cm between rows. Three kernels were planted per stand and later thinned down to one plant two weeks later.

Each row treated as "complete" received the following fertilizers: 100 kg N/ha at planting as Urea and 50 kg N/ha top dressed in two splits. One was added at four weeks after planting and the other at about tasseling; 60 kg P/ha as single superphosphate 80 kg K/ha as KCl; 20 kg Mg/ha as $MgSO_4$; 4.5 kg Zn/ha as $ZnCl$, 3 kg Fe/ha as $FeSO_4$; 2.5 kg Cu/ha as $CuSO_4$; and 5 kg Mn/ha as $MnCl_2$.

The analytical grades of these chemicals were used. The minus-1 rows received all the basal fertilizer elements except the element being investigated. These nutrients were mixed up in a plastic bucket and banded in an 8-10 cm deep groove about 7.5 cm away from the seeds and covered up with soil. Thirty core soil samples, taken (0-15 cm depth) from each row before planting and fertilization, were properly mixed up as a composite and processed for soil analysis. The plants in each row were harvested dry, dehusked and weighed. The shelling percentage of the grains were computed at 12% moisture content.

The percentage of relative yield of the dry grains was calculated as:

$$\text{Relative yield (RY) \%} = \frac{\text{Yield of "minus row"}}{\text{Yield of "complete row"}} \times 100$$

Correlation was run between the soil nutrient values extracted with Brays P1 + 0.005 M DPTA and relative yield. The Cate and Nelson model was used for determining the critical level of each nutrient.

On each of the 30 locations, a randomised complete block experimental design with four replications was used to evaluate six treatments consisting of five levels each of P, K, Mg, Cu, Zn and a control having all basal fertilizer minus the one being determined. Three seeds of TZPB maize variety were planted on flat at 90 by 25 cm spacing in 4.5 m^2 plots and thinned to a density of 44, 444 plants per hectare two weeks later.

RESULTS AND DISCUSSION

Fertility characteristics of the soils. The means and ranges for the soil properties are shown in Table 2.

Mean pH was 6.5, with a range of 5 to 8.2, 18% of the soils have medium acidity while 73% are in low acidity range thereby indicating the soils as slightly acid to neutral. Soil organic matter varied from 0.1 to 7.9 with a mean of 1.9%. Total N with a mean value of 0.15% varied between 0.02 to 0.70%. About 65% of samples had less than 0.15% total N considered as optimum for maize (Sobulo and Osiname, 1981). Available P ranged from 0 to 130 me/100 g with a mean of 11.4 me/100 g. Exchangeable K varied between 0.06 to 1.00 me/100 g with a mean of 0.34 me/100. Only 17% of the soils are lower than 0.20 me/100 g. Exchangeable Ca varied between 0.3 to 70.0 me/100 g with a mean value of 5.2 me/100 g. Mean exchangeable Mg is 1.3 me/100 g. About 90% of the soils seem to be sufficient in exchangeable Mg. Extractable Mn ranged from 13.0 to 196.1 mg/kg with a mean of 64.1 mg/kg while Fe has a mean of 41.7 mg/kg. These values indicate than Mn and Fe deficiencies may not occur, however toxicities are probably likely under poor soil management. Available Zn varied between 0.0 to 6.5 mg/kg, while

Table 2. Mean and ranges of physical and chemical characteristics of soils from Ekiti-Akoko Agricultural Development Project.[1]

Soil properties	Range	Mean
Sand %	46 to 91	77
Silt %	4 to 36	14
Clay %	5 to 15	9
Soil pH in H_2O	5.0 to 8.2	6.5
Soil organic matter %	0.1 to 7.9	1.9
Total N%	0.02 to 0.7	0.16
Brays P1 (available P) mg/kg	0 to 130	11.4
Exchangeable K me/100 g	0.06 to 1.00	0.34
Exchangeable Ca me/100 kg	0.3 to 70	5.2
Exchangeable Mg me/100 g	0.0 to 3.2	1.3
CEC me/100 g	1.0 to 20.0	5.0
Exchangeable Mn mg/kg	13.0 to 196	64.1
Exchangeable Zn mg/kg	0.0 to 6.5	1.6
Exchangeable Cu mg/kg	0.0 to 3.1	1.4
Exchangeable Fe mg/kg	5.6 to 178.1	41.7

[1] Range and means of 410 soil samples.

available Cu which is equally low has a mean of 1.4 mg/kg. These two nutrients are likely to be deficient in these soils.

Soil fertility evaluation. Using the established critical levels for Ekiti-Akoko soils (Table 3), no soil was highly acidic, while the bulk of soils were slightly acid to neutral. Over 83% of the soils contained less than 3% organic matter, with a low mean (1.9%) resulting from decreasing fallow lengths, burning and continuous cropping. About 65% of soils contained less than the 0.15% total N, considered optimum for maize. Although mean available P was 11.4 me/100 g, most soils were deficient in P, while available K was 0.34 me/100 g soil, which shows that only about 17% of soil would respond to K application assuming 0.16-0.20 me/100 g soil critical level. Mean exchangeable Ca, 5.2 me/100 g soil was higher than 2.0 me/100 g soil critical level and, in relation to the low acidity, Ca availability should not limit crop production. About 90% of the soils were adequately supplied with exchangeable Mg while mean Mg (1.3 me/100 g) exceeded 0.40 me/100 g as soil critical level. Values of extractable Mn and Fe (mean of 64.1 and 41.7 mg/l respectively) indicate that their deficiencies may not occur, although toxicities are likely under poor soil management. Using 3.0 critical level, about 60% of the soils were deficient in available Zn while 62% were deficient in available Cu. Under intensive cultivation, micronutrient nutrition may become problematic because commonly used fertilizers do not contain these nutrients. Therefore, for optimum crop production, soil testing for evaluating the nutrient status is a must. Fertilizer recommendations should, therefore, include both macro and micronutrients and should take into consideration cropping history, while efforts should be directed towards maintaining soil organic matter at sufficiently high levels.

Table 3. Soil test interpretation for Ekiti-Akoko soils.

Soil property	Low	Medium	High
Acidity (pH)	6.0-6.9	5.0-5.9	5.0
Available P (Brays P1) ppm	0-8.5	8.5-12.5	12.5
Exch. K (NH_4OAC) me/100 gm	0-0.15	0.16-0.31	0.31
" Ca "	0-1.5	1.6-4.0	4.0
" Mg "	0-0.5	0.6-1.0	1.0

Selection of extractant. Means and ranges of nutrients determined with the different extractants (Table 4) show that Bray's P1 + EDTA extracted the highest P, while $NaHCO_3$ + DPTA gave the least value. However, all the evaluation indices gave a somewhat clear picture of P availability. Exchangeable K was least from Bray's P1 + DPTA (0.41 me) while $NaHCO_3$ + DPTA gave the highest K (0.61 me/100 ml), which indicates that all extractants are efficient for assessing K status. $NaHCO_3$ + EDTA or DPTA extracted highest Mg while Bray + DPTA extracted the least; all other extractants were comparable with NH_4OAC, the recommended Mg extractant. Available Zn was highest in AHDF. Its value decreased with chelation, while for $NaHCO_3$, the chelates were equally efficient. Bray's P1 + EDTA extracted the highest available Mn while $NaHCO_3$ + EDTA had the highest available Cu. The choice of an extraction method does not lie on the relative quantity extracted, but correlation with growth response or nutrient uptake. The correlation value with uptake (Table 5) shows that Bray's P1 AHDF single or chelated and $NaHCO_3$ extractants were good indices of P and K availability. $NaHCO_3$ + EDTA correlated well with the micronutrients, while Bray's P1 + DPTA correlated well with the uptake of all the nutrients. Therefore Bray's P1 + DPTA can be used as a multi-nutrient extractant. Bray's P1 + EDTA showed some promise for the Cu and Zn assessment. A similar study with rice, showed that Bray's P1 + DPTA was the best multi-nutrient extractant.

Bray's P1 + DPTA has been selected as the multipurpose extractant for the zone. This extractant was later used for sorption, the studies used for determining the amount of nutrient required to increase soil nutrient by 1 ppm.

The average amounts of nutrient extracted by Bray's P1 DPTA at different rates of nutrient addition and incubation times vary. Table 6 indicates the amount of zinc extracted (ug/ml) by Bray's P1 DPTA procedure at different rates of Zn addition and at different times for 5 of the 30 soil samples used.

The same procedure was repeated for P, K, Mg, Cu, Fe and Mn.

There were two phases and an initial rapid decline in available nutrients which continued until the 28th day. Subsequent decreases were less rapid and Brays P1 + DPTA extract values differed only slightly with increased incubation time. At this steady fixation phase, the amount of nutrient needed to increase the soil nutrient value of soils by 1 µg/ml was calculated from the relationship the nutrients required:

$$\frac{\text{Nutrient added at rate R}}{\text{Nutrient recovered at rate R - Nutrient in untreated sample}}$$

.../...

Table 4: Extractable nutrients determined from the various extractants.

Extractant	K	Mg	P	Cu	Mn	Zn
	me/100g		mg/kg			
Bray's P1	0.55 (0.21-0.91)[1]	1.52 (0.26-3.20)	10.4 (2.5-43.7)		-	-
AHDF	0.54 (0.21-0.81)	1.61 (0.14-4.34)	10.9 (0.5-51.4)	0.9 (0.2-1.6)	75.3 (2.0-306.0)	8.5 (3.0-15.0)
Bray's P1 + EDTA	0.51 (0.26-0.88)	1.74 (0.64-3.52)	13.4 (2.1-50.4)	0.9 (0.1-2.3)	385.1 (58.0-726.0)	7.4 (5.9-9.3)
AHDF + DPTA	0.52 (0.12-0.91)	1.35 (0.62-2.94)	10.3 (0.2-38.6)	1.7 (0.4-3.2)	213.4 (39.0-379.0)	2.8 (0.6-7.1)
$NaHCO_3$ + DPTA	0.68 (0.26-1.04)	2.45 (0.84-4.32)	6.2 (2.1-21.6)	1.6 (0.7-3.0)	29.4 (6.6-67.2)	4.3 (2.8-7.9)
$NaHCO_3$ + EDTA	0.58 (0.21-1.01)	3.15 (1.02-5.34)	8.2 (0.5-40.6)	2.1 (0.3-4.3)	68.2 (2.0-148.0)	4.3 (2.9-6.7)
Bray's P1 + DPTA	0.41 (0.16-0.78)	1.14 (0.66-2.10)	9.0 (3.9-20.6)	-	-	-
NH_4OAC	0.55 (0.20-1.06)	1.77 (0.83-3.50)	-	-	-	-

1 ( ) Ranges of soil nutrients determined by extractants.

Table 5. Correlation coefficients of nutrients with uptake by rice in the soils.

Extractants	P	K	Mg	Mn	Cu	Zn
Bray's P1	0.88**	0.93**	0.27	-	-	-
AHDF	0.89**	0.86**	0.20	0.81**	-0.20	0.13
Bray's P1 DPTA	0.88**	0.78**	0.61*	0.60**	0.45*	0.55*
AHDF + DPTA	0.87	0.72	0.31	0.01	0.20	0.05
Bray's P1 + EDTA	0.87**	0.85**	0.31	0.01	0.36	0.22
$NaHCO_3$ + EDTA	0.84**	0.82**	0.23	0.49**	0.44**	0.83**
$NaHCO_3$ + DPTA	0.88**	0.51*	0.37	0.53*	-0.36	0.10
NH_4OAC	0.37	0.88**	0.34	-	-	-

*,** Denote significance at 5 and 1% respectively.

The mean and range of fertilizer for each nutrient is contained in Table 7. Correlation coefficients of soil nutrients with the values for F show that soil pH, Al, Fe, oxides control how much nutrient is needed to increase the soil available nutrient to a derived level (Table 8).

Table 7. Fertilizer factors obtained from the nutrient fixation/release studies.

Nutrient	Mean	Range
P mg/1	3.1	1.0-6.9
Fe "	1.9	0.8-4.0
Cu "	2.1	0.8-5.0
Mn "	0.8	0.2-2.5
Zn "	6.4	4.7-8.4
K me/1001	4.5	2.12-8.2
Mg "	3.0	2.10-6.0

Table 8. Correlation coefficients between P, fertilizer factor and soil properties.

	Bray's P1 DPTA	Clay Silt	O.M	Al_2O_3	Fe_2O_3	p^H
Fertilizer factor	-0.13	0.21-0.02	-0.[illegible]	0.69**	0.97**	-0.58*

* Significant at 1% level

** Significant at 0.1% level.

<u>The use of the fertilizer factor in making fertilizer recommendations.</u> After the soil has been extracted with Bray's P1 DPTA, (0.03N NH_4F + 0.25N HCl + 0.005M DPTA) the appropriate fertilizer factor was used as a multiplier, bearing in mind the critical level of the nutrient in question and the economic factor of the farmer.

For example, if the soils analysis indicates that the soil has 3 mg/1 of P, the fertilizer factor for P is 3.1 mg/1 and the critical level for P in the area is 6 mg/1. In the first instance, one must calculate the amount of P required to raise soil P from 3 mg/1 to 5 mg/1. Since the farmers are poor, it is better to raise the yield to about 90 to 95% of maximum yield. This has been found to be 10 mg/1. When soil level is 10 mg/1; there is no assured response. Therefore the P needed:

(1) to reach critical soil P is 6 mg/1 - 3 mg/1 x 3.0 = 9 mg/1 or 18 kg/ha,

(2) to achieve 90 to 95% of maximum yield is 10-3 x 3.0 = 21 mg/1 or 42 kg/ha.

Table 6. Amount of zinc extracted (ug/ml) by Bray-DTPA procedure for different rates of Zn additions at different time periods.

Location	Rate at applied Zn	Time Periods		
		1 day	7 days	42 days
		u/ml		
1	0	4.5	5.6	
	4	5.5	6.8	6.6
	8	7.7	7.9	6.5
	16	7.1	7 4	8.0
	32	9.8	12.1	10.1
	64	15	18.0	16.0
2	0	5.0	7.0	6.2
	4	5.7	6.9	6.5
	8	6.4	7.8	6.6
	16	7.3	9.0	8.5
	32	9.8	11.5	10.5
	64	14.1	18.7	16.0
3	0	5.2	5.7	6.2
	4	6.1	6.3	6.6
	8	6.1	6.8	7.3
	16	7.9	9.2	8.0
	32	8.8	12.2	16.8
	64	18.5	18.9	16.3
4	0	4.6	5.9	5.9
	4	6.1	7.1	6.5
	8	6.2	7.6	12.3
	16	7.8	8.5	8.5
	32	10.3	10.3	12.2
	64	15.3	14.7	16.1
5	0	9.8	4.9	6.6
	4	6.0	5.9	7.5
	8	6.5	6.2	7.6
	16	7.8	6.6	8.3
	32	10.2	7.7	11.4
	64	15.7	10.5	18.3

$$ff = \frac{RX}{Zn_{xt} Zn_0}$$

Where ff = fertilizer factor,
Zn = Extractable Zn at time t and rate X (RX),
Zn_0 = Extractable Zn when no Zn is added.

Based on the soil properties and the critical levels for optimum crop yield in the zone, fertilizer recommendations which recognise the fertilizer factors have been formulated and tried alongside the familiar blanket recommendation. Yield data shown in Table 9 for some food crops indicate a superiority of using the proposed method for fertilizer use. Nevertheless, variations in crop requirement and soil characteristics need to be considered for profitable fertilization.

Table 9. Comparative yield of food crops with fertilization based on fertilizer factor and blanket rates.

Crop	Blanket 300 kg/ha PK: 15-15-15 + 200 kg/ha S.A.	Fertilizer factor 120 N + 30 P + 60 K + 20 Mg + Micronutrients
Maize	3.72	6.03
Rice	1.76	3.45
Cassava	28.81	36.70

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SUMMARY

Soil testing programs are in their infancy in Nigeria. Farmers have long been disappointed with the yield and produce resulting from applying recommended amount of fertilizer based on blanket fertilizer recommendations. An attempt was therefore made to introduce soil analysis as the basis for fertilizer recommendations to farmers in the Ekiti-Akoko Agricultural Development Project Area under multiple cropping.

The research phase covered a selection of suitable extractants, greenhouse correlation, field correlation and calibration, and the use of sorption studies for determining the amount of nutrient needed to increase soil nutrient by 1 ppm.

Resulting from this exercise, $0.03^{N}NH_4F + 0.025^{N}HCl + 0.005^{M}$- DPTA (Brays P1 DPTA) was selected as a multipurpose extractant, extracting available P, K, Mg, Zn, Fe, Cu and Mn in one shaking. After sorption studies with the extractant, the amount of nutrient required to increase soil nutrient by 1 ppm was calculated from the relationship:

$$\text{Nutrient required: } \frac{\text{Nutrient added at rate R}}{\text{Nutrient recovered at rate R - Nutrient in untreated samples.}}$$

The fertilizer factors computed from this relationship in mg/l are P = 3.1; Fe = 1.9; Cu = 2.1; Mn = 0.8; Zn = 6.4; with 4.5 and 3.0 me/100 ml for K and Mg respectively.

The fertilizer factor was involved in the interpretation of soil analysis for making a fertilizer recommendation. The crop yield resulting from the application of the recommended fertilizer based on soils analysis

was significantly different than that of the yield obtained from the blanket fertilizer recommendation. Maize yield increased from 3.72 to 6.03 t/ha, while rice and cassava increased from 1.76 to 3.45 t/ha and 28.81 to 36.70 t/ha respectively. The result of such farm experiments increased sales of fertilizer in the area by 70% during the last growing season , restored faith and confidence in fertilizer use and has encouraged the authorities to set up a soil analysis laboratory which is now nearing completion.

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DEVELOPMENT OF SORGHUM VARIETIES IN WEST AFRICA

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DEFINITION OF VARIETAL IMPROVEMENT

According to A. Gallais, varietal improvement in genetic terms may be defined as "the transformational operations which turn a group of individuals not having all the qualities at the required levels into a new group of reproducible individuals, that is, the variety which shows some progress with regard to some features" (Fall, 1984). There are two stages:

(1) a phase of variability build up in the species under study, and

(2) a phase during which this variability is used for a purpose previously defined with appropriate methods.

In the case of sorghum, different situations may arise in relation to the floral biology of this cereal, to the development of variability and to the heritability of the characters to be improved.

METHODS OF SORGHUM BREEDING

Under normal conditions, sorghum is an autogamous plant; however, a low allogamy of 5% to 10% is generally encountered. This rate may vary according to climatic conditions and varieties. Under normal conditions, it requires self-pollination for the fixation of the features searched for.

Furthermore, systems of cytoplasmic male sterility were discovered and used in the USA, which makes it possible to create hybrids in sorghum and thus to use heterosis (Stephen and Holand, 1954).

Finally, systems of genetic sterility may also be used to develop populations (House, 1980).

Two cases may be retained depending on whether it is existing variability or a directed variability that is being considered.

Existing variability. The evaluation of plant variability, in the country where the breeding work is taking place, is the basis for a varietal improvement programme. Through investigations, one starts by sampling the variability of the species under study. In the case of sorghum, different collections of local ecotypes were or are being made in each sahelian country. The best traditional cultivars are identified with the help of mass selection. This work has resulted in the development of Ngor Gatna, RT 50, SH 60 in Senegal, of Tiemarifing in Mali, of S 29, Noingomsoba, Frikan, Gnofing in Burkina and Babadia Fara in Niger.

One may also go beyond the variability of a species, in a given country by testing introductions from other areas of the world. Thus ICRISAT, in Burkina, has identified the value of an Ethiopian variety as E 35-1 or of a variety of South Africa as Framida. In Senegal, IRAT has envisaged the extension of a Chadian ecotype 51-69.

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Directed variability. The method most currently used in West Africa consists in developing strains by recombining parents with complementary qualities and by searching for favorable segregates in the progeny through self-pollination (Rives, 1984). This is pedigree breeding applied to the progeny resulting from the crossing of selected parental lines. In this way, IRAT has developed CE 90, ISRA-IRAT 204 in Senegal or C 10 in Niger. Recently, ICRISAT has developed ICSV 1002 from a crossing between E35-1 and Framida.

When an existing adapted variety has a simple hereditary defect that needs to be corrected, the backcross breeding method can be used. For the backcross method a corrective parent is crossed once with the variety to be improved. Then a series of return crossing is performed with the variety to be provided (the recurrent parent). This eliminates all the genes of the corrective parent except the gene (s) which are of interest. At the end of the process, an isogenic strain without its initial defect is produced from the recurrent strain.

This type of breeding was carried out at IRAT in order to produce local varieties of Guinea sorghum with shortened straw such as S 7 which is one 3/4 Oueni or S 8 which is 3/4 Safdou (Labeyrie, 1977). This breeding is currently carried out to change the ISRAT-IRAT 202 with a brown layer into an identical strain without testa.

In the case of cytoplasmic male sterility, the variability of the two parents, one sterile, the other a restorer of fertility, is used in such a way as to come out with the best combining ability (Schrestz and Holand, 1982). Results have been obtained on sorghum in West Africa which, for the time being, have not had any impact on development.

Finally, genic sterility allows for the formation of populations in which a variability is developed from constituent strains of this type of material, judiciously selected by the breeder. The interesting elements appearing in these populations are extracted and fixed by the same method as in pedigree breeding. Work on populations of sorghum is presently well underway at ICRISAT, Mali.

CRITICAL ANALYSIS OF VARIOUS METHODS OF SORGHUM BREEDING

Some methods are rapid but are efficient only on easily heritable features. This is the case for mass selection practiced on introductions. These methods have a limited effect on the improvement of features such as yield. Only part of the potential variability is selected for by these methods.

The methods of crossing between complementary parents followed by a pedigree breeding among the progeny requires five to six years before coming to the stage of the homogeneous strain (generally stages F5-F6). After that, it is appropriate to test the selected lines for yield, for a minimum of three seasons of trials possibly at several locations and at farm level. Then the potentials for the stabilization of production are assessed. The method uses only a limited number of recombinations because as early as stage F2, 50% of the heterozygous loci in F1 are already fixed. In addition, the effects of linkage intervene to limit the recombination which tends to favor parental genotypes. In total,

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some 10 years of work are required before one can produce a line that brings about improvement with respect to the already existing one.

The backcross method is efficient only for specific objectives consisting of improving a variety for a single feature or which involves a small number of simply-inherited characters. However, it requires cycles of crossing and self-pollination phases, especially if the feature to be modified is recessive or polygenic. Therefore, several years are required in order to correct a variety with respect to a given defect and, at the same time there is a risk that a superior product might be produced with other breeding methods, (Van Der Have, 1979).

The production of hybrids profits from the heterosis which may be expressed in terms of yield by a superiority over the best parent. Unfortunately, this situation is mostly due to the effects of dominance and overdominance which cannot be fixed. Therefore, it is necessary to plant hybrid seed each year, if one wishes to grow hybrids.

The method of population improvement, with the help of sterile genes, produces a material with perpetual recombination which favours the separation of linkages and the appearance of new genotypes. By alternating the selection cycle of strains extracted from populations and their recombination (recurrent selection), the genetic variability is preserved and the frequency of favourable alleles is increased (Bhola, 1982). An important aspect of this work is the choice of strains to initiate populations. The method is not easy to apply and it requires a number of cycles of recurrent selection before producing, at acceptable frequency, good strains to be fixed by pedigree breeding. Its interest is not immediate, it can only be appreciated in the medium or long term.

SORGHUM BREEDING IN DIFFERENT ENVIRONMENTS

With respect to varietal evaluation of the experimental material, the following major situations may be identified:

(1) breeding in a controlled environment without a limiting factor,
(2) breeding in a controlled environment with the study of the response to a stress, or screening for a varietal feature,
(3) breeding in a lightly controlled environment.

Breeding in a controlled environment without a limiting factor. One evaluates the potential of on-station varieties in very good conditions of management, nutrient and water supply assuming that the superior material in those conditions will remain superior in difficult conditions. This hypothesis would be fairly well confirmed for hybrid material but not for the homozygous material (Blum, 1979). The interest of this type of breeding is that it is easy to carry out at station level. On the other hand, one can test a great number of materials at the experiment station level. Unless it is applied with discernment it eliminates the material which has certain major agronomic defects.

Breeding in a controlled environment with response to a stress or screening for a varietal feature. This situation arises when, for instance, material is being studied on-station for resistance to drought, or for resistance to striga as is done by ICRISAT in Burkina (Ramaiah and Parker, 1982) or for a feature such as vigor at plant emergence (as is done by

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IRAT in Senegal). The method is only focused on one of the behavioral aspects of the plant. Quite often it happens that the material thus screened also has defects. However, the material retained may serve as a genitor in a program of pedigree breeding or backcross. The screening test requires special devices and the setting up of controls. It requires many replications for reconfirmation.

It is not possible to test varieties as rapidly and in as great quantity as the previous method. In the case of study of progeny submitted to pedigree breeding, the test must start early so as not to let favorable combinations escape.

Breeding in a lightly controlled environment. The material under study in lightly controlled environments is submitted to many and varied stresses generally related to climatic hazards and pests. This case is frequently witnessed at the farm or station level when material is tested under conditions of traditional cropping. The assumption here is that the material that behaves well in these conditions may be hardy and well adapted to difficult environments. However, the interpretation of results is difficult. The method is not an efficient one. Because of various heterogeneities that occur between and within tests, the results are easily biased.

In a lightly controlled environment, heritability for yield or even the components of yield is poor (Blum, 1979). The breeder must compensate for this fact by conducting several repetitions of the tests at the expense of the number of cultivars studied which, of course, must include a local control.

In fact these three breeding situations are not at variance with one another. After selection for vigor at plant emergence, we evaluate the material which is bred in good conditions so as to establish its yield potentials and agronomic qualities. The lines retained are then tested in less controlled conditions similar to the traditional type of cropping without traction or fertilizer. ICRISAT, on the other hand, multiplies on-farm trials. The integration of all the results makes it possible to analyze the yield stability of the varieties and then to choose numbers associating high performance and stability of production. What is required is a material which, under improved cropping practices, should respond to improved agronomic techniques and inputs.

CHARACTERISTICS OF THE LOCAL MATERIAL AND OF THE SELECTED MATERIAL

In sorghum, the major characteristic of the local material is that it is hardy. The essential elements of this hardiness are found in the Guinea type. They are: good seedling emergence, the power to compensate for tillering, rapid root development related to the strong vegetative development, the length of the cycle which leads to a satisfaction of the mineral needs better stretched out in time, photoperiod sensitivity which makes it possible to reduce the negative phase in case of late seeding and finally resistance to local diseases which have developed over centuries of cropping in a selective environment.

However, the local varieties do not have only good qualities. Most local varieties have limited yield potentials. Furthermore, their large height results in a large straw/grain ratio. The use of fertilizers does

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not improve this situation; on the contrary, these fertilizers seem to be more effective on the vegetative parts than on the reproductive parts of the plant. Lodging and breakage occur frequently. Finally, their long cycle makes local varieties sensitive to late-season droughts which now characterize rainy seasons more and more. Thus over the last few years, long cycle traditional ecotypes of the sahelian zone have disapeared.

Comparatively, selected varieties are characterized by shorter straw, poor tillering, an earlier ear emergence that is not very sensitive to photo-period, higher production potentials mainly due to the improvement of two yield components: the number of grains per panicle and grain weight. Generally speaking, more than local varieties, they respond to improved agronomic techniques and inputs when the latter are applied with discernment. Here lies the difficulty because as it is often less hardy than the traditional ecotypes, the selected material requires more attention and care. The constraints are more numerous when it comes to seeding dates, densities, thinnings, weedings and to soil fertility of course.

Concerning grain, there is great diversity in local varieties ranging from vitreous small white grains to floury red grains. This diversity is related to the multiplicity of traditional cooking practices: couscous, acid of alkaline "tô", beer.

In West Africa, selected varieties show greater uniformity. Breeders generally aim at producing clear-coloured grains without brown layer and, larger than the average local ecotypes.

The large size of kernels is associated with absence of anthocyanic pigments and an endosperm with a relatively large floury portion. The consequence of this situation is certain susceptibility to molds and insect attacks.

Presently, a serious breeding effort is being made in West Africa to produce material drawing from the traditional varieties a number of features insufficiently recovered in our current varieties. Thus progress can be made in terms of vigour at plant emergence, preservation of partial photoperiod sensitivity for medium and late maturing types, resistance to diseases and grain quality. Despite the antagonistic aspect of some associations of characteristics, we are far from having used all the possibilities of sorghum. The expansion of the variability under study, the use of new breeding methods such as the recurrent selection, a greater emphasis on testing in collaboration with farmers are resulting in selections which are better accepted than the previous ones and meet the demand of the rural world better. If this effort is carried on, we may yet reasonably expect to improve the situation and better participate in the development of food crops which is a requisite for food self-sufficiency.

EXAMPLES OF SELECTED VARIETY: ISRA-IRAT 204

ISRA-IRAT 204 is a strain extracted from crossing CE90 x 73 71. At plant emergence its vigour is superior to that of CE 90. Its type is Caudatum Tan, its size is about 1.40 m. It has a 90 day semi-marurity cycle. Its panicle is quite free, thick but aerated. Its grain is white, fairly vitreous and consumers like its taste. It is resistant to drought and well adapted to the 500-600 mm zone. Before being

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introduced into Burkina, it was developed in Senegal under both intensive and traditional conditions.

Test without a limiting factor. In 1984, in an irrigated plot in the Sourou valley of Burkina, with ample fertilizer, ISRA-IRAT 204 yielded an average of 62 q/ha on a 2,500 m^2 plot. This gives an idea about the high potentials of the variety in a totally controlled tropical environment.

Papem trials. ISRA-IRAT 204 has been tested over the last three years at the experimental location of the ORD of Yatenga. The comparison is made with the local variety under conditions of controlled cropping practices, except for rainfall which is the major limiting factor (Dugue, 1983, 1984).

The results in Table 1 indicate the yield resulting from the use of a good selected variety.

Table 1. Comparison ISRA-IRAT 204 and a local variety.

Trial	Yield		Useful rainfall
	ISRA-IRAT 204	Local variety	
	kg/ha		mm
1982 Sabouna	2062	1156	403
1983 Sabouna	1420	986	320
1983 Ziga	948	254	311
1984 Sabouna	0	0	195
Average yield of local control	1107 (185)	599 (100)	
Days to panicle emergence (days)	55	77	

With semi-intensive agronomic techniques and under limited rainfall conditions, the yield of ISRA-IRAT 204 is nearly twice that of the local variety. A 300 mm seasonal rainfall still makes it possible to produce 10 q/ha. However, there is a limit to the possibilities of resistance to drought of the selected material that was reached in 1984. With 195 mm of useful rains, ISRA-IRAT 204 scalded.

On-farm trials. At farm level, at Sabouna, the effect of ploughing on ISRA-IRAT 204 was studied in comparison with the local variety. This experiment was located in lowlands receiving poor rainfall over the last few years.

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Table 2. Effect of ploughing on ISRA-IRAT 204 and on a local variety.

Ploughing	Yield ISRA-IRA 204	Yield Local variety
	kg/ha	
Direct seeding, average 1983/84	1585 (8)	1371 (8)
Ploughing, average 1983/84	2439 (8)	1587 (8)
Yield increase (%) due to ploughing, 1983/84	54	16

1 Number of trials indicated in parentheses.

In direct seeding, ISRA-IRAT 204 is slightly superior to the control. With ploughing, the selected variety is more profitable than the local variety in terms of soil preparation.

The comparison ISRA-IRAT 204 /local variety was also made in 1984 on gravel lands of Yatenga, with and without fertilizer.

Table 3. Effect of fertilizer on ISRA-IRAT 204 and on a local variety.

	Yield ISRA-IRAT 204	Yield Local variety
	kg/ha	
Without fertilizer	277 (23)	216 (7)
With fertilizer	684 (23)	lack
On-farm rainfall	260 to 400 mm	

1 Number of trials indicated in parentheses.

The yields are poor but these results of 1984 were obtained under limited rainfall conditions and on poor soils with poor capacity of water retention. They show that with the most unfavourable treatment, ISRA-IRAT 204 reveals a hardiness that can be compared to that of the local control. Here we do have the selected variety that we wanted, that is a variety which responds to improved agronomic techniques and inputs to a greater degree than the local varieties without being inferior in a stress situation.

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ROLE OF ADAPTIVE RESEARCH IN TECHNOLOGY ADOPTION: THE CASE OF MANGROVE SWAMP RICE FARMERS OF WEST AFRICA

Kwame PRAKAH ASANTE[1]

Failures in technology adoption by the West African rice farmer are usually blamed on weak extension services and on the inappropriateness of technology developed by scientists. Technology which is inconsistent with the socio-cultural and economic values of the farm community is not appropriate and will be rejected. On the other hand, a new technology that has a chance of "fitting" the farm community must be supported by efficient extension services. In most West African countries, however, extension services are inadequate.

For example, the results of a cross-sectional baseline study of the Great Scarcies in Sierra Leone, 1982, indicated that out of 96 farmers interviewed in eight villages, only 11% had met the area extension field staff, an event that took place more than a year previously. Weak extension services leave the West African rice farmer low in productivity and income. Efforts should therefore be made to alleviate the situation in order to achieve higher outputs. In an environment of inadequate extension services, the methodology of adaptive research should be used to improve the efficiency of national extension services and other recognized "change agents" who, in the long run, are the "messengers" of new technology.

The Regional Mangrove Swamp Rice Research Station (RMSRRS) of the West Africa Rice Development Association (WARDA) in Rokupr, Sierra Leone, incorporates both the extension and appropriate technology factors into its framework of adaptive research. The adaptive research program of the station is staffed by a multi-disciplinary team of scientists. They collectively work to ensure that the technologies developed for the farmer fit his socio-cultural and economic aspirations and that the technologies can be transferred with minimum extension effort. For the purposes of adoption of technology that need farmers' involvement.

The timely participation of farmers at all levels of adaptive research enables scientists to determine their socio-cultural attitudes towards a promising technology. It also affords the opportunity of joint assessment of economic viability. Properly planned farmer participation creates the appropriate MOTIVATION which is a vital prerequisite to technology ADOPTION. Adequate motivation allows a new technology to seep through naturally to the community for adoption. Even if the new technology is rejected, it is done honourably.

Generally, the approach applied by RMSRRS for different countries or zones is similar, but socio-economic and attitudinal diversities may sometimes call for different treatments or emphases in program implementation. Socio-economic research is the main tool used for farmer involvement. Properly programmed and cautiously executed, it can generate a "family" type of farmer-researcher relationship.

This paper discusses the sequence of phases followed by the multi-

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disciplinary team of the RMSRRS to stimulate the transfer of new technology to mangrove swamp rice farmers. It discusses the concerted farmer-scientist approach in Sierra Leone, Guinea, and the Gambia, and attempts to draw some conclusions that could be usefully applied in similar circumstances.

The methodology section of the paper comprises a description of the various phases of activities directed toward eventual technology adoption. The results and discussion section focuses on previous evaluations of the influence of the station's involvement approach to technology adoption.

In the context of this paper, the terms below are defined as follows:

New technology: a new technique of carrying out farm activities that is introduced into the farming system by station scientists. New technology includes the use of new inputs and /or new farm practices (e.g., fertilizer, new varieties, new cultivation methods).

Innovation: sometimes synonymous with "new technology", but including new ideas such as optimum time of planting, etc., which in the usual sense cannot be classified as technology.

Technology transfer: encompasses all the processes involved in introducing a new technology to the farmer for adoption. It includes both creation of awareness among the farm community of the benefits of a new technology and education as to its application.

Technology diffusion: refers to the rate at which a given technology spreads throughout a community.

Technology adoption: refers to widespread and relatively permanent use of a technology in a given community.

Adaptive research: research efforts aimed at developing technologies or innovations which can be fairly easily adapted to the existing socio-cultural, economic, bio-physical and farming systems.

Station researcher/scientist: a member of the multi-disciplinary team of the Regional Mangrove Swamp Rice Research Station.

METHODOLOGY

The following section describes the activities involved in different motivation phases and the special techniques used to suit specific situations.

Phase 1: Maiden contacts. In this phase, the RMSRRS team of researchers, composed of biological and social scientists, explore the areas in which their promising technology is likely to show favourable results. Literature review and informal visits are the main tools. The involvement of the farm community is minimal. However, the researchers usually introduce themselves to traditional chiefs and identify other local leaders for later contacts.

Phase 2: Initial interaction: During this phase, the researchers make organized visits to the farm community, hold meetings, discuss production constraints, and visit farms to observe their farming systems and identify some of their problems. At this point, farmer participation is rather cautious but important. The information is then assembled, the problems provisionally diagnosed, and action taken where possible. The problems that require more detailed study are deferred to the next phase.

In Sierra Leone and the Gambia, the initial contact with the village community is fairly easy, but in Guinea it must be endorsed by a high government official (the Director of Agriculture). He issues an "order of mission" without which the researchers may be refused audience. Later contacts, however, can be made without necessarily obtaining the official permit. In the Gambia, initial farmer meetings tend to exclude women. Since women do the rice farming in the Gambia the station researchers make special requests for their participation, and plan meetings at times when their household work is low. Use of the correct approach in this phase encourages further cooperation from the farmers.

Phase 3: Confidence development. In this phase, the scientists and their representatives raise the level of confidence to the point that the farmers begin to assimilate them into their community. Usually it is in this phase that detailed information on the farmers is collected.

The RMSRRS scientists use the FAO Farm Analysis Package (FARMAP) pre-coded questionnaires for data collection. Enumerators are normally assigned to work within their own ethnic area, though usually not in their own villages. However, in some instances, RMSRRS scientists have found it expedient to recruit enumerators from within the villages of operation. This is found particularly helpful when data-collection questions smack of commodity tax. Later, when adequate mutual confidence is established, such enumerators are replaced and, when possible, offered other assignments. In such circumstances, one often needs to exercise special tact to obtain accurate information on output, income, and expenditure. Unless the information is absolutely necessary, the RMSRRS scientists sometimes avoid such delicate issues until an adequate level of confidence is developed. In this phase, an important consideration is the definite attempt to establish cordial and perhaps "family type" relationships with the community. If this is achieved, the farmers become motivated for the joint farmer-field trials which, in turn, greatly prepares them for technology adoption.

Phase 4: Concerted farmer-researcher action. In this phase, the researchers, working in close collaboration with the farmers, have identified the problems which are soluble with new technologies. The RMSRRS scientists conduct researcher-managed farmer-field trials at different locations to test the placidity of technology packages. The farmers already motivated for participation willingly donate portions of their land and sometimes provide labour for the trials. Promising technology packages are then nominated for further multi-locational farmer field at the farmer management, rather than researcher management level. These are referred to as adaptive trials.

The selection of packages for the farmer managed trials is based upon the profitability ranking of the researcher managed trials and the "fit" of the new technology into the existing farming system. The individual elements of these packages are also tested to determine their separate effects. The results are then evaluated against the baseline output from farmers' traditional practice and the package is recommended for adoption if it satisfies the evaluation criteria. In this phase, the involvement of the farm community is mounting to a peak. They can evaluate the various aspects of the new technology and can judge its performance in conjunction with the scientists.

Phase 5: Introducing the innovation. At this stage, the farmers and researchers would have jointly assessed the viability of a new technology to their farm community. The new technology package judged to be adequately economical, socio-culturally adaptable, and bearing minimum risk is selected for multi-locational demonstrations. In Sierra Leone the package of mechanical cultivation - fertilizer injection - improved variety was selected for demonstration to farmers in the mangrove swamp ecology, especially to those who had not been associated with the earlier farmers' field trials.

In the farm demonstrations, the recommended package is "grafted" to selected farms and arrangements are made for the farm community to visit the demonstration plots at different growth stages to observe the crop performance. More importantly, at the end of the season, village groups are organized to harvest the demonstration plots and farmers' fields of equal size for comparison. The rice is threshed, winnowed, and sometimes weighed on the farm in order that the observers may note the difference in volume and weight, and thus assess the performance of the new technology against their traditional practice. At the demonstration stage, the RMSRRS scientists solicit the involvement of not only farmers, but also the policy-makers and development agents who will later play a major role in the diffusion and adoption of the new technology.

Phase 6: Continuous evaluation. Station scientists continue to monitor the performance of an adopted technology in order to be able to react promptly to any developments that may call for advice or for modification, or even complete withdrawal of the technology. This is usually carried out in conjunction with development agents.

RESULTS AND DISCUSSION

In this section, some results and observations on technology adoption emanating from the RMSRRS methodolgy are cited and discussed. It is particularly indicated that an attractive technology sells itself. The section also underscores the important role of adaptive research in technology adoption.

Adoption of Simple Technology. Adoption can be observed even before the "maiden contacts" phase. The farmers in the area around the Rokupr research station, for example, are believed to be growing rice varieties which "leaked" out during the early stages of experimentation on station. Such "traditional" varieties usually bear the names of the farmers who introduced them. Thus improved varieties such as Rok 10 and CP4, when tried on farmers' fields near the Rice Research Station, have not performed better than the best of the farmers' varieties.

The "pre-extension" kind of adoption, however, is most noticeable in the adaptive research phases. Especially after the multi-locational researcher managed trials, innovations can diffuse into the farm community. The case of Moribaia, an RMSRRS sample village (in a saline area) is a good example. In that village, the station scientists had introduced a new variety, Rok 5, at the level of multi-locational researcher managed farmer-field trials in 1980. The results indicated that Rok 5 could cutyield the traditional varieties by 50% on average. Moreover, it matured a little earlier than most traditional varieties. The difference in maturity period was large enough to afford escape from salt injury, though not so large as to disrupt the farming system.

The diffusion of the new variety in the village was monitored by means of interviewing samples of 40 to 50 farmers annually (Table 1).

Table 1. Diffusion of the Improved Variety, Rok 5, in the RMSRRS Village, Moribaia.[1]

Factors	1981	1982	1983
Number of household heads interviewed	47	43	43
Number of household heads growing Rok 5	5	12	19
% Household heads growing Rok 5	11	30	44
Total quantity of seed rice nursed	8.2t	7.8t	7.4t
Quantity of Rok 5 nursed	0.2t	0.5t	1.6t
% Rok 5	2	6	21

[1]Source: Station Report: Stenhouse, et al., Rockupr 1983.

According to the results, not only had the number of household heads growing Rok 5 increased from 5% to 10% in two years, but farmers nursed eight times as much of Rok 5 in 1983 as they did in 1981.

In another area, Kychum, the farmers were hesitant n accepting Rok 5, though it outyielded existing local varieties. The decisive factor was that the new improved variety fit into the Moribaia farming system better than it fit into the Kychum system. In Kychum, Rok 5 matured about two weeks earlier than their local varieties and thus required extra bird-scaring labour. Adoption of Rok 5 in Kychum would therefore occur slowly, if at all.

Joint evaluation of the performance of Rok 5 by the RMSRRS adaptive research scientists and the farmers resulted in the trial of a new improved variety, Kuatik Kundur, which matured about the same time as the existing local varieties. In this way, continuous cooperative action between the adaptive research scientists and the farmers enables a timely replacement of inappropriate technology with a more adaptable one. Technology that is simple, inexpensive, profitable, and amenable to the existing farming system, (Rok 5 in Moribaia, for instance) is more likely to be adopted by farmers in the early farmer-field trials of adaptive research.

Ad tion of Unfamiliar Technology. Technology which requires new techniques, such as the use of knap-sack injection equipment for fertilizer application, may have to pass through the adaptive farmer-field trials and demonstration stages. The adoption process may be gradual, or it may never take place at all. However, in all cases, intimate cooperation with the farmers is considered by the RMSRRS team to be the key to the evolution of appropriate technology. It has been observed that certain farmers who view the use of the injector as too complex, instead apply fertilizer by broadcasting. Though its marginal return was lower than that of the injection method, broadcasting was not discouraged since it was still profitable. In the meantime, those who were interested in the use of the injector were given training to enable them to more efficiently apply the fertilizer in mangrove swamps.

This highlights the important point that continuous farmer-researcher evaluation of new technology in the adaptive research phases can help modify the technology to suit different "adoption sectors" of the farm community. Insistence on a particular method which seems initially unacceptable to the community may prejudice the adoption of the new technology in the long run.

It should be emphasized that acceptance of new technolgy in a community does not mean adoption. For example, the mangrove swamp farmers in Sierra Leone and Guinea immediately accepted the use of single axle power tillers for cultivating their fields. Though it is marginally profitable at best, the farmers considered it a symbol of relief from the drudgery of manual cultivation of the swamps. The farmers valued the intangible benefits accruing from the new technology. Nonetheless, the technology had not truly been adopted since it was not being practiced by most farmers due to its scarcity.

Normally, the RMSRRS adaptive research scientists would not introduce a new technology into the farmer-field trial phases unless its availability was assured. In the case of power tillers, it was done for the specific purpose of offering the opportunity for policy makers to evaluate the performance of the new technolgy, and the reaction of the farmers towards it, on their own field trials. Reports on the economic and technical implications of the use of tillers were also discussed with the policy makers, i.e. the minister and deputy ministers of agriculture and their technical staff.

In Sierra Leone, the strategy gave favorable results. The use of power tillers is now given a policy priority. It is being promoted by newly established Integrated Agricultural Development Projects (IADPs). Different makes of tillers are being tried by the farmers and IADP staff to determine the most suitable ones for their environment. In Guinea, policy makers are currently giving serious thought to the use of power tillers.

The approach adopted by the station adaptive research scientists in the power tiller example demonstrates a certain flexibility in the sequence of the different phases of adaptive research discussed earlier. "Putting the cart before the horse" sometimes proves to be the most effective method. An accepted technology may have a high potential for adoption, but adoption is sometimes dependent upon national policy back-up.

Adoption of Composite Packages. Experience indicates that farmers tend to adopt the individual elements of a technology package rather than the whole package. This is natural, especially when acquisition of certain inputs (e.g. fertilizer injectors, power tillers) is a slow process for those farmers who do want to use them.

The station adaptive research scientists nevertheless pursue package trials with the farmers to assess the package effects on productivity. In Sierra Leone, for example, the aggregate of power tiller, fertilizer injector and improved variety exceeded the traditional practice by 80% on average for 24 demonstration sites. An average yield of 3.2 t/ha was recorded for demonstration plots compared to 1.8 kg/ha on farmers' fields.

In farmer-field adaptive trials in Guinea, the same package resulted in yields of 2.8 t/ha and 2.3 t/ha for improved package and traditional practice plots respectively, an increase of 20%. In the Gambia, in farmer field adaptive trials, the package of an improved variety plus fertilizer gave a yield of about 1.6 t/ha, roughly 34% higher than the traditional practice.

The packages were profitable, but generally, farmers were not capable of adopting them. In such situations, the RMSRRS adaptive research team has linked with development agencies (e.g. the IADPs), to develop package programs for farmers. For example, along the Great Scarcies of Sierra Leone, several "package groups" have been formed by the IADP to use the power tiller-improved variety-fertilizer package. The adaptive research team assists in training farmers to use the new equipment, such as fertilizer injectors and power tillers, provided by the IADP in the region. This was also an indication of the contribution which adaptive research can make in preparing the farm community to adopt more complex technologies.

Adaptive Research Model of Technology. In the foregoing paragraphs the adaptive researcher has been portrayed as a catalyst for technology adoption. Emphasis on concerted farmer-researcher trials and evaluation, with occasional involvement of the policy makers, has been the main strategy of the station adaptive researcher. Perhaps it is the most appropriate technique for the evolution of technology appropriate to the socio-cultural, economic, and the existing farming system of the farmers.

The traditional technology transfer model depicting the researcher and the farmer situated at the two poles with the extension worker in between does not appear valid in the West African situation wherein extension is deficient. Researchers should adopt the strategy of adaptive research, thus involving the farmers in technology generation as well as its transfer. In West Africa, the model (Fig.1) which is practised by the Règional Mangrove Swamp Rice Research Station of WARDA, may be more relevant.

In this model, the functional relationship among the three units of technology transfer is circular and two-way. Both the adaptive research scientists and the extension workers interact directly with the farmers. "Hot cake" innovations are adopted in the pre-extension or adaptive research phases. The "slow moving" innovations are eventually passed on to the extension or development agents for final delivery to farmers.

The concept to be stressed is that the adaptive research scientists are not a separate functional entity from the extension workers. Referring to the methodology described earlier, one recognizes the effective role adaptive research plays in motivating farmers for technology adoption. In popular extension terminology, the extension worker promotes technology adoption among his or her clients by first creating awareness and interest which later develop into evaluation and trial of the technology. This is the route to technology adoption. This same route is followed by adaptive researchers.

While it should not be concluded that adaptive research is synonymous with extension it is submitted that the difference between them, in the context of technology adoption should only be a matter of degree. Increased awareness of this important role played by adaptive research scientists can lead to greater mutual cooperation with national extension and development agencies, thus continuing toward the common goal of helping the farmer. Generating a new technology and giving it to a weak extension service to transfer will leave dedicated adaptive research scientists frustrated in their efforts to make an impact at the farm level. This is the West African situation.

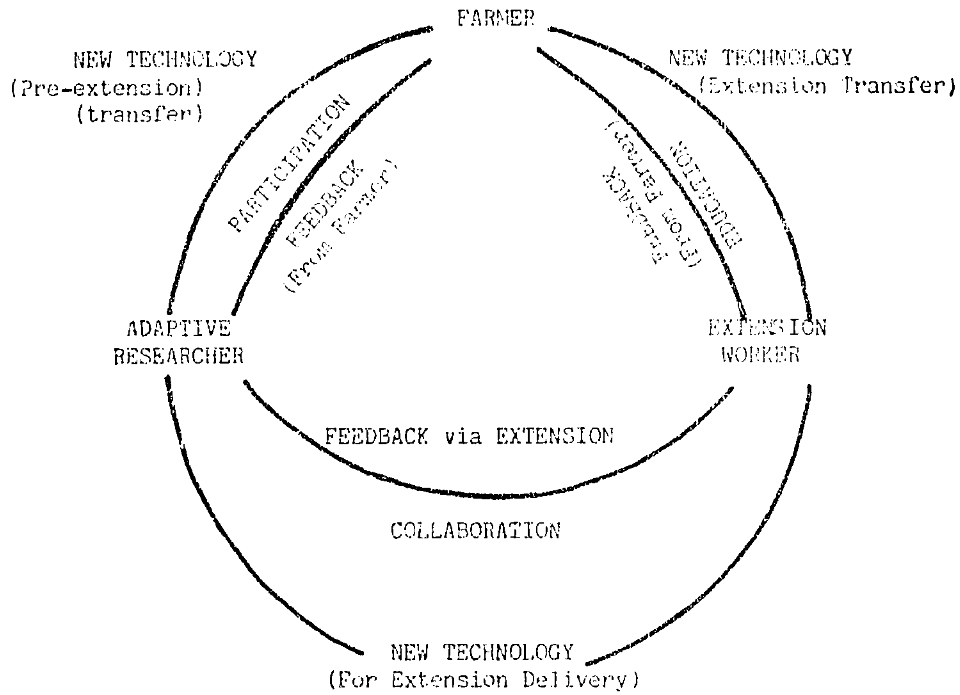

Fig. 1. Researcher-Farmer-Extension Concerted Technology Transfer Model.

SUMMARY

Adoption of technology among the West African rice farmers depends on two basic factors:

(1) adaptability of a new technology to the farming system, and to the socio-cultural and economic conditions of the farm community, and
(2) efficient extension service.

In West Africa, however the national extension services are generally inadequate. Therefore there is need for adaptive researchers to collaborate with national extension and other development agencies in order to achieve satisfactory results in technology transfer.

The Regional Mangrove Swamp Rice Research Station (RMSRRS) of the West Africa Rice Development Assication (WARDA) has an approach for its adaptive research program which, ensuring the appropriateness of a new technology through farmer involvement, also motivates the farmers towards technology adoption. Its program can be graduated into six phases, each of which contributes to technology adoption. The phases are:

(1) a probe into the unknown,
(2) initial interaction,
(3) socialization
(4) concerted farmer-researcher action,
(5) introducing the gospel, and
(6) continous evaluation.

Experience shows that relatively low cost technology that fits the existing farming system is adapted in the early phases of adaptive research trials. The more complex and unfamiliar technology may pass through the later phases and may even require the intervention of policy makers before adoption occurs.

A new improved rice variety (ROK 5) which was placed in researcher managed farmer-field trials, for example, was accepted outright, while a package comprised of power tillers, improved variety and fertilizer injection required special package programs for adoption. Thus, packages found profitable in Sierra Leone, Guinea and the Gambia are sometimes adopted at a rather slow pace.

The traditional technology transfer model of the extension worker standing in between the researcher and the farmer does not appear valid under conditions of inadequate extension services such as those found in West Africa. A more realistic model calls for constant interaction of the adaptive researcher with both the farmer and the extension units. This appears to be the most effective strategy to develop appropriate technology and expect to achieve a satisfactory level of adoption in the farm community.

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A CRITICAL REVIEW OF OBJECTIVES, METHODS AND PROGRESS TO DATE IN SORGHUM AND MILLET IMPROVEMENT: A CASE STUDY OF ICRISAT/BURKINA FASO

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Crop improvement programs for both cash crops and food grains have existed in the West African semi-arid tropics (WASAT) for several decades. But compared to significant advances in cash crop improvement which have already been diffused to small farmers, little progress has been achieved for food grains. The least success has been achieved in the improvement of sorghum and millet, the region's predominant foodgrains. It is estimated that despite the years of research on these two crops, less than 5% of their combined cultivated area in the WASAT is sown to varieties developed through modern plant breeding research (Matlon, 1983).

This paper considers some of the reasons for this slow progress and suggests changes in crop improvement strategies to improve this situation. We consider in particular ICRISAT's sorghum and millet improvement programs in Burkina through an examination of their objectives, methods, and results to date. Although the focus is on these particular programs, we believe the case study to be generalizeable with important implications for crop improvement programs elsewhere in the region.

The paper is organized into three sections. In Section One we review a range of possible crop improvement objectives, and their relevance to WASAT conditions. We then critically consider the objectives and methods employed by the ICRISAT crop improvement programs within this context. Section Two contains a detailed examination of results obtained during four years of on-farm tests of the most promising materials coming out of the ICRISAT programs. Finally in Section Three, we derive conclusions concerning changes in the goals and methods needed to improve the probability of success in both the near- and long-term.

CROP IMPROVEMENT STRATEGIES IN THE WASAT

The undeniable success of the high yielding variety/fertilizer package approach in parts of Asia during the 1960s and 1970s has had a substantial and lasting impact on the setting of goals in crop improvement programs throughout the WASAT. In the so-called "green revolution" a relatively small number of rice and wheat cultivars were developed which, when accompanied by improved agronomic practices, chemical inputs and adequate soil water (often through irrigation), were easily transferred to a large number of locations. The success of this approach, however, was largely a function of environmental, infrastructural, and economic conditions which prevailed in those particular regions where adoption rates were high. Because of the lasting influence of the green revolution experience on policy makers, donors, and plant breeders alike, we open our discussion of crop improvement objectives with a brief description of the physical environment and farming systems of the WASAT, drawing contrasts, where relevant, to the Asian situation.

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Environmental Considerations. Stoop et al. (1982) and Matlon (1983) have described the major characteristics of soils and rainfall in the WASAT which importantly determine crop improvement strategies for sorghum and millet based systems. These reviews underline the critical differences between the WASAT with those found, for example, in the semi-arid zones of India where important gains have already been made in the adoption of high yielding sorghum and millet varieties and hybrids.

Within India, high potential vertisols are located over large areas whereas in the WASAT, such soils are rare and only occur in isolated patches. Moreover, the red alfisols which are found in both continents, but which predominate in the WASAT, are less fertile and subject to greater water stress in West Africa than in India. In India such alfisols generally contain more clay and larger amounts of illite and montmorillonite in contrast to the more sandy African alfisols which contain small amounts of kaolinitic clay (Table 1). As a result, the cation exchange capacity and exchangeable cations are lower for the African soils, a fact which reduces their natural fertility, fertilizer-use efficiency, and water-holding capacity.

Overlayed on the poorer WASAT soils are more difficult and variable rainfall patterns. Data summarized by Oram (1977) comparing the Indian and West African SAT, for example, show that in areas of similar total annual rainfall amounts, the growing season is between 20 and 30 days shorter in the latter. Poorer water holding capacity which restricts post-season growth on residual soil moisture further limits the effective season length. Even in years of "normal" total rainfall, the distribution of rainfall tends to be erratic in the WASAT with drought periods of two weeks or longer common in the Sahel. Rainfall variability is particularly high during early season planting periods which places considerable stress on seedlings, often forcing multiple replantings. Finally, annual potential evapotranspiration in the WASAT varies between two and four times the average annual rainfall. Evaporative demands are highest in May and September, during planting and grain filling periods, respectively, which increases the risk of early and late season water stress. In contrast, there is a single period of maximum potential evapotranspiration in the Indian SAT, during April-May when it poses a minimal threat to crop growth (Charreau, 1977).

Current Farming Systems. In response to these physical factors and due to lower pressure on the land, farming systems in much of the WASAT are land extensive (low cost per unit area), diversified, and fragmented. Low man/land ratios have encouraged long bush-fallow systems with little use of non-labor inputs. Thus, for example, the consumption of chemical fertilizers in the WASAT is the lowest of any developing region in the world. The average units of NPK applied in 1978/82 was less than 3 kg/ha among the eight Sahelian states, and less than 5 kg/ha for West Africa as a whole. In contrast, consumption in Asia as a whole is 73 kg/ha.[1]

Mechanical tillage is also the exception in the WASAT. It is estimated that less than 15% of WASAT farmers employ animal traction equipment, and that less than 5% of sorghum/millet area is plowed before planting (Matlon, 1983). Inadequate animal health, nutrition, and training, lack

[1]Data from the United Nations FAO Fertilizer Yearbook for the years 1981 through 1983.

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Table 1. A comparison of soil properties for topsoils (0-15 cm) of some major groups of agricultural soils in the world with soil data from various fields in the ICRISAT study villages, Burkina Faso[1].

	Soil Properties								
	Soil Texture				pH	Exchangeable Cation			
	Sand	Silt	Clay	OM[2]	H_2O	CEC[3]	Ca	Mg	K
	%					me/100 g soil			
Black clay soils (Vertisol, India)	22.3	16.5	61.1	1.03	7.6	57.6	47.3	8.5	0.6
Red soils (Alfisol, India)	64.5	6.0	29.6	0.46	6.7	10.0	6.7	1.5	0.7
Tsjernozem soils (Mollisol, Romania)	-	-	39.5	2.6	7.1	33.9	22.4	6.6	0.6
Alluvial soils (clay) (Inceptisol, Holland)	-	-	48.9	3.0	7.4	18.5	15.1	2.0	1.2
Burkina Faso									
Sahel Djibo area (Alfisol-bush field)	93.6	3.9	2.6	0.17	5.7	2.0	0.01	0.06	0.12
North Sudanian									
Yako area (Alfisols-bush field)	70.2	21.7	8.2	0.95	6.6	6.3	1.80	0.40	0.25
South Sudanian									
Boromo area (Alfisols-bush field)	65.5	28.4	5.9	0.96	6.5	4.7	0.9	0.25	0.13
Boromo area (Alfisols-household field)	59.3	30.7	10.1	1.07	7.4	5.7	2.0	0.45	0.45

[1]Source: Vierich and Stoop, 1984
[2]Organic matter.
[3]Cation Exchange Capacity.

of manpower, conflict with timely planting, and poor yield response for local varieties contribute to the low adoption rates (Jaeger, 1984; Sargeant et al., 1981).

Finally, compared to the common monocrop patterns in parts of Asia, the diversified and fragmented cropping systems of the WASAT derives from the goal of farmers to reduce aggregate production risk while exploiting micro-variability in soil types. This variability is linked both to the toposequence position and to the distance from habitation points i.e., organic matter availability (Stoop et al., 1982; Prudencio, 1983). The result of the above factors is that one finds a wide diversity of sorghum and millet based low input cropping systems even within a single agroclimatic zone. It is within this framework that one should evaluate local sorghum and millet varieties, and into which new cultivars and technologies need to be fit to achieve impact in the short term.

<u>Alternative Crop Improvement Objectives for the WASAT.</u> We distinguish three general crop improvement goals:

(1) yield potential at high management,
(2) yield stability through enhanced resistance to biotic and abiotic stress factors, and
(3) changes in agronomic characteristics of cultivars to fit new cropping systems.

Most crop improvement programs in the WASAT have defined several objectives to varying degrees, but priority has traditionally been given to yield potential - that is, to the development of high yielding cultivars under high management. Although this approach is generally consistent with the one which achieved substantial production gains in Asia during the 1960s and 1970s, the critical differences in the WASAT environment which we have just reviewed have blocked progress to date.

First, the high yielding variety package approach requires increased plant density, high use of chemical fertilizers and adequate soil moisture to obtain production potential. However, yield response to fertilizer and to increased plant densities are substantially lower, and the risks higher, on soils with low water holding capacity or when water control or other water conservation measures are absent. As described above, soils in the WASAT generally have lower water holding capacity than soils in the Asian SAT. In addition, the density of irrigation is insignificant in the WASAT when compared to Asia[1]. Second, the density of extension support is lower, and more costly, and the infrastructure to supply chemical inputs on a timely and assured basis is considerably less well developed in the WASAT than in most Asian countries. Third, because there is substantially lower land pressure in the WASAT compared to the Asian SAT, there is less economic incentive to intensify land use at the expense of traditional risk reducing land extensive strategies which have lower production costs per unit area.

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[1]It is significant that in the Indian experience the highest rates of adoption of high yielding sorghum cultivars and the greatest use of chemical fertilizer have both tended to concentrate in areas of more assured rainfall and in areas of greater irrigation density (Jha et al., 1981). Adoption of HYVs is lowest in areas of lower rainfall and where soils are characterized by poor water holding capacity. These two conditions describe much of the WASAT.

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A second possible crop improvement objective is to increase yield stability through breeding for resistance to the most common pests and diseases as well as to other environmental stresses. This includes: resistance to downy mildew in millet; to sooty stripe, grain mold, and charcoal rot in sorghum; to Striga in both sorghum and millet; and to shoot fly, aphids and midge in sorghum. Greater drought resistance and improved seedling vigor are equally important. The magnitudes of such potential gains are not easily defined, however, as precise yield loss assessments are not generally available. But production increases achieved through this objective alone could be minor since most local varieties, having evolved in this environment, already have a measure of resistance or tolerance to many biotic and abiotic stresses. Thus the stability objective, in most cases, should be interpreted as ensuring that new cultivars incorporate at least equal tolerance or resistance to stresses in addition to enchanced yield potential. Considerable additional basic research and methodology development is needed. For example, because the physiological reactions and resistance mechanisms of crops to such key stresses as drought are not yet well understood reliable screening methods in some cases do not yet exist.

The third general crop improvement objective which we consider is the development of cultivars with a wider range of agronomic characteristics such as plant canopy or reduced crop cycle. Such change could increase farmers' management options by opening new intercrop or relay cropping possibilities, by permitting farmers to plant late without yield loss following failure of early rains or after soil preparation, or by permitting cropping on the most drought prone soil types where soil moisture limitations reduce the effective growing period. As with breeding for resistance, however, the impact of such a strategy would likely be marginal in terms of aggregate production though it would achieve greater production stability in the near term.

ICRISAT Goals and Methods in Burkina. The ICRISAT/Burkina program, which was initiated in 1975, now has three crop improvement programs: a general Sorghum Improvement Program, a general Millet Improvement Program, and a program of Striga resistance for both sorghum and millet. It is perhaps not surprising that each of these programs has articulated a combination of the three objectives just described. Although it is probably true that in practice greater weight is given to selecting for yield potential, stability criteria are also addressed through multilocational testing and through screening elite cultivars to the region's major pests and diseases, with a major accent given to Striga resistance. Lacking reliable procedures to screen for drought resistance, little formal evaluation is done for this stress factor. On-station screening for seedling establishment under low tillage is done in only one of the three programs. Direct screening for tolerance to soil nutrient stress has been only recently begun.

The third objective suggested above, that of modifying crop agronomic characteristics to fit new cropping systems, is partially recognized by each program to the extent that materials and operational goals are grouped into either two or three maturity cycles (long duration, about 140 days; medium duration, about 120 days; and short duration, less than 110 days). Until 1983, complementary agronomic trials were also conducted using a limited number of elite cultivars to determine the yield response to land types and to date of planting, and to determine compatibility

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with various intercropping systems. Early systematic screening of all elite materials is done only for date of planting response but not for fit to land types or to intercropping.

In the early years of each crop improvement program, major emphasis was placed on the evaluation of exotic lines which were drawn from a wide range of sources. Since 1975, approximately 7000 sorghum entries and 3000 millet entries have been screened for local adaptation. The majority were advanced breeding lines or elite materials obtained through the ICRISAT Center's breeding programs and Germplasm Unit or through cooperators elsewhere in Africa, the Middle East, and the United States. Only some of these lines (up to 50% in the millet program but less than 5% in the sorghum program) were of West African origin.

Many of these entries included high yielding varieties and hybrids which had already had considerable success in India. It was hoped to identify some which were already well adapted to WASAT conditions thereby permitting major gains to be achieved immediately through direct introductions. Eventually it was planned that from crosses of selected locals by high yielding exotics, it would be possible to isolate lines combining the adaptation traits from locals and high yield potential from exotics. A systematic evaluation of local material collections, however, was not begun until relatively recently.

The "technology transfer" or direct introduction approach has shown only mixed success to date for sorghum, and no success for millet. It was observed for example, that the millet materials originating from India were highly susceptible to African races of mildew, smut, and ergot. Moreover, a set of physiological factors tended to accelerate the growth of the varieties of Indian origin causing them to be spindly and partially sterile (Scheuring, 1980). Similarly the high yielding sorghum hybrids CSH5 and CSH6, which had considerable success in India, experienced severe problems of charcoal rot and lodging under WASAT conditions. An additional set of problems associated with some of the introduced materials was related to plant characteristics which had been fashioned from the green revolution experience. These problems have included:

(1) growth cycles which are too short for wide adoption in local systems,
(2) insufficient planting date flexibility due to photoperiod insensitivity,
(3) overly short straw length which reduced the economic value of crop residues while increasing the risk of damage due to livestock, and
(4) overly compact heads which contribute to grain quality problems.

As a final note it is important to recognize that within the ICRISAT Burkina programs all selections are done under moderately high management conditions. This involves improved fertility (37: 23: 15 kg NPK/ha), deep plowing, tied ridges, precision thinning, and a high level of weed control.

Breeders are well aware that this level of management is non-existent on farmers' fields, and indeed that it is probably not even economic.[1] Nevertheless, breeders consider:

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[1]Rough calculations have shown that at on-station levels of labor and non-labor inputs use, average grain yields would have to exceed 6 tons/ha to achieve breakeven returns.

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(1) that a moderately high base fertilizer treatment and deep plowing are necessary to reduce the effects of inter-plot soil quality differences (a source of unexplained variance in trials);
(2) that plants cannot adequately express their potential genetic differences under low input levels;
(3) that measures to enhance soil moisture, such as tied ridges, are necessary to ensure useable results in drought years; and
(4) that for soil fertility, in any case, response curve cross-over at low fertility levels probably doesn't occur - that is, selections are unaffected since the ordering of cultivars with respect to yield is generally stable irrespective of fertility levels.

With this as background, we examine how well materials which were selected following these program objectives and under these conditions have actually performed in realistic on-farm situations.

THE ICRISAT PROGRAM OF ON-FARM TESTS

Beginning in 1980, a collaborative program of on-farm tests was begun in two pilot villages of central Burkina involving scientists in ICRISAT economics and crop improvement programs. By 1982, the on-farm testing program had expanded into six long-term study villages (Fig. 1) which were selected following national reconnaissance surveys as being representative of the country's three major agroclimatic zones: the Sahel (Djibo villages, 570 mm long-term annual rainfall), the Sudanian savanna (Yako villages, 750 mm) and the northern Guinean savanna (Boromo villages, 970 mm). The on-farm tests have continued through 1985 with the participation of a common panel of approximately 25 farmers in each of the six villages.

By 1984, 13 promising sorghum and millet varieties and hybrids had been tested by participant farmers. Once transfered to on-farm conditions, all cultivars demonstrated significantly different performance than that which was observed on the research station. Weaknesses and advantages not previously seen became evident when they were exposed to new stress factors on farmers' fields. Data generated in these farmers' tests have provided a rich base from which to rigorously analyse these performance differences. In subsequent sections we examine five measures of performance:

(1) the yield-gap between on-station and on-farm conditions,
(2) seedling establishment under low tillage,
(3) yield stability accross micro-environments,
(4) yield response to improved inputs, and
(5) yield components.

<u>The Station-to-Farmer Yield Gap</u>. Data in Table 2 show that most of the elite cultivars tested by ICRISAT since 1980 have experienced a yield loss of between 40 and 60% when transfered from research station trials to farmers' management, with all comparisons made at similar levels of fertilization. Moreover, because the yield superiority of elite over local cultivars observed in on-station trials is often absent or reversed under farmers' management, this suggests that the yield gap may be less for local than for elite cultivars.

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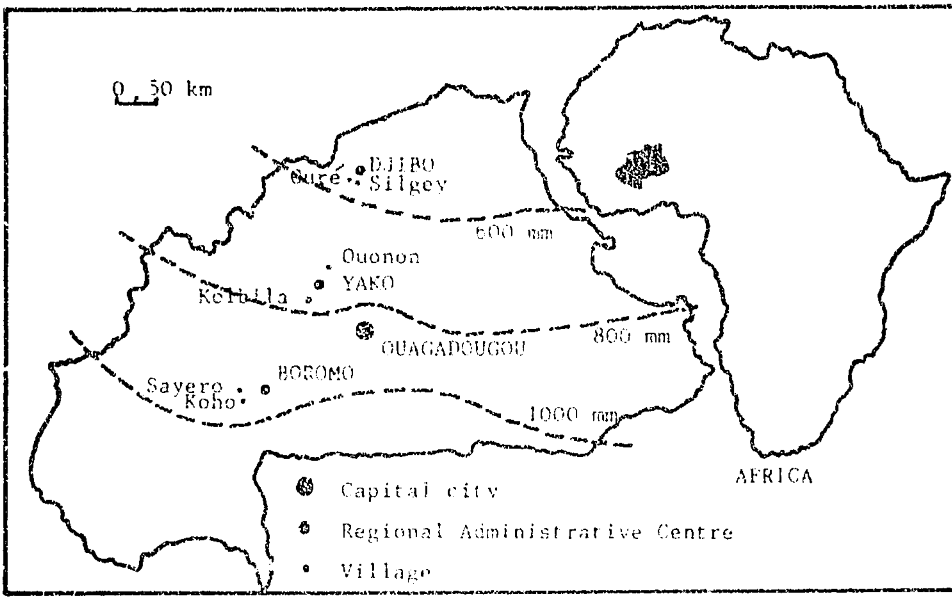

Fig. 1. Locations of ICRISAT study villages and agroclimatic zones of Burkina Faso.

Note: Since 1968 rainfall throughout the region was generally below long term averages, thus the agroclimatic zones pictured on the map have in fact been displaced southwards during the period of study.

Table 2. Yield gap for elite cultivars between trials at Kamboinse station and ICRISAT farmer's tests in Burkina, 1980-83.

Year	Crop and variety	Grain Yields		Difference
		Station	Farmer	
		kg/ha		%
1980	Sorghum E35-1	2520	1300	48
1981	Sorghum E35-1	2190	1280	42
1981	Sorghum CSH5	2240	1290	42
1982	Sorghum ICSV1001	1560	730	53
1983	Sorghum ICSV1002	1630	1370	16
1983	Sorghum 82S47	1280	1200	6
1983	Millet IKMV8101	1280	520	60
1983	Millet IKMV8201	1530	570	62
1983	Millet IKMV8202	1000	310	69

During 1984 we initiated a three-year researcher-managed on-farm experiment to measure the major determinants of this yield gap for sorghum. Data on farmers' cultivation practices taken from the farmers' tests and from ICRISAT baseline surveys suggested that five management factors, which differ between the station and farmer, were important:

(1) plowing or direct seeding,
(2) timing of fertilizer application,
(3) presence or absence of tied ridges,
(4) planting arrangement, and
(5) weeding frequency.

The five management factors explained between 65 and 90% of yield variation in the Boromo and Yako sites, respectively (ICRISAT, 1984). The largest and most significant main effects were for tied ridging which increased yields by 40% in Yako and by 75% in Boromo (Table 3). In Yako, significant main effects at the .05 level of probability were also observed for deep plowing (40% yield increase) and timely weeding (20% yield increase).

If confirmed in subsequent seasons, these results may carry important implications for crop improvement programs. We mentioned that several years' results from on-station trials and from farmers' tests suggest that the yield gap is less for local than for improved cultivars. Since tied ridges and deep plowing are the major determinants of the yield gap, this reflects the fact that local varieties, being more rustic, may be better adapted to zero plowing but at the same time less responsive to improved tillage practices. Results from experiments conducted by ICRISAT's Soil/Water Management Program support this inference (ICRISAT, 1981).

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Table 3 Sorghum yields from five management factors applied at levels corresponding to research station trials and farmers' tests, results of yield-gap trial (plot size 22 m^2) 1984.[1]

Main effects of management factors	Sudan zone Station level	Sudan zone Farmer level	Guinean zone Station level	Guinean zone Farmer level
	kg/ha			
Fertilization timing	881	897	1344	1061
Plowing	1034 ***	744	1376	1029
Tied ridges	1030 ***	748	1526*	879
Planting arrangement	931	847	1151	1254
Weeding timing	969*	809	1194	1211
Mean	889		1202	
SE	±39		±133	
Significant management factor interactions	Plowing X Tied ridging (negative) **			
	Plowing X Weeding timing (positive)*		None	
	Fertilization timing X Plowing X Weeding timing (negative) *			

[1]Station levels (S) and farmer levels (F) for management factors were the following. Fertilizer timing: NPK before seeding and urea 30 days later (S) and both NPK and urea applied at first weeding approximately 30 days after planting (F); plowing: deep plowing (S) and direct seeding or shallow scarification (F); Tied ridges: yes (S) and no (F); planting arrangement: one plant per hill at 20 cm intervals between hills and 80 cm between lines (S) and alternating two and three plants per hill at 60 cm intervals and 80 cm between lines (F); weeding timing as necessary for weed-free surface (S) and first weeding at 30 days, second weeding at 60 days (F).

*, ** and *** indicate significance at probability levels, respectively, .05, .01 and .001.

But neither tied ridging nor deep plowing are generally practiced by farmers of sorghum production in the WASAT. With few exceptions, most farm level evaluations of tied ridging have shown that major labor bottlenecks and poor yield responses for local cultivars under on-farm fertility conditions constrain adoption. Other factors including inadequate animal health and nutrition, lack of manpower, conflict with timely planting, and poor yield response to plowing also inhibit the adoption of mechanized plowing. More responsive cultivars, particularly those which have a somewhat shorter cycle, thus relieving the labor constraint, could make both practices more economic. Conversely, these practices may be considered as necessary complements to ensure the competitive performance of the current elite cultivars developed at the research station.

Seedling Establishment Under Low Tillage. In all farmers' tests, we evaluated the plant stand 10-15 days after planting by recording the percentage of hills with at least one live plant. The observations were then grouped by method of pre-planting soil tillage, and the plant stand rates for local and elite cultivars were statistically compared within each tillage category. In Table 4, we summarize the comparisons at the lower tillage levels (zero tillage and shallow hand scarification).[1]

It is clear that poor seedling establishment has been an important problem, particularly for the elite sorghums tested. In two-thirds of the 27 sorghum cases examined, the elite cultivars had lower establishment rates than their local controls. Of the nine sorghum cultivars tested, only two showed consistently better establishment across zones and years - Framida and the hybrid CSH5 - whereas six had consistently worse rates than the locals.

It must be emphasized that the problem of inadequate seedling establishment under low soil tillage had not been previously identified for the majority of cultivars in on-station trials. This was due to the generalized on-station practice of deep plowing before planting and therefore the failure to screen systematically for seedling establishment in a low-tillage stress environment which would have made varietal differences more distinct.

Yield Stability. Our brief description of the physical environment and farming systems of the WASAT stressed the variability of the environment. Because of farmers' risk aversion, the probability of wide adoption of a new cultivar will be greater, ceteris paribus, to the extent that the cultivar shows stable yield superiority over a range of physical and management environments.

Stability analysis techniques have been developed to compare the performance of cultivars across such variable environments. A commonly used technique which can be applied to data drawn from a large number of test sites is to regress the yield of each cultivar at each site against the mean yield of all cultivars at each site (Weil and Quoi, 1984; Hildebrand, 1984). The mean site yield then represents a type of environmental index. A site (in our case a particular farmer's test block) where yields are low, due either to management or to physical site characteristics, is considered a poor environment, and vice versa.

We have modified the standard approach slightly by fitting the following regression model:

$$Y_{ikj} = a + b_1\overline{Y}_j + b_2X_i + b_3\overline{Y}_jX_i$$

where Y_{ikj} = yields for the elite cultivar i and the control k at location j,

$\overline{Y}_j$ = the average yield of all cultivars at location j, and

X_i = a dummy variable for elite cultivar i.

[1]The variable relative performance of the same cultivar in different years and/or regions is due to different rainfall patterns, soil types, and local variety controls.

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Table 4. Comparison of seedling establishment of elite cultivars of sorghum and millet with local variety checks, results of ICRISAT farmers' tests, Burkina, 1980-84.

Cultivar	Region	Year	Cultivation method[1]	Effect of elite cultivar[2]
		Sorghum		
ICSV1002	Sudan	83	1	+ *
ICSV1002	Guinea	83	1	+
CSH5	Sudan	81	1	+
CSH5	Sudan	81	2	+
Framida	Sudan	82	1	+
Framida	Sudan	82	2	+
Framida	Guinea	82	1	+
Framida	Guinea	82	2	+
82S47	Sudan	83	1	+
ICSV1004	Guinea	84	1	0[3]
SPV35	Sahel	82	1	-
SPV35	Sahel	82	2	-
82S47	Sudan	83	2	-
82S47	Guinea	83	2	-
ICSV1002	Sudan	84	1	-
ICSV1002	Guinea	84	1	-
ICSV1002	Guinea	84	2	-
ICSV1003	Sudan	84	1	-
E35-1	Sudan	81	1	-
E35-1	Sudan	81	2	-
82S47	Guinea	83	1	- *
38-3	Sudan	81	2	- *
SPV35	Sahel	83	1	- **
E35-1	Sudan	80	2	- **
38-3	Sudan	81	1	- ***
ICSV1002	Sudan	84	1	- ***
ICSV1003	Sudan	84	2	- ***
ICSV1004	Guinea	84	2	- ***
		Millet		
IKMV8202	Sahel	83	1	+ ***
IKMV8201	Sahel	83	1	+ **
IKMV8201	Sudan	83	2	0[3]
IKMV8101	Sudan	83	2	0[3]
IKMV8201	Sudan	83	1	-
IKMV8201	Sahel	84	1	-
IKMV8201	Sahel	84	2	- *
Souna 3	Sahel	82	1	- *

[1]1 = zero pre-planting tillage; 2 = shallow hand scarification.
A "+" indicates that seedling establishment rates were greater for the elite cultivar than for the local check, and a "-" indicates the opposite.
[2]Differences were tested using the Chi-square test on grouped data for 1980-82, and using a t-test with independent groups in 1983-84. Probability levels for the significance test were * = .05, ** = .01, *** = .001.
[3]Establishment rates were identical for the elite and local cultivars.

In this way we fit a single regression for each pair of elite and local cultivars, while automatically obtaining test statistics for the change in intercept (b_2) and the change in slope (b_3) for the elite as compared to the local. Because we assumed that the factors which define a "good" or "bad" environment would probably be different at different levels of fertility, we fit the regressions twice, first by using data from the zero fertilizer plots, and second by using data from the test plots which received either 14: 23: 15 kg/ha (1981-82) or 37: 23: 15 kg/ha (1983-84).

Using the estimated regression coefficients, we categorized and grouped the elite cultivars (separately for each year, zone and fertility level) according to 4 standard stability types, A through D, which are graphically depicted in Fig. 2[1]. Type A represents those elite cultivars which are superior to locals across all environments (b_2 and b_3 are positive). Type B represents cases where the elite is superior to locals only over a range of poor environments (b_2 is positive but b_3 is negative). Type C represents the case where the elite cultivar is inferior in poor environments but superior in better environments (b_2 is negative but b_3 is positive). Type D represents the worst case where the elite cultivar is inferior over all environments (b_2 and b_3 are negative).

We summarize the results in Table 5 for the unfertilized plots and in Table 6 for the fertilized plots. We also present the cross-over yield by indicating over what range of local variety yield levels the elite variety is superior. Examining the zero fertilizer case first, the results of the stability analysis highlight several points. For sorghum we observed no cases where the elite cultivars were superior to locals over all environments (type A); however, three cases of uniform and significant inferiority (type D) were identified. The most frequently significant cases are those where the elite cultivar is superior only in better environments (type C). These represent 40% of all cases. If we combine type C and type D, we see that in 60% of all cases the elite cultivars were either less stable and/or absolutely inferior. The millet results are uniformly poor with two type D cases, and two type B cases, for which elite superiority is projected over a very minor range of extremely low yields.

Stability analyses conducted on the sorghum data from fertilized plots (Table 6) again show that the most common and significant case is type C stability with elite superiority occurring only in better environments. In four cases the elite cultivars were found to be uniformly inferior over all environments. In contrast, three type A cases were identified, which suggests that with improved fertility, elite varieties with wider adaptability can and have been identified. Finally, the elite millet varieties tested showed that even under improved soil fertility they had very poor adaptation.

[1]Ideal data for this analysis would have included the same set of elite cultivars over a common number of locations and years. Because all cultivars would have faced identical environments, unambiguous inter-cultivar comparisons would have been possible. Because we lacked such data and because many cultivars were tested in only a single year or zone, individual analyses were done by year and zone. The reader will note that stability types change for certain cultivars under different macro-environmental (year and zone) conditions.

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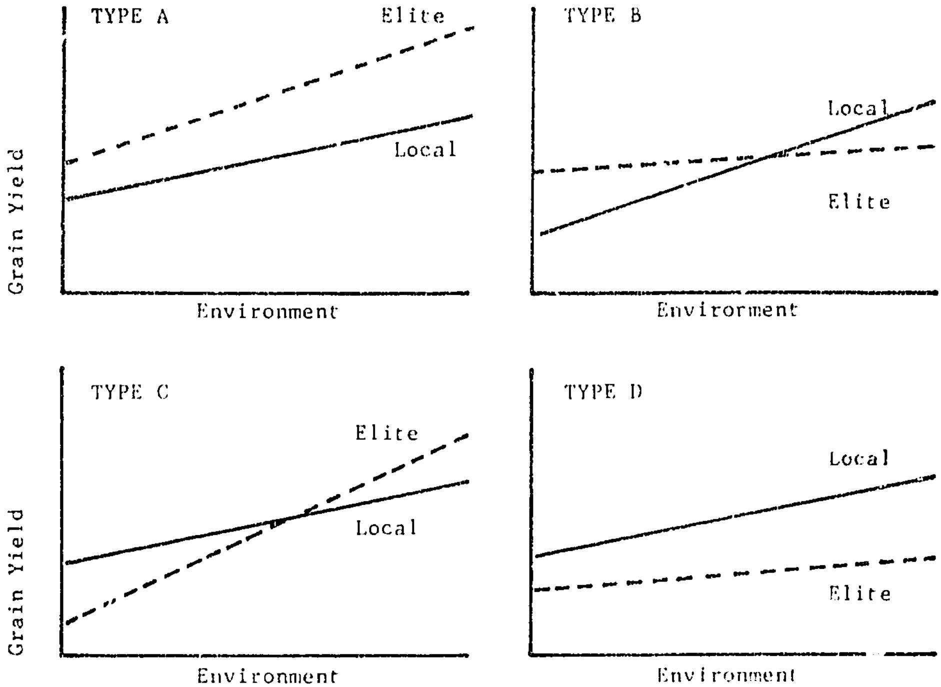

Fig. 2 Four stability relationships between elite and local cultivars over varying environments.

Table 5. Stability analysis of elite sorghum and millet cultivars at zero fertilizer; ICRISAT farmers' tests, Burkina, 1981-84.

Cultivar	Zone	Year	Elite cultivar interaction with Intercept (b_2)	Elite cultivar interaction with Slope (b_3)	Stability type[1]	Cross over yield[2]	Average test yield[3]
			Sorghum			——kg/ha——	
SPV35	Sahel	82	+	-	B	< 1160	120
ICSV1002	Sudan	83	+	-	B	< 1080	570
CSH5	Sudan	81	+	-	B	< 760	600
82S47	Guinea	83	+	-	B	< 870	840
ICSV1002	Sudan	84	+	-	B	< 70	120
ICSV1003	Sudan	84	+	- ***	B	< 30	100
ICSV1002	Guinea	84	-	+ *	C	> 200	470
Framida	Sudan	82	-	+	C	> 180	270
E35-1	Sudan	81	-	+	C	> 480	600
Framida	Guinea	82	-*	+ ***	C	> 510	560
ICSV1004	Guinea	84	-	+ *	C	> 400	440
ICSV1002	Guinea	83	-	+	C	> 910	760
82S47	Sudan	83	-	- *	D	None	410
38-3	Sudan	81	-*	-	D	None	500
SPV35	Sahel	83	-	- ***	D	None	180
			Millet				
IKMV[4]	Sudan	83	+	- ***	B	< 30	270
IKMV[4]	Sahel	84	+	- ***	B	< 10	20
IKMV[4]	Sahel	83	-	-	D	None	390
Souna[3]	Sahel	82	-	-	D	None	110

[1] See Figure 2.

[2] Indicated is the range of yields for the local cultivar over which the elite cultivar is projected to be superior.

[3] Calculated as the mean yield across locations of all cultivars tested at the zero fertilizer level.

[4] We have combined IKMV8101, 8201 and 8202 for this analysis.

*, ** and *** indicate significance at the .05, .01 and .001 levels, respectively.

Table 6. Stability analysis of elite sorghum and millet cultivars on fertilized plots, ICRISAT farmers' tests, Burkina, 1981-84.[1]

Cultivar	Zone	Year	Elite cultivar interaction with: Intercept (b_2)	Slope (b_3)	Stability type[2]	Cross-over yield[3]	Average test yield[4]
			Sorghum			----kg/ha----	
Framida	Sudan	82	+	+	A	All	700
Framida	Guinea	82	+	+	A	All	870
82S47	Guinea	83	+	+	A	All	1380
CSH5	Sudan	81	+	-	B	< 17750[5]	1140
82S47	Sudan	83	+	-	B	< 1060	980
SPV35	Sahel	82	-	+	C	> 40	300
ICSV1002	Guinea	84	-	+	C	> 180	950
ICSV1002	Sudan	83	-	+	C	> 270	1380
E35-1	Sudan	81	-	+ *	C	> 260	1200
ICSV1002	Sudan	84	-	+ *	C	> 160	280
ICSV1002	Guinea	83	-	+ *	C	> 880	1290
ICSV1003	Sudan	84	-	-	D	None	230
ICSV1004	Guinea	84	-	-	D	None	780
38-3	Sudan	81	-	-	D	None	1050
SPV35	Sahel	83	-	-	D	None	340
			Millet				
IKMV[6]	Sudan	83	+	- ***	B	< 290	570
IKMV[6]	Sahel	84	+	-	B	< 10	70
Souna[3]	Sahel	82	-	+	C	> 270	200
IKMV[6]	Sahel	83	-	- ***	D	None	570

[1]The fertilizer rates are 14: 23: 15 kg/ha in 1981-82 and 37: 23: 15 kg/ha in 1983-84.
[2]See Figure 2.
[3]Indicated is the range of yields for the local cultivar over which the elite cultivar is superior.
[4]Calculated as the mean yield across locations of all cultivars tested on fertilized plots.
[5]Due to the extremely high projected cross-over yield, this case can effectively be considered a type A.
[6]We have combined IKMV8101, 8201, and 8202 for this analysis.
*, ** and *** indicate significance at the .05, .01 and .001 levels respectively.

Response to Improved Management - the Issue of Response Curve Cross-over. Our analysis of input response focussed on several questions. First, are elite cultivars more responsive to modern inputs when cultivated under farmers' management - that is, are their response curves steeper than locals over an economic range of input levels and when facing on-farm stresses? Second, do the response curves cross, such that the ordering of cultivars with respect to yield changes significantly between low and high input levels? If so, at what input levels does cross-over occur? And for what inputs?

To address these questions we fit yield function regression models to the farmers' test data. The models were of the form:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1X_2 + b_5X_1X_3 \times b_6X_2X_3$$

where Y = grain yield,
X_1 = dummy variable for the elite cultivar,
X_2 = dummy variable for plowing, and
X_3 = dummy variable for fertilizer.

Only data from plots with zero fertilizer and 14: 23: 15 kg/ha (1981-82) or 37: 23: 15 kg/ha (1983-84) were employed in the analysis. Using the regression coefficients we then calculated estimated yields at various input levels for the local and elite cultivars. By estimating b_6 (the coefficient on the plowing X fertility interaction term) we have removed all possible complementary effects to measure only the main plowing and main fertilizer effects. The results are summarized in Table 7.

We note first that in 60% of the sorghum cases and in 100% for millet, the local varieties outyielded elites when grown under typical farmer conditions of zero fertilizer and no plowing. The exceptional cases where the sorghum elites outyielded locals at zero input levels are particularly worth noting since these include the same cultivars found to be the most stable above: the hybrid CSH5, Framida, E35-1, and ICSV1002 (Sudanian zone, 1983) which is itself a progeny of Framida and E35-1.

Due to high variance, the significance levels were low on all response coefficients. Nevertheless, we can draw some tentative conclusions by comparing the magnitudes of response increments. Among the sorghum tests, the size of yield responses to both plowing and fertilizer were somewhat greater for the elite cultivars in two-thirds of the cases. The average yield increments to plowing across all sorghum cases was 190 kg/ha and 140 kg/ha, for the elite and local cultivars, respectively. As for the fertilizer dose tested, the average yield increments were 450 kg/ha and 390 kg/ha, for the elite and local cultivars respectively. In short, while our data do not conclusively prove that ICRISAT selection procedures have resulted in more management responsive cultivars, they are largely consistent with that hypothesis.

Combining data from base yields at zero input levels with the response increments, we then grouped the response curve relationships between the elite and local cultivars for each factor within the cross-over type categories developed earlier.

The results in Table 7 demonstrate that under the stress conditions and low yield levels encountered at the farm level, response curve cross-over was identified in six cases for plowing and in seven cases for

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Table 7. Yield response of elite and local sorghum and millet cultivars to plowing and fertilizer, ICRISAT farmers' tests, Burkina, 1981-84.

Cultivar	Zone	Year	Base yields with no plowing or fertilizer: Local cultivar (a)	Base yields with no plowing or fertilizer: Elite cultivar (a+b1)	Yield increment from: Plowing: Local cultivar (b2)	Yield increment from: Plowing: Elite cultivar (b2+b4)	Yield increment from: Fertilizer[1]: Local cultivar (b3)	Yield increment from: Fertilizer[1]: Elite cultivar (b3+b5)	Type of response curve relationship with local cultivar[2]: Plowing	Type of response curve relationship with local cultivar[2]: Fertilizer
			kg/ha							
					Sorghum					
Framida	Sudan	82	280	290	80	360	300	330	A	A
Framida	Guinea	82	490	650	-220	110	340	290	A	A-
ICSV1002	Sudan	83	240	590	430	100	930	1310	A-	A
CSH5	Sudan	81	510	570	370	500	550	450	A	B
E35-1	Sudan	81	470	540	530	390	640	800	B	A
ICSV1003	Sudan	84	60	90	90	- 10	100	10	B	B
82S47	Guinea	83	790	700	190	330	500	710	C	C
ICSV1002	Guinea	84	460	440	- 30	80	370	450	C	C
SVP35	Sahel	82	110	100	20	180	90	110	C	C
ICSV1002	Guinea	83	620	600	260	250	200	430	D	C
ICSV1004	Guinea	84	430	290	20	220	420	240	C	D
82S47	Sudan	83	510	410	-160	-190	430	540	D	C
38-3	Sudan	81	530*	270	280	330	490	480	D+	D
ICSV1002	Sudan	84	60	30	100	105	120	120	D+	D
					Millet					
IKMV[3]	Sahel	83	440*	250	30	-130	230	150	D	D
IKMV[3]	Sudan	83	300	170	80	50	280	270	D	D
IKMV[3]	Sahel	84	30	10	-20	- 10	70	70	D+	D
Souna 3	Sahel	82	170	60	80	180	60	90	D+	D+

[1]Fertilizer rates were zero at the base level and 100 kg/ha 14: 23: 15 in 1981-82 and 100 kg/ha 14: 23: 15 plus 50 kg/ha urea in 1983-84.

[2]See Figure 3. Note that a "+" or "-" has been added to indicate those cases where the slope of the response curve for the elite cultivar was either greater or less than the local variety but where cross-over did not occur over the observed range of input levels.

[3]IKMV8101, IKMV8201, and IKMV8202 are combined for this analysis.

*, ** and *** indicate significance at the .05, .01 and .001 levels, respectively.

fertilizer. Moreover, in the majority of these cases cross-over was the expected type C - that is, the elite cultivar was inferior at the low management level, but superior at the high level. Cases of the desired response curve relationship (type A) were identified for three sorghum cultivars with respect to plowing (CSH5, Framida, and ICSV1002) and to fertilization (Framida, ICSV1002, and E35-1).

Finally, we observed type D cases (uniform inferiority of the elite cultivar at both input levels) in five of the 15 sorghum cases for plowing and in three cases for fertilization. Because these cultivars had been selected on the basis of significant yield superiority over local varieties at the research station, these results strongly suggest that type C response curve cross-over occurs for these varieties as well, but at higher levels of management than that observed in the farmers' tests. This is particularly true for millet, for which all cases were type D.

Additional evidence that the ordering of a common set of varieties according to yield is not necessarily identical at high and low management levels comes from ICRISAT's on-farm researcher-managed trials. During 1983 and 1984, the Striga Resistance, Millet Improvement, and Economics Programs carried out 13 researcher-managed trials to determine the performance of advanced cultivars in six locations in Burkina. The trials, each of which included between seven and nine entries, used a split plot (1983) or split-split plot (1984) design which screened the cultivars at two levels of management: high (plowing and 37: 25: 15 kg/ha) and low (no plowing or fertilizer). In 1984 the trial design also included two dates of planting. For both years there were two replications for each treatment combination.

The ranking of entries at the two management levels were rarely similar. Spearman rank correlation tests showed that in only two of the 13 trials could one safely reject the null hypothesis of no positive correlation between the high and low management rankings at a probability level of .05. These results reinforce the conclusion that by selecting strictly under high management breeders may be systematically overlooking varieties with superior performance under greater stress conditions.

Yield Components. We analyzed the separate components of grain yield in an effort to more precisely identify in which aspects the elite cultivars were deficient when stressed by on-farm conditions. Plants per hectare, panicles per plant, and grain yield per panicle were compared for each elite and local cultivar by using a t-test to determine the significance of mean differences. The analysis was done separately for the unfertilized and fertilized farmers' test plots. Results are summarized in Table 8.

The data indicate that the major limiting factors for yield among the elite cultivars were low plant stand and low numbers of panicles per plant. Depending on the particular cultivar, low plant stand was due to poor seedling vigor, low resistance to drought for the more mature plants, or to a combination of both causes. The low number of panicles per plant was due both to poor head exertion under water and fertility stress as well as to genetic differences in tillering. It is equally clear, however, that the elite cultivars of sorghum had consistently superior grain production per panicle, which in part offset the low overall panicle production.

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Table 8. Comparison of yield components for etlite and local sorghum and millet cultivars, ICRISAT farmers ' tests, Burkina, 1982-84.

Cultivar	Zone	Year	Unfertilized plots: Plants per ha	Unfertilized plots: Panicles per plant	Unfertilized plots: Grain weight per panicle	Fertilized plots[2]: Plants per ha	Fertilized plots[2]: Panicles per plant	Fertilized plots[2]: Grain weight per panicle
					Sorghum			
Framida	Sudan	82	+[1]	–	+	+	–	+
Framida	Guinea	82	+	.	+	–	+	+
ICSV1002	Sudan	83	+	–	+	+	–	+*
ICSV1003	Sudan	84	–**	–	+**	–***	–	+
82S47	Guinea	83	+	+	–	–	+**	+
ICSV1002	Guinea	84	–**	–	+***	–**	–	+***
SPV35	Sahel	82	+	–	+	–	+	+
ICSV1002	Guinea	83	–	+	–	–	+	+
ICSV1004	Guinea	84	–***	–	+**	–***	–*	+**
82S47	Sudan	83	–*	–	+	–	–***	+***
ICSV1002	Sudan	84	–	–	+	–*	–	+*
SPV35	Sahel	83	–*	+	+**	–***	–	+***
					Millet			
IKMV[3]	Sahel	83	–	–	–*	+	–**	–*
IKMV[3]	Sudan	83	–	–	–	–*	–***	+
IKMV[3]	Sahel	84	–*	+	–	–	+	–
Souna 3	Sahel	82	–	–	+*	–	–	–

[1]A positive sign denotes those cases where the elite cultivar surpassed the local cultivar, and negative for the opposite.
[2]Fertilizer rates were 14: 23: 15 kg/ha in 1982 and 37: 23: 15 kg/ha in 1983-84.
[3]IKMV8101, 8201, 8202 are combined for this analysis.
*, ** and *** indicate significance at the .05, .01 and .001 levels respectively.

These results could reflect a possible bias in current selection methods. Due to the high management condition provided to on-station trials (deep plowing, high fertility, immediate replanting of empty hills, frequent cultivation, etc.) the breeder may rarely observe such problems as poor establishment or poor panicle exertion on the research station. Giving appropriate weight to relevent stress resistance characteristics to identify these and other "rusticity" characteristics may well be necessary to select against these deficiencies.

SUMMARY AND CONCLUSIONS

This brief review of ICRISAT farmers' test results carried out in Burkina Faso since 1980 shows that when elite cultivars are transfered off the research station, on-farm stresses severely reduce their yield performance. Among some 7000 sorghum introductions screened by ICRISAT in Burkina, nine cultivars were found to be sufficiently promising in on-station trials to warrant on-farm tests. Of these only two cultivars have been found to be generally superior under farmer conditions. Among some 3000 millet entries screened, five cultivars have been advanced to on-farm tests but no superior cultivars have yet been identified.

These results might have been anticipated as the product of an inappropriate transfer of breeding goals and methods from the "green revolution" experience. In that experience, farmers essentially modified their production environment to fit the new, and demanding, high yielding cultivars. The same accent on yield potential under a substantially modified high management environment effectively characterizes most crop improvement programs in the WASAT. But for reasons described earlier, the differences, particularly with respect to soil water holding capacity, result in lower response and greater risk to the high plant stand and high fertilizer approaches used in Asia. This reflected in part by fertilizer use rates in the WASAT which are the lowest of any region in the developing world. Major irrigation facilities are not now available and will probably not be economical in the forseeable future (Matlon, 1983). As a result, rainfed systems dominate and, when combined with the poor water holding capacity of the region's soils, create a highly variable and risky cropping environment. Finally, in most areas of the WASAT population densities are still a fraction of rates observed in Asia. As such, factor price ratios and poorly defined land tenure systems combine to guide farmers toward land extensive systems which discourage investment in land improvements. The net result is that rather than modifying the environment, the majority of small farmers fit a diverse set of crops and varieties into the variable landscape by using low input land extensive systems with the goal of meeting subsistence needs while minimizing aggregate production risk.

<u>Alternative Breeding Strategies in the Short and Long-Term</u>. These differences demand a fundamental reassessment of the goals and methods used for sorghum and millet improvement programs in the WASAT. To do this it is necessary to clearly distinguish the time frames and target groups which are relevant for alternative crop improvement strategies.

We depict the key choices graphically in Fig. 3. In 3a we have drawn curves to represent three typical yield responses to various levels of fertilizer. We use fertilizer level here simply as a proxy for various aspects of improved management or superior environment. Curve I represents

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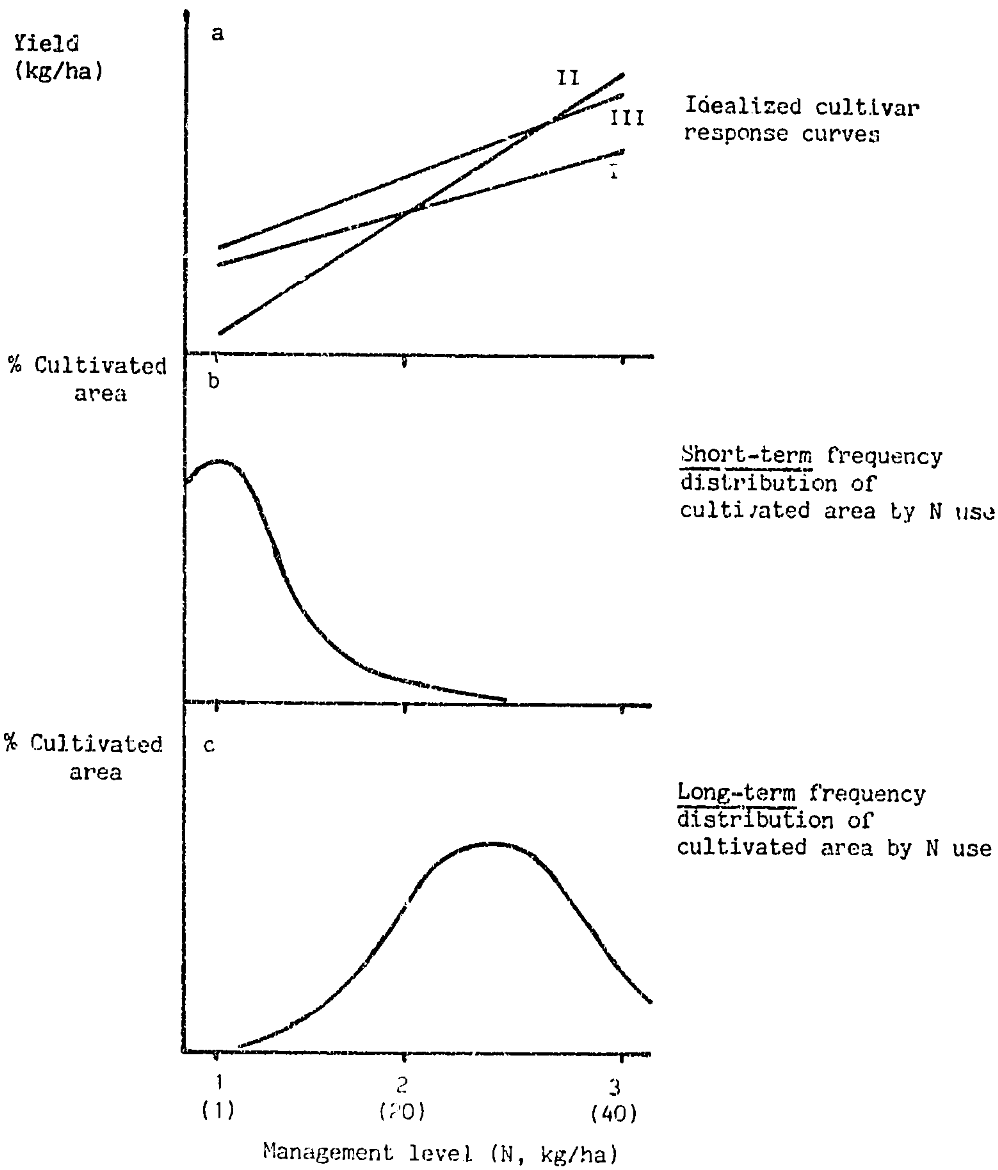

Fig. 3. Cultivar response curves and frequency distributions of management levels in the short and long-term.

Nitrogen rates (kg/ha) represent a simplified proxy for broader management levels.

the local cultivar and curve II an elite cultivar which shows the common type C cross-over trait seen earlier. Curve III represents the desirable type A response curve relationship with the local cultivar which we observed in a small number of cases. We have also shown three levels of fertilizer: level 1 is the low current modal use rate at the farmer's level in the WASAT; level 2 is the rate at which curves I and II cross; and level 3 is the rate currently employed on the research station.

The current (short-term) frequency distribution of farmers with respect to rates of fertilizer application to millet and sorghum is shown in 3b. The pattern, which closely resembles the situation in Burkina today, shows a concentration of farmers applying N at rates of less than 1 kg/ha, but a strong positive skew with few "progressive" farmers as outliers in the right hand tail. We see that only a very small fraction of the farmers currently apply fertilizer to cereals at rates greater than the cross-over point, level two.

This frequency distribution means that, in the short-term, elite cultivars with response curves similar to II will be attractive only to that same small fraction of farmers lying to the right of point 2. Continued development of such cultivars, without a simultaneous shift in the distribution of farmers to the right, would ensure that adoption rates will remain low, aggregate production impact negligible, and the effect on income distribution adverse.

Broad adoption will occur in the short-run only for those cultivars with yields superior to locals at relatively low technology levels, such as for cultivars with response curves represented by curve III. This can be accomplished by giving greater weight to stability in crop improvement programs through the development of cultivars with increased resistance to major yield-loss factors, tolerance to poorer land types and to drought, improved emergence, and moderately shorter cycle lenghts (though with photoperiod sensitivity to give farmers some planting date flexibility) for forced late planting situations. Although the impact of this strategy would not be large, probably realizing aggregate production gains of less than 25 %, reduced production variability would also be achieved.

It should be obvious that over the long-run major breakthroughs in cereal production can only be realized through substantial improvements in the physical and management environment of the majority of small farmers; that is, through a shift in the distribution of farmers to the right as per section c of Fig. 3. This can be accomplished primarily through the development of profitable farmer adapted methods of improving soil water and soil fertility on a sustainable basis, and by developing extension and input delivery systems to more efficiently transfer these new technologies to farmers.

Trends in exogenous economic factors generally favor those developments over the long-run. Rapidly increasing rural populations will put greater pressure on the land thus changing factor price ratios to encourage the adoption of more intensive production systems. These changes are already occuring in transitional portions of the WASAT. Cereal deficits will also tend to shift real terms of trade in favor of agriculture thus further favoring agricultural investment.

.../...

Crop improvement programs have a critical role to play in accelerating this process through the development of cultivars which are not only more stable but which are also more responsive to improved management; that is, by ensuring that the slope of curve III exceeds that of curve I. By increasing returns to complementary inputs, farm level demand for inputs will increase thereby providing greater economic incentives for both public and private sectors to supply the needed materials and services.

However, given the extremely difficult physical environment and generally poor current level of infrastructure throughout the WASAT, we must recognize that such changes in management and infrastructure will be costly, time consuming, and uneven across farm types and sub-regions. For these reasons, in order to ensure broad adoption patterns in the long-term to reduce farm-level risks associated with adopting new seeds, and to achieve some production gains even in the short-term the development of cultivars with type III rather than type II response curves is and will remain essential.

Finally, we note that while our recommendation to give greater weight to stability criteria is important for sorghum, it is particularly crucial for millet. Due to the special role of millet in WASAT cropping systems, improved management will come slower and will attain lower long-term levels for millet than for sorghum[1]; that is, the shift of farmers from b to c in Fig. 3 is substantially more problematical.

<u>New Approaches On-Station and On-Farm</u>. Implementing this strategy requires new screening and selection procedures on the research station as well as a greater accent on on-farm research. Farm level stress factors which cause instability and response curve cross-over need to be measured and introduced on the research station at an early stage of selection. To do this efficiently, greater <u>a priori</u> understanding is needed of small farmers' physical, technical, and economic environments. Systematically combined with conventional selection under high management, cultivars can then be identified as more or less tolerant to a range of environmental stresses, and more or less responsive to improved management.

Programs to screen advanced lines on-farm also need to be expanded. Due to criteria used in choosing research station sites and due to years of improved soil management, the micro-environments of most research stations fail to reflect representative farmers' conditions.[2] In these cases, only on-farm tests which include variation in the key management and environmental stress factors can validly characterize yield stability and input response.

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[1] In both the Guinean and Sudanian zones where farmers have the option of growing either millet or sorghum, millet is allocated to the most shallow and less fertile land types; and, due to poorer response, it receives significantly lower labor and non-labor inputs per unit area than the alternatives, sorghum or maize. And in the Sahel where millet cultivation dominates, lower rainfall and sandy soils create an environment where most improved inputs are less economic and substantially more risky.

[2] Stations are often located on atypically good soils and/or near lowland catchments to provide off-season irrigation capacity.

.../...

This approach requires an interdisciplinary effort involving specialists in physiology, plant protection, agronomy, food science, and economics, as well as breeding. The role of the physiologist is particularly important since crop mechanisms for tolerance or resistance to the major stresses, and interactions among environmental stresses, are not yet adequately understood. Knowledge in both of these areas is needed in order to develop reliable and efficient screening techniques. This approach also requires greater work with farmers themselves at several stages of the breeding effort, not simply at the final stage of pre-extension screening. An early and continuing interactive relationship with farmers to define appropriate breeding objectives and to test concepts and materials will reduce the time necessary to arrive at truly adapted improved cultivars.

Finally, greater accent needs to be given to using materials of West African origin. Because the local varieties already have adaptive hardiness, it is more likely that higher yield potential with good adaptation will be achieved in breeding programs which utilize the best local varieties together with the most promising introductions as parents.

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PRODUCTION SYSTEMS IN LOWER CASAMANCE AND STRATEGIES ADOPTED BY FARMERS FOR THE WATER SHORTAGE

Joshua POSNER, Mulumba KAMUANGA and Samba SALL[1]

For over the past fifteen years, considerable changes have occurred in the Lower-Casamance region. These changes were largely due to rainfall shortage. The climatic characteristics changed the food situation in the region from self-sufficiency to shortage. For purposes of characterizing these changes and formulating adequate solutions, the ISRA is now placing emphasis on a system of approach praticed by a regional team. This document examines farmer's strategies of adaptation to the drought and analyses research themes taken up by the SPT/Lower-Casamance team.

Lower-Casamance is located in southern Senegal (Fig.1). It stretches over an area of 7,300 km^2, from the Soungrougou valley to the Atlantic coast. It became an administrative region in July 1984 and thus covers the Zinguinchor[2], Oussouye and Bignona departments.

Climate and hydrology. Lower-Casamance has a sub-Guinea type of climate with a strong maritime influence and two seasons : a dry season from November to May and a rainy season from June to October. The highest rainfalls are recorded in August.

The hydrologic regime is dominated by the sea due to a very flat relief and the current rainfall shortage. The coastal part of the Casamance river extends inland up to 200 km and the salt water regularly rises. The region possesses a network of quite dense backwaters which encourage the spread of soil salinity.

Soils. The soils are clayey-sandy on the plateau but are more sandy at the surface. Two types of soils are predominant :

(1) slightly desaturated red ferralitic soils with a higher clay content in the subsoil,
(2) tropical ferruginous leached and beige soils localized in the badly drained central parts of the plateau.

At the fringe of the thalwegs, the "bolongs" and of the river itself,there are sandy areas (grey upland soils) which are temporarily hydromorphic constituting the preferred sites for palm-groves. Then there are the lowlands of the thalwegs where the practice consists of rice growing in the rainy season and market gardening in the offseason.

On the major river bed, the last position on the toposequence, there are salty soils : the strips (para-sulphated-acid or sulphated-acid) and potentially sulphated-acid soils. It is the area for mangrove rice where cultivation depends on the extent of flooding by rains which helps in leaching the soils.

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1 Research team on production systems and transfer of technologies. Senegalese Agricultural Research Institute (ISRA). Contributions made by Dr. Curtis Jolly and other members of the team are sincerely appreciated. Paper presented by Samba Sall.

2 Current name of the region.

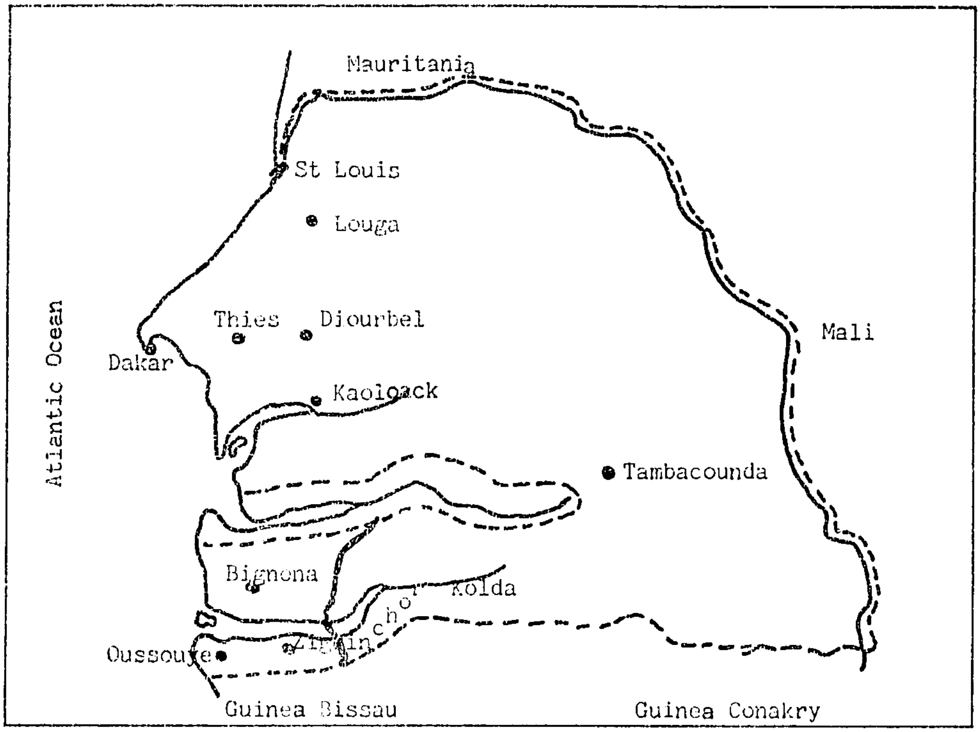

Fig. 1. Senegal and Lower-Casamance (Ziguinchor region).

Demography. The rural population in Lower-Casamance is estimated at 261,000 inhabitants[1] distributed over almost 330 villages. The population is unvevenly distributed with low densities of 10 persons per km^2 at the northeastern part of Bignona, 35 per km^2 at the central part towards Baila and over 60 inhabitants per km^2 in the southwest.

The area is characterized by a very youthful and quite mobile population, where about 45% of the inhabitants are under 15. Recent estimates indicate that 20-40% of the active labor force engage in seasonal migration.

There are two major ethnic groups :

(1) the Diolas constituting an overwhelming majority (85% of total population) are themsleves made up of several distinct subgroups (Kassa, Blouf, Fogny...) ;

(2) the Mandingues, a minority group (5%) with a marked influence in the northern, northeastern and around Ziguinchor area. Several other minority tribes (Mancagnes, Mandjak, Balante...) originate mainly from Guinea Bissau

1 This figure was obtained by subtracting the total population of the region estimated at 36,200 inhabitants from the overall population for the Ziguinchor, Bignona and Oussouye urban centers.

Agriculture and animal husbandry. Lower-Casamance is basically an agricultural area. Besides the area's rainfall regime, it occupies a major position in the Senegalese agricultural strategy[1]. Groundnut, rice, millet/Sorghum and maize constitute the major crops. At the moment, the government has directed efforts towards the development of rice growing especially by making use of anti salt dams and some structures made by farmers for the protection and desalination of lands that can be cultivated with rice. (70,000 ha).

Cattle in Lower-Casamance is made up of different species (N'Dama cattle, sheep and caprinae of the Guinea breed as well as pigs). There are very few horses and donkeys.

The herds of cattle are unevenly distributed in the three departments (84% at Bignona, 9% at Ziguinchor and 7% at Oussouye). The modes of organization and management vary from the north to the south of the region.

RAINFALL SHORTAGE AND ITS IMPLICATIONS FOR AGRICULTURAL PRODUCTION IN LOWER-CASAMANCE

Rainfall shortage. In Lower-Casamance, there has been a considerable reduction in rainfall over the past 20 years as in the other regions in Senegal. From 1940 to 1960 the region was located on the average isohyet of 1,500 mm. In the past ten years, average rainfall has decreased to 1,100 mm at Ziguinchor. This average however conceals the wide inter-annual variations. If for the three departments we are to draw a minimum rainfall line below which the cropping system could be jeopardized (Fig. 2) we could count several very droughty years in the decade (five at Bignona, four at Ziguinchor and seven at Oussouye).

Trends in agricultural production. We have examined the available regional statistics for the last two decades. There were considerable fluctuations in rice production with a declining trend between 1971-1974 and 1977-1980. Similar trends characterize millet and sorghum. Only maize showed a sustained growth between 1970 and 1982 (19% annually). The reduction in rainfall caused a salination of rice fields particularly in the southern part of the region. Farmers had to modify their cropping system which was formerly based on aquatic rice farming. They accelerated agricultural colonization of plateau lands where they developed cereals for consumption and groundnut as a cash crop.

Statistical analysis led to the following observations (Table 1) :

(1) both the cultivated area of land and total cereal production highly correlate with the rainfall ;

(2) the effect of rainfall is much more noticeable on rice fields and rice production (Bignona, Oussouye) than on other crops ;

(3) correlation between production and rainfall is lower for groundnut, millet and sorghum.

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1 The region has a PIDAC (Integrated Agricultural Development project of Casamance) development project financed by USAID. PIDAC specializes in all rural environment activities including technical control and guidance.

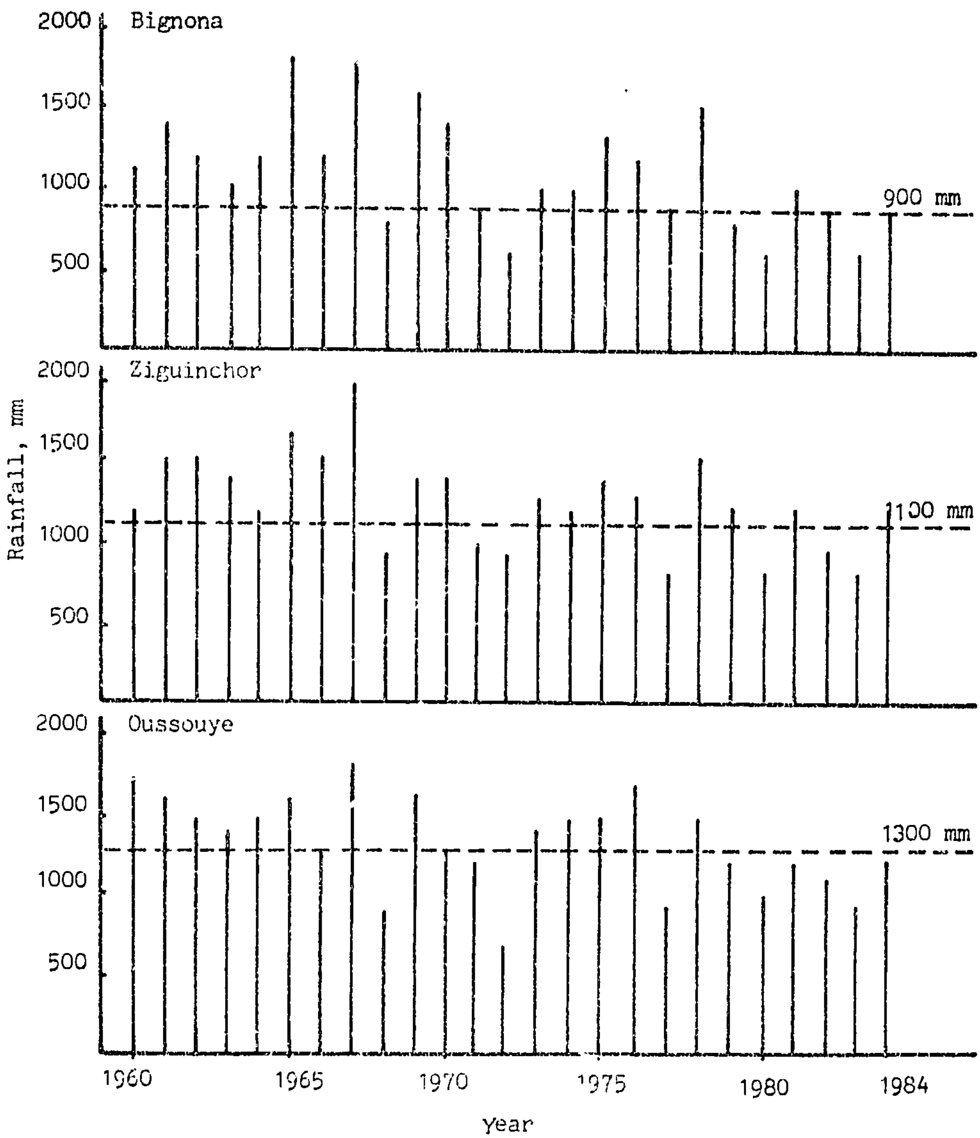

Fig.2. Annual rainfall trend for 25 years in the Bignona, Ziguinchor and Oussouye Departments.

Table 1. Simple correlations between the rainfall readings and some agricultural statistics, Ziguinchor region, Senegal.

Statistics	Departments (1963-1983)			
	Bignona	Ziguinchor	Oussouye	Region[1]
Total cultivated area	0.63++	0.15	0.59++	0.84+++
Rice area	0.71+++	0.14	0.59++	0.83+++
Groundnut area	0.42	0.49+	0.14	0.69++
Millet and sorghum area	0.36	0.05	0.06	0.49+
Cereal production, t	0.62++	0.05	0.53+	0.80+++
Rice production, t	0.75+++	0.18	0.54+	0.85+++
Groundnut production, t	0.52+	0.16	0.15	0.63++
Millet and sorghum production, t	0.14	0.11	0.004	0.34

1 The overall statistics of the Ziguinchor region have been correlated with annual rainfall at Bignona. This department supplies between 50 and 75% of the regional production. Source : DGPA, Ziguinchor.

*, ** and *** indicate significance at the 0.05, 0.01 and 0.001 levels respectively.

For these crops, varieties used by the farmers are able to complete their cycle even in dry years. Other factors such as the availability of groundnut seeds and insect attacks on millet seem to be more influential on production.

Observations on the rainfall shortages and correlations with cultivated area and agricultural production are sumarized in Table 2. If we examine the two extreme areas over a period of 20 years, we observe a very remarkable reduction in total cultivated area (53% at Bignona and 68% at Oussouye). This reduction particularly affected rice, reducing by about 11% of the total cultivated area at Bignona and by 77% at Oussouye. Food production was therefore affected. These areas that recorded surpluses in 1962-1963 (over 100 kg per capita at Bignona and over 181 kg per capita at Oussouye) are now facing shortages (Bignona-170 kg/capita, and Oussouye-121 kg). With the present circumstances it has become very difficult to remove such a deficit with the sale of groundnut as the only cash crop in the region. Rice importations to Lower-Casamance increased from 2,000 to 3,000 t between 1960 and 1965 to almost 30,000 in 1982/83 (DGPA, 1983).

For purposes of arresting these different changes occuring in the area, the government of Senegal decided to strengthen agricultural research by creating a research team for production systems[1]. The mandate of this research team is to get in touch with the farmer to understand his objectives and constraints so as to propose different research and development strategies. These strategies must be directed towards specific zones or agricultural situations.

AGRICULTURAL SITUATIONS IN LOWER-CASAMANCE AND STRATEGIES OF FARMERS

Agricultural zones. Even if Lower-Casamance is a small area dominated by a single ethnic group, production systems and their organization are still very heterogeneous there. Accordingly the region has been divided into agricultural situations taking into consideration specific characteristics of each zone for purposes of eventual formulations of recommendations :

(1) Division of labor between sexes : among the Dioulas from the south and northeast, men specialize in ploughing whereas women engage in rice transplanting and harvesting. Among the Mandingues and the Dioula "mandingues"[2], division of labor between sexes is more pronounced and is based on the toposequence : men cultivate on the plateau, and women cultivate rice on lowlands.

(2) Proportions of land under emerged cultivation/flooded cultivation : with the southwestern/northeastern rainfall gradient one moves from zones where aquatic rice growing (transplanted rice) is a dominant activity to zones where plateau farming is by far the most common. Surveys carried out during the last three years

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1 The first team began its work in March 1982 at the CRA in Djibélor. After some exploratory surveys and the classification of the area into agricultural zones, different research themes were initiated. The team now comprises two agricultural economists, two agronomists and a zoological scientist.

2 A term used for the Diola groups having undergone the cultural influence of the mandingues (political and regious domination) in the past.

Table 2. Trend of mean agricultural production for 20 years in the Oussouye and Bignona Department, Ziguinchor region, Senegal[1].

	Bignona		Oussouye	
Statistics	1962 and 1963	1983 and 1984	1962 and 1963	1983 and 1984
Rainfall, mm	1,257	784	1,450	1,049
Total cultivated area, ha	76,751	35,969	12,699	4,005
Groundnut area, ha	30,225	21,619	718	772
Millet/sorghum area, ha	20,970	7,722	100	-
Rice area, ha	22,975	3,995	11,000	3,084
% of area cultivated with rice	30	11	86	77
Groundnut production, t	28,078	23,901	646	658
Millet/sorghum production, t	16,013	5,119	60	-
Rice production, t	31,299	2,665	12,100	3,450
Cereal deficit[2], kg/capita	+ 100	- 170	+ 181	- 121

1 The 1962 and 1963 data are furnished by DGPA-Ziguinchor. The 1983 and 1984 data are from SOMIVAC (Regional development unit)

2 The cereal deficit is calculated on the basis of cereal production and total population in each department. Cereal requirements are estimated at 200 kg/capita according to FAO criteria.

have shown that cultivation on the plateau represents less than 60% of total area in the southwest whereas in the north, the proportion is over 80%. The proportion of time devoted to work on the plateau reflects this division of labor : 65% in the north and 46% in the south.

(3) Utilization of ox traction : the degree of adoption of ox traction introduced a differentiation in the farming system in Lower-Casamance. More than 90% of the area on the plateau in the Sindian-Kalounayes zone (northeast) and 50% in the villages of Fogny-Combo (north) are tilled with a plough. Tillage with oxen is almost unknown in the southwest.

Fig. 3 illustrates the five agricultural situations in Lower-Casamance. This grouping excludes the sparsely populated coastal islands and the southern small border fringes near Guinea Bissau where an itinerant forest agriculture is practiced. In examining the strategies adopted, we will always refer to two groups of agricultural zones : those of the north (Sindian-Kalounayes and Fogny-Combo) and the southwest (Oussouye).

Recent rainfall trend (1982-1984). Before making any comment on farmers' strategies and research efforts deployed by the systems team, it would be necessary to examine the cumulative trend of rainfall in a northern and a southern site during the past three seasons. This gives a clear picture of the cropping season in the north and the south.

It could be observed, in the first place that the rains begin in the north (Boulandor) before extending to the south (Loudia-Ouolof). In 1982 and 1983, the rains began in the third decade of May in the north, but the southern area had rains in the second decade of June. Both in the north and the south, the overall mean rainfall for the three years was below normal if compared with rainfall records for the past 15 years.

At Boulandor, total amount of rains in the three rainy seasons varied widely. The 1983 season was the most dry with less than 600 mm of rain. From July 20 to August 20 only 60 mm of rain was recorded. Total amounts of rains recorded in 1982 and 1984 were almost equal (1,015 and 944 mm) ; moreover in June and July 1984, critical months for cropping and weeding, cumulated rains exceeded 1983 rains for the same months (562 mm vs 208 mm). Such an inter-annual variation in the rainfall pattern obliges farmers in the northern lands to concentrate more effort on directly sown crops with quite early sowing dates. They place little emphasis on aquatic rice-growing.

On the other hand, at Loudia-Ouolof, there was very little inter-annual rainfall variation in the last three years. This holds for both the accummulated total and monthly distribution. In 1982 and 1983, heavy rains in the third decade of August[1] (the slope of the curve suddenly becomes sharper in Fig.4) helped in filling the border strip which thus determines the right time for transplanting the rice. If there are sufficient rainfalls thereafter in September and October, (mean of 317 mm for the last three years), one could expect a normal harvest. The Oussouye farmers speculate on this reasoning whereby the rains begin in June, followed

1 The rainfall readings were respectively 232 and 212 mm in 1982 and 1983.

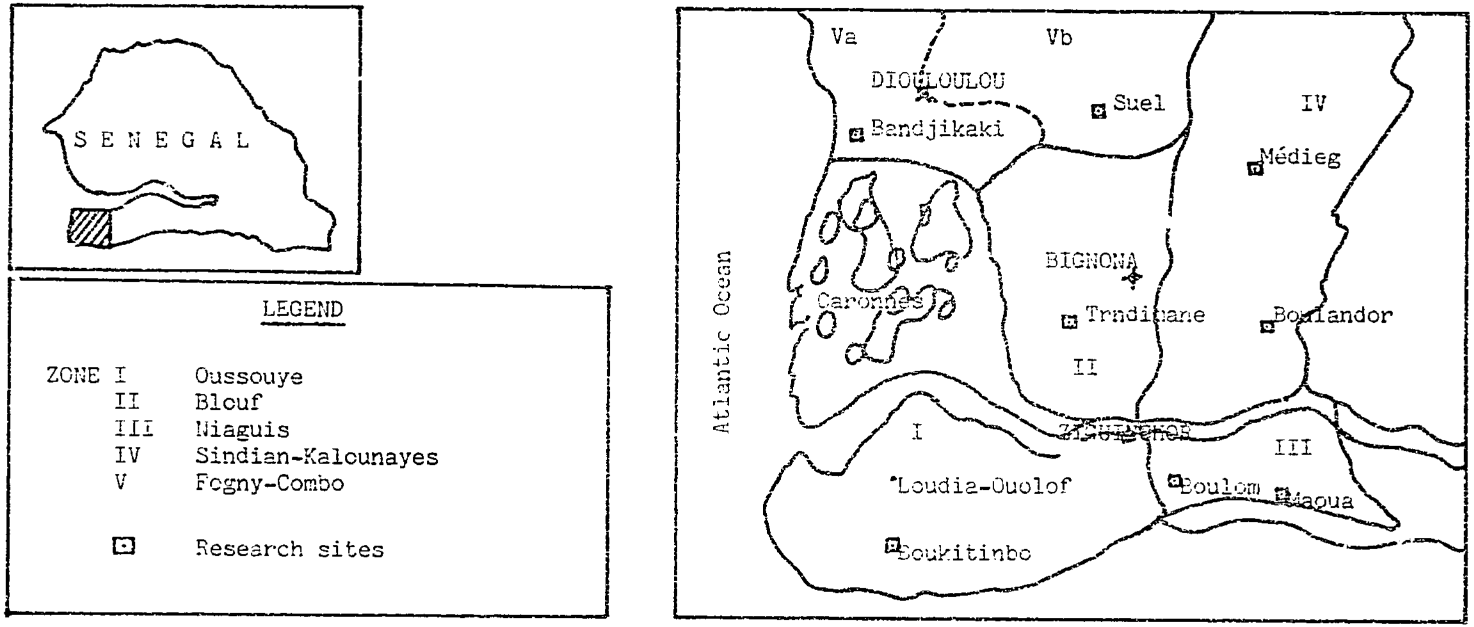

Fig.3. Agricultural situations in Lower-Casamance.

ZONE I Social organization of work-Diola Type, absence of animal traction and predominance of transplanted rice.

ZONE II Same type of organization as in Zone I, but with a relatively significant plateau cropping and direct sowing of rice.

ZONE III Social organization of work-Mandingue type in the east, but intersected in the central and western parts by Diola villages. Animal traction is not widespread and direct sowing of rice is quite significant.

ZONE IV Social organization of work-Mandingue, animal traction quite developed, plateau farming very significant.

ZONES V Social organization of work-Diola type, animal traction developed and aquatic rice growing relatively important.

CARONNES ZONE : Martitime not covered by the SPT team.

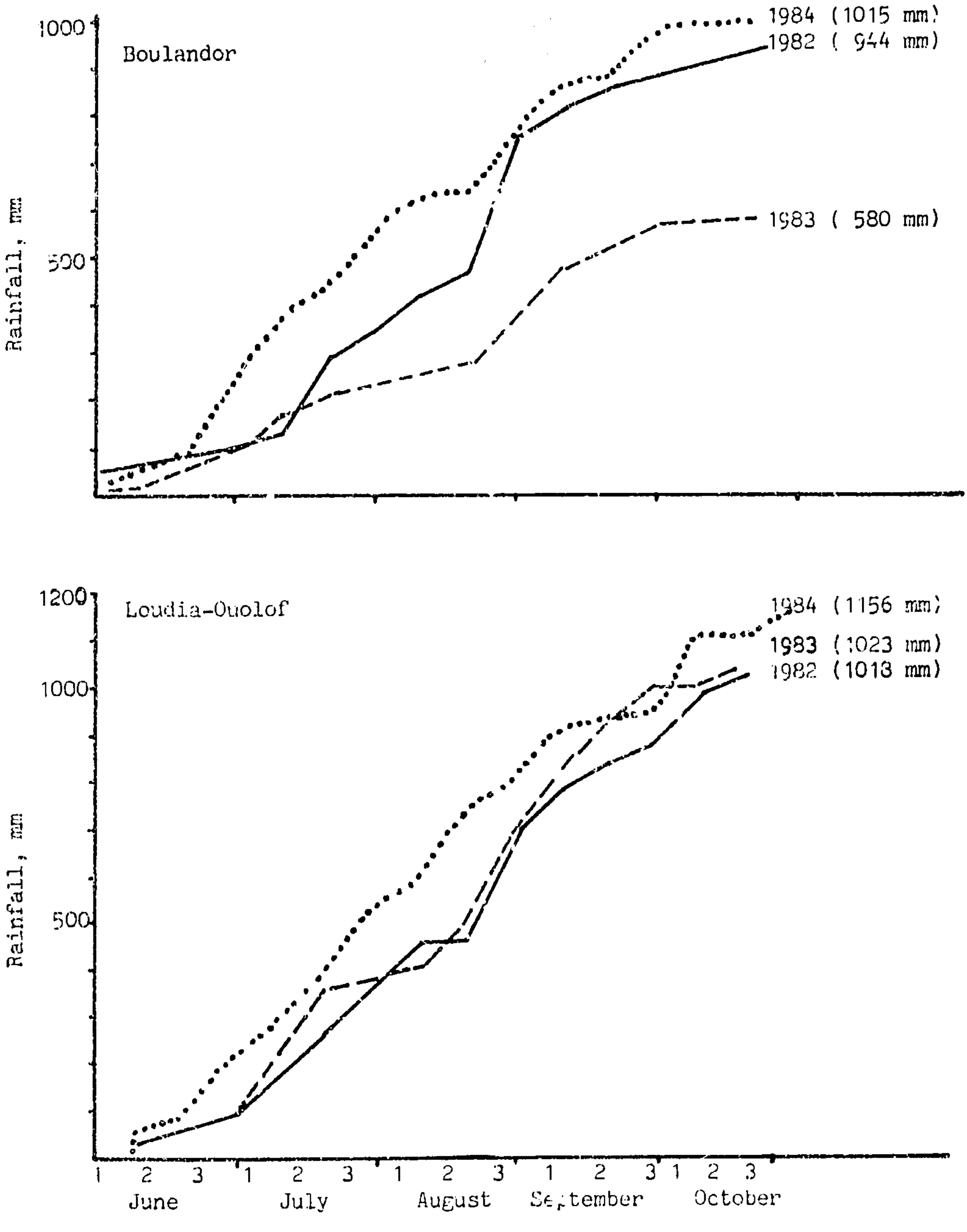

Fig. 4. Total rainfall for 1982, 1983 and 1984 cropping seasons in the northern (Boulandor) and southern (Loudia-Ouolof) parts of Lower-Casamance.

by heavy rains between end of August and early September and then an end of rainy season with abundant rains to gather the hope that aquatic rice growing will be a success.

Farmers' strategies. The major objective of Lower-Casamance farmers is firstly to produce a sufficient quantity of cereals for self-consumption and then to obtain a surplus that could be marketed (opinion survey made by the Production and Transfer Systems team in 1983). Since the past fifteen years many of the farmers have been facing considerable food shortages resulting from the reduction in rainfall. Surveys conducted in 1982/83 and 1983/84 in 10 villages dispersed over the whole region, have revealed that with respect to performance in cereal production, only two villages had achieved the stipulated mark of 200 kg[1] per capita per annum. Recent studies have demonstrated that for a family consuming a regular daily ration (besides unusual occasions such as festivals, dinners and visits by strangers) the available quantity of rice gets exhausted within six months after harvesting (Jolly et al., 1985). Farmers make up the difference in consumption mainly by buying white rice.

Even if on the whole, different farmers are observed to have similar motivations and preferences, it is still found that farmers' available resources and opportunities differ from one agricultural situation to the other. Population density for example is over 60 inhabitants per km^2 in the southwest whereas in the north and northeast, the figure is not above 15 inhabitants per km^2. Consequently they have to deploy different strategies to attain identical objectives. One element of difference in these strategies is the possibility of acquiring land on the plateau.

The abundance of plateau lands[2] and the use of farming practices facilitating the exploitation of these lands enabled farmers at the northern and northeastern areas of the Casamance river to adjust to the current drought cycle by putting more emphasis on groundnut, millet and maize cultivation. On the other hand, in the southern part of the river where access to emerged lands is relatively limited, farmers have implemented strategies based on the intensification of suitable rice fields, the development of market gardening and picking. Between these two extreme situations, there is an intermediate zone with a more or less "restrictive" production system because farmers have less suitable rice fields than in the southwest and less plateau lands than in the north. The production system of the Mandingue Diolas in the Sindian-Kalounayes area is essentially based on plateau farming. This system gives some advantages that enable farmers to adapt easily to a situation of scanty rainfall :

(1) the system orginates from the Mali plateau where farmers have been familiar with millet, sorghum and maize for a long time ;
(2) farmers in this area have long-dated experience in animal traction and this partly explains why larger stretches of land are farmed than on the southern part of the river ;
(3) agricultural farming is generally organized on the basis of compounds with several households and there is the possibility of mobilizing a large number of people (seven to nine per farm)

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1 Minimum standard set by FAO.

2 It is estimated that there are over 150,000 ha of cultivatable plateau lands in Lower-Casamance and that about 20 to 30% of these lands are cultivated presently (SOMIVAC, 1985).

as soon as the rains begin in June. Almost concurrently, all active household members are deployed for ploughing (men on the plateau and women on rice fields) thereby helping to accelerate the tempo of the cropping process. Moreover, diversifications on the plateau diminish risks in production.

The agricultural time-table in the northeastern zone (Fig.5) illustrates the broad outlines of farming systems implementation among the Mandingues-Diolas. Maize is sown along with the first July rains on compound fields. Plateau ploughing begins just after clearing. Thus involves traction using the UCF plough (or the ridger). Millet is firstly sown (dry sowing on ridges) ; this is followed by groundnut sowing. Almost at the same time the women move down to the valleys to cultivate rice on the lowlands. Here they undertake all the farming operations up to the harvesting period. From then on, labor peak would be in June-July (Fig. 6).

All the active household members are mobilized between June and September and they accordingly offer 74% of the total labor hours required for the cropping season. According to explanations given by farmers, it is only at the end of September that they are able to appreciate the success or failure of the campaign depending on rainfall distribution and the possibility that they had in alleviating labor constraints on farms (Sall et al., 1983).

The so-called plateau strategy applied by farmers at the northern side of the river is characterized by two major approaches :

(1) particular interest in early sowing[1] and

(2) intensification and diversification on the plateau.

The desire for a rapid implementation of the campaign is manifested in respect of both the plateau and the rice field. In connection with the plateau cultivation, there is a general tendency to carry out sowings before end of June. This was the case in 1983 (droughty year) when all the followed-up maize and millet farms were sown towards the third week in June, and in 1984 (more or less rainy year) when over 80% of these same farms were sown before the 10th of June (Fig. 5). In some cases such as Boulandor in 1984, early groundnut sowings were effected with the seed drill on plots that had not been tilled. On rice fields, direct rice sowings on the lowlands by women, is an adaptation to the drought particularly in villages like Boulandor where 84 of the 90 plots of rice followed up in 1984 were transplanted 10 years ago. At Medieg, 17 of the plots directly sown today, were transplanted less than 10 years ago whereas the rest (62 out of 79) were aquatic rice growing plots before 1973-74. In practice, direct sowings of layer or sheet rice in the north take place around mid-July because the soil on the rice fields is heavy and requires precipitation of 100 to 200 mm before it can be easily worked to ensure a good emergence. There is also the new technique of dry soil tillage (shallow ploughing by women) from the month of May, the use of early varieties of rice and the introduction of

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1 There are some empirical proofs of the strong correlation between the date of early sowing and yield : Sall's work (1981) at Mampalago is an example. In 1984 a study carried out by PIDAC as part of the "quartered hectare" program using an econometric model, indicates a loss of 140 kg of maize per week on farms sown after June 15 in Lower-Casamance.

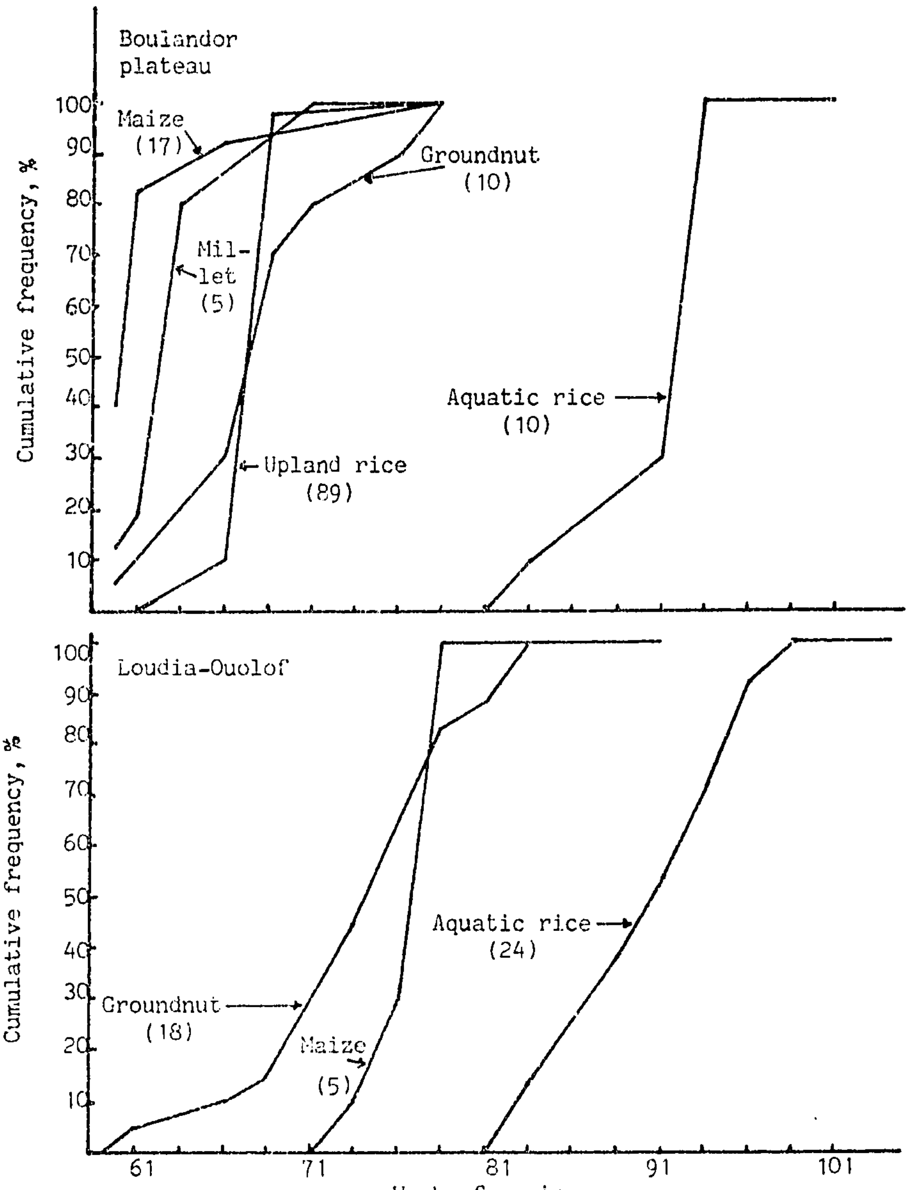

Fig. 5. The 1984 cropping season : date of commencement of seeding and the number of follow-up plots.

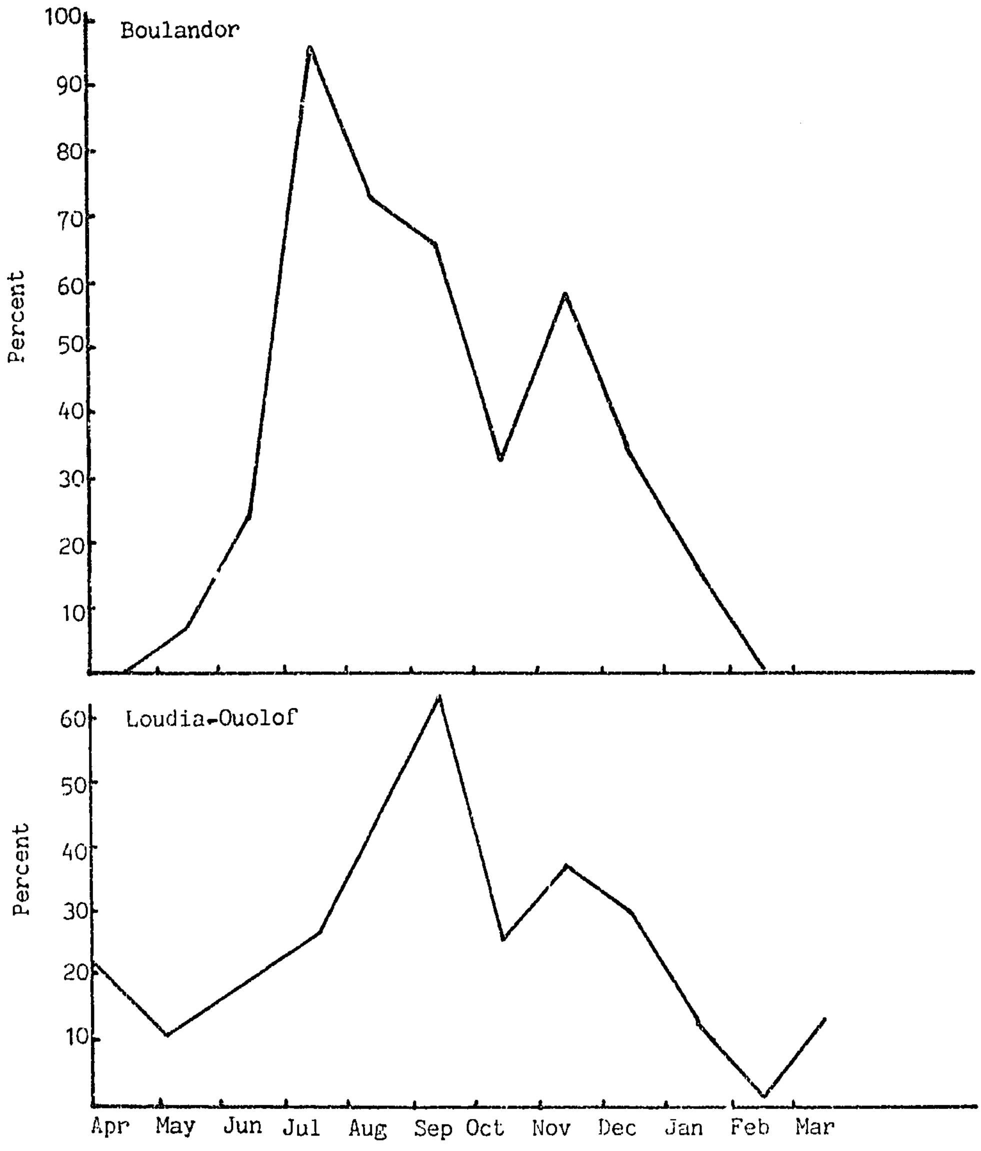

Fig. 6. Time-table of the rate of utilization of household manpower.

the seed drill on rice fileds as a practice reflecting the same desire for an early launching of the field season so as derive benefits from the constraints posed by the current climatic characteristics (rainfall shortages and short-lived seasons).

The effort towards intensification and diversification is reflected in the emphasis placed on certain farming practices. In this way, the manuring of millet and maize plots by folding has become a common practice in some villages even though it was formerly rare : 30% of followed-up millet and maize plots in the Sindian-Kalounayes area and 15% in Fogny-Combo were manured by folding in 1983-84. Further northwards, as is the case in Toukara, rice growing has been completely abandoned since the past five to seven years, in favor of other cereals. Women are redeployed on the plateau where they cultivate individual groundnut and sorghum plots.

Generally, the "plateau" strategy in the northeast is based on a more sustained exploitation of plateau lands as reflected in the increasing demand of farmers for animal traction equipment. In effect, the results of a recent survey indicates a strong association between the presence and use of animal traction and the larger farm sizes on one hand, and on the other hand the use of animal traction and higher daily incomes (Annual report, 1983-84, Production Systems team)[1].

Rice field strategy. The production system commonly encountered in Oussouye, some coastal villages in Blouf and the Ziguinchor area towards the west orginates from the muddy areas in Oussouye. The system is essentially based on aquatic rice growing (transplanting). Division of labor according to sex is complementary because the men work on both the rice fields and the plateau, with the women concentrating on harvesting and rice transplanting.

Major prospects of this originally Diola system are the following :

(1) Abundance of lowland rice-fields with high clay and organic matter contents due to considerable manure deposits, and hence the possibility of an intensive rice monoculture.

(2) Flexibility in the agricultural timetable due essentially to the importance of transplanted rice in the farming system. In effect, after the end-of-cycle tillage, the most strenuous labor activity is transplanting ; since the latter only takes place in August-September a considerable amount of labor would still be available for the activities to be carried out at the beginning of the rainy season (June to mid-August).

(3) Presence of several easily flooded low lying areas and the Guinea type of forest ecology (at Oussouye) helps in diversifying extra curricular and non agricultural activities.

Here, the field season begins slowly with some groundnuts and some rice nurseries ; it normally ends towards the end of July. Tillage is carried out using the "cayendo", a traditional manual instrument for making

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1 Well-equiped farms in Boulandor have an average area of 6.75 ha. At Medieg where there is a small quantity of such equipment, the average area of a farm is 4.2 ha. In these same villages, labor productivity is 770 FCFA/day for farmers using animal traction and 600 FCFA/day for manual farming.

ridges ; the tilled areas of land are therefore limited. With the flooding of rice fields in mid-August and September, the tillage and transplanting of rice fields are the dominant activities leading to a maximization of the demand for labor (Figs. 5 and 6).

The system in the southwestern area is efficient when rainfall is "normal" (a minimum of 1,300 to 1,400 mm) and the flooding of rice fields occurs just at the end of August. In effect before the present drought cycle, this system used a highly intensive labor input in rice growing and the productivity of labor sufficed in maintaining a population density of 65 inhabitants per km^2 (Linares, 1981).

With the current climatic constraints, rice growing farmers in the southwestern area make an increasing exploitation of the labor surplus and the flexibility inherent in the system through a series of observed accommodations[1]. In the first place, the end of cycle tillage is more and more reduced due to the drought. This is because the soil gets hardened after the December-January harvest. Even though this practice was formerly common, in 1984 only 28% of followed-up plots in Boukitingo and 0.08% in Loudia-Ouolof were tilled at the end of the rainy season.

Furthermore it is observed that the cultivated area of land on the plateau depends on the impression of farmers with respect to the commencement of the season.

When rainfall is low in June and July, as it was in 1983 (375 mm), 73% of followed-up farmers increased the size of their groundnut plots by almost 30%. In 1984 (rainy year with 475 mm of rains in June and July), 75% of farmers on the same farm sample reduced the area of their groundnut plots so as to devote more labor to aquatic rice production.

Again, farmers must necessarily have to wait until the border strips are flooded to determine the number of rice fields to transplant. This offers them the possibility of saving labor and concentrating their effort on suitable rice fields (inundated and desalted). The follow-up conducted within the past three years indicated that approximately 2/3 of aquatic rice fields have been thus abandoned. This selective approach constitutes an advantage to the cultivation of transplanted rice as compared with the direct sowing of rice. Thus in 1983, 43% of plots cultivated with layered rice (sown in June-July were destroyed as against 30% for the whole of the transplanted plots[2].

Finally, depending on the nature of the rainy season and the availability of rice fields at different levels of the toposequence, the farmers establish their nurseries on a step by step basis and this helps in

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1 The term "accommodation" for the rice-growing area in the south-west is preferable to the concept of adaptation used for the north because there is no significant change in the established production system, but rather emergency adjustments while waiting for the rainy years.

2 Our analysis of the DGPA chronological series (25 years) actually demonstrate a significant correlation (0.59) between the size of area transplanted and rainfall, and a slight and insignificant correlation (0.16) between the rainfall and rice yields.

spreading the transplanting period. Surveys we carried out in 1983 when the beginning of the rainy season was dry, indicate that 2% of the nurseries were sown in June, 89% in July and 9% in August. It was observed that in the 1984 rainy season with more rainfall earlier in the season, 24% of the nurseries were sown in June, 58% in July and 18% in August.

There are however some strategies of adaptation to the drought, particularly by way of the intensification of rice growing, the importance of non agricultural incomes, and the extent of youth migration (40% of active household members in some Blouf villages). A typical example of intensification strategies on rice fields is given by the Mangagoulak village located along the southwestern coast of Blouf. In response to the rainfall shortage and with a very limited availability of plateau lands, aquatic rice growing has become very intensive there (210 man days/ha) with a mean yield of 2,800 kg/ha.

Farmers give a lot of attention to the nurseries and apply considerable quantities of manure to rice fields (Sall et al., 1983). This is a general practice in Loudia-Ouolof and Boukitingo ; at Tendimane, women also scatter mango leaves over rice fields.

Non agricultural and "extra-agricultural" activities (fishing, picking, palm wine and palm cabbage harvesting) and off-seasonal market gardening currently constitute an important source of pecuniary income among the Diola farmers from the south.

It has been demonstrated that in the case of Loudia-Ouolof and Boukitingo for example, incomes derived from the whole of these activities represent respectively, 122 and 150% of pecuniary agricultural incomes from farms (Report of Systems Team, 1984). A substantial part of these incomes is used in purchasing white rice during the soudure or hunger period.

Adaptations in the transition zone. In view of its location northwards of the river up-stream of the "bolongs", Blouf receives less rains than the southwestern rice-fields (mean rainfall for the three years in Tendimane is 765 mm compared to 1,067 mm in Loudia-Ouolof). The farmers have very little aquatic lowland rice.

They cultivate highland rice but the per capita ownership of rice-fields is still low as compared to the situation in the northeast[1].

One of the consequences of this situation is the gradual adoption of direct rice sowing on fields which were regularly transplanted previously and the progression of the system towards plateau agriculture. In 1984, almost all the followed-up upland rice in Suel and 20 of the 31 followed-up rice fields in Tendimane were aquatic fields (transplanted) converted to direct sowing 10 years before.

Since the production system is basically the Diola type, the concern of the Blouf farmer is for the success of his rice cultivation. From then on the strategy he adopts on the plateau is determined by the type of rice

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1 Rice fields owned per capita is related to the approximate population density of 20 to 25 inhabitants per km^2 compared to the density of 10 to 25 inhabitants per km^2 in the northeast.

field he is handling. In Suel for example where the rice fields are on highlands and are sandy, the farmer prefers first of all, to finish weeding and ploughing his groundnuts before moving down to plough the rice fields with an expected lower yield.

At Tendimane where the rice fields are more clayey and have a certain potential for yields, men alternate their time-table between the ploughing of groundnut fields and the ploughing of plots for upland rice.

The plateau strategy is mainly based on millet which was adapted only recently. Millet cultivation is beginning to compete with groundnut on the market and is gradually finding its place in diets which have for a long time been dominated by rice[1]. Another means of adaptation to the drought (not extensively documented) is youth migration to cities. The rate is around 40% in some Blouf villages. The migration reduces the number of individuals to be fed and in some cases constitutes a source of farm income through the transfer of the savings from migrants back to relatives.

Characteristics of northern and southern farms. The strategies that we have just outlined are part of a gradual scheme implemented by production units with quite distinguished characteristics existing between the north and south of the region. We are going to examine their essential elements (Table 3) before analyzing research efforts under way. The farms in the north are big from the point of view of the number of laborers and the total cultivated area. The former is explained by the social organization of work among family groups (a big compound for several households under the authority of a patriarch) ; the latter on the other hand is related to the use of animal traction. The household has an autonomy in agriculture and therefore it corresponds to an agricultural farm unit in the south. The number of labor hands is reduced (two to five) and the use of manual tools (Cajendo) for ploughing limits the total area of land that can be brought under cultivation.

In the north, there is a greater demand for credit for the purchase of equipment and materials (ploughs, seed drills). Emphasis is placed on groundnut which is a cash crop. In the south, farmers contact the development organization to seek farm credits (fertilizer in particular) and to make a demand for the rototiller to plough their rice fields. Emphasis is placed on rice for self-consumption.

The farm units in the north have more than 80% of their land located on the plateau and devote a considerable proportion of labor hours (65%) to such plateau farms. At Oussouye, the farmers cultivate 50 to 60% of their lands on the plateau but only devote 46% of labor there.

This allocation of labor between the plateau and the rice fields and the nature of farming practices established in each zone explain the essential differences in crop yields. With regards to maize, the limiting factor is the use of manure. In the north, the compound fields are manured by folding and this helps to obtain yields up to almost one t/ha.

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1 The area of land cultivated with millet in Tendimane which was 7% of the total in 1982, reached 12% in 1983 and 16% in 1984.

Table 3. Characteristics of farms in the northern and southern part of Lower-Casamance[1].

Characteristics	Farming in the north based on plateau cultivation	Farming in the south based on rice growing
Average dimension of farm, ha	6.21	1.55
Average number of labor hands per farm	7.2	4.1
Percentage of land farmed on the plateau	86	59
Percentage of labor hours devoted to plateau farming (millet, groundnut, maize,)	65	46
Percentage of labor hours devoted to rice	35	54
Yields, kg/ha		
Maize	838	221
Groundnut	954	621
Millet	539	-
Rice	1151	888
Percentage of total income derived from non agricultural activities	20	59

1 These data are obtained from surveys carried out at Boulandor and Medieg considered as typical northern villages and at Loudia-Ouolof and Boukitingo typical southern villages. Apart from percentages of labor hours calculated over a period of two years (1983 and 1984), the data for other items are mean values calculated over three years (agronomic follow-up).

At Oussouye, manure and cattle dung are reserved for rice fields. On the average 1/3 of such rice fields are treated annually. With respect to goundnut, weeding is a limiting factor of yields. At Boulandor and Medieg (northern villages) the interval between sowing and weeding is approximately 31 days on the average. At Oussouye it is 45 days. Groundnut yield is low because of the use of local varieties, even though these varieties tolerate weeds.

In the case of rice, differences in yield may arise first and foremost from the type of rice cultivated (upland rice in the north and aquatic rice in the south), and from the lack of water on formerly flooded aquatic rice fields. This delays the transplanting, during recent years, in places like Loudia-Ouolof and Boukitingo.

Yields are low also because of the ferric toxicity and the excessive salting of the valleys. Upland rice directly sown in the north can be harvested with low yield in a droughty year. At Bouloum near Ziguinchor for example the rice cultivation system is transitional. The farmers are beginning to proceed to direct sowing of rice in the border strips which were recently transplanted. Our results covering a period of two years indicate that the yield obtained from directly sown rice, is slightly higher than that from transplanted border strips (1112 kg/ha and 942 kg/ha respectively). However, labor requirements on directly sown rice is much greater (264 man days compared to 187 for transplanted rice).

Finally the difference between farms in the north and those at the southern part of the river is traced to the relative importance of non-agricultural activities in the creation of family incomes. In the south this contribution is almost 60% compared to 20% for farms in the north.

RESEARCH STRATEGIES

This discussion is based on farmers' strategies of adaptation to the drought as has been examined and analyzed since the creation of the Production and Transfer Systems Team in 1982. Even though it is not possible to comprehend and appreciate all the subtle adjustments made by the farmers in reaction to the present drought cycle, the systematic moves have enabled us to have a better understanding of their logic, motivations, aspirations and the potentialities of the environment. After exploratory surveys and the initial agronomic inspection of farm fields, we were able to outline four major research themes relating to the current preoccupations of farmers in Lower-Casamance and the orientations of the Development Organization. These strategies are diagrammed in Table 4.

Intensification of production on productive lands. As a reaction to the present drought cycle, intensification efforts are concentrated by manuring ; and moist lands down on the toposequence. Two complementary approaches are used :

(1) improvement of land productivity, and
(2) increase in labor productivity.

In the north, emphasis is placed on emerged cropping and the use of animal traction and this helps in propping up efforts being made by farmers. In connection with the improvement of land productivity, maize, millet and upland rice fertilization trials have been carried out. Generally the doses used are moderate (NPK at a dose of 52-18-27 kg/ha for cereals, and

6-14-20 kg/ha for groundnuts). These doses seem to be profitable considering the limited technical know-how of farmers and the current climatic conditions. Improved varieties of upland rice tested among farmers could demonstrate their potential in view of their short cycle, their tolerance to blast, rice diseases and farmers' appreciation of their type of grains. For example, DJ-12-59 and IRAT 133 have produced 3,350 and 2,700 kg/ha respectively in variety trials. In the course of large scale trials, these varieties offered a yield at least 20% higher than local varieties. With regards to labor productivity, agronomic follow-ups and trials carried out among farmers have shown that the major obstacle to an increase is the length of time between sowing and weeding. A longer interval of time has the effect of reducing yields from plateau cultivation. Mechanical weeding trials have been conducted. In the absence of appropriate weeding equipment, the UCF plough was successfully used thereby making it possible to derive a 60% time savings compared to manual weeding by farmers for the same level of yield.

On upland rice fields emphasis was placed on the control of weeds by use of herbicides and row-cropping. The advantage in the use of herbicides mainly lies in the time savings made during weeding (the period of time used in weeding can be reduced up to 1/3 of the time normally required for untreated plots). The introduction of the seed drill on upland rice fields (the example of Boulandor) makes it possible to save time weeding by practicing row-cropping (weeding time is reduced by half in comparison with broadcast sowing). It must be noted however, that there are no savings made in sowing time per se because broadcast sowing is more rapidly done.

In the rice growing area at the southern part of the river, intensification through productivity improvement per unit area mainly involved compound fields. These are enclosed areas of land on which household garbage is scattered. Part of this land is reserved for fruit trees[1] in some cases. The efforts of the team are concentrated on maize and cassava. Results obtained within the past two years indicate that under favorable conditions, maize yield can be increased up to 2,000 kg/ha. The considerable rainfall in July and the resulting remporarily hydromorphic effects, tend to reduce maize yields. Because of their tolerance for cochineals (<u>Phanacocus manihoti</u>) and mosaic virus, new cassava varieties have performed well in preliminary trials.

With regards to regularly flooded rice fields (without any problem of salinity and ferric toxicity), intensification involves fertilization and improved varieties. Recent results indicate that the DJ-684D variety has an average yield of 2,600 kg/ha representing a 54% increase compared to the yield of local varieties.

In the absence of animal traction, farmers make use of more efficient manual practices and improving labor productivity. Farm tests have thus demonstrated that in the case of upland rice fields and maize, ridging is faster and at an equal yield ridging makes it possible to have a better control over weeds than flat tillage.

<u>Diversification of the farming system.</u> This involves the introduction into the agricultural time-table, of crops that could be sown towards the end

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1 Very soon a research unit on tree planting in villages will be intiated.

Table 4. Diagram of research strategies of the Lower-Casamance systems team.

Location	Intensification[1]	Diversification	Utilization of residual moisture	Retrieval of abandoned lands
Northern zone concentrated on the plateau	Soil productivity : -fertilization MA, GR -varietal performance UR varieties IRAT 133, DJ-12-59 Labor productivity : -sowing-weeding interval. GR, MA -[illegible] weeding -herbicides, row cropping UR	Increasing farming intensity ; -sowing at end of rainy season SG, CP -varietal performance CP ; varieties NB (58-57) varieties SG (V2, V6)		
Djibelor station				-trial on toposequence; highland rice fields MA, SG, CP, SP -salt leaching trial
Southern rice producing area, concentrating on aquatic rice production	Soil productivity -compound fields MA -fertilis. AR -varietal AR variety DJ-684D -ridging	Reduction of farming risks -crops for filling in deficit SP, CP -varietal perform. varieties SP (Ndargu) NB (58-57)	Off seasonal cropping ; SP -mid-Oct. sowings highland rice fields -Jan. sowing lowland rice fields	

1 Abbreviations : MA = maize ; GR = groundnut ; SG = sorghum ; CP = cowpea ; UR = sheet rice ; SP = Sweet potatoes ; AR = Aquatic rice-growing.

of the rainy season without over-loading the farmers' time-table. In areas where farmers apply the "plateau" strategy, (northern villages), the objective is to spread agricultural activities (increase farming intensity) with crops that can be sown just after the major task of groundnut sowing and weeding (Fig. 5). Sorghum and cowpea conveniently fulfil this condition. During the past three years, in performance tests on sorghum, the V2 and V6 varieties gave an average yield (950 kg/ha) three times that of local varieties (315 kg/ha).

When trials were conducted at a normal scale, varieties sown within the period from August 1 to 10, gave an equal performance in all cases (average yield 1,011 kg/ha as compared to 383 kg/ha). In performance tests on cowpea (variety 58-57) sown between August 15 and September 1, the average yield was 775 kg/ha and 248 kg/ha for the local variety.

The diversification in the southern rice growing area aims at reducing the risk of farming during droughty years when aquatic rice growing does not succeed. In effect as indicated above, transplanting is only effected at the end of August or at the beginning of September. From then on, if there is a rainfall shortage, it often becomes late for the farmers to sow another crop to make up the deficit. It is in this vein that the team began to work on cowpea and sweet potatoes in order to make up for the shortage. Results over the past three years on cowpea (variety 58-57) indicate that an average yield of 496 kg/ha can be obtained compared to 103 kg/ha for the local variety. Results obtained on sweet potatoes over a two-year period have demonstrated that the Ndargu variety sown on the plateau within the period from August 15 to September 15 can produce yields in the neighborhood of 5,000 kg/ha compared to an average of 1,911 kg/ha for the local veriety.

Utilization of residual moisture on rice fields. This theme which is especially applicable in the southern area covers both of the first two themes (intensification and diversification). Sweet potatoes have undergone tests in some Oussouye villages as an off-season crop cultivated just after rice harvesting. They can therefore be transplanted on the upland rice fields in mid-October to complete their cycle by making use of the morning dew and the rise in the capillary fringe (average yield 2,500 kg/ha). On the other hand, in border strips with aquatic rice, sweet potatoes can only be transplanted in early January and need to be watered within the first two weeks for the suckers to shoot before the completion of the cycle solely be taking advantage of the rise in the capillary fringe (average yield of 4,200 kg/ha).

Retrieval of abandoned lands. A substantial proportion of upland rice fields both in the northern and southern part of the river have been abandoned for lack of flooding because of the marked lowering of the water table. Some lowland rice fields are over-salted by the water current and the rise of the "bolong table". It is estimated that over 1/3 of rice fields which were formerly utilizable have been abandoned because of this[1].

The objective of our intervention on abandoned upland rice fields was to utilize such fields through the system of ·· ·ged cropping, which has a moderate water requirement and which dema·· · ttle effort in weeding.

1 Information gathered during exploratory surveys.

This is the idea behind our trials on maize, sorghum, sweet potatoes and cowpea at the Djibelor station. On these abandoned rice fields, maize performed better than rice and as well, enabled savings to be made in weeding time. A year ago, sorghum and sweet potatoes were introduced into experimentation (sown on August 13) with a respective yield of 1,000 kg/ha and 3,300 kg/ha, which compares very favorably with 800 kg/ha obtained from rice on the control plots.

With respect to salinized rice fields, the team is working in collaboration with a specialist in hydraulics for soil tillage, the spacing of the drainage ways and the control of the water tide which could be techniques capable of facilitating the leaching of salts.

CONCLUSIONS

Agriculture in Lower-Casamance is still dependent on rainfall trends even though the region has many endowments. Since the early 1970's, there has been a decreasing trend in rainfall coupled with a reduction in the duration of the rainy season. This situation is reflected in major changes made within the local production systems. The general conditions of production have deteriorated and the situation of cereals on farms has become much more risky in some villages.

In effect, regional statistics indicate a reduction of over 50% in total cultivated area within the last 20 years. Rice production decreased 79% in terms of total cultivated area in the Bignona department.

By making use of a systematic approach, the SFT team-ISRA, at Djibelor has underlined five different agricultural situations in Lower-Casamance. Each of them presents some prospects facilitating the adaptation or accommodation to the present drought cycle as well as some specific constraints which call for localized solutions. In this document we have discussed two extreme agricultural situations the Sindian-Kalounayes area at the northern side of the river Casamance and the Oussouye area at the southeastern side. The two situations contrast from the point of view of the cropping system, the trends of the agricultural time-table, the structure of the production units and consequently, adaptations to the current climatic conditions. The agricultural research unit and the local development body must take into consideration, these variations and differences in production systems to arrest this threat to rural development. There is no unique solution to the agricultural problems in Lower-Casamance.

The Production Systems team has researched these realities from exploratory surveys carried out in 1982, surveys made within farm units and follow-up of farm fields as well as agronomic trials.

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IMPROVED SORGHUM PRODUCTION TECHNOLOGY IN NORTHERN NIGERIA: AN ASSESSMENT

Thomas A. BANTA and Samm BBUYEMUSOKE[1]

Sorghum is one of the most important staple crops in Nigeria, and is the most important cereal food in the Northern (Sahel, Savanna, and Guinea Savanna) states (Anonymous, 1978b). The grain is made into various local foods and drinks, the leaves and grains go into livestock feed, and the stalks are used to construct fences and thatch houses. More total land area is devoted to sorghum than to any other crop in the Northern Guinea Savanna Zone, and 1.1 hectares of the average family land-holding of 3.95 hectares is devoted to sorghum production (Norman, 1972).

In the Northern States, sorghum contributes 73 percent of the total calorie intake and 52.3 percent of the per capita protein intake (Simmons, 1976). The estimated weekly consumption of sorghum is 2.14 kg per capita, while that of millet and other cereals is 0.50 kg and 0.25 kg, respectively (Simmons, 1976).

Projections for the years 1975 to 1985 showed that sorghum supply would continuously fall short of anticipated demand for the foreseeable future (Olayide, et al., 1972). This deficit problem is further aggravated by the fact that sorghum is one of the staple foods not currently being imported. Hence, in order to wipe out the deficit, there must be a significant increase in domestic sorghum production.

One way to achieve such a production increase is through the introduction of improved production technology. Scientists at the Institute for Agricultural Research (IAR) have developed and packaged such technology, aimed at rapidly increasing the yield of sorghum. This technology was disseminated through the Guided Change Project (GCP). Under experimental conditions, yields from the IAR package have been as high as 4,000 kg of sorghum per hectare (Egbarevba, 1979). Under traditional technology, yields are at best only about 1,000 kg per hectare.

However, it is not clear how economically or technologically appropriate the adoption of the improved package would be in the context of the traditional, mainly peasant, setting of Nigerian farming. This study examined the profitability of the improved sorghum production technology disseminated under the GCP, its effect on farm income, the level of adoption in the study area, and the reasons for the adoption or non-adoption of the recommended production techniques.

The GCP was a joint venture of the Kadune State Ministry of Agriculture and Natural Resources and IAR. It arose from the observed difference between the performance of crops on the IAR experimental fields and the performance under farmer conditions. A research project was deemed appropriate in order to find ways of making farmers in the Northern parts of Nigeria adopt the modern farming techniques developed at IAR. The proposed duration of the project was five years starting in 1974. The major

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objectives were as follows (Huizinga, 1977):

(1) to apply theoretical agricultural research to the problem of practical implementation of such research in a known environment;

(2) to select particular aspects of technical agricultural research which can be successfully introduced to farmers on the basis of sound practical and theoretical socio-economic consideration.

To achieve these objectives, the project tried to test three alternative input provision strategies in three different groups of four villages each. The testing was conducted in the Giwa District of the Zaria Local Government area. The strategies were as follows:

(1) a cash program: inputs were made available to farmers in their villages at the appropriate time in the growing season; farmers could buy a package of inputs on the condition of cash payment;

(2) credit program: the facilities of the cash program were supplemented by a credit/savings scheme, whereby farmers could obtain "packages" of inputs through a combination of advance savings and credit, or through credit alone;

(3) extension program: in addition to the cash and/or credit facilities, farmers also participated in the CCP's extension program to increase their knowledge about the proper use of improved farm inputs and practices.

MATERIALS AND METHODS

Table 1 shows the three alternative packages of improved inputs that were supplied to farmers. Table 2 shows the improved sorghum production recommendations developed by IAR for the project's ecological zone. These recommendations were introduced to farmers by the Ministry of Agriculture and the project staff. Table 2 also shows the corresponding indigenous practices in the study area.

Analytical tools. Gross margin analysis and linear programming were used to study the profitability of the improved sorghum technology. Normally, gross margin analysis is used to test the effects of changes that do not alter the fixed costs of production, especially the cost of land and other durable factors. The gross margin of an enterprise is presented as:

Table 1. Improved agricultural input packages supplied to the farmers by the GCP.

Package I	Package II	Package III
Two 50 kg bags of superphosphate fertilizer	Two 50 kg bags of superphosphate fertilizer	Two 50 kg bags of superphosphate fertilizer
One 50 kg bag of sulphate of ammonia fertilizer	Two 50 kg bags of sulphate of ammonia fertilizer	Two 50 kg bags of sulphate of ammonia fertilizer
Six packets of Aldrex 'T' seed dressing	Six packets of Aldrex 'T' seed dressing	Six packets of Aldrex 'T' seed dressing
8.8 kg of short Kaura seeds	15.4 kg of short Kaura seeds	8.8 kg of improved maize seeds
		6.6 kg of short Kaura seeds

$$GM = TR - VC$$

Where

GM = gross margin,
TR = total revenue or value of output from the enterprise,
VC = variable cost (i.e. costs that are specific to producing the output).

This was used to determine the potential profitability and effect on farmers' farm income of the improved sorghum production technology. This formula has the advantage of being simple as well as useful in the analysis of the profitability of small farms that have small fixed costs, as is the case of the project area.

However, on its own, gross margin analysis does not generate figures on the optimum farm income resulting from different farm activities which are based on the farmer's objective function and constraints. Nor does it reveal the optimum combination of activities consistent with available resources or the marginal value product of resources. It cannot be used to show the effects of changes in input and output prices on the magnitude of net farm revenue. To be able to perform these analyses, a linear programming model was applied to the problem. The linear programming model took the following form:

$$\text{maximize } Z = \sum c_i x_i \quad \text{subject to } \sum a_{ij} X_{ij} \leq A_j \quad X_i \geq 0$$

Z is the level of farm income. X_i are the activities involved in the generation of Z. These include crop production, labour hiring, crop selling, and home consumption activities. Home consumption activities are especially important in subsistent and semi-subsistent communities. C_i are the unit prices associated with the activities. The prices of home consumed crops were assumed to be zero. The constraints and restrictions (A_j) were comprised of available resources transfer rows and the minimum household

Table 2. The improved and the indigenous sorghum production technologies in Guinea Savanna Zones of Nigeria.

Element Specification	Improved Recommendation[1]	Indigenous Practices[2]
1. Variety	Short Kaura (SK 5912)	Farafara, Kaura Mori Yargunki
2. Seed dressing	One packet of Aldrex 'T' of Fennassan 'D' to three mudus[3] of seed	Chemicals were used when available at rate of one packet to six mudus of seeds, ash is used for seed dressing
3. Land preparation	Ridges to be made 1 m apart	Mostly sown on old furrows that are 1 m apart
4. Time of planting	mid-May to early June	Highly varied, May to July
5. Seed rate	11-14 kg seed/ha or three to five seeds per 2.5 cm deep hole	Average of 10.2 kg of seeds/ha other aspects were not quantified
6. Interstand spacing	30 cm apart on ridges that were 1 m apart	45 cm apart
7. Thinning	Stands should be thinned to two plants	Stands thinned to two plants
8. Weeding	As required	As required
9. Fertilizer requirements		
(i) Superphosphate	150 kg/ha	Manure mainly was used
(ii) CAN (calcium ammonia nitrate	250 kg/ha	

[1] Anonymous, 1978a.

[2] Authors' observations.

[3] A mudu is a local unit of measurement in Northern Nigeria; it weighs approximately 1 kg.

requirements of the home-consumed commodities.

Data. The gross margins of the improved sorghum production technology were determined using input-output data collected on improved sorghum production by the GCP staff. The data used to determine the effect of the improved sorghum production technology on farm income were partly generated by the GCP staff and by the authors. The data on the household farming model were obtained from the GCP files. The data on the overall gross margins of 15 farmers who grew the improved sorghum and the 15 who did not were collected by the principal author.

The data used to analyse the adoption levels of the improved sorghum production technology were based on primary data generated on a sample of 153 farmers taken from the GCP area in August/September 1980.

RESULTS AND DISCUSSION

Gross margin analysis. The first analysis of profitability was based on 30 experimental GCP researcher-managed farmers' plots on which the improved sorghum production technology was applied. Close monitoring ensured that the package's recommendations were strictly adhered to. Gross margin analysis was used to determine the profitability of the improved sorghum package on each of these farmers' plots.

Only one plot generated a negative gross margin. This plot had suffered from poor researcher management, in particular from the inability to perform various operations at the appropriate time. Gross margins on the 29 remaining farmers' plots ranged from N21.28 to N1,212.69 per hectare, with an average of N482.81 per hectare when input prices were subsidized. Without input subsidies, the average gross margin is N459.86 per hectare.

This analysis is based on researcher-managed farmers' plots. To see how well the improved sorghum production technology fit into the existing farming system in the study area, a linear programming model was used in the context of the farmers' resource constraints, family consumption requirements, competing enterprises and the objective to maximize income.

Linear programming analysis. The linear programming model was based on 500 households, randomly selected from 973 households that were surveyed under the GCP. A household farming model was developed on the basis of traditional practices and the improved sorghum technology as used by the farmers.

The most prevalent crop enterprises, based on the frequency with which such crop enterprises were grown by the farmers, formed 10 of the 32 activities. Sorghum production by the improved technology was then the 11th crop production activity. The labour hiring for each of the 12 months comprised 12 activities, while there were seven crop selling activities, and two subsistent home consumption activities. Maximum constraints were 1.48 ha of land and 250 man-hours of labour per month. Cash for labour hiring and crop transfer rows were also in the maximum constraints column. Minimum constraints were put on home consumption of sorghum and millet.

The GCP-implemented sorghum production technology did not affect the farmers' income significantly enough for the improved crop to come into the optimal plan (Table 3). Instead, the farmers grew the indigenous sorghum using traditional technology: 1.04 ha of indigenous sorghum in mixture with millet, 1.12 ha in mixture with millet and groundnuts, and 1.26 ha as a sole crop. Thus it was more profitable to grow indigenous sorghum using traditional techniques than to grow the improved sorghum using the new technology.

Table 3. The linear programming optimal plan incorporating the improved technology as used by the farmers.

Activities in optimal plan	Unit of activity	Level of activity	Price/unit of activity	Net Revenue[1]
		ha	——— ₦	———
Indigenous sorghum	ha	1.26	31.16	-39.26
Millet/indigenous sorghum	ha	1.04	57.31	-59.66
Millet/indigenous sorghum/groundnut	ha	1.12	53.78	-60.34
June labour hiring	Manhour	2.42	0.06	- 0.21
July labour hiring	Manhour	4.19	0.06	- 0.25
Sorghum selling	₦/kg	1,007.970	-0.58	587.04
Groundnut selling	₦/kg	429.400	-0.74	317.41
Millet selling	₦/kg	120.835	-0.72	86.62
Sorghum consumption	kg	1,199.940	0.00	0.00
Millet consumption	kg	619.940	0.00	0.00
Total gross margin				831.35

[1] The negative values in this column refer to the cost of crops production or labour hiring activities. The positive values refer to the returns from the sale of crops.

This result was further confirmed by the detailed examination of 15 farmers that grew SK 5912 (the improved sorghum) against 15 others who did not grow SK 5912 in the 1980 farming season[1]. The total farm gross margin of the farmers who did not grow SK 5912 was ₦4,946.80 while that of those who grew SK 5912 was ₦3,009.49. A smaller per farm gross margin was thus associated with growing SK 5912.

Further, relevant data for sorghum production at IAR were built into the household farming model as an additional (twelfth) activity. Table 4 shows the experimental sorghum production activity entering the optimal plan at 1.16 hectares. Also, the average gross margin of ₦1,247.51 per hectare associated with the IAR sorghum production activity is more than twice that associated with the GCP implemented gap exists between the ex-

[1] The sample was purposely chosen to comprise people whose main occupation was farming.

perimental research results and what is obtained at the farm level. Specifically, unless farmers follow the recommended technology as a package, and not in parts as most farmers did, the new sorghum variety cannot be profitable for them to produce.

The next two sections of the study are devoted to analysing the level of adoption of the improved sorghum production recommendations, and the reasons for the farmers' failure to adopt them.

Farmer adoption of the improved sorghum production technology. The level of adoption of the improved sorghum production recommendations (Table 2) was obtained from the farmers' responses to the following questions:

(1) Do you know the recommended practice?

(2) Are you following the recommended practice?

For each recommended practice, the level of adoption was expressed as the percentage of farmers who knew and were following the improved practice out of the total number (153) of farmers in the sample. Table 5 shows the level of adoption of the nine inovations that were introduced in the study area. Of the 153 farmers sampled, 111 had participated in the GCP while 42 had not taken part in the GCP. The overall adoption level of 29 percent is low, considering that the survey was made only three farming seasons after the GCP folded up. Even among the GCP participants, there was only a 34 percent adoption level.

The inovation that could be said to have been embraced by the farmers in general was the recommended seed dressing, with an overall adoption level of 84 percent. The recommended variety was the second most adopted recommendation. However, this result was to be treated very cautiously, since no farmer grew only SK 5912 variety to meet his domestic sorghum requirements during the year. The improved variety, whenever grown, was grown along with other indigenous varieties, possibly to curb any risk and uncertainty associated with it.

The study also focused on the knowledge and adoption scores of the improved sorghum production recommendations. The knowledge and adoption scores are the average number of the applicable inovations known and adopted by the farmers out of the nine inovations that made up the improved sorghum production technology. A farmer scores one for knowing the inovation and zero for not knowing; one for adopting and zero for not adopting. For the 153 sampled farmers the average knowledge score is 3.3, while the average adoption score is 2.5. This indicate that only about two of the nine recommended practices were popular with the farmers.

These observations led to an examination of the reasons for adoption or non-adoption of the improved sorghum production recommendations.

During August/September 1980 (as the farmers tended their fields), the 153 sampled farmers were asked to give reasons for rejecting or accepting each of the recommended practices. In cases where the farmers did not know the recommended practices, they were asked reasons for following their own practices. These reasons and the number of farmers that had similar reasons are considered below.

Improved sorghum variety (SK 5912). The SK 5912 improved sorghum variety was accepted by 63 farmers (41.2%). These farmers based their acceptance on the higher yields obtainable from the improved variety. Thirty-five farmers (22.9%) rejected the SK 5912 variety on the basis that its food

Table 4. The Linear Programming Optimal Plan after including the IAR experimental sorghum production as an activity.

Activities in optimal plan	Unit of activity	Level of activity	Price/unit of activity	Net Revenue
		ha	₦	
Millet/indigenous sorghum	ha	1.037	57.31	-59.43
Millet/indigenous sorghum/groundnuts	ha	1.073	53.78	-57.71
Millet/indigenous sorghum/groundnut/cowpea	ha	0.020	65.70	- 1.31
IAR sorghum production	ha	1.158	68.88	-79.76
November labour hiring	Manhours	12.52	0.06	- 0.75
Groundnut selling	N/kg	400.954	0.74	296.71
Millet selling	N/kg	95.614	-0.61	58.71
Cowpea selling	N/kg	2.605	-0.72	1.88
IAR sorghum selling	N/kg	1,619.511	-0.55	906.93
Millet consuption	N/kg	619.40	0.00	0.00
Sorghum consumption	kg	1,199.740	0.00	0.00
Total gross margin				1064.88

Table 5. Level of adoption of the improved sorghum production recommendations in the GCP area.

Sample description	Sample size	Recommendations[1]									
		1	2	3	4	5	6	7	8	9	Average
		%									
Members of GCP	111	60	96	24	15	6	15	27	20	40	34
Non-members of GCP	42	12	50	10	5	0	0	10	21	26	25
Total	153	47	84	20	12	5	11	22	20	36	29

[1] Described in Table 2.

value is less than that of the local variety, and because they could not use stalks of the improved variety, which were too short, for roofing and fencing. Twenty-four farmers (15.7%) did not accept the improved variety because they said it needs more fertilizer than the local varieties. Nineteen farmers (12.4%) did not grow the improved variety because they did not find SK 5912 seeds readily available. Ten farmers (6.5%) said they would not grow the improved variety because it has a lower after harvest price (despite the higher yield) than the local varieties and because it does not store as well as the local varieties. Two farmers (1.3%) refused to adopt the improved variety because they considered it more susceptible to the weed striga than the local varieties.

Chemical dressing for seeds. The seed dressing recommendation was accepted by 130 farmers (85.0%). Eighty-five farmers (55.6%) accepted it because they believed the dressing prevented seed destruction by pests. Forty-five farmers (29.4%) said they accepted the recommendation because the chemical protected the seeds and prevented the formation of the sorghum head smut disease. The reasons for rejecting the seed dressing recommendation did not show that the farmers were unaware of the usefulness of the practice. Some of the rejectors said they had no money, while others said the chemicals were not available. Only one farmer rejected the recommendation out of ignorance.

Land preparation. Only 28 farmers (19.3%) accepted the recommended practice of making ridges before the sorghum is planted. Seventeen farmers (11.1%) accepted the recommendation because they believed they would get higher yields by using ridges. Eight farmers (5.0%) accepted the recommendation because they believed sorghum grows faster in ridges.

Despite the agro-technical advantage of ridging, certain socio-economic cultural restrictions did not allow farmers to widely accept the recommendation. Seventy farmers (45.8%) rejected ridging simply because they found the traditional practice of zero cultivation easier. Sixteen farmers (10.5%) preferred zero cultivation because it is the inherited practice in the area. Twenty-three farmers (15.0%) could not adopt the practice because the implements for making ridges were not available; this reflects on capital scarcity in the project area. Thirteen farmers (8.5%) could not incorporate ridging in their practices because the labour needed to carry out this recommendation was not available. Three farmers (2.0%) found the soil at the time of seed bed preparation too hard to make ridges.

Planting time. The beginning of the rainy season in the project area varies from year to year. Only 8 farmers (5.2%) accepted the recommended planting date. The other farmers rejected the recommended planting date, and the reasons showed their strategy for overcoming the uncertain rainfall conditions in Giwa district. Eighty-one farmers (52.9%) reasoned that it was unwise to plant between mid-May and early June because that period is not the time everyone else plants. The remainder (41.8%) rejected the recommended planting date because they were convinced that during that period the rains are not established well enough to guarantee good germination.

Seed rate. Only four farmers (2.6%) accepted the recommended seed rate of three to five seeds per hole. They gave the rather vague reason that sowing at that rate saved seeds. One hundred fifteen farmers (75.2%)

planted more than five seeds per hole because, they reasoned, some of the seeds might decay. This is especially likely if rains are interrupted for a long period of time after planting. Eight farmers (5.2%) said they had inherited the practice of planting more than five seeds per hole, indicating the incompatibility of the seeding recommendation with existing practice Twenty-six farmers (16.7%) rejected the recommended seeding rate because they found the practice of counting out the three to five seeds too hard and time consuming.

Spacing. Few farmers (7.2%) accepted that the recommended spacing would enable them to obtain higher yields. Eighty-three farmers (54.2%) rejected the 30 cm spacing recommendation because they believed they would obtain larger panicles of sorghum at wider spacing. Thirty-eight farmers (24.8%) believed that wider spacing would allow the plants to be better aerated. Twelve farmers (7.8%) rejected the recommended spacing because it could not permit mixed cropping. The authors observed here that, although the overwhelming majority of crops in the project area are grown in mixtures, the recommended technology package is only for the production of sorghum as a sole crop. Finally, five farmers (3.3%) rejected the recommended spacing because it required more fertilizer than if the spacings were wider. This also reflects the farmers' limited ability to acquire, and the need to economize the required inputs.

Thinning. Only 14.4 percent of the sample farmers accepted the thinning recommendation of two plants per stand. Seventy-seven farmers (50.3%) rejected this recommendation on the basis that three to four plants would give them higher yields. Thirty-one farmers (20.3%) believed that more plants in a stand naturally gave higher yields. Twenty-three farmers (15%) rejected the two-plant recommendation on the basis that their inherited practice was to keep more than two plants per stand.

Weeding. The recommendation was to weed as required throughout the growing season, but only 37 farmers accepted this recommendation. Sixty-six farmers (43.1%) did not accept to weed the sorghum throughout the growing season as required because other fields required their attention. Twenty-five farmers (16.3%) rejected the weeding recommendation because they had no money to hire additional labour for weeding. Another 25 farmers preferred to weed only twice during the growing season because this is the inherited practice.

Fertilizer application rate. The 56 farmers (36.6%) who adopted the recommended fertilizer application rate naturally observed the resulting increase in yield. However, the majority of farmers did not apply fertilizer up to the prescribed rate, if at all: 71 farmers (46.4%) said the fertilizer was not available for purchase; 24 farmers (15.7%) had no money to purchase the fertilizer on the open market; two farmers (1.3%) preferred to use manure since it was cheaper.

General comment on adoption level. The improved sorghum production technology disseminated in Giwa District cannot be said to have been accepted since only one out of the nine recommended practices had an acceptance level greater than 50 percent. Even this practice of seed dressing does not increase the yield of sorghum *per se*; it has to be utilized along with other recommendations before the impact of the technology is noticeable. Over 50% of the farmers could not apply inorganic fertilizer, which is a major component of the improved technology, either because they had no money or because the fertilizer was simply not available. Similarly, the recommended ridging was rejected mainly because farmers could either not afford the implements it required or they lacked money to hire labour that would do it at that time.

SUMMARY

The results of this study show that only three seasons after the project's end, the GCP implemented technology for sorghum production was not widely practiced in the Giwa area. A fairly high number of farmers were observed to be growing the improved sorghum variety alongside the indigenous varieties. But there was no widespread adherence to the other recommendations of the package, except for seed dressing. More importantly, no single farmer was observed to have grown only the improved variety of sorghum.

Gross margin analysis showed that the technology was profitable *per se*. However, given the farmers' resource base (particularly capital, labour and management) the results of the linear programming analysis showed that the farmers were rational in following the indigenous methods of sorghum production, which appeared to be relatively more profitable than the improved practices.

It can be concluded that the improved semidwarf varieties of sorghum disseminated by the GCP were high yielding only with the use of specific cultural practices. For example, the indigenous varieties require little or no fertilizer for a dependable yield, whereas there would be a total crop failure if fertilizers are not applied to the improved SK 5912 variety.[1] Often, the farmers cannot afford the resources required to implement the recommended practices. Moreover, the indigenous varieties had other uses for the peasant farmer, like roofing and fencing, to which the short-stem improved varieties could not cater.

It was implicity understood that the resource requirements for a farmer growing the improved sorghum variety would be greater than that of one growing the indigenous variety. Nevertheless, it appears that the development of the improved sorghum production technology has not been undertaken with the view that low resource base farmers would be the ultimate beneficiaries.

Acceptability of an improved technology by farmers is strongly related to the socio-economic characteristics of the farmers, the nature of the technology, and the vendor of such technology. There is also a need to understand the roles of existing indigenous technology in the lifestyle of the farmers. For example, unless alternative provision is made for the farmers to fence and roof their houses, they will naturally prefer the traditional sorghum variety to the improved variety.

Specifically, the following recommendations can be made:

(1) Prior to starting the development of the improved production technology, farmers' requirements and needs should be ascertained through a socio-economic technological survey as well as through discussions with the farmers who stand to benefit the most from the technology.

(2) The resource base of the targeted farmers needs to be considered

1 These observations were made by the principal author during the August/September 1980 survey period.

in developing the technology. The profitability analysis showed that the resource base for a farmer growing the improved sorghum was necessarily greater than that of the farmer growing the indigenous sorghum.

(3) The producers and consumers of the crop involved ought to be incorporated at an early stage of the technology development. This would ensure a system of feedback between the scientists and farmers as every element of the technology is tested by the farmers themselves.

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CROP ASSOCIATIONS IN THE SEMI-ARID TROPICS OF WEST AFRICA: RESEARCH STRATEGIES PAST AND FUTURE

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Intercropping, the growing of two or more crops simultaneously on the same field (Andrews and Kassam, 1976), is common feature of smallholder agriculture in the tropics (Papendick et al., 1976). Eighty percent of the cultivated area in the West African tropics is under intercropping (Stern, 1984). In Niger, for example, it was estimated that 73% of the cultivated area contained mixed crops (Swinton et al., 1984). In northern Nigeria Norman (1970) found eighty-three percent of the area was devoted to crops grown in association. As long as agriculture continues to be dominated by smallholder agriculture in the semi-arid tropics (SAT) of West Africa, there appears to be no technical reason why intercropping should not continue to play an important role in food production in the region.

Research on intercropping in Africa is a rather recent phonomenon. Baker, Crawford and Eicher (1982) report that, although extensive research was undertaken on intercropping in the area as early as the 1930s, between 1930-1960 colonial administrators and researchers concentrated their research and extension efforts on sole crops. Interest in intercropping systems was renewed in the 1960s and most of the pertinent research has been accomplished in the last fifteen years. Four international meetings have been held on the subject since 1976 (Monoyo et al., 1976; IDRC, 1980; ICRISAT, 1981; ICRISAT/INSA/IDRC, 1984) and two major reviews have been undertaken (Willey, 1979a, b; Stern, 1984).

The purpose of this paper is to review intercropping research in SAT West Africa and to outline crop association strategies for improved agriculture production in the region. This review has relied heavily upon the general principles of intercropping systems as proposed by Willey (1979a, b) and Stern (1984), but has attempted to use examples from the West African SAT to support them. The review covers the West African SAT as originally defined by Troll (1965) and modified by ICRISAT (Virmani et al., 1978). This area includes all of the southern Sahelian zone, and most of the Sudanian-Savanna.

INTERCROPPING IN TRADITIONAL CROPPING SYSTEMS

Norman's pioneering work in the late 1960s established the importance of intercropping in traditional smallholder agriculture in the Zaria and Sokoto regions of northern Nigeria (1970, 1974, 1977). Norman (1970) found that sole crop stands occupied only 17% of the cultivated area in his survey zone. Findings have been similar for the Filingue and Madarounfa regions of Niger (Swinton et al., 1984) and for three regions of Burkina Faso (Sawadogo and Kaboré, 1984). In northern Nigeria, 156 distinct crop combinations were recorded in farmers' fields, although 40% of the land was under two-crop mixtures such as millet/sorghum, millet/cowpeas, etc. (Norman, 1974). Similar results have been reported for Burkina Faso (Matlon and Bonkian, 1980; McIntire, 1981). In northern Nigeria it was shown that while the returns to individual crops often decrease when grown in mixtures, gross

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and net returns per hectare were higher from crop mixtures (Norman, 1974). Average gross and net returns per acre were respectively 60% and 62% higher from crop mixtures than from sole crops, and returns increased with the number of crops (Norman, 1977). These findings were supported by Abalu and D'Silva (1980) who concluded that growing crops in mixtures is consistent with the goal of income maximization. Moreover, the absolute and relative variation in the gross return per unit of input for mixed crops is lower than for sole crops (Norman, 1977), implying that less risk can be expected from crop mixtures.

The principal reasons given by farmers for intercropping fall into four categories: (1) tradition, (2) the need to maximize the return from the factor which is most limiting (3) the need for security and (4) the beneficial effect of legumes on other crops (Norman, 1977). Abalu (1977) concluded that the farmers of northern Nigeria used intercropping to diversify activities as an insurance against biological and economic risks, a finding supported by results from Niger (Swinton et al., 1984). Matlon (1985) summarized production characteristics of the soil fertility gradient away from the farm dwellings on 185 farms at Nonghin, Burkina Faso. He found that farmers divided this gradient into fertility management rings and that intercropping, as well fallow systems, became increasingly important in maintaining soil fertility as one moved farther from dwellings.

In most cases intercropping increases labour input per unit area, but may reduce the overall labour input per holding as the necessary output is obtained from smaller areas. Norman (1973) found that crop mixtures required, on the average, 62% more labour per acre than sole crops, although this was reduced to 29% in the June-July labour bottleneck. Thus, intercropping leads to a more even distribution of labour throughout the season and moderates labour peaks (see also Swinton et al., 1984). Norman (1977) found that the average gross returns per man-hour were the same for sole and mixed cropping, except during the June-July peak period. The gross return per man-hour was higher for crop mixtures.

McIntire (1983) reported on the interaction of animal traction and intercropping from farmer production surveys in two villages on the Mossi Plateau of central Burkina Faso. It was concluded that mixed cropping is unrelated to technique or farm size, implying that it is scale neutral. This finding suggests that with existing animal traction (ATR) equipment use patterns, ATR neither helps nor hinders current mixtures and that mixed cropping research need not depend on associated ATR techniques.

ON STATION INTERCROPPING RESEARCH

Types of Associations

Cereal/legume. Generally cereal/legume-based cropping systems have the cereal as the major crop with a legume as a secondary crop. Typical examples of this system are the sorghum-based cropping systems in northern Nigeria described by Norman (1973). Sorghum is intercropped with cowpeas, groundnuts, and millet, and with cowpeas and cotton in the sudanian savanna. In the drier northern sudanian savanna and the southern sahelian zones (less than 600 mm), millet becomes the dominant food crop. In these zones millet is intercropped with groundnuts and cowpeas (Stern, 1984; Swinton et al., 1984).

Millet/cowpea or sorghum/cowpea are intercropping systems which have been studied in Niger (IRAT, 1976; Cunard, 1980; Abrams, 1983; Huyez,

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1983; Fussell, 1984; Reddy and Jada Gonda, 1984; Mai Tanimouné, 1984), Nigeria (Andrews, 1972), Burkina Faso (Stoop, 1981; Sawadogo and Kaboré, 1984), Mali (Hulet and Gosseye, 1984; Serafini, 1984). In this system, the millet is planted before or at the same time as the cowpeas and it matures before the late maturing cowpea. In general, the research findings report significant increases in biological yield with this intercrop over the sole crop (up to 51%, see Fussell, 1984). However, under most conditions intercropped cowpea grain yields have been poor (e.g. IITA/SAFGRAD, 1980; Fussell, 1984).

Substantial gains in biological yield and gross return have been demonstrated for maize/cowpea relay cropping in the sudanian savanna of central Burkina Faso (Reneaud and Furst, 1979; IITA/SAFGRAD, 1980; Stoop, 1981; IITA/SAFGRAD, 1983; Muleba and Brockman, 1984) and Mali (Simpara, 1984).

In trials where millet was intercropped with a mungbean genotype and three morphologically different genotypes of cowpea, millet grain yields did not vary significantly, although some yield from each of the legume crops was attained (Sawadogo and Kaboré, 1984).

Experiments on sorghum/groundnut intercropping systems in Chad showed a 25% yield advantage over the sole crop system(s) (Anonymous, 1959). Schilling (1965) reported similar yield gains over sole crops in trials conducted in Senegal between 1960-64.

In the IRAT trials in Niger, millet/groundnut intercropping showed no advantages: land equivalent ratios (LERs) were less than one (1965). In trials conducted later by Cunard (1980) and Huyez (1983) in which other density combinations were used, LERs of greater than one were observed for this cropping system. Trials in Senegal also demonstrated yield advantages, the order of 30% for this system (Schilling, 1965).

Baker (1978) demonstrated that groundnuts grown with either maize, millet, or sorghum were more productive than sole groundnuts. Three-crop mixtures involving groundnuts and any two of these cereals was even more productive. Other three-crop mixtures, sorghum/millet/cowpea and maize/sorghum/cowpeas, have been shown to give higher returns (up to 80%) than sole sorghum in Northern Nigeria (Andrews, 1972). Cunard (1980) also investigated millet/sorghum/cowpea combinations in eastern Niger and observed improved total production from various combinations in comparision with the sole crops.

<u>Cereal/cereal</u>. Sorghum/millet as an intercrop has been researched by a number of groups in the region (Andrews, 1974; Baker, 1974; IRAT, 1976). The general finding is that combining late sorghum (130-160 days) with early millet (70-90 days) is a potentially productive combination, though this combination does not seem to perform as well in the northern areas of SAT West Africa (Baker, 1974 cf. IRAT 1976).

Baker (1979b) studied all paired combinations of maize, sorghum and millet and observed that yields of mixtures were rarely reduced when components differed by a certain margin in height and age at maturity.

<u>Other monocot/dicot</u>. A maize/cotton associated crop in the sudan savanna of central Burkina Faso produced a 59% (LER) advantage in terms of the yield of the relay crop over the sole crop (IITA/SAFGRAD, 1983).

Baker (1979a) intercropped cotton with three cereals, millet, maize,

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and sorghum. Cereal yields were not affected, though cotton yields were drastically reduced.

Agroforestry. Agroforestry incorporates several important intercropping techniques which have been sorely neglected in the development of improved farming systems appropriate for the semi-arid West African farmer. Not only are trees an important source of fuel and food, but they also protect and improve the soil resource base. Integrating trees into the cropping system maintains soil fertility by reducing erosion and cycling nutrients from deep in the soil and depositing them as a part of mulch and roots left at the surface (Stern, 1984). The integration of trees may benefit some crops by reducing evapotranspiration through shading and raising the humidity of the canopy.

The importance of trees to traditional agriculture in the SAT West Africa was highlighted by Charreau and Vidal (1965) in their work on the role of Acacia albida in indigenous cropping systems. Their assertion was later confirmed by the work of Dancette and Poulain (1969). These studies showed a strong fertility gradient away from the trunks of Acacia albida in Senegal. Soil characteristics, including increased nitrogen available phosphorus, exchangeable calcium, and cation exchange capacity (CEC), were improved around the tree. When grown under the trees, groundnuts, sorghum, and millet showed yields up to double the yields obtained 15 m distant. Dancette and Poulain (1969) demonstrated that this effect occurred only when no fertilizer was added. Yields were similar when fertilizer was added to the system. This is an important traditional system that maintains and improves the soil environment. Nonetheless, the findings regarding improved fertility conditions under the tree need to be interpreted with caution, as no account was taken of the fertility and moisture foraging effects of the trees that go beyond the tree canopy (Breman et al., 1984).

Dancette and Poulain (1969) attempted to quantify some of the agroclimatic influences of A. albida on the associated crop. They were unable to show reduced evapotranspiration as a result of shading, possibly due to poor instrumentation. Relative humidity was higher under the tree during the cropping season and the maximum temperature was lower. It is clear that there are some important reasons why Acacia albida holds a prominent place in traditional agriculture in the region (Charreau and Vidal, 1965; Dancette and Poulain, 1969). With intensified agricultural systems that use machinery and animal traction, these researchers proposed that the trees be organized into windbreaks in squares of 100 m on each side.

Bognetteau-Verlinden (1980) has demonstrated a 29% increase in millet grain yields on a total area basis when Neem sp. was used as a windbreak in the Majjia Valley of eastern Niger.

Sources of Advantages with Crop Associations

Spatial/temporal relationships. The component crops in an intercrop need to be complementary in their resource use patterns. If the component crops do not exploit the resource base in exactly the same way there will be more intra-crop competition than inter-crop competition at the same cropping intensity (Willey, 1979a). Willey states that maximizing intercropping advantages involves maximizing the degree of complementarity between the components and minimizing the inter-crop competition. Experience indicates that the greatest advantages in resource use may be achieved by manipulating the spatial and temporal differences between the component crops.

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Spatial differences are differences in height, plant architecture, and density arrangement. Manipulating spatial relationships may reduce competition for light, water, and nutrients. The literature on intercropping in the SAT West Africa provides numerous examples of the advantages partially or largely resulting from spatial complementarity.

Andrews (1974) showed a 27% increase in grain yield when dwarf sorghums were used instead of tall varieties in a millet/sorghum intercrop. This increase was due to both plant architecture and higher dwarf sorghum plant densities.

Variation in the spatial arrangement of cowpeas in a maize/cowpea relay crop was reasoned to be a cause of yield variations in this system (IITA/SAFGRAD, 1983). In Mali, sowing cowpeas in the same hill as millet has been shown to reduce the advantages of the intercrop system, compared to alternate row planting of the two crops (Hulet and Gosseye, 1984, Serafini 1984). In the presence of adequate nitrogen fertility, cowpea densities and yields may be increased without sacrificing cereal yield in the sudannian zone (Serafini, 1984). Other advantages associated with spatial effects will be discussed more fully under management factors.

The most important sources of complementarity occur in intercropping situations where the growth patterns of the component crops differ in time in such a way that the crops make their major demands on resources at different times (Willey, 1979a). Better temporal use of resources occurs when the associated plants have different maturity periods. Many of the advantages that have been shown for specific intercrops in the SAT West Africa can be attributed to this type of complementarity.

In central Burkina Faso, investigations on maize/cowpea relay cropping indicated that temporal aspects were important yield determinants in this system. The delay in planting cowpea after maize had an important impact on cowpea yields in that it affected the duration of the overlap between the two crops and the length of the growing period available to the cowpea. In this system, the use of late varieties of cowpea was important in achieving a yield advantage. Erect, early types performed poorly compared to the late types (IITA/SAFGRAD, 1980 and 1983).

Early maize maximized the temporal complementarity in a maize/cotton associated crop, contributing to a 59% advantage for the relay crop system (IITA/SAFGRAD, 1983). As opposed to an early sorghum, a late millet provided a more productive association with maize in the Sikasso region of Mali (Serafini, 1984).

Serafini (1984) demonstrated that early harvesting of cowpeas for hay created important intercrop advantages (over 100%) in cereal/legume mixtures.

Baker (1979a) reported that sorghum suppressed the growth of cotton more than millet or maize because of its longer growing season in experiments in northern Nigeria.

In practice, it is not always easy to separate spatial and temporal effects. Where varieties differ in both plant height and maturity, or where the legume matures later than the cereal yet has a deeper rooting system, both types of complementarity come into play. For example, using millet, maize, and sorghum mixtures, Baker (1980) demonstrated that differences in both height and maturity accounted for the major part of the yield benefit resulting from the associatio .

Resource use: Light. In intercropping, where dominant plants are associated with dominated plants, the aim is to reduce competition for light without reducing light interception (Stern, 1984). Light use efficiency may be improved through the use of relay cropping, planting of dominant crops in double rows, increasing leaf inclination, and use of multi-storey intercropping systems.

Improved light use efficiency has been demonstrated in many of the intercrop systems researched in SAT West Africa, although, in general, it has not been quantified. For example, the success of the late, rampant types of cowpeas (compared to the erect, early types) in the maize/cowpea relay crop indicates more efficient use of light (IITA/SAFGRAD, 1980). In a maize/cotton crops minimised light competitition from an early, short maize. genotype with poor leaf area development contributed to important intercropping advantages (IITA/SAFGRAD, 1983).

Fussell (1984) quantified improved light interception (up to 10% throughout the season in a millet/cowpea intercrop compared to pure stands of the component crops.

Moisture. Competition for soil resources begins early in the growth period of an intercrop because of the preferential development of roots over shoots at this stage. It has been clearly demonstrated in certain regions (Willey, 1979a,b; Stern, 1984) that intercrop systems make more efficient use of soil moisture, resulting in some of the observed intercrop advantages. This effect has been quantified in only a few instances in the SAT West Africa, however.

Muleba and Brockman (1984) showed that moisture availability in the month of September is a critical determinant of cowpea yields in maize/cowpea relay crops in the sudannian savanna. Maize yields were not affected by the cowpea relay crop if the cowpeas were planted one month after the maize. This system demonstrates an important temporal relationship in which moisture use efficiency is improved through use of late season moisture.

Half of the yield advantage indicated by improved LER's was attributed to measured higher interception of radiation and increased moisture use by the millet/cowpea intercrop over the sole crops (Fussell, 1984).

Fertilizer. Research from other regions has demonstrated that intercropping systems make better use of soil resources, resulting in increases in the uptake of the nutrients, N,P, and K (Willey, 1979a, b; Stern, 1984). This has been attributed to non-interference of component crop root systems and exploitation of different soil layers. Hulet and Gosseye (1984) noted a synergistic effect at higher proportions of cowpea in the millet/cowpea intercrop in the presence of added phosphate.

When groundnuts were intercropped with either sorghum or millet in Senegal, it was found that intercropped cereals made better use of fertilizers than sole cereals (Schilling, 1965). The uptake of both N and P in the cereals was increased when measured by foliar analysis.

Nitrogen fixation. Although the importance of symbiotically fixed nitrogen in achieving yield gains has been demonstrated in other parts of the world (Willey, 1979a,b; Stern, 1984), little empirical proof is available from the research in SAT West Africa. Serafini (1984) demonstrated substantial yield advantages (> 100%) when the legume was harvested early. In some cases, this lead to higher cereal yields in the intercropped plots than in the sole

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plots. It was hypothesized that this was due to nitrogen that had been fixed by the legume and then released for uptake by the cereal with the decomposition of residues left after the legume was harvested.

Higher yield advantages of intercrops under low fertility conditions compared to high fertility conditions are probably associated with a "nitrogen-saving effect" (Stern, 1984). It is argued that, in a replacement cereal/legume mixture, a sub-optimal cereal density should be able to take up more mineral nitrogen per plant than the optimal density sole crop. The potential importance of "nitrogen-saving" is demonstrated in the 1976 intercropping trials report for Niger (IRAT). In this presentation, millet/cowpea and millet/groundnut showed little improvement in the intercropping advantage with added fertilizer (N and P), although the sorghum/millet system was much improved over the sole crop systems with added fertilizer. It may be possible to explain this occurence, at least in part, by the improved uptake of N per plant by the cereal in the low fertility cereal/legume mixture. This is possibly a partial explanation of the improved uptake of N in the cereal for other cereal/legume mixtures (Schilling, 1965).

In contrast, in central Mali Serafini (1984) demonstrated that cereal grain yields can fall in the absence of adequate nitrogen fertility for the cereal (millet or sorghum) where cowpea competition is favored by planting the cowpea at the same time as the cereal, at high cowpea density or late harvest of the cowpea. Similarly, Stoop (1981) showed reduced cereal yields in low fertility situations with modest intensification of the cowpea intercrop culture. Both hypothesized that the cowpea was an aggressive and efficient N forager early in the season.

Management factors. Interactions in intercropping systems are considerably influenced by the plant population and spatial arrangement. It has been noted that the total optimum population of intercrops may be higher than that of either of the sole crops. Indeed, higher total populations are likely to give yield advantages (Willey 1979b). Willey concludes that the optimum total plant density can be increased in intercropping systems in which the interference between neighbouring plants is less than in the sole crop, i.e., where intercrop competition is less than intracrop competition. This phenomena has been demonstrated in intercrops of sorghum/millet/cowpea (Andrews, 1972; Cunard, 1980), maize/sorghum (Baker, 1980), sorghum/cowpea (Baker, 1980; Serafini, 1984), maize/cowpea (Baker, 1980; IITA/SAFGRAD 1980, 1983), millet with either cowpeas or groundnuts (Abrams, 1983; Fussell, 1984; Serafini, 1984; Swinton et. al., 1984; and cotton with either millet, maize or sorghum (Baker, 1980). In summarizing the findings of Huyez (1983) for millet/cowpea and millet/groundnuts in Niger, Swinton et al., (1984) concluded it was necessary to have a population pressure at least comparable to, if not higher than the sole crops. In support of this argument, Serafini (1984) found that when cowpeas were intercropped in millet or sorghum in the presence of adequate N fertility, the cereal grain yield was usually not adversely affected by high cowpea densities (up to 50,000 plants/ha) if the legume was planted after the cereal or harvested as hay before the cereal flowered. With these systems, LERs over 2 were obtained.

Baker (1979b) concluded that in cereal/cereal mixtures (replacement mixtures), yield advantage was associated with reduced competition during the reproductive stage as a result of a reduction in the number of plants flowering at any given time. Yield gains come from larger plants, though

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the harvest index was the same. In the Sikasso region of Mali the intercropping advantages of long season millet planted late into maize were clearly of this type (Serafini, 1984). In superimposed mixtures of cereals and non-cereals, yield gain is associated with absence of competition at the reproductive stage. Moreover, the harvest index of the cereals remains the same, though the noncereal harvest index increases. Long season cowpeas planted late into maize presents advantages of this type (IITA/SAFGRAD, 1980 and 1983).

Important advantages can accrue from intercropping situations where the spatial arrangement of the crops are manipulated. Stoop (1981) reported from trials at Kamboinse that millet performed best when intercropped in paired rows rather than alternate rows. Groundnuts performed best when planted in alternate rows. Similarly, in central Burkina Faso, improved yields (100%) were obtained in maize/cowpea and sorghum/cowpea mixtures by modifying the spatial arrangement and density of the component crops, while maintaining (Reneaud and Furst, 1979) or increasing (IRAT, 1978) overall density pressure.

Stoop (1981) reported interactions between crop combinations and soil type in central Burkina Faso. For the shallow, gravelly, sandy loams on the plateau and upper slopes, millet interplanted with early cowpea and groundnuts gave better total yields. On intermediate to deep sandy loams situated centrally on the slopes, millet or early sorghum interplanted with early cowpea were more likely to perform well. In the deep sandy loams of the 'bas fonds', late sorghum interplanted with either late cowpea or early maize gave the best relative yields. Thus, the choice of the dominant cereal (millet or sorghum) depends upon the nature of the soil as well as the expected rainfall (Stoop et al., 1982). Accordingly, the choice of the best crop mixture depends on the nature of the soil as well as the agroclimatic context.

Serafini (1984) was able to show that the relative time of planting of the two intercrops, their spatial arrangement, and the time of removal of the competitive effect of the legume was critical in determining the yield gain and its source in cereal/legume intercropping systems in central Mali. Planting cowpeas at the same time, or in the same hill, reduced the contribution of the cereal and enhanced the yield of the legume. Early harvest of the legume resulted in maximum hay yields of the legume with little or no reduction of the cereal yield.

Stability and flexibility. Yield stability has been proposed as a major advantage of intercropping systems (Willey, 1979a,b; Stern, 1984). This occurrence is explained by the ability of one crop to compensate for the poor performance of the other. When one component crop suffers from stress (e.g., drought, disease, insect attack), the loss in vigour is compensated for by the other crop(s). For an extensive review on insects and their effects on intercropping and on yield stability, one should refer to the excellent review by van Huis (1984).

Baker (1980) attempted to demonstrate yield stability of the intercrop system using Finlay + Wilkinson's (1963) method of stability analysis. He found that there was no difference between the stability of the intercrop (groundnut/cereals) over the sole crops for northern Nigeria. Using probabilities of failure based on a 'disaster' level of income, these intercropping systems were found to be more stable. In the presence of a severe streak virus attack on maize in southern Mali, millet/maize inter-

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crops gave higher grain yields than pure stand maize (Serafini, 1984), thus demonstrating the better stability of the intercrop.

Most research results show a higher gross revenue with intercropping (Andrews, 1972; Andrews 1974; Baker, 1978; Reneaud and Furst, 1979; Baker, 1980; Cunard, 1980; Fussell, 1984). An exception was reported where cereals (millet, maize, sorghum) were intercropped with cotton (Baker, 1979a). The cereals drastically reduced the higher-value cotton yield in the intercrop, lowering gross revenue, when compared to sole cotton, but not sole cereal. Significantly, cereal grain yields were not affected by the cotton intercrop. In as much as the subsistence farmer may be largely concerned with a stable supply of food grain, such crop mixtures may meet his objectives.

INTERCROPPING RESEARCH IN THE FARM ENVIRONMENT

Historical perspectives. It is best to begin our discussion with an examination of the historical development of intercropping research in SAT West Africa. Baker (1981) points out that while intercropping research is for the most part, a recent phenomenon, experiments on this subject began many years ago in Nigeria. He reports that between 1924 to 1960, scientists at the Institute of Agriculture Research carried out over 300 experiments on crop mixtures. Intercropping reviews do not (see Willey, 1979a,b; Stern, 1984) refer to this work and as a result, the findings of these experiments have contributed little to the present state of knowledge on the subject.

Interest in intercropping systems was renewed in the sixties. Norman's on-farm socio-economic studies were particularly important in bringing about this change in perspective (1970, 1973, 1974, 1977). Nonetheless, interest has generally been intermittent or very recent. The ongoing program in northern Nigeria at Samaru is the only important exception. Since the mid-sixties, a sustained and coordinated research effort there has led to on-farm testing of improved intercropping packages (Bbuyemusoke, 1974). Findings from this work will be presented in this workshop.

In examining intercropping research elsewhere, there are few reports from Chad and Senegal. There is an agroclimatologist and an Agronomist working on millet/cowpea intercropping systems in Senegal at the present time. In Mali, intercropping research appears to be largely confined to the last six years (Simpara, 1984), while in Burkina Faso the work encompasses a slightly longer period of time (Sawadogo and Kaboré, 1984). In Niger, research on intercropping has been intermittent. Several studies were undertaken in the mid-and late 1960s, followed by renewed but short-lived interest in the late 1970s, interest revived again in 1982 and continues today (Swinton, et. al., 1984). There has been little continuous study of any one cropping system. The result is limited knowledge about numerous cropping systems (see previous section).

Given this historical context of poorly coordinated research, it is not surprising that there has been little on-farm testing of intercropping research findings.

Extent of on-farm research. As a logical outgrowth of its relatively extensive research program on mixed cropping, the Institute for Agriculture Research (IAR) at Samaru, Nigeria, began an on-farm testing program of improved mixed cropping packages in 1983 (Bbuyemusoke, 1984). Although the effects of single component additions (fertilizer, varieties, etc) to the existing mixed cropping system had been tested in on-farm trials by develop-

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ment programs (IADP, 1982; KNARDA, 1983; KNARDA, 1984: all cited by Bbuyemusoke, 1984), the IAR effort was the first to study the feasibility of production packages for mixed cropping systems.

The first package IAR tested in farmer run trials involved a maize cotton mixture (Bbuyemusoke, 1984). In the Samaru-Zaria area where the package was tested, cotton is a cash crop and maize is both a cash and food crop. The package recommended that the two crops to be planted at the same time, in the same row, at high densities, with a basal fertilizer dose of 46 kg/ha N and 45 kg/ha P_2O_5, and a sidedressing of 46 kg/ha of nitrogen. The 28 farmers who participated in the test were supplied with all inputs, including herbicide and insecticide for adequate weed and pest control. The results from the test reflect the problems associated with running on-farm experiments with any improved package herbicide, and are not inconsistent with findings from this kind of experimental work elsewhere. For example, few, or no, farmers applied the herbicide or insecticide. Nonetheless, the majority (83%) of the farmers were satisfied with the yield from the intercrop, although yields of both crops were lower on the average than in similar studies on the research station. Partial budget analysis indicated that the package was profitable on the average. Although there were important adoption problems for the complete package, these findings largely conformed with research station results. These problems are typical of those encountered with improved sole crop packages as well.

In central Burkina Faso, ICRISAT has reported two types of on-farm intercropping research: researcher - managed and farmer - managed (Matlon, 1984). There were two researcher-managed trials. In the first, an unreplicated intercropping trial was executed in four villages in a relatively high rainfall zone (950 mm). Results from two of the four villages showed that net returns to labour increased by an average of more than 60% as cowpea density increased above traditional levels in a sorghum/cowpea intercrop. This improvement was greater with the local sorghum than the improved sorghum because its denser canopy inhibited cowpea development. Nonetheless, the improved sorghum yielded higher than the local variety. Although these results were consistent with on-station findings, farmers were dissatisfied with the higher cowpea densities. Some of the reasons offered were (a) lowered sorghum yields, and (b) increased labour demands. Farmers felt that the existing system with its low cowpea densities sufficiently met their production objectives given their available labor.

The second researcher-managed on-farm trial was similar to the sorghum/cowpea experiment discussed above. It was also executed in the higher rainfall zone. It investigated the feasibility of increasing the sorghum density in the traditional sorghum/groundnut intercrop. Improved returns, resulted from increasing the density of sorghum above that normally practiced. The increased sorghum density reduced groundnut production, however, and farmers attached more importance to the latter crop. Thus farmers felt that the mixture needed to be accompanied by a modified planting pattern that would reduce space and light competition from the sorghum and increase the groundnut yield component. Early maturing, erect-leafed varieties and improved planting patterns are now under investigation by the ICRISAT program.

The same intensification methods and villages were used in the farmer managed sorghum/cowpea experiments (Matlon, 1984). Two cowpea intercrop densities (3000 & 15000 plants/ha) were constrasted using the local sorghum and cowpea variety at two fertility levels (0 added fertility and 100 kg

14: 23: 15 plus 50 kg urea/ha). Farmers did not appear to view changes in cowpea densities as a new technology needing testing. Therefore, they did not respect the recommended cowpea densities, resulting in a wide range of densities. Results indicated that there was an overall increase in the labour requirements for planting and weeding, (the peak labor period demand) of more than 40% overall, with a shift from sole sorghum to a sorghum/cowpea intercrop with 5,000 to 10,999 cowpea plants/ha. Planting labour increased by 20% when the two species were seeded in separate hills rather than together. A profit function linking returns to labour and cowpea plant stand indicated important differences in the optimal cowpea density between agroclimatic zones. Optimum cowpea densities were lower in the lower rainfall zones. Optimal densities were relatively stable across fertility treatments. The study concluded that optimal densities for the spreading cowpea type intercropped with sorghum are probably lower than research station results would suggest, and that they do not differ greatly from current practice. The use of erect cowpea varieties sown in the same pocket as the sorghum was suggested as a promising avenue for research, since this practice would reduce the labour demand at planting and weeding.

Contrast between on-farm and on-station results. In reviewing the on-farm research results presented above, it is indeed unfortunate that more research of this kind has not been conducted. It is clear, nonetheless, that the behavior of the experimental material, the pertinent data which may be collected, and the interpretations that are possible, all vary greatly, depending upon the experimental methodology (researcher-managed on-station, researcher-managed on-farm, or farmer managed). In the example above, the farmers, when presented with the experimental objectives and materials, chose to apply different treatment levels. The information gained by observing the work demands created by the new cropping pattern also provided a perspective which would have been unattainable on the station or in researcher-managed experimentation. The resulting understanding of the validity of the production technology would not have been possible in another experimental context. One must conclude that there is a risk that experimental results when obtained in the absence of feedback on treatment effect in farmers fields, will be irrelevant when transferred to that environment. All three types of experimentation are necessary and need to be conducted simultaneously for the behavior of the experimental material to be adequately understood.

IMPORTANT RESEARCH NEEDS RELATED TO CROP ASSOCIATIONS IN SAT WEST AFRICA

This review has highlighted research areas which have been important in understanding intercropping systems. In a number of these areas, a more intensive research effort is required:

Genotype adaptation. Crop varieties used in traditional cropping systems are a result of years of natural selection. Moreover, attempts to increase the productivity of traditional cropping systems by introducing improved varieties have not always met with success (Stoop, 1981). In general, there is no correlation between the performance of cultivars in sole and intercropping system (Stern, 1984). However, in some cases, the best sole crop cultivars are also best for intercropping, e.g. sorghum, Baker (1974). This was not the finding for cowpeas (IITA/SAFGRAD, 1980), and it is the reason why some national and regional programs in West Africa are selecting for cultivar suitability to intercropping. Moreover, when choosing any crop com-

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bination, specific varietal characteristics need to be defined (e.g., plant morphology, photoperiod sensitivity, appropriate maturity periods, plant density responsiveness, etc.). Stoop (1981) demonstrated compatibility or incompatibility of improved genotypes of millet and sorghum in intercropping based on tillering capacity, maturity periods, and density responsiveness. Such compatibility requirements have been incorporated into the breeding programs of cowpeas (IITA/SAFGRAD, 1980) and sorghum (Stoop et al., 1981), for example.

Soil fertility management. If one assumes that crop associations increase nutrient uptake, it follows that either soil fertility will be depleted more rapidly, or what has been removed will have to be replaced. It is also possible that if there is a change in harvest index, it will result in more N, P, K in the economic parts, while the total uptake will not have changed. Baker (1979b) did not show a better harvest index with cereal/cereal intercrops, although this was the case in cereal/legume intercrops. In either case, the increased nutrient take off would have to be replaced if production were to remain stable.

Given the effects of competition for nutrients discussed previously, fertilizer placement would appear to be one of the management tools which could be used to manipulate these relationships. Effects on plant development, in time and the resource use effeciency of the component species could make this a powerful tool.

Maximize spatial and temporal advantage. A long growing period is the precondition for mixing crops of different maturity periods. The growing period is defined as the period when both water and temperature permit crop growth. The growing period is longer than the rainy season, owing to residual soil moisture (FAO, 1978). Stern (1984) asserts that yield advantages can no longer be obtained in areas with a growing period of less than 120 days. Nonetheless in these climates (northern sudanian savanna and sahel), intercropping systems of less intense, short-duration crops are predominant and likely to remain so.

Emphasis should also be placed on effective season length, which takes into account not only rainfall, but also soil type. Stoop (1981) emphasized this concept in most of his work in Burkina Faso. He researched different crop combinations for different positions on the to posequence, and saw the possibility of two major cropping systems in SAT West Africa:

System 1. For conditions which allow cropping for ≥120 days--i.e., in the zone of 700 mm rainfall or more, or in drier regions further north where there are deep soils near the bas fonds. This system allows the combination of full-season crops (e.g., photoperiod sensitive sorghums) with early maturing intercrops (e.g., millet, maize, nonphotoperiod sensitive cowpeas). These systems, as indicated in the review, are known to give large yield advantages.

System 2. For conditions which allow cropping for ≤ 120 days--i.e., the northern zone of 450 to 650 mm rainfall or the adjacent higher rainfall, shallower-soil zones further south. This season is generally too short to combine two crops with different maturity cycles. Therefore, intercropping advantages should be realized by means of crop combinations able to exploit the environment (soil, nutrients, light, and moisture) more effectively in each others' presence than could be achieved in sole stands. Because there are no temporal advantages to be exploited, yield gains from intercropping are expected to be somewhat less than in the first system.

The presence or absence of yield gains reported in this zone where crops of different cycle lengths were combined is probably due to the short season and variation in seasonal rainfall.

Nevertheless, the authors feel that manipulation of temporal relationships between the crops is possible in the lower rainfall zones. For instance, one can employ management techniques such as harvesting one or part of the crop early for biomass yield, thus reducing the plant density and hence competition. Converting biomass into meat is often a profitable enterprise. The association of short duration ($<$90 days) and longer season ($>$ 110 days) cereals, as either an inter-or intra-specific association, is also a technique that could contribute to cropping efficiency and stability.

The importance of symbiotically fixed nitrogen. The importance of symbiotically fixed nitrogen in intercrop systems has received the attention of researchers in many parts of the world (see reviews by Willey (1979a,b and Stern (1984). In SAT West Africa, however, it has been alluded to (Cunard, 1980; Stoop and van Staveren, 1982), though, for the most part, not pursued. As the price of commercial fertilizer increases and the length and possibility of the fallow period decreases, the possible benefits of symbiotically fixed nitrogen become more important to the smallholder farmer of the region (Matlon, 1985). While there is no direct evidence of a quantitatively significant transfer of nitrogen from legumes to non-legumes during the life cycle of the legume, non-legume crops profit from residual nitrogen from short duration associated legumes or legumes harvested before the flowering period of the cereal (see cereal/cowpea intercrop, Serafini, 1984).

While there have been some attempts (Stoop and Van Staveren, 1981) to look at the residual effect of intercrops on succeeding crops, this area of research has not received the attention it deserves. One would assume that an intensified legume intercrop would leave more residual N than that left by presently practiced techniques.

Maximize resource use. The objectives of intercropping research-the quest of "complementarity" between crops, the more efficient use of limited resources, light, water, nutrients, time, and labor-make a movement towards "maximum resource use" implicit in the endeavor. At the same time, maintaining cropping systems which have resulted in increased resource use effeciency elsewhere has required more sophisticated and expensive cropping strategies over time.

Stability of yield. In an uncertain cropping environment, "hedging" is a basic tool of farmers everywhere. While the results discussed previously are not conclusive, it is clear that improved intercropping strategies lead to "yield stability" to the degree that they can avoid, minimize, or compensate for risk. Once again, the nature of the objectives in intercropping research make this a probable outcome of the exercise, and there is a real need to quantify this effect.

Agroforestry. When one looks at the traditional SAT West Africa cropping systems, one discovers that trees and shrubs, which are significant contributors to the productivity of the system, are omnipresent. Even casual observation of such associations reveals the presence of many of the characteristics of intercropping systems which lead to improved resource use and increased efficiency of the overall system. While *Acacia albida* is not the only example, it is the most widely researched and is, in many ways, a clas-

.../...

sic case. It becomes vegetatively active only at the end of the normal cereal crop cycle and then grows into the dry season greatly increasing the growing period while minimizing intracrop competition. It has a strong tap root system which allows it to exploit moisture and fertility normally unavailable to annual crops. It produces nitrogen and, with the other minerals and organic matter it deposits on or near the surface, has a profoundly beneficial effect on the cropping environment. It provides complementary yield products, fodder and fuel. It also acts as a windbreak, increasing turbulence and reducing wind speeds and resulting soil movement which may be critical to the survival of the crop in the seedling stage.

Long periods of time are necessary to grow trees and systematically study their impact. As a result, precious little research has been done in this subject area. The authors feel that while it is an inherently difficult experimental subject to deal with, it has the potential of making important contributions to the overall productivity and stability of the cropping systems in this zone.

Technical and socio-economic constraints. Not all traditional intercropping systems are going to be readily amenable to intensification. For example, Brockman (IITA/SAFGRAD, 1980) concluded that, without cowpea insect resistance, there is little point in investing scarce research resources on cowpeas as an intercrop for grain production similarly, Baker (1979a) demonstrated that cotton, if sown later than three weeks after the cereals, was suppressed to the extent that the costs of insect control was not recovered.

From the socio-economic viewpoint, labor is often the limiting factor in the farm environment, and cropping strategies which do not address this constraint are often counterproductive at the farm level. Elsewhere there have been significant interactions between mechanization and other improved practices. This is likely to be the case with intercropping as well.

CONCLUSION

The widespread use of intercropping by farmers in SAT West Africa supports the assertion that it is an appropriate technology. This review has indicated that there are no technical reasons why intercropping systems should not continue to play an important role in food production under intensified agriculture. This does not mean that all intercropping systems have been shown to be better than sole crop systems. The research results do demonstrate, however, that there are important yield and socio-economic advantages to some intercropping systems used in SAT West Africa. In SAT West Africa the lack of continuity in, and the newness of, intercropping as a research area has limited its progress and applicability. With the renewed interest in the subject, it is hoped that continuity, and the exchange of research findings through networking, will overcome these shortcomings.

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IMPROVED MIXED MAIZE-COTTON PRODUCTION TECHNOLOGY FOR THE SMALL-SCALE FARMER IN THE NORTHERN GUINEA SAVANNA ZONE OF NIGERIA

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Mixed cropping, the set of cropping patterns whereby more than one crop is simultaneously grown on the same land, is very widely practiced in northern Nigeria. In the Zaria area of Kaduna State, Norman (1974b) identified 156 different crop mixtures; In this study, sole crops were reported to have taken up only 16.6 percent of the cultivated land acreage. On the other hand, two-crop mixtures took up 42.1 percent of cultivated land acreage, three-crop mixtures 23.7 percent four-crop mixtures 12.1 percent and five-and six-crop mixtures 5.5 percent.

Despite the overwhelming popularity of mixed cropping it has attracted relatively little coordinated research. It has been suggested that this may be due to the persistent psychological notion that serious or "progressive" scientific research would not concern itself with a practice that is so closely linked to subsistence agriculture (Norman, 1974b). Toward the 1970s, researchers at the Institute for Agricultural Research (IAR), Samaru, began systematic, if not intense, work on the mixed cropping in northern Nigeria. A brief review of this effort is provided below.

The development of mixed cropping research to date at the IAR, Samaru may be viewed in terms of four distinct, if sometimes overlapping, phases. The first phase in the late 1960s was spearheaded by Norman (1967, 1968, 1970). It concentrated on the establishment of the importance of mixed cropping in northern Nigeria and the need for researchers and policy makers to be aware of its importance in designing their work and implementing their policies. The second phase, from the late 1960s through the early 1970s, consisted of a series of experiments and farm level surveys aimed at rationalizing the practice. Its importance had been established in the first phase; the central question of the second phase was thus why and how farmers make sense out of mixed cropping. Five reasons were advanced to explain the continued and probably growing, importance of mixed cropping:

(1) Mixed cropping allows for the more efficient utilization of such environmental factors as moisture, nutrients, and light; it takes advantage of the symbiotic relationship between the nitrogen-fixing and other plants; and long-stalk grains like maize and sorghum can support the creepers, (Andrews and Hassan, 1975; Norman, 1974b).

(2) Mixed cropping reduces adverse conditions, like the intensity of diseases and pests, in the ecosystem (Caswell and Raheja, 1972; Hayward, 1975; Norman, 1974b).

(3) Mixed cropping prevents soil erosion (Norman, 1974b).

(4) Mixed cropping provides higher yields and returns. (Baker, 1974; Kassam and Stockinger, 1973).

(5) Mixed cropping reduces the risk of crop failure associated with sole cropping (Baker, 1974; Caswell and Raheja, 1972; Hayward, 1975; Norman, 1974a).

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The third phase of the work on mixed cropping, at Samaru began in the mid-1970s and continues today. This phase consists of the design and execution of experimental work aimed at the development of mixed cropping packages that are suitable for the Institute's ecological zones. Andrews, 1974, 1975; Baker, 1974; Caswell and Raheja, 1972; Hayward, 1975; Kumar and Ogunlela, 1984; and Fisher, 1984a, 1984b; have been instrumental in this effort. In addition to the experimental work at Samaru, many of the packages developed have been tried and evaluated at State Experiment sites in various locations.

The fourth and latest phase of mixed croppings research at IAR has only just begun. This phase involves the on-farm testing and verification of the technology packages designed in phase three, in order to remove constraints and increase agricultural production in an area. Using information from village studies, the yields and improvement prospects of crop mixtures developed at Samaru, and the evaluation studies of the State Agricultural Development Projects (ADPs), the Farming Systems Research Program (FSRP) at IAR has set up a list of priority mixtures for experimental study and on-farm testing. Maize-cotton was the first mixture selected for on-farm testing in 1983.

Although on-farm testing by IAR of a mixed cropping technology package first occurred in 1983, some of the State ADPs had tested mixed crop packages somewhat earlier. By 1982, both the Ilorin Agricultural Development Project (IADP) and the Kano Agricultural and Rural Development Authority (KNARDA) were carrying out their own on-farm trials on crop mixtures (Ilorin, 1983; Kano, 1983, 1984). The IADP trials tested single components (e.g., fertilizers, varieties, weed management, and pest management) in the existing, largely mixed, cropping pattern. This approach constrasts somewhat with the IAR and KNARDA approaches which take the form of feasibility studies of whole production packages for given crop mixtures. At the IAR-sponsored workshop on on-farm adaptive research in Samaru in April 1984, these two strategies were noted. It was suggested that both were useful and that the circumstances under which each is most appropriate needs to be defined (Farming-Systems Research Program, 1984).

It has been recognized only in the past decade or so that maize production is ideally suited to the physical environment of the Guinea savanna zone of Nigeria (Baker, 1975; NAS, 1974; Norman, 1976). Experimentally, maize has yielded several times more grain per hectare than improved sorghum and millet (Baker, 1975). Thus the greatest potential for maize production in Nigeria lies in the Guinea savanna zones rather than in the traditional maize growing areas further south, including those areas that are capable of supporting two crops of maize in a year.

Little or no inorganic fertilizer is used in the production of cereal crops under indigenous conditions in the savanna areas. To obtain any worthwhile maize yield, however the application of fertilizer is required (Baker, 1975). Thus the enormous potential for maize production can only be realized with high levels of fertilizer inputs.

On-farm, maize is riding a crest of popularity as both a cash and food crop, despite its relatively recent appearance and the fact that it requires more inputs than the area's traditional cereal crops.

In contrast to maize, cotton is believed to have been grown in northern Nigeria for hundreds of years. The savanna zones produce about

95 per cent of Nigeria's output. Cotton growing is a declining activity in the area, however, mainly because of unfavorable farm prices and competition from imports.

Both crops are grown primarily by small-scale farmers who average about a half-hectare of cotton and one hectare of maize, though there are several large-scale, mechanized growers of maize.

The relative newness of maize offers both extension and research people a unique and early opportunity to influence the maize production technology that will eventually dominate the area. Moreover, since cotton seems to be declining, its combination with the highly popular maize could be a way to stem this decline. The farmers themselves seem to be aware of this possibility. A survey of 79 farmers in Mairuwa showed that in 1983, close to 15 per cent of the total land devoted to maize in the area involved the maize-cotton mixture.

Recommendations for maize-cotton mixed production have been tested on-station for several years, but their value under practical farming conditions has not been assessed. The objective of this study was to evaluate the maize-cotton technology at Mairuwa (just northeast of Funtua) with a view to ascertain its technical and economic feasibility.

METHODOLOGY

The project was undertaken at Mairuwa in the northern Guinea savanna zone by the staff of the Farming Systems Research Program of IAR. The proposed three-year project began in 1983. Twenty-eight farmers were provided with TZB maize seed, dressed S77 variety cotton seed, BSP and CAN fertilizers, Aldrex T seed dressing, Lasso 480 EC herbicide, and Cymbush insecticide. About 10 sprayers were also made available on a first-come-first-served basis. Project staff provided extension advice. The two enumerators stationed in the village were acquainted with and given copies of the package to enable them to advise the farmers in addition to monitoring their activities. Daily input-output data on all fields were collected by enumerators, and a post-harvest questionnaire was administered to the farmers to determine the general level of satisfaction with the package.

The selection of farmers was based on expressed interest on the part of individual farmers rather than on a simple random sample. It is likely that some farmers expressed interest in the project to gain access to inputs that are generally in short supply on the open market, thus making the urge to gain access to the technology itself secondary. However, the individual differences in attitude and performance appears to indicate that no serious bias resulted. Farmers were encouraged to follow suggestions made in the package, although changes made by farmers to suit their particular requirements and environment were not discouraged. Thus, the results can be considered to be fairly typical of a situation in which extension services are available and the supply of inputs assured.

The overwhelming majority of farmers in the study area used ox-drawn equipment for certain farm operations, unlike the typical farmer who relies solely on manpower.

The following mixed cotton/maize production package was compiled and communicated to the farmers:

Crop varieties. Any recommended maize variety is acceptable, but TZB is favored because of its whiteness and grain quality. Currently supplied cotton varieties are acceptable.
Sowing date. For best results, both cotton and maize should be planted at the same time and not later than June 15. Sowing on the morning after a heavy rain ensures good establishment. Cotton yields will be poor if cotton is planted more than 14 days after maize.
Seed dressing. Thoroughly mix Aldrex T or Fernasan D with the maize seed (one packet to three mudus of seed). Normally the cotton seed provided is already dressed.
Spacing and arrangement. Highest yields of maize and reasonable yields of cotton are obtained with high plant densities, and with the two crops mixed on the same ridge. Plant four maize seeds at 44 cm spacing and five to six cotton seeds midway between the maize stands. Thin both to two plants per stand at 10 cm tall.

Alternate ridges give slightly lower maize yields but are easier to weed and spray. It is also better suited to tractor and bull ridging. If this system is preferred, sow alternate ridges with maize stands at 20 cm spacing and thin to one plant (or 40 cm with two plants).
Fertilizer. On a hectare, apply 250 kg of boronated superphosphate (BSP) plus 200 kg of CAN or 100 kg of urea. Make basal application at or just before sowing. Fertilizer can be spread along the old furrows or on harrowed land before splitting the ridges, or it can be buried in a band on one side of the new ridge away from direct contact with the seed. If reluctant to apply before sowing, apply the basal dressing in a small hole about 10 cm from stand, or buried in a band to one side of the ridge, very soon after the crops emerge.

Compound fertilizer is less suitable, but if BSP is not available, use 200 kg/ha of 20:20:20 or 300 kg/ha of 15:15:15. A side dressing of 200 kg/ha of CAN or 100 kg/ha of urea should be applied five weeks after sowing. In mixed row systems it may be buried in holes about 10 cm from each stand or in a band along the side of the ridge. In the alternate ridge system, apply about two-thirds of the side dressing to maize and the rest to cotton in the manner just decribed.
Weed control. Farmers with tractors or bulls can remould ridges up to the time the maize becomes too tall. Hand weeding should take place soon after the crop emerges. A second weeding is usually necessary after three to four weeks, and the cotton should be weeded soon after maize harvest.

In the early season, herbicides may substitute for hoe-weeding. Crops should be sown immediately after land preparation in a weed-free ridge, and the herbicide applied not more than two days after sowing. If herbicides are to be used, best results are obtained if both crops are planted at the same time. If not, apply herbicide before germination of the first crop, with a Knapsack Sprayer, apply 4 1/ha "Lasso 480 EC" (2 kg Alachlor) or 3 1/ha of "Dual 500 EC" (1 1/2 kg Metolachlor) in about 200 1/ha of water, preferably using a CP3 sprayer. Very low volume application with the "Herbisprayer" applicator is also acceptable. For this, use about 12 1/ha of water, Hand-weed once when weeds have developed, and remould ridges at the same time.
Insecticide. Insecticide spraying is benefical for cotton that is sown before the end of June, well fertilized, and in good stands. Late-sown and weed-infested cotton makes insecticide spraying uneconomical. The synthetic pyrethroids (Cymbush, Ambush, Decis) are cheaper than the older insecticides (Audugatox, Vetox 85, etc), since the farmer needs only three

applications of the former, as opposed to six applications of the latter. Harvesting. Harvest maize as fresh cobs or dry grain and cut the straw down immediately to reduce shading of cotton and to facilitate spraying. Cotton should be harvested as the bolls split.

Analysis. The main concern was to assess the costs and returns to the individual farmer of this technology package. Consequently, each farmer's field was given equal weight by expressing all variables in per hectare terms prior to analysis. Some rounding inaccuracies resulted from this procedure and from the conversion from imperial units (in which some of the output date were collected): to metric units.

Two farmers who planted separate maize and cotton fields and one farmer who planted only maize are left out of the aggregate analyses altogether. Of the 25 remaining fields, only two were sparayed with a pre-emergence herbicide. In drawing up the partial budgets for participants, the two above farmers were separated from the 23 who used no herbicide. Although comparisons are made between these two groups of farmers, much caution is advised due to the very large discrepancy in sample size.

RESULTS

Rainfall, 1983. There are no long-term rainfall figures for Mairuwa since the weather station there is fairly new. Therefore the rainfall figures available for 1983 are presented alongside those for Daudawa village, about 6 km morthwest of Mairuwa. The two villages were considered close enough to each other to have similar amounts and distribution of rainfall. In 1983, the rains started late and finished early (Table 1).

Table 1. Amount and distribution of rainfall around the project area in 1983[1].

Village	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mairuwa	0	0	0	0	93	120	120	253	-[2]	0	0	0	-[3]
Daudawa	0	0	0	0	94	97	150	285	127	0	0	0	751
Daudawa[4]	0	2	4	41	104	167	225	300	199	38	1	1	1082

1 Sources : Kaduna State Integrated Rural Development Project, and Norman (1974b).
2 Figures not available.
3 Not calculable due to unavailable September figures.
4 1944-69 long-term average.

Total rainfall was only 69 per cent of the long-term average, and in all months rainfall was below the average. TZB maize variety matures in about 95 to 110 days after sowing, while cotton matures in about 130-170 days. The long-term average growing season at Daudawa has been estimated to be in excess of 170 days (Norman, 1974b). The package could be sufficiently implemented in spite of the drought of 1983; this phenomenon may figure very prominently in the acceptance of the technology.

The latest recommended planting date for the mixture is June 15, but the rains did not prove sufficient until the fourth week in June. The mean planting date was July 2 for maize and July 4 for cotton.

Non-labor inputs. Non-labor inputs for the 23 non-herbicide-using farmers cost an average of ₦ 96.85 per hectare (Table 2). For the two farmers who used herbicides, non-labor inputs cost ₦ 129.24, which included ₦ 41.43 in herbicides. This is about equal to the ₦ 41.51 spent on the first weeding by the non-herbicide users. Overall, the two farmers who applied herbicides appear to have performed very poorly compared to the rest of the group. This may be due in part to the rather complacent attitude towards weeding that these two farmers adopted. Only one of these two farmers bothered to weed his field at all, and even this farmer spent fewer hours on this operation than the rest of the farmers spent on the second and subsequent weedings alone (Table 3).

Overall, herbicide application proved too complicated for most farmers and they did not even consider it. The two fields that were sprayed were done by IAR staff.

The value of maize seed was set at the prevailing market price in the local markets at the time of planting. Cotton seed was supplied free to farmers by the Nigerian Cotton Board (NCB). Fertilizer was calculated at its government-subsidized price of ₦ 0.036 per kilogram in 1983. Seed dressing was valued at the 1983 market price of ₦ 0.25 per packet.

Most farmers did not consider insecticide to be of any value. In fact, some of them believed the insecticide to be harmful to their animals left feeding in the fields after the cotton harvest. The project staff managed to spray five fields, but insecticide application was not included in the economic analysis since 1983 was exceptionally dry and relatively free of most cotton pests.

All farmers used ox-drawn equipment to fulfil their land preparation and ridge moulding functions. The oxen and associated equipment belonged to certain farmers who hired them out to other farmers for a fee. For those hiring an ox-team, it is valued at the actual cost per bull-hour minus the wage of the operators which is taken to be ₦ 0.625 per manhour. ₦ 0.625 per manhour is the average wage rate in the study area and is also assumed to be the cost of family labor.

Inputs other than labor accounted for an average of 37 percent of the total cost of the maize-cotton package. Animal accounted for 64 per cent of all non-labor costs, while fertilizers took up 27 percent of these costs.

Labor. The average total labor requirement of maize-cotton production was 296.5 manhours for the 23 farmers who used no herbicides, and 171.9 manhours for the two farmers who applied herbicides. Again, the latter two farmers were lax in their weeding, thus reducing both their labor requirement and their yields. Among our 23 core farmers, hired labor comprised 76 percent of the total labor requirement. No formal attempt was made to study the source if this rather high percentage, but it may be due to the relatively large farm size in the airuwa area and the apparent absence of adult (14-40 year-old) young men in many of the families considered in the study

Table 2. Cost and returns of maize-cotton mixture per hectare.

	23 Non herbicide using farms	2 herbicide-using farms
Gross returns		
Maize yields, kg/ha	1163.4	332.2
Value, of maize, N/ha[1]	989.2	282.3
Cotton yield, kg/ha	260.4	303.8
Value of cotton, N/ha[1]	182.3	212.6
Inputs		
Labor, manhour/ha[2]		
Family	71.4 (44.6)[3]	107.8 (67.4)
Hired	224.9 (126.4)	63.9 (140.2)
Total	296.4 (171.5)	171.7 (207.6)
Land, ha	0.9	0.8
Other inputs, N		
Maize seed	7.4	8.2
Cotton seed	0.0	0.0
Seed dressing	1.5	1.7
CAN fertilizer	15.8	19.7
BSP fertilizer	10.5	12.3
Herbicide	0.0	41.4
Animal hire	61.7	45.9
Total cost of materials	96.8	129.2
Net returns, N		
Per hectare	903.2	158.2
Per manhour (all labor)	3.1	0.9

1 The value of maize is based on an estimated farm price of N 0.85kg for December 83 to May 84. The value of cotton is based on the Cotton Board's prescribed farm price of N 0.70 for grade A cotton. It should be noted, however that in most cases, cotton buying agents pay farmers less than the legal price.

2 The following conversions were used for man-hour equivalents: Children 7-14 years, 1 hour = 0.5 manhours; Women above 14 years, 1 hour = 0.75 manhours; Men above 14 years, 1 hour = 1.00 manhours.

3 Figures in parentheses are the cost of the labor in N. Hired labor is valued at actual cost; family labor is valued at N 0.625/manhour, the estimated average cost of hiring labor in the area.

Table 3. Labor distribution by operation.

Operation	23 Nonherbicide-using farms			2 Herbicide-using farms		
	Household	Hired	Total	Household	Hired	Total
	hr					
Basal Fertilizer application	7.8	5.2	13.0	9.6	0.0	9.6
Land preparation	1.5	5.4	7.0	3.2	3.4	6.7
Sowing	2.1	25.0	27.0	15.3	6.8	22.1
Herbicide application	0.0	0.0	0.0	0.0	3.1	3.1
Fertilizer sidedressing	6.2	4.7	10.9	15.0	0.0	15.0
First weeding[1]	26.0	29.8	55.8	10.1	0.0	10.1
Second and other weedings	8.2	17.7	26.0	0.0	0.0	0.0
Ridge moulding	2.5	4.6	7.1	7.4	0.0	7.4
Maize harvesting[2]	12.5	84.6	97.1	24.5	27.2	51.6
Cotton picking	4.4	48.3	52.7	21.6	24.7	46.3
Total[3]	71.2	225.3	296.5	106.7	65.2	171.9

[1] Includes thinning.

[2] Includes threshing.

[3] Total figures may vary slightly from those in Table 2 because of rounding.

Table 3 gives a breakdown of labor inputs by operation. Since all fields had been in cultivation in the previous season, the labor input for land preparation was relatively small, and virtually all of it went to ridging. All preparation used oxen-drawn equipment.

Most farmers made ridges and then spread basal fertilizer along all the ridges. Some farmers broadcast the basal fertilizer on the old furrows or harrowed land before splitting the ridges. Compared to Norman's Daudawa study (1976) where fertilizer was applied as dressing to each plant, basal fertilizer application in the current project was simple and not time-consuming. The fertilizer side dressing which took fertilizer to each individual stand used up almost the same amount of time as the basal application despite the fact that the former was only about 40 percent of the latter in quantity.

Apart from harvesting, weeding and remoulding the ridges had the largest labor requirement, taking up 88.9 manhours on the average. Weeding the crops planted on the same row took up considerably more labor than weeding the crops planted on alternate rows, presumably because of the higher

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plant densities in the former arrangement.

Labor for harvesting accounted for 51 percent of the total labor input in the production of the maize-cotton package. Maize harvesting alone took up 84.6 manhours and the vast majority of these hours were spent in removing the crop from the field and threshing it. The amount of time and money spent on cotton harvesting may be undervalued because most of the operation is left to old women and children who are paid only a meagre fraction of the wage rates paid to men.

Output. The average yield of maize was 1163.4 kg/ha. One farmer obtained zero maize yield, while the highest yield of maize was 3021.2 kg/ha. The per hectare yield of cotton also varied from zero on two fields to 1151.5 kg/ha on the highest cotton-producing field, while the average yield was 260.4 kg/ha. On experimental plots in Samaru using alternate rows of cotton and maize, Fisher had obtained average yields of 1236.0 kg/ha for maize, and 1160.4 kg/ha for cotton. Other experiments have achieved considerably higher yields of maize. On experimental plots in Samaru between 1980 and 1982, Kumar obtained yields of 3916.7 kg/ha for maize and 1278.3 kg/ha for cotton by mixing crops on the same ridge. On-farm trials were conducted by Abalu, et al., (1984) at Dutsen Wai (1983) using sole maize and sole cotton. They reported yields of 915.7 kg/ha for maize and 218.2 kg/ha for cotton.

There was only one case of maize failure (Table 4); the concerned farmer planted late and did not take good care of his crop through the establishment stage. In the three cases of cotton failure, the concerned farmers appeared to be interested only in the maize component of the package; in fact one of them planted his cotton almost three weeks after planting the maize. Although, on average, yields were considerably below those grown under the best experimental conditions, only one farmer (the one with the failed maize) did not manage to cover his costs. In fact, it is debatable whether we can expect the average farmer to reproduce the yields that are obtainable under experimental conditions.

Although no statistical tests have yet been conducted concerning the factors influencing yields, the scientists on the project suggested several variables that should be taken into consideration. One is the timing of the planting. Many farmers may have planted too late for the crop to become well established. The second factor is fertilizer use. According to the records, the amount of fertilizer provided to farmers represented a rate of fertilization that was somewhat greater than that recommended by the package. Nevertheless, some of the researchers felt that a number of the farmers may have diverted some fertilizer away from the project, thus leading to lower than expected yields, although there was no solid evidence of this assertion. Some researchers believed that the method of application did not ensure maximum utilization of the input by the crop. Stand count was the third variable thought to have strongly influenced the yields. No dependable records of plant densities were maintained. Nevertheless, the researchers felt fields having the largest plant densities also produced the largest yields. Some farmers expressed opposition to the rather close spacing suggested in the package because they felt that close rows were difficult to seed and/or the closeness of the plants resulted in small maize cobs (Bbuyemusoke, 1984). The fourth factor thought to influence yield was the effectiveness of the weeding operation, which was in turn largely a function of its timing. It was hypothesized that those who weeded early reduced the competition between the weeds and the young crops and thereby increased their yields.

Table 4. Mean yield of maize and cotton for each farmer.

Farmer	Area	Maize Total harvest	Maize Yield	Cotton Total harvest	Cotton Yield
Code	ha	kg	kg/ha	kg	kg/ha
01	0.534	694.9	1301.3	148.6	278.3
02[1]	0.592	436.6	442.2	126.4	127.5
03	0.520	638.2	1227.3	104.1	200.2
04	0.736	948.3	1288.4	55.0	74.7
05	0.722	726.0	1005.5	109.1	151.1
06	0.498	409.1	821.5	40.0	81.2
07	0.817	2203.6	2697.2	135.0	165.2
08	1.300	693.7	533.6	164.0	126.2
09[1]	0.579	128.6	222.2	278.0	480.1
10	1.240	1278.7	1026.4	366.8	271.6
11	0.810	1169.5	1443.8	154.0	190.1
12	1.025	1662.6	1662.0	0.0	0.0
13	0.771	1849.9	2399.4	406.0	526.6
14	0.935	1776.0	1899.5	218.0	233.2
15	0.318	219.1	639.0	49.0	154.1
16	1.130	664.3	587.9	351.0	310.6
17	0.872	1030.4	1181.7	345.0	395.6
18	0.662	2000.0	3021.2	366.0	552.9
20	1.030	2635.0	2558.2	1186.0	1151.5
21	0.775	0.0	0.0	157.0	202.6
22	0.877	456.8	520.9	256.0	291.9
23	1.420	730.4	514.4	373.0	262.7
24	0.781	340.9	436.5	180.0	230.5
25	1.387	1635.0	1178.8	0.0	0.0
27	0.844	503.4	596.5	0.0	0.0

1 Used herbicide.

It is apparent that in order to grow the improved maize-cotton mixture successfully, a farmer should adopt the compete package of improved practices. He should not adopt only those parts that fit his particular farming system and ignore the rest.

Profit. Profit is, of course, calculated from the volume of output, the prices of the output, and the cost producing the output. The results show a profit of ₦ 903.19 per hectare for the 23 core farmers, equal to ₦ 3.08 net return per manhour (Table 2). These figures many seem high when compared, for example, to Norman's figures for the production of sole maize in Daudawa in 1973 and 1974 (Norman, 1976), but one has to take into account the fact that the general price level in Nigeria has gone up by 300 to 400 percent in the last 10 years.

Again, no statistical tests have been conducted on the relationship between yield and profits, but a cursory look at the budgets suggests that farmers with the higher yields show higher profits than the farmers with lower yields. This contention appears to be supported by the fact that costs have a lower variance than yields, gross returns, and profits, suggesting that costs represent a constant for the various farms studied.

Profits may also have been boosted by the fact that the price of maize rose sharply in the 1983/84 post-harvest season because of the general grain shortage that accompanied the 1983 drought. For example, the seed planted by farmers in 1983 was valued at ₦ 0.40/kg, but the farmers' maize output was valued at ₦ 0.85/kg between December 1983 and May 1984.

The legal farm price of ₦ 0.70, as set by the Cotton Board, was used to calculate revenues from cotton. Often, however the Board's Licenced Buying Agents pay less than the set price. A survey of 13 of the project's farmers revealed that they received an average of ₦ 0.60/kg for their cotton. If this lower price were used, net returns would decline by ₦ 26.04 per hectare.

Markets for maize and cotton. Inevitably, the farmer's assessment of the market for maize and cotton dictates both the amount planted and the extent to which farmers are willing to adopt improved production technologies for those crops. Although no provisions were made for studying the markets for the outputs in the current project, any results would have to be tempered by this consideration.

Little *a priori* information exists on the market for maize in northern Nigeria, mainly because the crop is relatively new. But Norman (1976) has suggested that the potential for this market hinges on :

(1) the willingness of northern consumers to substitute maize for sorghum in their diets,
(2) the ability to tap the southern market for human consumption,
(3) the development of a feed grains outlet, and
(4) the development of agro-industries like starch and oil processing.

An informal survey of the project farmers indicated that they consumed some of the maize in the household, sold some in the local human market, and kept some for planting. In 1983, the drought made maize market conditions very favorable for the farmer since there was a general shortage of cereals. If increases in production are to be sustained in the future, however, greater attention needs to be paid to developing markets as well as to marketing systems for maize.

As already mentioned, cotton production is on the decline in the northern Guinea savanna. The primary reason for this decline is unfavorable market conditions. The farmers feel that the price paid for their crop can hardly cover the cost of production. Indeed, some of the project farmers expressed a wish to grow maize-sorghum or maize-cowpea mixtures rather than the maize-cotton mixture, due to the higher market value of the former crops. It was also obvious to the project researchers that farmers greatly preferred the maize component of the package, and that to some extent the cotton crop suffered because of the lower level attention given to it.

CONCLUSION

The maize-cotton mixed cropping package performed fairly well under the adverse weather conditions of 1983. One should be quick to point out, of course, that the profitability of the package was greatly enhanced by the very favorable maize prices that prevailed at the end of the growing season. Despite the drought, the highest maize yield (3021.2 kg/ha) was close to yields obtained under experimental conditions in Samaru; and there were several yields of 2000 kg/ha and over. The highest cotton yield (1151.5 kg/ha) also compared well with yields under experimental conditions. The results would indicate that even better performances should be expected under more favorable weather conditions.

The development of maize markets and marketing facilities should enhance the acceptability of the package. It is also imparative that existing market arrangements for cotton be radically improved to make the cotton component of the package more attractive.

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CEREALS-COWPEA ASSOCIATIONS IN BURKINA FASO

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Crop Association is a traditional agricultural practice in Burkina Faso and throughout sahelian West-Africa. Such association may involve cereals only, cereals and grain legumes, and cereals and certain cash-crops. Village studies conducted by FSU/SAFGRAD have shown that a very small portion of cereal fields are solecropped: 1% to 13% of millet fields, 1% to 27% of red sorghum fields, 10% to 50% of white sorghum fields and 7% to 22% of maize fields (Singh, Lebrberg and Morris, 1984). Among the types of associations, the most frequently and generally encountered are those involving cereals and cowpea. Indeed, cowpea is associated in 70% to 92% of millet fields, 33% to 84% of red sorghum fields and 25% to 100% of white sorghum fields (Singh, et al., 1984). However, cowpea is very rarely associated with maize and cowpea solecropping is more of an exception than a general practice.

An important advantage of crop association is the minimization of risks including: the possibility of improving crop density, the minimization of negative effects resulting from soil heterogeneity, insect pest and disease control, the escape of or minimization of various climatic stresses by at least one of the crops in association, the protection and improvement of soil fertility, the decrease in soil temperature, a better utilization of solar radiation, reduced weeding, and savings in land, labor and capital.

The socio-economic studies made by FSU/SAFGRAD (1982), in particular those studies on farmer's aims and objectives in managing his farm, have shown that in practicing the system of crop association, the farmer's objective is to maximize cereals production and to obtain grain or foliage surplus from the associated crop. Therefore, the farmer's prime interest lies in the cereal crop and any form of association that would lead to a decrease in the yield of the cereal would not be readily adopted by farmers. Cowpea is primarily grown for its grain, but its edible leaves are greatly in demand for human consumption during the hungry season. Also, the leaves are harvested and used as cattle feed during the dry season. The grain which has a high protein and energy content adds to the diversification of the diet especially during the cropping season.

Several important conclusions relative to crop associations can be drawn from studies conducted by ICRISAT (1983):

(1) the profitability of the system of crop association is specific to the type of soil and is evaluated mainly in terms of soil moisture and available fertility,

(2) cowpea and millet are more competitive in the use of soil nutrients than sorghum,

(3) in the system of cereals-cowpea association, cereals with compact plant structure are more conducive to cowpea fodder production than cereals with open plant structure,

(4) sorghum-cowpea association responds better to fertilizers than millet-cowpea association.

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Muleba and Brockman (1984) have shown that in the sudanian savanna, soil and water management appears to be a decisive element in the system of maize-cowpea relay-cropping. By using early maturing maize cultivars and tied ridging techniques, it is possible to demonstrate that cowpea can be successfully cultivated in relay with maize without causing a decrease in the yield of the cereal, if cowpea is planted one month after maize. However, the grain yield of cowpea is mainly affected by the quantity and distribution of rains in September.

The objective of FSU/SAFGRAD studies reported here was to determine the performance of the systems of cereals cowpea association in competition with cereals sole-cropping or with traditional systems of associations. The trials were conducted over several years, but here we are reporting those trials of 1983 and 1984.

MATERIALS AND METHODS

The experiments were conducted on maize and millet associations with cowpea. They were conducted on farmers' fields near the FSU research village sites, at Bangasse, Nedogo and Poedogo, located respectively 110 km and 30 km north-east and 130 km south of Ouagadougou and at Dissankuy, 120 km north-east of Bobo-Dioulasso. These locations represent different ecological and socio-economic environments. The experiments were carried out by the FSU agricultural technicians stationed in each village, under the supervision and monitoring of the researchers. The treatments involved local millet varieties, local and introduced maize and cowpea varieties, two levels of management practices (traditional and improved) and several densities of association and dates of seeding. The levels of improved management involved tied ridges and the use of fertilizers and insecticides. The local varieties of cowpea are rampant (spreading) and photoperiod sensitive whereas the introduced varieties are photoperiod insensitive and have an erect habit of growth.

The economic analysis required information about the prices of cereals, cowpea, fertilizers, insecticides and the capital cost of the sprayer. For the purpose of comparison, the prices of products and factors of production in 1984 were used to analyze the data of 1983. The additional labor required for seeding, weeding, applying fertilizers and spraying was also required for the analysis. These parameters were synthesized from field experiences of FSU field staff. This information is footnoted in Tables 1, 2 and 3.

The economic analysis only considered the revenues from the millet/ maize and cowpea grains. Benefits received from other sources such as the use of the stocks for fencing or in the household or the use of the cowpea vegetation for human consumption or animal fodder is not included in the budget analysis. Carryover effects of fertilizer have also not been included in the analysis. However, a sensitivity analysis using a 25% carryover of both 14-23-15 and urea at an opportunity cost of 15% gives economic results that do not alter the points made in the Results and Discussion part of the paper.

Experiment I: Millet-Cowpea Association, 1983. The objective of this experiment was to determine the performance of millet-cowpea associations under farmers' conditions in relation to millet solecropping or to traditional low density associations.

The experiment was conducted in 1983 at Bangassé and Dissankuy. The experimental design was a randomized complete block with four blocks. The seven treatments including three population densities and two management levels were the following:

(1) millet solecropped at a seedling density of 31,250 plants/ha;
(2) millet at 31,250 plants/ha and local cowpea at 7,800 plants/ha seeded along every second row of millet;
(3) millet at 31,250 plants/ha, local cowpea at 31,250 plants/ha, cowpeas were seeded along the rows of millet.
(4) millet and local cowpea at respectively a seedling density of 62,500 plants/ha, cowpeas were seeded in rows between the rows of millet;
(5) millet at 31,250 plants/ha, TVX 3236 at 7,800 plants/ha seeded as in Treatment 2 above;
(6) millet and TVX 3236 at 31,250 plants/ha seeded as in Treatment 3 above;
(7) millet and TVX 3236 at 62,500 plants/ha seeded as in Treatment 4 above;

For all treatments, rows of millet were 80 cm apart. Millet and cowpea were seeded on the same date. Under Treatments 3, 4, 6 and 7, cowpea was treated with Thiodan (1 l/ha) at flowering time and 10 days later.

Experiment II: Millet-Cowpea Association, 1984. The objective of this experiment was to evaluate the performance of on-farm millet-cowpea association in comparing traditional densities and in combining various densities of cowpea and millet. The experiment was conducted at Poedogo and Bangasse in 1984. The experimental design was a randomized complete block. The seven treatments were the following:

(1) millet solecropped at the density of 31,250 plants/ha:
(2) millet at 31,250 plants/ha and local cowpea at 7,800 plants/ha, cowpeas seeded in rows between every second row of millet:
(3) millet and local cowpea at 31,250 plants ha each, cowpeas seeded in rows between rows of millet;
(4) millet at 31,250 plants/ha and local cowpea at 62,500 plants/ha cowpeas seeded in rows between rows of millet;
(5) millet and local cowpea each at 62,500 plants/ha, cowpeas seeded in rows between rows of millet;
(6) millet at 31,250 plants/ha and TVX 3236 at 62,500 plants/ha, seeded as in Treatment 4 above;
(7) millet and TVX 3236 each at 62,500 plants/ha, seeded as in Treatment 5 above.

For all treatments, rows of millet were 80 cm apart. Millet and cowpeas were seeded on the same date. No fertilizer was applied. Cowpeas were treated with 1 l/ha of DECIS and Thiodan respectively at flowering time and 10 days later.

Experiment III: Maize-Cowpea Association. The maize varieties were SAFITA-2 (developed by IITA) and local maize; the cowpea varieties included the (photoperiod sensitive and rampant) local variety and TVX 3236 (photoperiod insensitive and with erect habit). The improved management involved tied ridges, the application of fertilizers and insecticides whereas the traditional management was the farmer's practice without tied ridges and without fertilizers.

The experiment was conducted at Poedogo and Nedogo in 1984. The experimental design was a randomized complete block with three blocks. The six treatments were the following:

(1) Local maize and local cowpea under traditional management: without fertilizer and without tied ridges. At Nedogo, maize and cowpea were seeded at the same date, whereas at Poedogo, cowpea was seeded three weeks after maize.
(2) Local maize and local cowpea under improved management: tied ridges constructed prior to seeding, 200 kg/ha of cotton fertilizer, 14-23-15, applied in a band at 10-15 cm from the rows of maize at seeding time and 50 kg/ha of urea applied in pockets at 10-15 cm from the maize seedlings one month after seeding.
(3) SAFITA-2 and TVX 3236 under traditional management. Cowpea was seeded one week after maize had reached 50% of silk at Nedogo and, four weeks after maize seeding at Poedogo due to the late date of maize seeding.
(4) SAFITA-2 and TVX 3236 under improved management: as in Treatment 2. The dates of cowpea and maize seeding were the same as in Treatment 3.
(5) SAFITA-2 and local cowpea under traditional management, as in Treatment 1. Cowpea was seeded three weeks after maize at Nedogo and Poedogo.
(6) SAFITA-2 and local cowpea under improved management as in Treatment 2. Cowpea was seeded three weeks after maize at Nedogo and Poedogo.

Insecticide treatments were applied to the cowpea at the rate of 1 l/ha of DECIS and Thiodan, respectively at flowering time and 10 to 14 days later. At the two locations, the plots were on slightly sloping soils considered by the farmers as soils fit for sorghum.

RESULTS AND DISCUSSION

Experiment 1. At Dissankuy where the conditions of soil moisture and fertility were favorable, it is noted that medium and high densities of cowpea (31,250 and 62,500 plants/ha respectively) did not cause a decrease in millet yield (Table 1). Under Treatment 7, (high density cowpea), millet yield was even higher than yield under solecropping. The high and medium population densities of cowpea resulted in yields significantly higher than that of the low population density of cowpea. Total grain yield of the two crops was significantly higher under inter-cropping than millet solecropped. Except for Treatment 6, total yields of the two crops were higher with high and medium densities than with low densities.

At Bangasse under limiting conditions of soil moisture and fertility, the medium and high densities of cowpea tended to decrease millet yield (Treatments 3 and 4). For all treatments involving medium and high densities of cowpea, (Treatments 3,4, 6, and 7) cowpea yields were significantly higher (Treatments 3, 4, 7) or equal to (Treatment 6) than the yield of cowpea at the low population density (Treatment 2).

The economic analysis indicates that at Dissankuy, all the millet-cowpea associations (Treatments 2 through 7) gave a greater net return than did solecropping (Treatment 1). Also, all the millet-cowpea associations gave a positive return/hr for the additional labor required over sole-cropping. Treatments 4 and 7 gave the largest net returns. However,

Table 1. Millet and Cowpea Intercrop, 1983.

	Treatments 1/							
	(1) LM2	(2) LM2 LC1	(3) LM2 LC2	(4) LM3 LC3	(5) LM2 TVX1	(6) LM2 TVX2	(7) LM3 TVX3	2/ S.E.
				Dissankuy				
Millet Yield, kg/ha	1592	1812	1969	1853	1860	1792	2048*	111.2
Gain in Millet Yield Over Treatment 1	-	120	177	161	188	100	356	
Cowpea Yield, kg/ha	-	263	703#	889#	124#	422#	601#	43.2
Gain in Cowpea Yield Over Treatment 2	-	-	440	626	-139	159	416	
Millet + Cowpea Yield, kg/ha	1692*	2075*	2572*#	2742*#	2093*	2214*	2729*#	107.6
Gain in Millet + Cowpea Yield Over Treatment 1	-	383	680	1050	311	522	1037	
Net Revenue, '000 CFA. 3/	156	193	231	249	185	196	246	
Gain in Net Revenue Over Treatment 1, '000 CFA.	-	37	75	93	29	40	90	
Return/hr of Additional labor, CFA. 4/	-	-	2500	3100	166	211	474	
Gain in Net Revenue Over Treatment 2, '000 CFA.	-37	-	38	56	-8	3	53	
Return/hr of Additional labor, CFA. 4/	-	-	585	862	-	13	236	
				Bangasse				
Millet Yield, kg/ha	464	391	293*	244*#	450	307	391	69.0
Gain in Millet Yield Over Treatment 1	-	-73	-171	-220	-14	-77	-73	
Cowpea Yield, kg/ha	-	164	316#	262#	67#	235	319#	37.2
Gain in Cowpea Yield Over Treatment 2	-	-	152	119	-97	71	155	
Millet + Cowpea Yield, kg/ha	464	555	609	526	516	622	710*	92.7
Gain in Millet + Cowpea Yield Over Treatment 1	-	91	145	62	52	158	246	
Net Revenue, '000 CFA. 3/	43	52	48	40	48	48	57	
Gain in Net Revenue Over Treatment 1, '000 CFA.	-	9	5	-3	5	5	14	
Return/hr of Additional labor, CFA. 4/	-	-	167	-	29	26	74	
Gain in Net Revenue Over Treatment 2, '000 CFA.	-9	-	-4	-12	-4	-4	5	
Return/hr of Additional labor, CFA. 4/	-	-	-	-	-	-	22	

1/ LM = local millet varieties; LC = local indeterminate cowpea varieties; TVX = TVX 3236 determinate cowpea variety (IITA). Densities of 7,800, 31,250, and 62,500 plants/ha are identified by the numbers 1, 2, and 3 respectively following the millet and cowpea idenitifiers. No tied ridging or fertilization. Millet and cowpeas were planted on the same day in different pockets.

2/ S.E. = standard error of the difference between two treatment means. In the table, yields with an asterisk (*) indicate that the difference between this mean yield and the mean yield of treatment 1 is greater than twice the standard error. Yields followed by a (#) indicate that the difference between this mean yield and the mean yield of treatment 2 is greater than twice the standard error. The coeficient of variation (CV%) for millet, cowpea and millet + cowpea at Dissankuy are 17.0, 23.8 and 13.2 and at Bangasse 36.9, 32.3 and 31.3 respectively.

3/ Net Revenue = yield of millet and cowpea x price minus the costs of insecticides, sprays and the capital cost of the sprayer. The millet price is 92 CFA/kg (1984 fall OFNACER price) and the cowpea price is 100 CFA/kg (1984 post harvest price). DECIS and Thiodan insecticide cost 5000 CFA/litre. The capital cost of the sprayer is 800 CFA/ha.

4/ Return/hr of additional labor is calculated as the gain in net revenue ÷ additional labor hours required over treatment 1 or treatment 2 for planting, spraying and weeding. The additional labor required above that of treatment 1 is 0, 30, 30, 175, 190, and 190 man-equivalent hours respectively for treatments 2 through 7. When comparing treatments 1 and treatments 3 through 7 to treatment 2, the additional labor required is 0, 65, 65, 210, 225 and 225 man-equivalent hours respectively.

when labor is limiting as it usually is, Treatment 4 (high density millet and local cowpea) followed by Treatment 3 (medium density millet and local cowpea) gave the greatest return/hr for the additional labor. When comparing the low density millet-cowpea (Treatment 2) to the other millet-cowpea associations (Treatments 3 through 7), Treatments 3, 4 and 7 gave a higher net return along with a positive return/hr for additional labor requirements. Again, Treatments 3 and 4 gave the highest return/hr for the additional labor that is involved. At Bangasse, only Treatment 7 gave a higher net return than solecropping. The net returns of the low density millet-cowpea (Treatment 2) were higher than the net returns of Treatments 3 through 6. The return/hr for the additional labor of Treatments 3 through 6 is at best zero and is negative for all treatments 3 through 7 when considering the opportunity cost of the labor.

Under favorable conditions of rainfall and fertility (Dissankuy), it may be more economical for the farmers to increase the population densities of their millet-cowpea associations with respect to their current practice. But under very limited conditions of rainfall and fertility (Bangasse), the densities presently used by farmers seem more profitable.

Experiment II. At Poedogo, cowpea associations caused decreases in millet yield as compared to solecropping (Table 2). This was due to severe drought at the beginning of the season which jeopardized the development of the cereal. However, it is noted that under these conditions, traditional practice resulted in the highest yield of millet. The local variety of cowpea yielded more than the TVX 3236 variety. The high and medium population densities of local cowpea resulted in yields at least equal to cowpea yield at the low density (Treatment 2) whereas the TVX 3236 variety had significantly lower yields (Treatments 6 and 7).

However, the highest grain yields of the two crops combined were obtained with the traditional system of association. Total grain yields of cowpea and millet in association were not significantly different from the grain yield of solecropped millet. (Treatments 3 through 7) vs Treatment 1).

At Bangasse, because of favorable rainfall early in the season, the cowpea association did not cause a significant decrease in millet yield (in comparison with solecropped millet). No treatment had a grain yield higher than the traditional treatment (Treatment 2). In terms of total grain yield of the two crops, only Treatment 4 did not have yields higher that the yield of solecropped millet (Treatment 1). As at Poedogo, millet at 31,250 and cowpeas at 7,800 plants/ha resulted in the highest total grain yield.

The early-flowering, determinate cowpea variety, TVX 3236, produced greater yields than the indeterminate variety, Ouahigouya local, at Bangasse. TVX 3236 developed good growth early in the season because of favorable rainfall, and began flowering on 27 July and the seeds were well-filled by mid-August when the drought stress began. The indeterminate cowpea variety began flowering at mid-August.

The economic analysis indicates that at Poedogo, where there was severe moisture stress early in the season, only the low density millet and local cowpea (Treatment 2) gave higher net returns than solecropping

Table 2. Millet and Cowpea Intercrop, 1984.

	Treatments 1/							
	(1) LM2	(2) LM2 LC1	(3) LM2 LC2	(4) LM2 LC3	(5) LM3 LC3	(6) LM2 TVX3	(7) LM3 TVX3	2/ S.E.
				Poedogo				
Millet Yield, kg/ha	958*	706*	427*@	419*@	391*@	599*	630*	59.2
Gain in Millet Yield Over Treatment 1	-	-252	-531	-539	-567	-359	-328	
Cowpea Yield, kg/ha	-	542	616	667*	622	302*	302@	57.2
Gain in Cowpea Yield Over Treatment 2	-	-	74	125	80	-240	-240	
Millet + Cowpea Yield, kg/ha	958*	1248*	1043@	1086	1013@	901*	922@	92.4
Gain in Millet + Cowpea Yield Over Treatment 1	-	290	85	128	55	-57	-26	
Net Revenue, '000 CFA, 3/	88	108	90	94	87	75	77	
Gain in Net Revenue Over Treatment 1, '000 CFA.	-	20	2	6	-1	-13	-11	
Return/hr of Additional labor, CFA. 4/	-	-	67	200	-	-	-	
Gain in Net Revenue Over Treatment 2, '000 CFA.	-20	-	-18	-14	-21	-33	-31	
Return/hr of Additional labor, CFA. 4/	-	-	-	-	-	-	-	
				Bangasse				
Millet Yield, kg/ha	193	234	287	240	287	219	370*@	66.1
Gain in Millet Yield Over Treatment 1	-	41	94	47	94	26	177	
Cowpea Yield, kg/ha	-	221	143	99*	99@	169	153	43.9
Gain in Cowpea Yield Over Treatment 2	-	-	-81	-122	-122	-52	-68	
Millet + Cowpea Yield, kg/ha	193*	455*	430*	338	385*	389*	523*	78.8
Gain in Millet + Cowpea Yield Over Treatment 1	-	262	237	145	192	195	330	
Net Revenue, '000 CFA. 3/	18	33	30	21	26	26	39	
Gain in Net Revenue Over Treatment 1, '000 CFA.	-	15	12	3	8	8	21	
Return/hr of Additional labor, CFA. 4/	-	-	400	100	267	42	111	
Gain in Net Revenue Over Treatment 2, '000 CFA.	-15	-	-3	-9	-4	-4	6	
Return/hr of Additional labor, CFA. 4/	-	-	-	-	-	-	29	

1/ LM = local millet varieties; LC = local indeterminate cowpea varieties; TVX = TVX 3236 determinate cowpea variety (IITA). Densities of 7,800, 31,250, and 62,500 plants/ha are identified by the numbers 1, 2, and 3 respectively following the millet and cowpea identifiers. No tied ridging or fertilization. Millet and cowpeas were planted on the same day in different pockets.

2/ S.E. = standard error of the difference between two treatment means. In the table, yields with an asterisk (*) indicate that the difference between this mean yield and the mean yield of treatment 1 is greater than twice the standard error. Yields followed by a (@) indicate that the difference between this mean yield and the mean yield of treatment 2 is greater than twice the standard error. The coeficient of variation (CV%) for millet, cowpea and millet + cowpea for Poedogo are 14.2, 15.9 and 11.9 and for Bangasse 35.8, 42.2 and 26.9 respectively.

3/ Net Revenue = yield of millet and cowpea x price minus the costs of insecticides, sprays and the capital cost of the sprayer. The millet price is 92 CFA/kg (1984 fall OFNACER price) and the cowpea price is 100 CFA/kg (1984 post harvest price). DECIS and Thiodan insecticide cost 5000 CFA/litre. The capital cost of the sprayer is 800 CFA/ha.

4/ Return/hr of additional labor is calculated as the gain in net revenue - additional labor hours required over treatment 1 or treatment 2 for planting, spraying and weeding. The additional labor required above that of treatment 1 is 0, 30, 30, 30, 190, and 190 man-equivalent hours respectively for treatments 2 through 7. When comparing treatments 1 and treatments 3 through 7 to treatment 2, the additional labor required is 0, 50, 50, 50, 210 and 210 man-equivalent hours respectively.

(Treatment 1). When comparing the low density millet and local cowpea (Treatment 2) with Treatments 3 through 7, none gave a higher net return. The return/hr of additional labor for Treatments 3 thorugh 7 is negative when considering the opportunity cost of labor. At Bangasse, all Treatments with the exception of Treatment 4 gave higher net returns than solecropping. None of the Treatments 3 through 7 gave a higher net return than the low density millet and local cowpea association (Treatment 2) and all exhibit a negative return/hr for the additional labor when considering the opportunity cost. At both locations, the traditional system of low densities of millet and local cowpea (Treatment 2) were economically superior to associations with higher density cowpeas.

Experiment III. At Poedogo, maize yield was significantly higher under improved management than under traditional management (Table 3). Total grain yield of the associated two crops was also significantly higher under improved management than under traditional management. On the contrary, at Nedogo, this difference was not significant, but yields under improved management were at least equal to those under traditional management. At the two locations, there was no significant difference in cowpea yields between improved management and traditional management. Associated maize yield was higher under improved management when cowpea was seeded four weeks later or one week after maize silking (Treatment 4).

The local variety of cowpea produced more grain than the TVX 3236 variety in association with maize at Poedogo. At Nedogo, where it was seeded on September 6, that is, one week after maize silking, the yield of TVX 3236 was zero. At the beginning of the season at Nedogo, the growth of cowpea was adversely affected by shading from the maize. TVX 3236 because it is photoperiod insensitive started flowering before reaching an adequate plant size. Furthermore, although rain and sun conditions became favorable at Poedogo in mid-October, TVX 3236 was already senescing and could no longer take advantage of these favorable conditions. On the other hand, the local photoperiod sensitive variety with indeterminate flowering habit, took advantage of these favorable conditions by continuing plant growth.

Intercropping of cowpeas and maize tended to suppress maize yields. Generally, maize yields with improved management were greatest when cowpeas were planted four weeks after maize or one week after 50% silk, intermediate when cowpeas were planted three weeks after maize was planted, and maize yields were least when cowpeas were planted on the same date as maize. When cowpeas are planted one week after 50% silk, one would expect little or no reduction of maize yield compared to yield of maize in pure stand because the maize would be nearly mature before it encountered appreciable competition from the cowpeas.

Very little of the nitrogen fixed by the legume, cowpeas, would have been available for the maize, particularly for those treatments in which planting of cowpeas was delayed. Possible benefits from nitrogen fixed by the legume, should be determined by future experimentation.

The economic analysis indicated that at Poedogo Treatments 2, 4 and 6, those with improved management, gave higher net returns than the traditional local maize and local cowpea association under traditional management (Treatment 1). The local maize and local cowpea association under improved management (Treatment 2) gave the highest net return and the

Table 3. Maize and Cowpea Intercrop, 1984.

	Treatments 1/						
	(1) LM LC TP	(2) LM LC IMP	(3) S-2 TVX TP	(4) S-2 TVX IMP	(5) S-2 LC TP	(6) S-2 LC IMP	2/ S.E.
			Poedogo				
Maize Yield, kg/ha	36	1910*	73	2302*	53	2155*	159.6
Gain in Maize Yield Over Treatment 1	-	1874	37	2266	17	2120	
Cowpea Yield, kg/ha	945	1584*	676	593	907	1051	263.4
Gain in Cowpea Yield Over Treatment 1	-	639	-269	-352	-38	106	
Maize + Cowpea Yield, kg/ha	981	3493*	749	2895*	960	3207*	206.1
Gain in Maize + Cowpea Yield Over Treatment 1	-	2512	-232	1914	-21	2226	
Net Revenue, '000 CFA, 3/	87	304	64	241	85	274	
Gain in Net Revenue Over Treatment 1, '000 CFA.	-	217	-23	154	-2	187	
Return/hr of Additional labor, CFA. 4/	-	1113	-	604	-	959	
			Nedogo				
Maize Yield, kg/ha	403	667	597	1125*	236	722	243.8
Gain in Maize Yield Over Treatment 1	-	264	194	722	-167	319	
Cowpea Yield, kg/ha	260	351	0*	0*	260	334	75.0
Gain in Cowpea Yield Over Treatment 1	-	91	-260	-260	0	74	
Maize + Cowpea Yield, kg/ha	662	1019	597	1125	496	1056	203.4
Gain in Maize + Cowpea Yield Over Treatment 1	-	356	-65	463	-166	394	
Net Revenue, '000 CFA. 3/	52	67	44	74	37	70	
Gain in Net Revenue Over Treatment 1, '000 CFA.	-	15	-8	22	-15	18	
Return/hr of Additional labor, CFA. 4/	-	77	-	113	-	133	

1/ LM = local maize varieties; LC = local indeterminate cowpea varieties; S-2 = Safita-2 maize variety (IITA); TVX = TVX 3236 determinate cowpea variety (IITA); TP = Traditional management practices ie., no tied ridging or fertilization; IMP = Tied ridges constructed prior to planting, 200 kg/ha 14-23-15 applied in a band 10-15 cm. from rows of maize at planting and 50 kg/ha urea applied in pockets at 10-15 cm. from maize seed pockets one month after planting

2/ S.E. = standard error of the difference between two treatment means. In the table, yields with an asterisk (*) indicate that the difference between this mean yield and the mean yield of treatment 1 is greater than twice the standard error. The coefficient of variation (CV%) for maize, cowpea and maize + cowpea for Poedogo are 17.9, 33.6 and 11.9 and for Nedogo 47.8, 45.7 and 38.4 respectively.

3/ Net Revenue = yield of maize and cowpea x price minus the costs of fertilizer, insecticides, sprays and the capital cost of the sprayer. The maize price is 92 CFA/kg (1984 fall OFNACER price) and the cowpea price is 100 CFA/kg (1984 post harvest price). Fertilizer prices are 78 CFA/kg for 14-23-15 and 66 CFA/kg for urea (1984 official spring price). DECIS and Thiodan insecticide cost 5000 CFA/litre. The capital cost of the sprayer is 800 CFA/ha.

4/ Return/hr of additional labor is calculated as the gain in net revenue - additional labor hours required over treatment 1 for tied ridging, planting, fertilization, spraying and weeding. At Poedogo, treatments 2 through 6 required 195, 60, 255, 0, and 135 additional man-equivalent hours over treatment 1. At Nedogo, Treatments 2 through 6 required 195, 0, 195, 0 and 135 additional man-equivalent hours of labor over that of treatment 1.

highest return/hr for the additional labor requirements. At Nedogo, none of Treatments 2 through 6 gave a higher net return than the traditional local maize and local cowpea association (Treatment 1).

SUMMARY

Three intercropping experiments, two of cowpea intercropped with millet and one of cowpea intercropped with maize, were conducted under several widely differing environments in 1983 and 1984 in Burkina Faso. Three population densities (7,800; 31,250 and 62,500 plants/ha of a cowpea variety of determinate flowering habit and a cowpea variety of indeterminate flowering habit and two population densities (31,250 and 62,500 plants/ha) of millet in association were compared to solecropped millet. Intercropped with maize, a determinate and an indeterminate variety of cowpea were seeded at several maize growth stages under traditional and improved (with tied ridges and fertilization) management.

The most limiting factors in the performance of cereals-cowpea associations are essentially soil moisture and fertility. Under favorable conditions of moisture and fertility (Dissankuy, 1983 and Bangasse, 1984) it is profitable for the farmers to increase cowpea density with respect to its present density in their system of millet-cowpea association. Under less favorable conditions, (Bangasse, 1983 and Nedogo, 1984), the present practice of the farmers seems to be more dependable and profitable. Under improved management cowpea densities somewhat greater than those currently used by the farmers are likely to be economically viable. The maize-cowpea intercrop appears to have potential only under improved management.

The climatic constraints and variabilities represented by the sample of location-year tests in this study are common in the central plateau of Burkina and in many other areas of the WASAT, emphasizing the importance of the stability of production offered by indeterminate cowpea varieties compared to determinate varieties.

The millet-cowpea and the maize-cowpea associations were evaluated in this paper for both technical aspects and profitability. The next step in the evaluation process is on-farm farmer managed trials. The on-farm farmer managed trials will be designed with the information gained from the on-farm researcher managed trials and feedback that has been obtained from farmer meetings. Important data from the farmer managed trials will be the yield and labor data and farmer feedback that can be used in the next stage of analysis; that of determining the best cropping association that fits into the farmers' production system with respect to such constraints as land and labor.

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THE DEVELOPMENT OF MIXED CROPPING TECHNOLOGIES IN NORTHERN GHANA

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Maize, sorghum and groundnuts are among the principal food crops grown in mixed cropping systems throughout the Northern Region of Ghana, but their importance varies according to the different areas of the Region, i.e. across different farming systems. It is evident that the importance of maize production declines with decreasing rainfall. However it should be noted that maize has gained its greatest importance in the farming systems around Tamale due to the influence of more commercialized farming with tractors and bullocks, while it has not reached that same importance in the more traditional farming systems around Sawla and Bimbilla, despite good environmental conditions. Yields per hectare are quite low in these areas, usually around 1 t/ha or 70 g per plant (Table 1).

Crop production is basically affected by more general and overriding problems, such as the scarcity of labour for soil preparation and weeding, and the very low soil fertility. Soil fertility problems, in particular, governed the considerations that led to the formulation of the on-farm experimentation program.

The general objectives of Nyankpala FSR work are to describe the prevalent farming systems in northern Ghana and identify the major problems that hamper production and to test newly developed technologies with respect to their feasibility and acceptability to farmers. To realize these objectives, the program was composed of farm management surveys and on-farm experiments.

In this paper, preliminary information from the 1984 on-farm experiments are presented. The objectives of these experiments were to induce farmers' participation in the development of new adapted technologies by stimulating farmers to comment on the experiments, to test the acceptability and performance of new varietal material from the station against farmers' varieties and to evaluate new technologies versus farmers' practices by estimating the costs and returns as well as the risk involved in each technology.

Table 1. Yields of major crops in five villages of Northern Region of Ghana.

Crop	Nakpanduri	Namburugu	Wantugu	Nakpala	Nakpa
	ton/ha				
Maize	1.18	1.06	1.08	1.19	1.87
Sorghum	0.86	0.75	0.45	1.15	0.39
Millet	1.09	0.69	-	1.03	0.28
Cowpea	0.29	0.32	0.19	0.12	0.24
Groundnut	0.54	0.71	0.63	0.60	0.45

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MATERIALS AND METHODS

We conducted trials in five villages, in the Northern region: Nakpanduri in Gambaga District; Namburugu in Karaga Zone; Wantugu in Nyankpala Zone; Nakpala in Sawla Zone; and Nakpa in Bimbilla Zone. Fifty farmers participated in our survey (Table 2).

Table 2. Percent area under major crops in five villages of Ghana.

Crop	Nakpanduri	Namburugu	Wantugu	Nakpala	Nakpa
			%		
Maize	12.7	79.0	84.7	55.6	61.0
Sorghum	14.9	16.0	59.0	78.3	46.6
Millet	95.5	71.0	25.5	21.4	5.7
Cowpea	57.4	46.2	42.4	33.4	14.9
Groundnut	21.4	40.4	72.8	16.2	45.6
Yam	0	0	0.7	33.1	87.9

In each of the five villages, we initiated five long-term trials consisting of three 20 x 20 m plots (A,B and C). Plot A and B were planted with new varieties from NAES, plot C was planted with farmers' own varieties. Plot B and C were completely under farmers' management, while the cropping pattern of plot A was designed by us and executed by farmers. This cropping pattern varied according to the location of the village as described below.

Varieties and planting densities. Tocumen and Pool 16 are a yellow flint and a white dent 90-day maize variety, respectively, whereas Composite 4 is a 120-day white dent variety. The sorghum varieties Mankaraga and Loc 29 are both late maturing photosensitive varieties whereas STMD is a Semi-tall medium-duration variety with higher yield potential. F mix is a 110-day bush type groundnut, and Katinga local is a photosensitive tall growing pigeon pea landrace. TN 8663 is a 60-day large white-seeded cowpea variety.

In Nakpanduri, Wantugu and Nakpa (Fig. 1) we planted an alley cropping design in which every 7th, 4th and 4th row was planted with pigeon pea instead of cereal/legume, resulting in rows of pigeon peas at every 4 m. During this first year of establishment, the pigeon peas were left to grow and produce seed, whereas during the coming seasons they will be pruned regularly to provide green manure for the intergrown cereals. In Namburugu and Nakpala, pigeon pea was relay-inter planted in the cereal rows at the time of the maize harvest in order to establish a planted fallow for 1985 and 1986. We considered the area of Nakpanduri as marginal for maize, and therefore, we did not include maize in the experiments there. In all other locations the designed proportions of maize and sorghum were kept equal because sorghum was considered to be the least susceptible to drought loss. The number of cereals planted was designed to account for the expected rainfall at each location as well as the expected failure of seeds. No thinning was practiced.

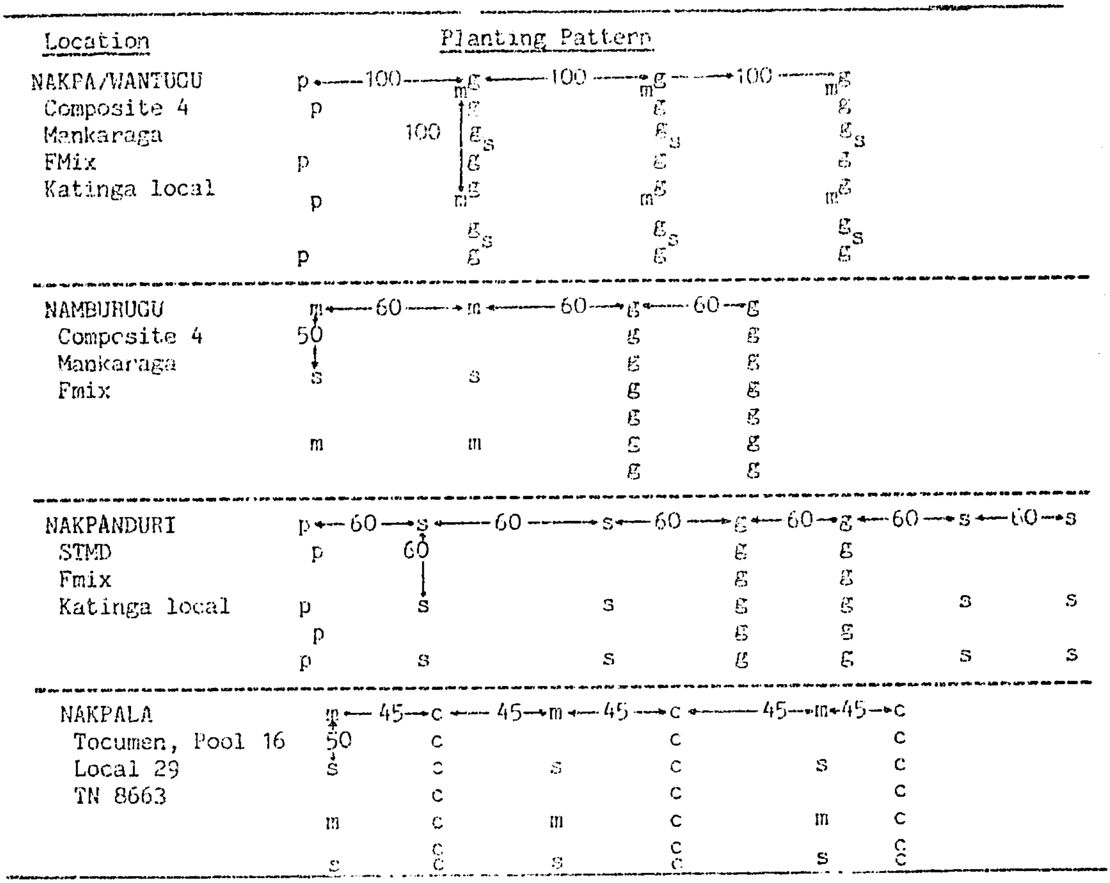

Fig. 1. Plot A planting patterns. Numbers are within-row or between-row distances in cm. m = maize, s = sorghum, c = cowpea (within-row distance = 25 cm), g = groundnut (within-row distance = 20 cm), p = pigeon pea (within-row distance = 30 cm). Names of crop varieties are indicated under locations.

Plot A was a complete package of practices, including the spatial arrangement of pigeon pea and other crops, and a moderate application of fertilizer (0.8 g N as urea + 0.5 g P as single super/maize plant; 0.1 g P as UV5/groundnut or cowpea plant, 0.5 g P as UV5/pigeon pea plant).

RESULTS AND DISCUSSION

Except for Nakpala, plot A maize densities were generally comparable to densities under farmers' management and not too different from what we designed (Table 3). Deep planting with a stick, covering and assuming 25% loss, however did work out.

For groundnuts, we approached the designed densities only in Nakpa, while in Nakpanduri, plot A densities were far below what we designed and what farmers planted in C plots. The STMD sorghum establishment in Nakpanduri and Namburugu was satisfactory, but with the Mankaraga we did not obtain designed densities.

Table 3. Plant densities, 1984.

Location and crop	Plot A Planted	Plot A Expected	Plot A Observed	Plot B	Plot C
	plants/ha				
Nakpanduri					
Sorghum (plants)	92000	23000	11530	14150	9958
Groundnut	22100	22100	10120	19305	37740
Pigeon pea	33333	8333	8860	-	-
Namburugu					
Sorghum (stands)	6950	6950	6006	12218	8933
Maize	13888	10500	8950	10119	8381
Groundnut	41670	41670	23520	18905	21770
Wantugu					
Sorghum (plants)	37500	9375	5860	8725	8225
Maize	12500	9375	9980	14840	10300
Groundnut	37500	37500	20890	16680	19160
Pigeon pea	33333	8333	24000	-	-
Nakpa					
Sorghum (stands)	7500	7500	6275	9180	12225
Maize	15000	11250	13070	11985	11150
Groundnut	37500	37500	32970	31130	22635
Pigeon pea	33333	8333	24075	-	-

In Wantugu and Nakpa, most pigeon pea seedlings survived and we let them grow in the resulting high densities in the hopes of growing some green manure in 1984. By the time the maize was harvested, however there was still very little vegetative growth on the pigeon pea plants. Relay planting of pigeon pea fallow was only successful where it was planted at the beginning of August on lower lying fields.

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Nakpala soils crust very easily after rains, which impairs germination of cereals planted with the stick. The reason for this is that farmers' wives plant with a small hoe which just scratches the soil open, and they don't step on the seed to cover it. Partridges also posed a problem.

Only our cowpeas germinated well and formed a nice soil cover. This, however, frustrated two later attempts at replanting the cereals. The cowpeas yielded very little (50 kg/ha) because of insect attacks. Only on some B plots did the Sorghum yield about 600 kg/ha.

Yields and farmers' assessment of new varieties. In general, yields were low. The top maize yield was 939 kg/ha for Composite 4 in a Namburugu B plot, accidentally fertilized by the farmer (fig. 2). The top groundnut yield was 583 kg/ha from F mix in another Namburugu B plot, and the top sorghum yield was 820 kg/ha from Mankaraga on a Nakpa B plot. Most of the sites were on land that had supported at least one season with cereal/groundnut intercropping before. The variability in yields was tremendous, so the average yields from five trials per location, as presented in Fig. 2, only show some trends. For a closer look at production, we used plant productivity as the variable, because of the low plant densities.

Maize yields were always higher from Composite 4 in the A plots in Nakpa and Namburugu and in the B plots in Wantugu. However, when yields on a per plant basis were considered (Table 4), Composite 4 only expressed a higher yield potential in the A plots where it was fertilized. In plot A, maize may also have had less competition from sorghum. Eighty percent of the farmers liked this variety because it was higher yielding, somewhat drought resistant, shorter and had better cob formation.

Sorghum yields of variety STMD were highest in A plots in Nakpanduri and Namburugu. B plots also yielded more than farmers' varieties, even though all Namburugu farmers complained about heavy bird damages to STMD because it ripened one month earlier than the local sorghum. This is due to higher per plant productivity.

Table 4. Plant yields with three packages of management at four locations in 1984.

Package	Location	Maize	Sorghum	Groundnut
		g/plant		
A	Nakpanduri	0	32	9
	Namburugu	42	28	16
	Wantugu	23	21	15
	Nakpa	36	17	6
B	Nakpanduri	0	25	9
	Namburugu	29	13	18
	Wantugu	21	27	14
	Nakpa	25	28	7
C	Nakpanduri	0	12	10
	Namburugu	34	14	10
	Wantugu	20	33	9
	Nakpa	31	22	4

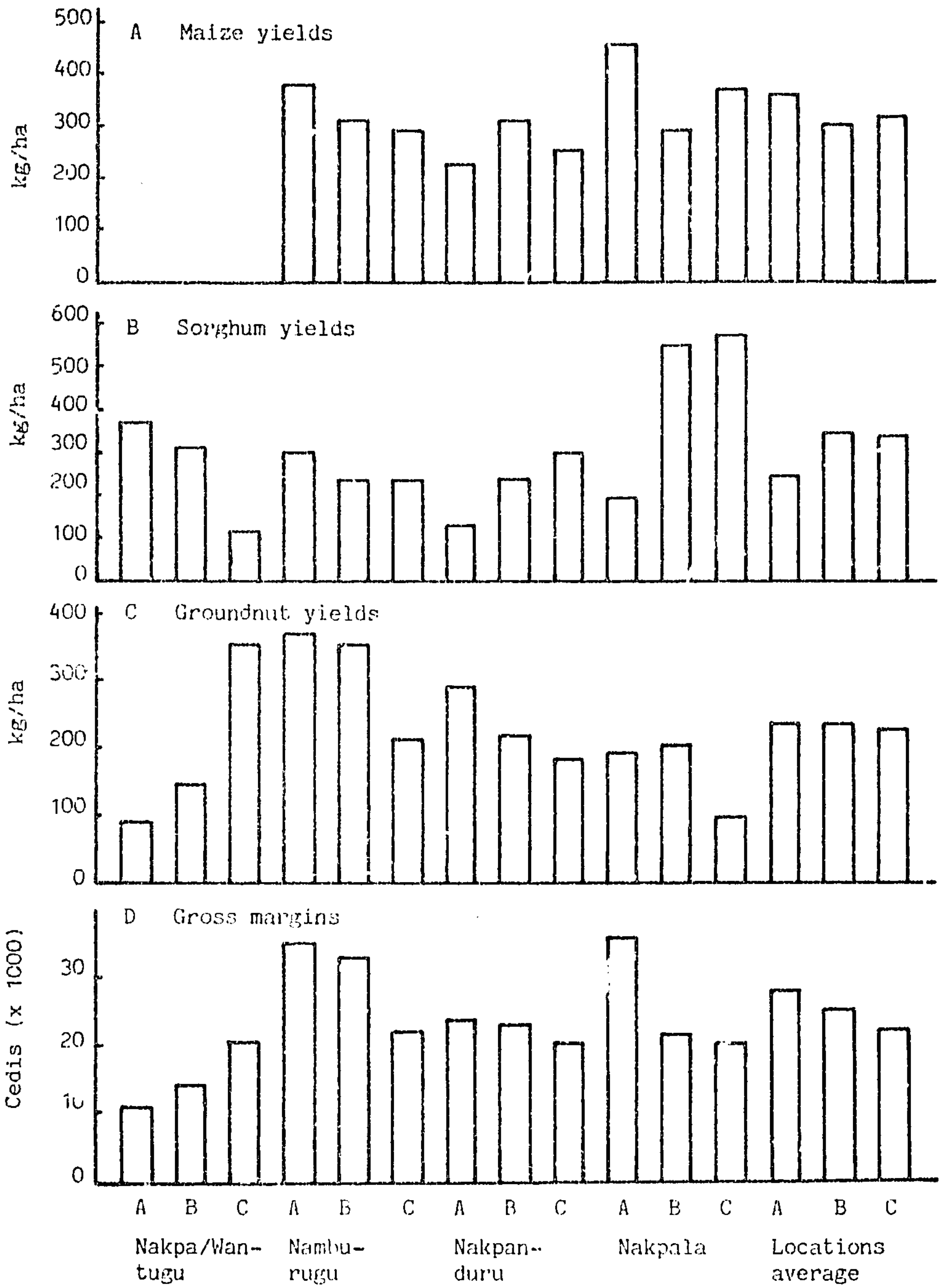

Fig. 2. Crop yields and gross margins achieved in on-farm experiments in four villages, 1984.

Sorghum yields from Mankaraga, a late maturing variety, in Wantugu and Nakpa were lowest on the A plots. Apart from the lower densities, alley cropping is to blame because of competition from pigeon peas. On a per plant basis, the Nakpa B plot sorghum was more productive than the farmers' variety, but in Wantugu the farmers' variety (a mixture including Mankaraga) was most productive, equal to STMD in Nakpanduri.

Groundnut yields of variety F mix were much higher than the farmers' varieties in Namburugu and Wantugu A plots, and in Nakpa B plots. In Nakpanduri, C plots outyielded F mix, but this was primarily due to the much higher plant densities. Per plant production of F mix versus the farmers' own variety was considerably higher in Namburugu, Wantugu and Nakpa. Differences in per plant productivity between A plots and B plots were not great, and no effect of rock phosphate application was observed. All farmers wanted to increase their area under F mix and many asked for more seed.

No pigeon pea seed yields were obtained in Nakpanduri or in Wantugu, primarily due to cattle and bush fire damage, but the results from Nakpa indicated a yield of 377 kg seed/ha. (Av. of 3 plots).

Assessment of new packages in Plot A. Nakpanduri. The area under groundnuts was not large enough. Sorghum did well and it always was taller than pigeon pea. So pigeon pea did not cause any visible competition for sorghum. In the beginning of the season, this system left the soil bare as only 2/7 of the area was under groundnuts. In addition both sorghum and pigeon pea have a slow initial growth, a factor which induces soil erosion risk. In order to make the system more attractive, pigeon pea should give some reasonable seed yield as well. Farmers appreciated the fact that this system was easier to weed and plant.

Wantugu and Nakpa. Groundnuts did well. The increase in groundnut yield compensated for the loss in area to pigeon pea rows. On a per plant basis, maize did well because of fertilizer. Moreover, if densities could be increased, maize would also help to compensate for the loss in area to pigeon pea rows. Pigeon pea probably competed for moisture with sorghum. Two farmers mentioned that pigeon pea also competes for nutrients (or responds to 15/15/15 fertilizer), while two others wanted to shift the site to more fertile soil because of poor pigeon pea yields. We never observed any nodules on pigeon peas. Farmers suggested to widen between-row or within-row spacing of pigeon peas and to use a shorter, earlier variety.

Namburugu. Double row intercropping was favourably received and farmers did not want any change. The fields of all crops were highest on the A plots, which all farmers agreed were the easiest to weed. The problem of bird damage may be reduced when STMD is grown by more farmers. Farmers doubted if they would have the labour available to put a large area under this more intensive system of planting. Quicker planting methods could be tried, as well as a within-plot annual rotation of groundnut and cereal.

Fertilizer was received very favourably by the farmers who used it. But none of the farmers in Nakpala have used it so far, nor have half of the farmers in Nakpanduri or Nakpa. All of the farmers questioned said they would buy fertilizer at 500 cedis/bag and apply it to their cereals. Eighty percent of the farmers complained about the unavailability of fertilizer and of the mismanagement of distribution by government agents.

Economic evaluation. The economic evaluation in terms of net result (NR)

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reflects the yields achieved in the various locations and treatments (Fig. 2). Moreover, it demonstrates the profitability of groundnuts due to their good market value. Thus the highest NR was achieved on the A plot in Namburugu, where the best groundnut yields were obtained. The lowest NR was on the A plot in Nakpanduri where groundnut yields were extremely poor. This correlation between groundnut yields and NR also affects the marginal returns achieved in the transitions from C to B to A.

With the exception of Nakpanduri, where some farmers obtained very good groundnut yields on the C plots, it would have been advisable for farmers to adopt only new varieties. In Namburugu, this alone resulted in a marginal benefit of c 11400 while the increase was c 6200. and c 2700. in Nakpa and Wantugu, respectively. As there is virtually no additional cost in the use of new seed, it is not surprising that farmers were always eager to try new varieties.

The transition from B to A plots yielded positive results in Nakpa, Namburugu and Wantugu, where marginal returns ranged from 900 to 9300 Cedis. Considering the substantial risks and cash expenses involved in this transition, however, these returns are still too low to encourage adoption. In Nakpanduri, it even resulted in losses of 3100. cedis, though this was essentially due to poor groundnut yields.

CONCLUSIONS

In spite of the high monetary value of groundnuts, farmers apparently tend to judge a cropping system primarily by the amount of sorghum and maize it produces, while the cash contribution of groundnuts seems to be less important. However, taste preferences towards maize or sorghum are different depending on the particular tribes. It can be observed that groundnuts take a much larger share of the fields that are controlled by the sons of household heads, whereas the fields that are managed by the household head to provide food for the family have usually high proportions of sorghum. These circumstances have to be taken into consideration when designing cropping systems for on-farm experimentation by allowing for a certain flexibility in the relationship of individual crops.

In the 1985 season, we will further pursue the pigeon pea alley/ cropping system, the pigeon pea plants, however will have to be pruned, spacing will have to be widened, and we will probably shift to a shorter photosensitive variety. In addition, more attention must be given to the correct time and method of planting in order to achieve better plant establishment. In the more remote areas, seed dressing to prevent seed losses due to partridge and rodents may also have to be considered. Finally, the results of the crop sequence trials on the station have reached a stage where on-farm testing would seem appropriate. Thus a crop succession of groundnuts followed by maize/sorghum is envisaged to suit farmers' crop requirements while simultaneously combining the beneficial effects of crop sequence and intercropping.

SUMMARY

This paper presents the preliminary results of farm surveys and on-farm trials in five locations in the Northern Region of Ghana. The trials consisted of farmers' varieties under farmers' practices, new varieties under both farmers' management or a complete package of new technologies. These packages consisted of two alley-cropping designs with pigeon

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pea and two row intercropping designs, all with rock phosphate application.

Plant establishment in the trials proved difficult under both farmers' management and under new technologies. However, some yield trends can be described.

Maize variety Composite 4 yields were equal to those of farmers' varieties under low soil fertility conditions. Groundnut variety F mix out-yielded farmers' varieties in three out of the four locations and was in high demand. Sorghum variety STMD and improved Mankaraga out-yielded farmers' varieties except where they were already largely made up of Mankaraga. Pigeon pea seed yield was not good because of too high plant densities, although pigeon pea growth seemed to respond to rock phosphate application. Groundnut did not respond to rock phosphate, which may have been applied too late.

The alley cropping design with double rows of sorghum and groundnut gave a reasonable sorghum yield but too low a groundnut yield. The alley-cropping design with maize/sorghum/groundnut in each ridge gave too low sorghum yields. Double rows of maize/sorghum and groundnut gave the highest yields of all crops and were the easiest to weed. The single row intercropping of cowpeas and maize/sorghum failed because of competition between cowpea and later interplanted cereals as well as insect attacks on cowpeas.

An economic evaluation of the varieties and packages showed the importance of groundnut for a high financial return. Adaptation by the farmer of only new varieties was profitable, but adaptation of the complete package gave variable results and often resulted in losses.

VARIETY DEVELOPMENT FOR ASSOCIATION CROPPING[1]

N. MULEBA[2], F. BROKMAN[3] AND D. KAGNE[2]

Cowpea is traditionally grown in mixture with cereals in Semi-Arid West Africa (Rachie and Roberts, 1974 and Steele, 1972). Several mixture arrangements are used: (i) cowpea and cereals seeds which are mixed prior to planting are sown as a random mixture with some hills bearing only cereals or cowpea plants, and others bearing both crops. (ii) cowpeas and cereals which are planted in separate hills almost simultaneously, resulting in a random mixture of both the crops (iii) cereals which are planted at the beginning of the crop season as well as cowpeas which are planted about one to one and half months after the cereals. Under this last arrangement, cowpeas are planted in patches where cereal plants either are missing or have poor growth. Cowpea yields obtained in such mixtures are generally low, 0.2 to 0.3 t/ha (Rachie and Roberts, 1974). This is due either to the dominance effect of the cereals or to the strong competition between the two crops.

Several attempts have been made to improve cowpea performance in mixed cropping with cereals. Good yields of cowpea (i.e., over 0.5 t/ha) have been obtained by planting cowpeas and cereals simultaneously and by manipulating cereal row-spacings and densities of both crops (Adetiloye, 1980; Cunard, 1981 and Haizel, 1974). Proper choice of cowpea cultivars has also been shown to reduce cowpea yield loss in intercropping with maize from 68 to 48% (Isenmilla, Babalola and Obigbesan, 1981). Adetiloye, 1980, showed that the yield of semi-erect and semi-prostrate cowpea cultivars was reduced by association with maize and ascribed this yield loss to shading. He also demonstrated that climbing cowpea cultivars performed satisfactorily in association with maize. Similar results were reported by Wien and Nangju, 1976; but the climbing cowpea cultivars caused severe lodging in maize, and thus lowered the maize yields more than the erect or spreading cultivars.

The shading effect of maize on cowpeas in intercropping was studied by Wahua and Babalola 1981. They showed that when more light was transmitted to cowpeas by a relatively short maize cultivar with erect upper leaves or by a liguleless, erect-leaf maize cultivar, the growth and yield of associated cowpeas was greater. It appears, therefore, that a great potential exists to increase the yield of cowpeas in association with cereals by properly choosing the cultivars of both crops. To test this hypothesis, experiments were conducted in 1981, 1982, 1983 and 1984 to study the effect of maize and cowpea cultivars on the performance of both crops in a relay cropping system in the northern Guinea savanna of semi-arid Africa.

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MATERIALS AND METHODS

Experiment 1. This experiment, initiated in 1981, studied the effect of cowpea cultivars, varying in maturity and daylength-sensitivity, on maize and cowpea performance in a maize-cowpea relay-cropping system in northern Guinea savanna (1100 mm rainfall, from June to mid-October). Three cowpea cultivars were used: VITA-4, a spreading and daylength-insensitive cultivar; 'Kaya local', an early, prostrate and daylength -sensitive, cultivar which flowers in late September; and IAR 1696, a late, prostrate and daylength-sensitive cultivar, which flowers in mid to late-October. They were planted at four dates under a maize crop: 23,36, 51 and 64 days after the maize. A 90-day maturing maize cultivar was planted in early June at 0.75 m spacings between and 0.25 m within the rows. Two maize seeds were planted per hill and thinned to one after two weeks. Maize plants were fertilized with N, P_2O_5 and K_2O (35, 25, 13 kg/ha, respectively) at planting and N (45 kg/ha) one month after planting. Cowpea plants were planted in solid rows alternating with maize at 0.75 m spacings between and 0.20 m within the rows. Cowpea plants were not fertilized, but were sprayed four times with insecticides. The experimental design was a 3 x 4 factorial in randomized complete blocks which were repeated four times.

The experiment was repeated in 1982 with a slight modification. The cultivar VITA-4 was replaced by VITA-5 because of the former's high susceptibility to foliar diseases. In 1983 and 1984 the experiment underwent major modifications. The number of dates of cowpea planting under maize was reduced from four to two: four weeks after maize planting and 10 days after maize silking. The number of cowpea cultivars was increased from three to seven. This included four daylength-sensitive cultivars (viz. 'Kaya local' and 'Ouahigouya local', both flowering in mid-to late-September; and 'Logofrousso local' and IAR 1696, both flowering in mid-to late-October) and three daylength-insensitive cultivars (viz. KN-1, TV x 3236 and VITA-5, all of intermediate maturing and spreading types). In 1984, IAR 1696 was replaced by the daylength insensitive cultivar TV x 1990-01F. The experimental design was changed to a split-plot with cultivars as main-treatments, and dates of planting as sub-treatments.

Experiment 2. This experiment was also initiated in 1981. It was designed to study the effect of maize cultivars, differing in maturity and morphological traits, on maize and cowpea performance in a relay cropping system. Two maize cultivars, one ninety days to maturity (Pool 16) and the other 105 days (IRAT 100), were relay-cropped with the three cowpea cultivars described in the first experiment. The maize crop was planted at a single date in early-June, whereas cowpeas were planted at two dates (i.e., four to five weeks after maize planting and slightly after maize silking). The agronomic practices used were the same as described in the first experiment. The experimental design was 2 x 3 x 2 factorial in randomized complete blocks which were repeated four times.

In 1982, the maize cultivar IRAT 102 (105 days to maturity) was substituted for IRAT 100. The experiment underwent major modifications in 1983 and 1984. The number of maize cultivars was increased from two to four, with two 90-day cultivars (viz. SAFITA-2 and JAUNE DE FO) and two 105-day cultivars in maturity (viz. SAFITA-102 and IRAT 178). IRAT 178 was substituted by IRAT 81 in 1984. In this same year, the number of cowpea cultivars was reduced from three to two: the "Ouahigouya local', an early, prostrate and daylength-sensitive cultivar; and the TV x 3236, a spreading and daylength-insensitive cultivar. The number of row-spacings was increased from one to two (viz. 0.75 m and 1.00 m). The experimental design was a split plot with maize cultivars as main-treatments and a factorial combination of two row-spacings and two cowpea cultivars as sub-treatments.

Our observations were taken as follows: Flowering and maturity dates were calculated as the number of days from planting to the day at which 50% of the plants bore flowers (or silk for maize) and 50% of the plants bore dry pods (or grains with a black layer in the middle of the ear), respectively. Maize plant height was measured shortly after silking and was calculated as the distance from ground level to the collar of the flag leaf. The leaf area index (LAI) was estimated at anthesis as plant density per unit land area times the average leaf area per plant. This can be calculated as leaf length x leaf width x 0.75 (Montgomery, 1911). Average leaf area per plant was based on five plants bordered by others in row number three of each plot.

RESULTS

Experiment 1. Cowpea cultivars did not affect maize seed yield during the four years in which the experiment was conducted. They also did not influence maize dates of silking or maturity, ear or plant heights, nor did they affect the LAI studied in 1983 and 1984. Cowpeas planted 30 days after maize did not have a detrimental effect on maize seed yield, except in 1983 when an 8% yield drop was observed (Table 1). On the other hand, cowpeas planted 21-23 days after maize reduced maize yield by 8% and 13% in 1981 and 1982, respectively. The differences was statistically significan in 1981. Since cowpea dates of planting had no significant effect on the maize date of flowering, or on ear and plant heights studied in 1983, the 8% maize yield drop observed that year (in plots where cowpeas were planted 30 days after maize) was attributed to drought damages. In fact,

Table 1. Effect on maize seed yield of dates for planting cowpeas as a relay crop in maize, Farako-Bâ, Burkina Faso.

	Years [1]			
Time of cowpea planting	1981	1982	1983	1984
	kg/ha			
21-23 days after maize	4400 b	4762 a	-	-
30-36 days after maize	4785 a	5570 a	3559 b	3095 a
47-51 days after maize	4813 a	5424 a	-	-
57-64 days after maize	4791 a	5450 a	3886 a	3197 a
LSD (5%)	237	NS	274	NS
CV (%)	6.1	18	14	14

[1]Means followed by the same letter are not statistically different at 5% probability level.

the rains ended in mid-September in 1983 when maize plants were in the grain-filling stage and cowpeas were 50 days old. A strong competition for moisture between cowpea and maize plants could have hampered the maize grain fill.

Delayed cowpea planting under maize significantly reduced seed yield of relay-cropped cowpeas, except in 1982 when the reduction was not statistically significant (Tables 2 and 3). The early daylength sensitive cultivar, Kaya local, yielded equally or significantly higher than daylength -insensitive and late daylength-sensitive cultivars at all the dates of planting during the four years. The only exception was 47-51 days after the maize in 1981. This cultivar appeared well adapted to the maize-cowpea relay-cropping system, particularly when planted thirty days after maize. It was followed by TV x 3236, a daylength insensitive cultivar.

Table 2. Effect on cowpea seed yield of dates for planting cowpeas and cowpea cultivars in relay-cropping with maize, Farako-Bâ, Burkina Faso, 1981, 1982.

Cowpea Cultivars	Dates of planting: 21-25 days after maize	30-36 days after maize	47-51 days after maize	57-64 days after maize	Mean
	kg/ha				
1981					
VITA-4	380	338	552	227	367
Kaya local	1599	957	796	745	1024
IAR 1696	1564	1097	998	865	1131
Mean	1181	979	771	612	841
1982					
VITA-5	767	555	645	668	659
Kaya local	822	838	849	785	823
IAR 1696	638	698	185	349	468
Mean	742	697	560	601	650

Mean Comparison	1981 LSD (5%)	1981 CV (%)	1982 LSD (5%)	1982 CV (%)
Date of planting	105 kg/ha	15.1	NS	41.8
Cultivar	91 kg/ha		199 kg/ha	
Date x cultivar	183 kg/ha		NS	

Table 3. Effect on cowpea seed yield of dates for planting cowpeas and cowpea cultivars in relay-cropping with maize, Farako-Bâ, Burkina Faso, 1983, 1984.

Cultivars	1983 30 days after maize	1983 64-70 days after maize	1983 Mean	1984 30 days after maize	1984 64-70 days after maize	1984 Mean
	kg/ha					
Kaya local	460	0	225	530	390	460
Logofrousso local	78	0	39	62	31	46
Ouahigouya local	451	0	226	378	173	275
IAR 1696	120	0	60	-	-	-
TV x 1999-01F	-	-	-	272	375	324
KN-1	365	0	183	328	205	266
TV x 3236	510	0	255	475	470	472
VITA-5	469	0	245	401	214	308
Mean	352	0	176	349	265	307

Mean comparison	1983 LSD (5%)	1983 CV (%)	1984 LSD (5%)	1984 CV (%)
Cultivars	100 kg/ha	54	179 kg/ha	39
Dates	64 kg/ha		60 kg/ha	
Cultivars x dates	NS		NS	

Experiment 2. In 1981, the intermediate maturing cultivar IRAT 100 produced a significantly higher yield (by 15%) than the early maturing Pool 16 (Table 4), whereas in 1982, the intermediate maturing IRAT 102 yielded equally to Pool 16 (Table 4). In 1983 and 1984, the intermediate maturing cultivars, IRAT 173 and SAFITA-102, yielded equally to the early maturing cultivars, SAFITA-2 and JAUNE DE FO (Table 5). However, the IRAT 81 significantly out-

Table 4. Mean plant height, flowering dates and seed yield of two maize cultivars differing in maturity groups, grown in a maize-cowpea relay cropping system, Farakao-Bâ, Burkina Faso, 1981 and 1982.

Maize cultivars	Plant height[1] 1981	Plant height[1] 1982	Silking date[1] 1981	Silking date[1] 1982	Seed Yield[1] 1981	Seed Yield[1] 1982
		cm		DAP	kg/ha	
Pool 16	-	153 b	-	56 b	5733 b	4306 a
IRAT 100	-	-	-	-	6602 a	-
IRAT 102	-	215 a	-	63 a	-	4202 a
LSD (5%)	-	11	-	1	206	NS
CV (%)	-	10	-	1	4	20

[1]Means followed by the same letter are not statistically different at 5% probability level.

yielded SAFITA-102 (by 27%) and the two early maturing cultivars (by 26% on the average) in 1984 (Table 5). The early maturing cultivars had a short plant height (except JAUNE DE FO) and a small LAI (Tables 4 and 5).

The Seed yield of relay-cropped cowpeas was significantly reduced by the later maturing maize cultivars (Table 6). Cultivar differences were also observed within maize maturity groups. IRAT 178 and IRAT 81 significantly reduced seed yield of relay-cropped cowpeas, especially when compared to the results of SAFITA-102 in 1983 and 1984. It should be noted that the depressing effect of JAUNE DE FO on the seed yield of relay-cropped cowpeas was not significantly different from that of SAFITA-102.

Table 6. Effect on cowpea yield of maize cultivars in a maize-cowpea relay-cropping system, Farako-Bâ, Burkina Faso, 1981 to 1984.

	Years[1]			
Maize Cultivars	1981	1982	1983	1984
90 days to maturity	kg/ha			
Pool 16	899 a	500 a	-	-
SAFITA-2	-	-	315 a	808 a
JAUNE DE FO	-	-	250 ab	613 b
105 days to maturity				
SAFITA-102		-	230 b	589 b
IRAT 100	628 b	-	-	-
IRAT 102	-	495	-	-
IRAT 178	-	-	161 c	-
IRAT 81	-	-	-	449
LSD (5%)	99	NS	70	108
CV (%)	18	36	36	11

[1]Means followed by the same letter are not statistically different at 5% level.

It appeared that the LAI influenced the seed yield of relay cropped cowpeas more than the plant height. In fact, JAUNE DE FO was as tall as IRAT 178 and IRAT 81, but had a significantly smaller LAI. Moreover, it reduced cowpea seed yield less than the latter two cultivars in 1983 and 1984. It is possible that differential competitive ability at the root level might have played a role in cowpea seed yield reduction within maize maturity groups.

DISCUSSION

As reported by Wien and Nangju, 1976; Adetiloye, 1980; Isenmilla et al., 1981; and Wahua and Babalola, 1981; cultivar differences were observed in the performance of cowpea and maize in mixed cropping, and the competitive effect of maize on cowpeas in a maize-cowpea relay cropping system. Daylength sensitive cowpeas, because of their critical photoperiod requirements for flowering (which may occur, depending on cultivars, in mid to late-September, early, or mid to late-October), were shown to be better suited to a maize-cowpea relay-cropping system than most of the daylength-insensitive cultivars (Tables 2 and 3). This is because they can be planted one month after maize (mid-July), will grow vegetatively and, depending on the photoperiod response, will flower slightly before or after maize harvest.

In contrast, daylength-insensitive cultivars, planted under the same conditions, flower after 45 days while still under the maize canopy and, as a result, compete with maize for light, water and nutrients. However, because of erratic rainfall in late September and October, the late maturing day-length-sensitive cultivars (which flower during this period suffered severe drought damages during those crop seasons where rains ended in mid-September or early October, as was the case in 1982, 1983 and 1984 (Tables 2 & 3). Their yields dropped to almost zero, a loss which the peasant farmers could not afford as they are highly dependent on cowpeas as a major source of protein. Thus, these types of cowpea cultivars did not appear to be suited to maize-cowpea relay-cropping systems.

On the other hand, the early maturing daylength sensitive cultivars were more adapted to a maize-cowpea relay-cropping system than late daylength sensitive and daylength insensitive cultivars. Cowpea seed yields varying from 0.5 to 1.5 t/ha were observed with the cultivar 'Kaya local' (Tables 2 & 3), a big improvement when compared to the reported cowpea seed yield of 0.2 to 0.3 t in traditional mixed cropping (Rachie and Roberts, 1974). The low yield of the 'Ouahigouya local' in this category was due to its high susceptibility to diseases (bacterial and web blight, scab and rust).

Increased shading by more leafy intermediate maturing maize cultivars appeared to be responsible for reduced cowpea seed yield in relay-cropping with maize. Similar results were reported by Wahua and Babalola, 1981. However, there were some indications that increased competition for water and nutrients within the root system might also be involved in the reduced seed yield of the relay cropped cowpea. This was supported by the existence of maize cultivar differences in depressing the effect of seed yield of the relay-cropped cowpea within maize maturity groups. LAI did not differ within maize maturity groups (Table 5). With respect to cowpea seed production, early maturing and less leafy maize cultivars appeared to be better adapted for maize-cowpea relay-cropping than the more leafy intermediate maturing ones. Maize seed yields varying from 2.5 to 5.7 t/ha were observed for these cultivars during the four years that the experiment was conducted (Tables 1, 4, 5). Thus, by carefully choosing the proper maize and cowpea cultivars, a good yield can be obtained from both crops in a relay cropping system in the northern Guinea savanna.

SUMMARY

Cowpea is traditionally grown in mixture with cereals in semi-arid West Africa. Seed yield obtained in the mixture is generally low, varying from 0.2 to 0.3 t/ha. Experiments were conducted in 1981, 1982, 1983 and 1984 to study the effect of maize and cowpea cultivar differences on the performance of both crops in relay cropping, and to determine ways to increase seed yield of relay cropped cowpeas. Our findings show that cowpeas planted 30 days after maize had no detrimental effect on maize seed

Table 5. Mean plant height, flowering and maturity dates, leaf area index, and seed yield of maize cultivars differing in maturity groups, Farako-Bâ, Burkina Faso, 1983, 1984.

	Plant height[1]		Silking date[1]		Maturity date[1]		Leaf area index[1]		Seed Yield[1]	
Cultivars	1983	1984	1983	1984	1983	1984	1983	1984	1983	1984
	cm		DAP		DAP		LAI		kg/ha	
SAFITA-2	132c	141c	64b	61b	92c	91b	1.39b	1.52b	2716a	[illegible]301b
JAUNE DE FO	166a	186a	71a	62b	94bc	91b	1.54b	1.70b	2091a	2631b
SAFITA-102	140bc	152b	70a	70a	98a	105a	1.80a	2.01a	2859a	2401b
IRAT 178	155ab	-	70a	-	96ab	-	1.84a	-	2497a	-
IRAT 81	-	180a	-	71a	-	106a	-	2.37a	-	3318a
LSD (%)	16	10	4	2	2	1	0.28	0.44	NS	633
CV (%)	13	4	7	2	3	0.4	21	14	21	15

[1]Means followed by the same letter are not statistically different at 5% probability level.

yield. Cowpea cultivars did not significantly affect maize seed yield at any of the tested cowpea dates of planting (21 to 64 days after maize). Early daylength sensitive cowpea cultivars (which flower in mid to late September) appeared to be better adapted to maize-cowpea relay-cropping than the late daylength sensitive cultivars (which flower in mid to late-October) and most other day length-insensitive cultivars. With respect to cowpea seed production, early maturing and less leafy maize cultivars appeared to be better suited to maize-cowpea relay-cropping than the intermediate maturing and more leafy maize cultivars. The former depressed less seed yield of relay-cropped cowpeas than the latter. Thus, by proper choice of cultivars of both crops, good yields of maize (2.5 to 5.7 t/ha) and cowpea (0.5 to 1.5 t/ha) were achieved.

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LIVESTOCK IN THE AGROPASTORAL SYSTEMS OF THE SAHEL-SOUDANIAN AND SOUDANO-SAHELIAN TYPE: PROBLEMS OF TECHNICAL CHANGE

G. SERPANTIE [1]

In this review, drawn up mainly from biographical elements, we suggest the bases of a reflection on technical change in the livestock-rearing field of the soudano-sahelian and the sahel-soudanian sector.

With various sectorial actions to promote this activity opening up in these areas, it seems important to recall the need to view this activity in the context of agrarian systems.

The context normally used to project a technical change is "the system of livestock-rearing". Generally defined in a restrictive manner as a sub-system of a production system "collection of workshops and the techniques enabling the production of animals and animal products in conditions meeting the goal of the cultivars under the contraints related to development activity" (Agriscope, 1983). This concept is worth taking up in a broader context, in our area ; indeed, here the weight of human factors (ethnic culture, the structure of social relations in production, collective management of resources), the importance of the relationship with other agrarian activities (agriculture and harvesting) or non-agricultural activities (displacement for work, trade), leads us to tackle the question of livestock-rearing in a broader context, namely the agropastoral system.

The interactions of this system is shown in Fig. 1 (Milleville et al., 1982). It becomes obvious that we shall not be able to tackle on its own the level of organization of the "production cell" in a context of collective use of resources, leading to exchange, complementarity or competition between specialized production cells. The agropastoral area, on which are expressed these complementarities and the cohesion of a social group, will be the appropriate level of study. This area will be completed by the addition of the spaces used occasionally (seasonal migrations, salt treatment) which are indispensible for the yearly operations.

We borrow from Lhoste (1985) his table of the features of a broadened livestock system (Fig. 2). It enables us to begin work on a study of the dynamics (operation and evolution) of these systems, to obtain a model to lay the foundations of a diagnosis, and particularly to assess the impact and the effects of a technical change. This diagnosis is also used to measure the sensitivity variations of the system according to a change in the socio-economic and climatic contexts.

Between the "pillars" of the systems (pastoral and agricultural resources, herd, peasant) are found some unifying elements which will show clearly the operations themselves and enable the diagnosis to be made; in particular, between the herdsman and the herd we see livestock strategies and pratices and the function of the agricultural area as a whole (food-wise, economic, cultural, religious, reproductive pattern), and methods of economic promotion (meat, milk, wool, manure, work based on animal traction, money).

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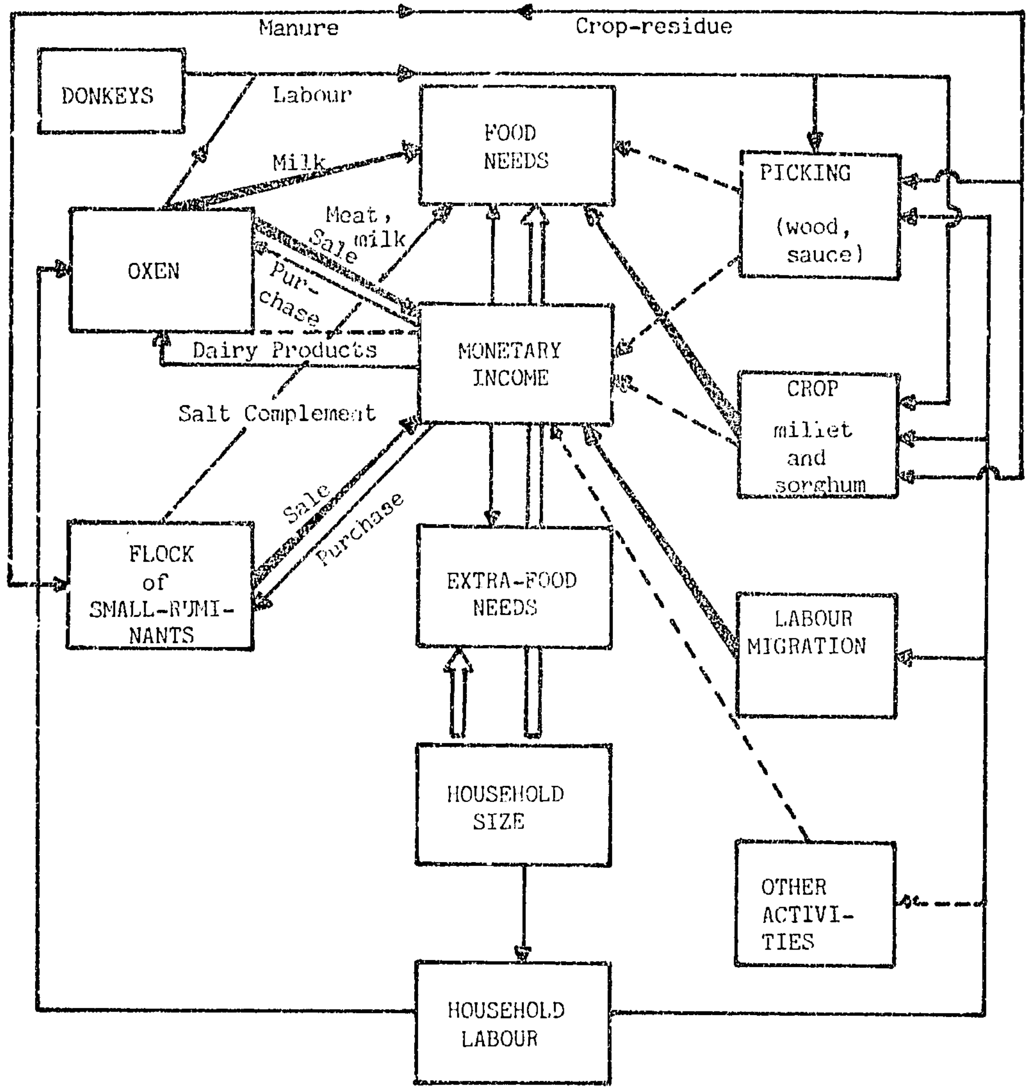
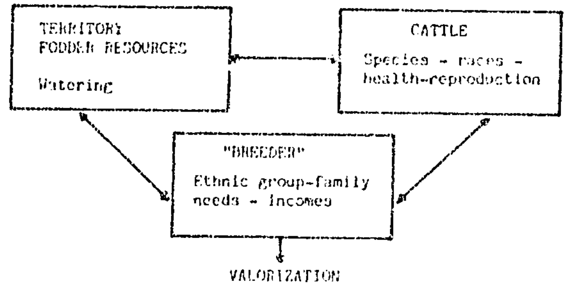


Fig.1. General scheme of an agro-pastoral farming system. By Milleville et al. (1982).

a) Poles

b) Component table



"POLES"	"COMPONENTS"	CHARACTERISTICS	PRODUCTS
TERRITORY	- Structuration	Fodder Resources Units Distribution -Areas	Card
AND	- Primary Production	Phytomass Chemical composition Food value	gross production (phytomass) Food value
(FARMING-SYSTEMS	- Animal use	Accessibility Appetibility Ingestibility	LOAD Utilization card
	- Temporal evolution	Seasonal variations Inter-annual variations Eco-system reproduction	"fodder spectrum" (according to BUDGET) Follow up of pasture-lands
(on inter-face: coherence levels)	- Diet and Spatial behaviour	Balances - organic matter - fertility (linkage with farming system) Fodder System	Fodder balance Area Typology (method of using)
CATTLE	- Structure (static characteristics)	- species, race, genetic type - establishment - composition	Age pyramids
	- DYNAMICS (dynamic characteristics)	- Reproduction (fertility, fecondity) - mortality - Exploitation and increase	Numeric Productivity
	- ANIMAL (individual condition)	- State of Health - physiologic stage - Development stage - individual performances	Selection criteria CALENDARS
	- BEHAVIOUR	- Cattle - Feeding - Reproduction	
	- PRODUCTOINS	- Meat, milk, wool - Manure, Labour, transport	"ANIMAL PRODUCTS"
	- PRACTICES Care Behaviour Know-how (economic, cultural, religious)	Roles of cattle MODE OF VALORIZATION	Product Diversity
BREEDER	- Ethnic group, Family, History - Projects - Livestock organisation, different agents - function, decision making center - Needs/Incomes - Relations with the community - Livestock Service and other organizations		"socio-economic logic" Budgets Social Organization
(Inter-face: coherances)	Land Tenure	Space and pasture-land management Strategies Transhumance, manure	
TERRITORY			

Fig. 2. Comprehensive presentation of the major components and characteristics of a generalized livestock production system. By Lhoste, 1985.

Between the resources (pastoral land, water resources and products of the cultivation and harvesting systems) and the herd, we notice a certain type of feeding habits, fodder and watering systems, and movements and we shall set up balance-sheets (fodder, water, fertility). Finally, between the herdsman and the resources is a system of land organization and a strategy for making use of the resources and the space.

In line with this organization an interdisciplinary team from ORSTOM is undertaking a study of an agropastoral system in the Yatenga (Bidi area), in collaboration with the Research Development project led by IBRAZ/CIRAD. This study is a follow-up of the "Oursi-Lake" project undertaken in a sahelian zone, where the agropastoral systems have been studied (Milleville et al., 1982 ; Lhoste, 1985) and a follow-up also of the numerous works of geographers (Benoit, 1982 ; Bartal, 1977 ; Marchal, 1983) in this region (Fig. 2).

The interdisciplinarity fits in well with the model in so far as for the observation of the poles and the interfaces we use a special competence which looks specifically at each level of development. The real difficulty in the way of agropastoral diagnosis remains the differential between the temporal rhythm to operation and the delay in specific responses of each sub-system.

We try to overcome these difficulties by working out case studies and wide-ranging investigations during which numerous unities are observed (simple experiments and historical method).

MAIN FEATURES OF THE SOUDANO-SAHELIAN AND SAHELO-SOUDANIAN AGROPASTORAL SYSTEMS

These ecogeographical zones (about 400 to 800 mm annual rainfall) are characterized by the coexistence of agricultural activities and of non-pastoral and pastoral livestock-rearing. The ways in which these three activities are integrated are demonstrated mainly by :

(1) animal traction (soil tillage, transporting) is not commonplace in Burkina,
(2) the production and use of manure : moving from sylvopastoral to agricultural systems,
(3) utilization of left-overs of the harvest for food supplies during the dry season and the fattening time of the herd,
(4) utilization of fallow fields.

These forms of integration are re-emphasized by complementary and competitive relationships according to the employment of factors of production.

In the sahelian pastoral zone, water for livestock can be the main limiting factor. On the other hand, in the sahelo-soudanian zone, the adequacy of fodder supplies for the animal population presents a highly crucial problem. Indeed, we witness a progressive reduction in fodder potential, while the human and animal pressures are rising. As a result, systems of production adapted to a weak pressure on the area and to space with few limits have become more and more fragile (Milleville et al., 1982).

The soudano-sahelian zone has been marked for a long time by increasing competition between livestock and agricultural activities with regard

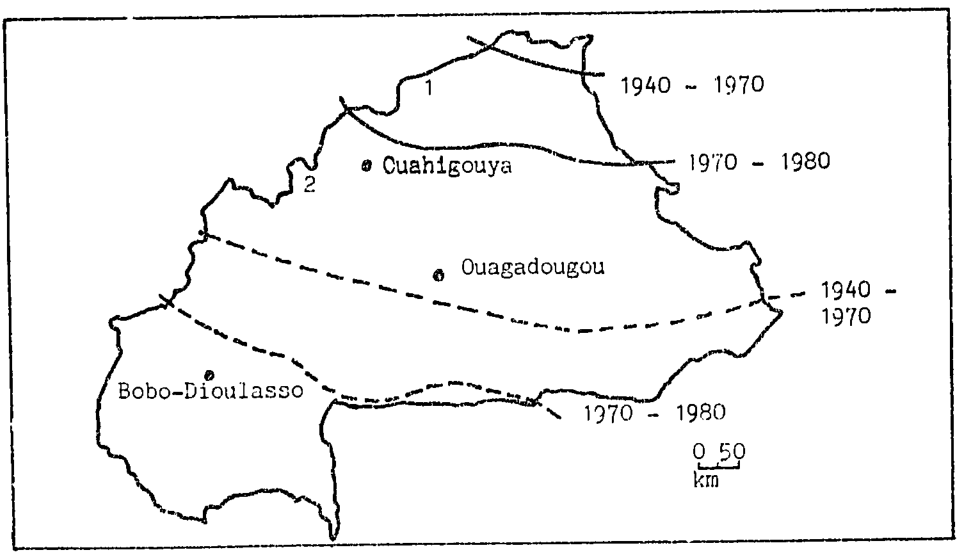


Fig. 3. Location of study areas in relation to isohyets. After Albergel et al., 1985.
1: Oudalan ; sahelo-soudanian zone.
2: Yatenga ; soudano-sahelian zone.
———: Isohyet 500 mm 1940 - 1970 and 1970 - 1980 .
- - - - -: Isohyet 900 mm 1940 - 1970 and 1970 - 1980.

to space. The animal population there in particular is unanimously described as over abundant (Couloub and Serres, 1980). The strong demographic pressure there leads especially to over-exploitations of the area. The trends towards degradation have been described by Marchal (1983).

One of the most important results of the studies carried out is that we are unable to conceive in any sector a model and stereotyped agropastoral system. Indeed, if certain conditions belonging specifically to the zone are inevitable (climate), the dispersion of resources over the area, in conjunction with a strong diversity of cultures and objectives existing side by side of systems for exploiting the area which are very different from one another, both at the regional level and at the level of the agropastoral unity.

FUNCTIONS OF THE ANIMAL POPULATION AND LIVESTOCK-REARING STRATEGIES

The livestock population, an animal group transforming plant resources, is above all a means of production and stockpiling. Its exploitation has to meet a part of the food and monetary needs of the family group. Nevertheless, it fulfills other functions : economic, social and religious.

Milleville et al., (1982) show in the Oudalan (sector sahelo-soudanian), that livestock is the only means of holding capital for families and individuals[1], or there exist rules for sharing livestock within the family and occasionally outside the family, the animal population plays a decisive role in the process of social reproduction. The passing-on of the livestock to the children of a surviving parent foresees thereby the possibility of splitting up the herd when a son is able to attain real autonomy. Other ways of passing on livestock (inheritances, dowries, exchanges and transactions) contribute to a high turnover in the owning of livestock. The distribution of livestock is therefore the result of a combined history of the herd and the family which controls it.

In addition to this strengthening of the ties of union between the different individuals who make up the family group, certain practices related to the guardianship and the yielding-up of livestock indicate the confidence of the relationships between different families.

These social necessities, added to the search for prestige and to the needs of hospitality and religious sacrifices lead by themselves to the permanent growth of the family's livestock population. This complements the obvious economic and technical advantage of holding a significant number of animals. Thus the size of the animal population plays a role of the highest importance with regard to the quality of conduct (guardianship, seasonal migration), and only the shortage of water for livestock in the dry season calls for work in proportion to the number of heads. Furthermore, the large size of the herd favours its exploitation (milk, manure, commercial uses), and improves zootechnical performances (competition between herdsmen and young animals with regard to milk). In addition the livestock practices adopted for the running of the large herds shelters them to some degree from the consequences of difficult years (the seasonal migrations are more frequent). Thus the logical result would be that the herd grows in size, so that it fulfills its multiple functions while minimizing the risks.

The structure itself of the herd reveals the same functions. For example, the practice of keeping a high contingent of male adults, which are the beasts

1 In so far as it is always owned on an individual basis.

the most able to adapt themselves to difficult conditions and which play a role in the cohesion of the herd.

In the soudano-sahelian zone, in addition to the functions already referred to, there is, for agropastoral systems, a role of work-force (animal traction). The rearing of small animals (small ruminants) fulfills a function of high investment. The fattening of sheep is developed by the cultivators from the point of view of short-term profit and for making use of sub-products, reacting to the spur to development actions.

THE EVOLUTION OF RESOURCES AND THE AGRO-PASTORAL SYSTEMS

In the sahel-soudanian and soudano-sahelian zone (as in the case of the Yatenga), there appear a contradiction between individual goals and what we might judge desirable at the level of a collection of resources and of collective expansion.

Forage resources. The zone's potential forage, represented by natural pastures, fallow, and sub-products has been described by Baudet (1985), and earlier by Coulomb and Serres (1980).

The sahel-soudanian sector of the sahelian pastures and the soudano-sahelian sector of the soudanian pastures make up the transitional region, with an average annual rainfall of between 400 and 800 mm, good year-round pastures and a high utilization of the soil by crops.

Lowlands	Productive pasture (*Echinochloa colona*, *Setaria pallide-fusca*.
Sandy soils, 50-70 days per year per hectare of pasture of one U.B.T.	Ligneous surface (Combretacian) increasing from north to south (5% to 30%). Shady graminaceae (*Pennisetum pedicellatum*). Mixed savannah or land open to sun (annual graminaceae (*Diheteropogon hagerupii*) and perennial (*Andropogon gayanus*).
Colluvial slopes, 25 days per year per hectare, 1 U.B.T.	Thicker ligneous surface : Acacia seyal in the north, large-leaned trees, deciduous in the south (*Butyrospermum paradoxum* and *Parkia biglobosa*). Mixed savannah dominated by *Andropogon gayanus*.
Denuded lands	In the north, open low woods of *Combretum micrantum* and *Pterocarpus lucens*.

The vegetation often looks like sage brush corresponding to a reduced steppe. Vegetation of the diminutive type with *Loudetia togoensis*, on very light slopes and underlying fine gravel, *Andropogon pseudapricus* on shelves with thicker soils, *Pennisetum pedicellatum* at sheltered points. Twenty days per year per hectare of pasture of 1 U.B.T. These pastures are not suitable.

The cultivation of millet and groundnuts is very widespread on paraplaned lands, colluvial slopes and the scattered sandy soils. The residue of the harvest is consumed by the village herds, which are joined by the migrating herds.

The fallow is leguminous-rich. (Zornia glochidiata).

In the north, the cultivated lands taken over from pasturelands, can be degraded as a result of repeated cultivation on fragile soils (particularly by work carried out without precautions on the bush fields), more serious in that the soil is insufficiently protected during the rains and that it suffers in the dry season from an intense aeolian erosion (mainly after the removal of the residue of the harvest (sorghum, groundnuts, millet, cowpea) and a breaking-up of the soil trampled on by the animals.

The routes used in the rainy season, and in particular the colluvial slopes composed predominantly of fine sand and silt, quickly become sterile and warped beaches where there survives only the grass Microchloa indica, which indicates a critical stage of degradation only a short time before the ablation of the superficial horizon, with the disappearance of the herbaceous carpet and the withering-away of the ligneous cover.

At the moment, overgrazing seems to be generalized and lead to a degradation of routes described by numerous authors (Benoit 1982, Baudet 1985, Grouzis 1979, Marchal 1983, Toutain and de Wispeleare 1985). In addition to degradation (destruction of trees, erosion, increase of certain graminaceae) there is the effect of the shortage of recorded rainfall since 1968 (Albergel and Grouzis, 1985). The work of ORSTOM at the lake of Oursi has thus shown the relationship existing between the herbaceous biomass of this reservoir and the average rainfall it receives.

The continued extension of the cultivated area over the grazing area, creates conflict between the herdsmen and the cultivators and the shortening of the fallow for grazing, arising from demographic increase without modifying the agricultural system, is the third cause of a dramatic reduction in the fodder resources in these sectors. Thus, in the sahelo-soudanian zone (Oudalan), Milleville et al.,(1982) observed land-clearing followed by the cultivation of the drained areas reserved for the first winter grazing and densely wooded areas. These agricultural extensions, coupled with the rivalries between groups of herdsmen, related to the diminishing resources, result in overcrowded areas, thereby hindering the seasonal migrations (Milleville et al., 1982).

The use of the residue of the harvest is also altered and we notice that the non-nomadic peasants use it for feed. The keeping of stocks, as well as other factors (reduction of available millet, increase of stock-farming by the non-nomads, use of alternative manures) result in, among other things, the gradual disappearance of "manure contracts" which formerly strengthened the complementarity of specialized production cells, and to a reduction in guardanship pratices.

This evolution in the erosion of fodder resources is translated by the expansion of cultivated surfaces, systems centerd on livestock-rearing, and the growth of animal-farming in systems based on agriculture (mainly through oxen and small ruminants). This evolution has been supported by development actions more oriented towards veterinary activity and non-nomadic animal-farming in the agropastoral systems.

Water resources. Although this factor could be only a little restrictive, the question of water is relevant to certain soudano-sahelian zones. In 1982, Benoit wrote : "with regard to the lowering of the underground water tables, three phenomena seem to take place at the same time : firstly the lower rainfall since 1968 ; then an extraordinary deforestation which causes the running-off of the water to accelerate at the expense of underground waters ; finally the excessive pressure of demand which uses up the reserves". On this last point, indeed we notice in certain areas, competition for the use of underground waters between domestic and animal needs on the one hand, and the new activity of gardening which is developing constantly in certain regions. During the dry season, a bovine uses between 20 and 30 litres, a small ruminant about 8 litres, and one single eggplant 5 to 10 litres of water.

Evolution of the systems. We have seen that logically, in systems mainly based on grazing, the herd should increase to fulfill its functions, which requires open land and abundant resources. In a framework of limited space and diminishing resources, the systems have to fit in to areas which are getting smaller, which leads to, besides conflicting rivalries, a deterioration in the quality of the systems : vulnerability, less efficiency, threatened reproduction potential.

Moreover, unbalanced competition for the use of resources with the non-nomadic activities (crops, gardening, trade in fuelwood), now makes one question the validity of systems which are mainly pastoral, to the benefit of agropastoral systems, and leads to the necessity for other forms of gain in every case (trade, panhandling, food crops). These migrations themselves break up the systems by unbalancing the work force.

It is far from certain that the agropastoral systems, although they receive better support from development actions, are the least vulnerable and the best adapted in so far as, on the one hand, their action on the area seems particularly unfavorable in certain respects (cultivation of fragile lands, animal traction in unprotected conditions, exporting of the straw) ; on the other hand their reliance on the provision of supplies (seeds, additional food-stuffs, fertilizer), on labour, prices, credit and above all unpredictable weather conditions is very clear. The lowering of production levels is furthermore a reality in this sector.

When the resources of an area diminish at the same time as human pressure increases and the cultivation methods are not changed, we can only bear witness to a process of growing poverty.

LIMITS AND HOPES OF TECHNICAL CHANGES IN RAISING LIVESTOCK

The context of this note will not permit a close evaluation of most of the appropriate technical themes, but we propose to give a brief review of the main ideas put forward by research.

Regional specializations. For Santoit (1983), the principle of the specialized use of space in a country "being born" (sylvopastoral zone of the north) and in a country where the organized fattening of animals (Velley, south) has been followed for about ten years by some sahelian states, should be questioned again. Based on essentially technical consideration, such a plan constitutes a framework which is too rigid and very badly adapted to the diversity of agropastoral systems, and to the equilibrium of the herd structures.

On the other hand, the destocking policies at the beginning of the dry season, the goals of which cover both a reduction in over-grazing and an encouragement for the commercialization of the herd, go against the herd's functions and can lead to some difficulties in leading a herd without its old males.

On the contrary, Milleville et al.,(1982), show that in certain conditions (sahelo-soudanian), intraregional development specialization between zones where the pastoral action is given priority and zones where the priority is accorded to cereal production, could result in encouraging a better intraregional complementarity and particularly in reducing the taking-over and the squeezing of the pastoral space by crops.

Pastoral-based systems. The preservation of the environment and its regeneration, improvement in fodder productivity, restoring of deteriorated pasture-land, replanting of ligneous stock on anti-erosive sites, partial defence measures, the gleaning and stocking of fodder to improve the quality while reducing losses, fodder cultivation ; for Milleville et al., (1982), so many activities which should be tested around agglomerations, certain camps, and in places ecologically appropriate. It seems illusory to expect significant results on the regional scale in the short term. The works of Toutain and De Wispelaere (1977) and of the CIDR, tend on the other hand to prove that certain areas have deteriorated too much to be able to envisage restoring them at an acceptable cost.The priority would be rather to try to contain the process of deterioration of those areas which have not yet reached this stage.

Nevertheless, Boudet (1985), strongly recommends the enrichment and the restoration of certain deteriorated links of the seasonal chain of certain areas. This operation, according to him, can only be effectively carried out by the herdsmen themselves, who are too scarce and insufficiently equipped to do this work. Yet the participation of the beneficiaries would be desirable so that they eventually hold a right of control and usage on the space concerned by the development.

Adjustment of the grazing land or running of pasture-land. A regional pastural service seems necessary for the definition of alarm thresholds for which the amount of the critical load strongly recommended by Boudet (1985), is lower than one of the load calculated. For Milleville et al., (1982), if a pastoral code were adopted, allocating the preferential use of geographic sectors to groups of herdsmen, it should take into account the present pattern of use of areas and the distribution.

These sectors should also be enlarged so that the herdsmen may benefit from this heterogeneity and neutralize certain unfavorable aspects, but they should be small enough for everyone to feel concerned with the necessity for protection (developments, fight against fires, systems of rules for pastures-land...). This code should not penalize, however, the most productive pastoral systems based on the use of larger space with big herds, demonstrating the value of "pastoral and ecological reserves" with a low level of utilization and difficult access.

In these sectors, besides adjusting the grazing load, it would be possible to begin improving the quality and the production of fodder.

According to Boudet (1985), a delay of 20 to 40 days between two grazings optimizes the usable capacity of pasture-land. This period of growth can be guaranteed by a strict rotation of the herd under supervision (closure of certain watering places, moving to different resting-places for the night). In the dry season, it would be necessary to protect the pastures from being trampled until the time when they can be used in their best condition.

Actions enabling an increase of the zootechnical performances. The techniques enabling the reduction of the mortality rate, the increase of fecundity, and the limitation of the consequences of under-nourishment during the period between crops, are well known ; vaccination compaigns and hygiene education, eradication of parasites, complementary nourishment (particularly nitrogenous-based) and extra minerals, development of fodder banks, ambivalent leguminous plants (cowpea) sown in areas previously used during the rainy season, hedges and antierosive fodder strips, the gleaning of natural fodder.

According to Milleville et al., (1982) the application of these techniques raises two questions :

(1) One, concerning the ways of introducing them, the supplying of the means, and the maintenance of the set-up. It favors measures which lead to lengthy training.
(2) The second concerns the accompanying measures, since one can only envisage "stock-farming development" as synonymous with an increase in the costs. It would mean especially an increase in the marketing function (prices, marketing channels, recovery of weak animals before being sold...).

In the agropastoral systems based mainly on agriculture, one should be careful about introducing themes of intensive cultivation (labor type) in a zone where there are high climatic risks (nitrogenous fertilizers, new varieties and exotic leguminous plants).

It is imperative to limit the extension of crop-farming on transitional pastures (lowland type) as well as on the unprotected lands which are the most vulnerable to erosion (filtering bank type, isohipses).

It is in these systems that the integration of agriculture and stock-farming should be promoted at the heart of the development (stocking of a part of residue of harvest, fattening of beef based on fine straw which in improved by molasses, stable manure, carts for transport, oxen and light ploughs, dry season gardening). The association of this sub-regional "agropastoral" unity with "pastoral" unities should enable traditional barter exchanges of manure, cereals and animals.

Agropastoral water systems will play a central role in the success of such an "agropastoral code", since water can become a major constraint in agropastoral systems during this dry period. The use of water above and below the surface must be controlled and the level of the reservoirs supervised. This can give rise to the inception of projects with, among other aims, the goals of encouraging the creation of a water stock available for the three uses (domestic water, drinking water for animals, water for gardening and tree-planting).

CONCLUSION

In the soudano-sahelian and sahelo-soudanian zones, demographic patterns, the dry climate and the weakness of the present controls and rights of usage (Benoit, 1982) lead to overexploitation of the area. Thus one observes a more or less irreversible deterioration of resources and of the viability of pastoral and agropastoral systems.

One of the actions which seems most relevant at the moment is the transformation of the rights and authorities "in being" into a collective agropastoral code which would take account of the diversity of local strategies, of the various levels of resources and needs, and would make it possible to work out development activities in a collective manner.

Objectively, one must admit that such a code will not be able to solve the problem of overpopulation and social reproduction, in a framework of saturation.

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PROFITABILITY OF ANIMAL TRACTION: FIELD STUDY IN BURKINA FASO

W. Jaeger and J. H. Sanders[1]

Since the beginning of the 20th century animal traction mechanization has been promoted in Sub-Saharan Africa. Yet less than 15% of semi-arid tropical African cultivated area now employs animal traction (Spencer, 1985). In Burkina Faso both international and national agencies have been promoting animal traction since the seventies (Munzinger, 1982). Nevertheless, outside of the southern and ..stern regions of Burkina introduction has been slow. This study evaluates some effects of animal traction in several villages in Burkina and considers some of the factors leading to differences in profitability estimates.

Agricultural technology has been divided into land and labor augmenting technologies as follows :

$\frac{Y}{L} = \frac{A}{L} \cdot \frac{Y}{A}$ where Y = Agricultural output; L = Labor use ;

A = Land area; $\frac{Y}{L}$ = Average product of labor or labor productivity;

$\frac{A}{L}$ = Land-man ratio; and $\frac{Y}{A}$ = Aggregate yields.

In this dichotomy, mechanical technology is expected to have its principal effect on increasing the land-man ratio, whereas biochemical technology -- improved agronomy and seeds, and use of fertilizer -- will have its principal effect on the latter, aggregate yields. However, yield effects for mechanization have been reported in the literature from improved timeliness, better soil preparation, and overcoming seasonal labor bottlenecks.

The effect of animal traction on the land-man ratio and then on yields will first be considered. Then, the costs and returns to animal traction in several regions of Burkina Faso will be estimated. Finally, some broader policy concerns will be raised.

Area expansion effect. The principal finding in this study is that an area expansion was made possible by the use of animal traction on most farms. The limiting labor bottleneck occurs at the first weeding, which also coincides with late planting. With animal drawn implements, the area cultivated was increased by up to 30%, or up to 3 ha. for an average size farm. Estimates from various sources ranged from 20% to 55% increases in area. Both donkey and oxen based systems performed weeding about seven times more quickly than a man alone. There appears to be no advantage to the stronger oxen for the weeding operation (Tables 1 - 3).

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With experience farmers were able to increase the cultivated area by 30% for cereals and 45% for peanuts in Nedogo. There was a learning curve involved as it took three to five years for farmers to learn how to utilize the implements and how to obtain these yield increases (Fig. 1).

The animal cultivator enabled farmers to overcome these peak seasonal demands for labor in weeding the cereal crop and permitted increased cash crop production. The planting of peanuts normally coincides with the weeding of millet and sorghum and therefore animal traction enables the expansion of the peanut area. Draft animals are also utilized for the second weeding and earthing-up. The latter operation consists of putting soil along the plant rows. This conserves moisture by slowing the run-off.

The acreage effect does require access to land. In the survey those with animal traction were able to substantially increase the land area cultivated. One potential explanation for some lack of adoption could be the lack of access to land.

When farmers were asked about their labor constraints, most identified the first weeding as being the principal problem time, though the planting and ploughing were also identified (Table 4). Farmers adopting animal traction reported an area expansion of the basic grains, millet and sorghum, and increased marketed surplus (Table 5).

Yield effects. With all be the other differences between farms and small yield effects it is often difficult to separate out the effect of animal traction (Tables 6-8). Discussion in the literature on the yield effect of mechanization has been heated (Binswanger, 1978). On the experiment station accurate measurement has been obtained. Holding constant the planting date, statistical estimates were obtained for 32% yield increases with donkey and 45% with oxen in sorghum production.

Profitability of animal traction. For animal traction to be profitable, the utilization rate needs to be reasonably high, 30 days or 150 hours. Low utilization levels can result from:

(1) Small farm size: To fully utilize a draft team, six active family members or more appear to be necessary. In the villages studied the mean family size in animal traction-utilizing households was approximately twice that in households not utilizing animal traction.

(2) The learning curve phenomenon is important. It takes three to five years for farmers to master the technology.

(3) Stages of technology evaluation: donkeys are cheaper and easier to operate but oxen represent a further improvement because they are more powerful.

(4) Combination of implements: The weeder is critical for overcoming seasonal labor bottlenecks. Combining the weeder with the plough can provide yield effects. There may be an important water retention effect for semi-arid regions.

(5) Late rains: The opportunity for ploughing is very limited with late rains. When the rains begin early, the plough can be used extensively. Here oxen have a definite advantage since they are stronger and ploughing is more power intensive. According to the statistical analysis, ox teams were 75% faster than a donkey.

(6) Financial constraints: There are time delays in the learning curve and in the payback period to the investment in animal traction.

Table 1. Area cultivated by crop in two villages in Burkina.[1]

Crop	Nedogo Manual tillage	Nedogo Animal traction	Diapangou Manual tillage	Diapangou Animal traction
	ha/worker			
Millet	0.609 (.004)[2]	0.813*** (.048)	0.802 (.118)	0.877 (.065)
White sorghum	0.141 (.026)	0.239** (.035)	0.042 (. 02)	0.080 (. 03)
Red sorghum	0.141 (.025)	0.110 (.015)	---	---
Maize	0.019 (.002)	0.031*** (.003)	0.035 (.007)	0.039 (.006)
Peanuts	0.044 (.009)	0.064* (.007)	0.026 (. 01)	0.054** (.008)
Bambara nuts	0.013 (.004)	0.007 (.001)	0.007 (.003)	0.009 (.004)
Rice	0.004 (.001)	0.003 (.001)	0.005 (.005)	0.012 (.004)
Soybeans	---	---	0.010 (.004)	0.019* (.003)
Cowpeas	---	---	0.002 (.002)	0.014** (.005)
Working household members	4.7	6.6	4.4	7.1
n	24	36	11	48

1 Source: W. Jaeger (1984) p. 47.

2 Standard errors are in parentheses.

*, **, and *** indicate significance at respectively the .10, .05 and .01 levels. Significance tests are between group means of animal traction and manual tillage households.

Table 2. Area cultivated by crop at the village, Boromo, Burkina.[1]

Crop	1981 Manual tillage	1981 Animal traction	1982 Manual tillage	1982 Animal traction
	ha/worker			
Millet	0.193 (.05)[2]	0.126 (.06)	0.150 (.03)	0.175 (.03)
White sorghum	0.333 (.07)	0.307 (.08)	0.291 (.05)	0.231 (.03)
Red sorghum	0.224 (.04)	0.140 (.05)	0.065 (.01)	0.097 (.03)
Maize	0.044 (.01)	0.044 (.01)	0.037 (.01)	0.049 (.01)
Peanuts	0.030 (.01)	0.081** (.02)	0.015 (.006)	0.033 (.01)
Cotton	0.300 (.04)	0.358 (.05)	0.199 (.03)	0.255 (.05)
Cowpeas	0.004 (.004)	0.006 (.006)	0.002 (.002)	0.005 (.004)
Bambara nuts	0.009 (.004)	0.002 (.001)	0.001 (.001)	0.001 (.001)
Rice	0.003 (.003)	0.001 (.001)	0.011 (.003)	0.007 (.002)
Working household members	4.0	7.7	5.3	1[illegible].6
n	15	10	34	24

1 Source: W. Jaeger (1984) p. 48.

2 Standard errors are in parentheses

*, **, and *** indicate significance at respectively the .10, .05 and .01 levels. Significance tests are between group means of animal traction and manual tillage households.

Table 3. Area cultivated by crop at the village, Djibo, Burkina.[1]

Crop	1981 season Manual tillage	1981 season Animal traction	1982 season Manual tillage	1982 season Animal traction
	ha/worker			
Millet	1.057 (.06)[2]	1.352 (.31)	0.992 (.08)	0.759* (.10)
White sorghum	0.026 (.01)	0.059 (.03)	0.029 (.007)	0.034 (.015)
Maize	0.012 (.001)	0.015 (.003)	0.013 (.002)	0.010 (.003)
Peanuts	0.001 (.001)	0.012* (.008)	0.002 (.001)	0.003 (.001)
Bambara nuts	0.002 (.001)	0.003 (.001)	0.004 (.001)	0.002 (.001)
Rice	.0002 (.001)	0.002** (.001)	.0001 (.001)	0.002 (.001)
Working household members	4.4	9.0	4.4	9.0
n	31	17	30	17

1 Source: W. Jaeger (1984) p. 49.

2 Standard errors are in parentheses.

*, ** indicate significance at respectively the .10 and .05 levels. Significance tests are between group means of animal traction and manual tillage households.

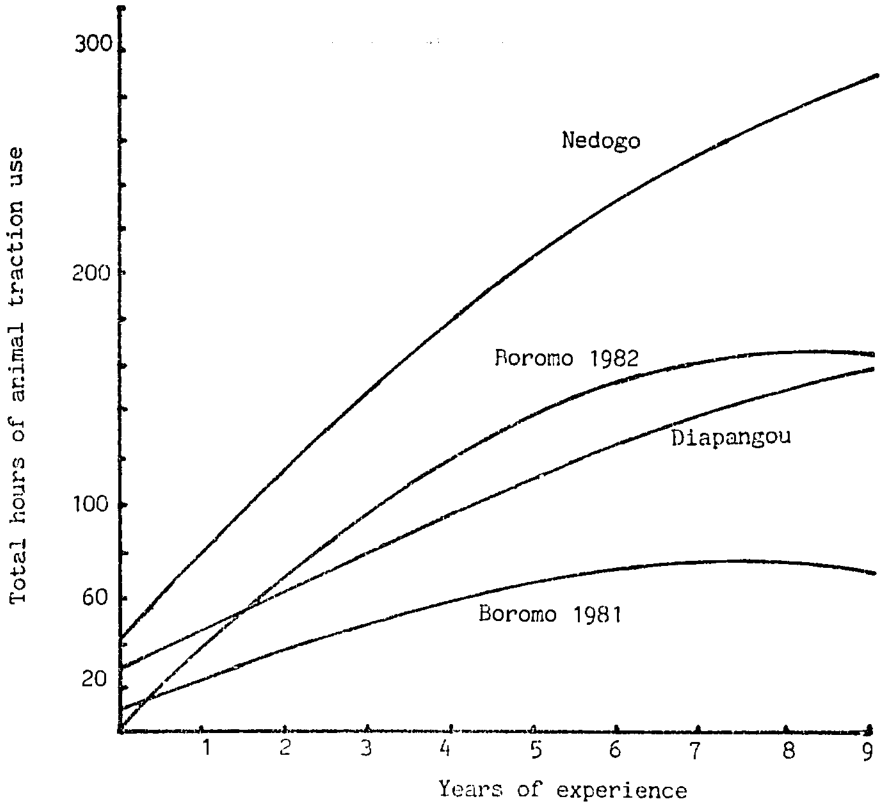

Fig. 1. Relationship between experience and use of animal traction. Source: W. Jaeger (1984).

Table 4. Labor constraints on increased farm production.[1]

Activity	Ploughing	Planting	First weeding	Second weeding	Labor not constraining
	— % of responses —				
Activity perceived by farmers to be most constraining					
Nedogo					
By hand tillage households		32	68		
By animal traction households		44	40		27
Diapangou					
By hand tillage households	22	44	33		
By animal traction households	6	34	40	9	11
Boromo					
By hand tillage households	25	34	34	6	
By animal traction households	9	30	22	4	35
Djibo					
By hand tillage households		15	60	20	5
By animal traction households			40		60
Activity perceived to be most constraining prior adopting animal traction:					
Nedogo		40	53	3	3
Diapangou	28	9	51	13	
Boromo	39	26	22	9	4
Djibo	8		58	8	25

1 Source: W. Jaeger (1984) p. 97.

Table 5. Changes in production and marketing since adopting animal traction: farmer's interview responses.[1]

Factors	Nedogo	Diapangou	Boromo	Djibo
Animal traction farmers				
Percentage of farmers who cultivate more land since acquiring animal traction, %	80	95	67	92
Crops for which area cultivated has increased (on family[2] fields)	Millet Sorghum	Millet Sorghum	Cotton Sorghum Peanuts	Millet Sorghum
Percentage of farmers who sell more of what they produce since adopting animal traction (produced on personal[2] fields), %	65	90	81	8
Crops sold	Millet Peanuts	Millet Peanuts	Cotton Peanuts Rice	Fonio[3]
Manual tillage farms				
Percentage of farmers who cultivate more land now than they did five years ago on family fields, %	58	75	48	68
Crops for which area planted has increased	Millet Sorghum	Millet Sorghum	Sorghum Cotton Maize	Millet Fonio

1 Source: W. Jaeger (1984) p. 99.

2 Family fields provide the family food supply; personal or individual fields are cultivated by individual household members for various uses including a source of cash income.

3 Fonio is a grass seed, sown by broadcast method.

Table 6. Crop yields at two villages in Burkina.[1]

Crop	Nedogo		Diapangou	
	Manual tillage	Animal traction	Manual tillage	Animal traction
	g/ha			
Millet	371 (28)[2] n = 24	356 (21) n = 36	395 (37) n = 11	499** (17) n = 47
White sorghum	554 (88) n = 19	363* (36) n = 30	226 (64) n = 5	532*** (55) n = 22
Red sorghum	503 (82) n = 20	465 (54) n = 32	---	---
Maize	1147 (219) n = 24	992 (120) n = 35	1429 (171) n = 11	1814* (109) n = 47
Peanuts	535 (73) n = 23	470 (57) n = 36	346 (33) n = 6	567*** (40) n = 40
Cowpeas	--- ---	94 --- n = 1	699 --- n = 1	295 (70) n = 11
Bambara nuts	327 (80) n = 19	332 (51) n = 24	577 (149) n = 4	877 (151) n = 22
Rice	1554 (561) n = 6	1285 (351) n = 7	2833 --- n = 1	1377 (228) n = 9
Soybeans	---	---	762 (168) n = 6	538 (151) n = 37)

1 Source: W. Jaeger (1984) p. 51.

2 Standard errors are in parentheses.

*, **, and *** indicate significance at respectively the .10, .05 and .01 levels. Significance tests are between group means of animal traction and manual tillage households.

Table 7. Crop yields at the village, Djibo, in Burkina.[1]

Crop	1981 Season		1982 Season	
	Manual tillage	Animal traction	Manual tillage	Animal traction
	kg/ha			
Millet	490 (31)[2] n = 31	393** (31) n = 17	178 (13) n = 28	205 (28) n = 17
White sorghum	492 (97) n = 12	1081 (518) n = 8	208 (319) n = 11	499 (453) n = 6
Maize	497 (103) n = 24	371 (72) n = 13	245 (142) n = 8	52 (13) n = 4
Peanuts	1135 (447) n = 9	744 (232) n = 10	296 (129) n = 2	125 (16) n = 2
Bambara nuts	1294 (325) n = 13	1450 (469) n = 12	199 (32) n = 9	227 (70) n = 3
Rice	2194 (1694) n = 2	2299 (1257) n = 4	--- ---	617 (199) n = 2

1 Source: W. Jaeger (1984) p. 53.

2 Standard errors are in parentheses.

** indicates significance at the .05 level. Significance tests are between groups means of animal traction and manual tillage households.

Table 8. Yield response of sorghum to ploughing: FSU farmer managed trial results, 1983.[1]

	Type of soil preparation		
	No ploughing	Donkey plough	Ox plough
	kg/ha		
Diapangou			
No tied ridges[2]			
No fertilizer	363 (39)[4]	481*** (43)	526*** (40)
With fertilizer[3]	719 (46)	837*** (64)	856*** (47)
With tied ridges			
No fertilizer	441 (37)	552*** (31)	578*** (35)
With fertilizer	753 (51)	871*** (56)	991*** (53)
n	24	25	25
Nedogo			
No tied ridges			
No fertilizer	399 (95)	444 (79)	---
With fertilizer	693 (98)	604 (104)	---
With tied ridges			
No fertilizer	409 (95)	544 (128)	---
With fertilizer	707 (183)	876 (205)	---
n	14	19	

1 Source: W. Jaeger (1984) p. 89.

2 Ridges are "tied" by connecting small dikes at intervals of one to two meters to block the furrows and prevent run-off. This was done 30 days after planting.

3 Fertilizer application consisted of 100 kg/ha of 14-23-15 fertilizer and 50 kg/ha of urea, applied at first weeding.

4 Standard errors are in parentheses.

*, ** and *** indicate significance at respectively the .10, .05 and .01 levels.

Internal rates of return were calculated over an eight year payback period with the purchase of the animal and the equipment. This calculation includes maintenance, depreciation, and expected losses due to deaths in bad rainfall years. The actual observed internal rates of return were 26% and 35%, respectively, for oxen and donkeys (Tables 9 and 10). If higher levels of use of the plough and the cultivator and shorter learning curves could be achieved to efficiently utilize these implements and expand the area cultivated, then these internal rates of return could be increased. With favorable assumptions, those internal rates of return could be increased to 68% and 114%, respectively. It is probably not possible, however, to obtain these types of utilization this quickly. Note that weeding equipment would need to be rapidly combined with land area expansion. Moreover, it would be necessary to utilize the ploughing equipment in the land preparation.

CONCLUSIONS

In summary, field observations showed that animal traction was moderately profitable but could be much more profitable if the time period for the learning curve were shorte and multiple use of implements were achieved. With Linear Programming (LP) analysis the profitability of various types of mechanization are illustrated in Fig. 2. The most profitable complete mechanization (cultivation and ploughing) is achieved with oxen. If only cultivation is mechanized or if the feed supply were extremely limited, then donkey traction would be the most profitable. However, at higher utilization, rates of about 100 hours oxen traction result in superior profitability (Fig. 3). By inference, some of the variation in the performance of animal traction between regions is expected to be explained by the learning curve and the number of operators mechanized. To achieve these high rates of return farmers need to be able to rapidly master the use of the animal cultivator and the plough. They also need to expand the area cultivated over a shorter time period. Hence, good management, the use of several implements, and healthy animals all appear to be necessary.

Large families with more accumulated wealth and perhaps better opportunities for extending the land area seem to invest more in animal traction. Many of the failures in animal traction introduction (Sargent, et al., 1981) appear to have resulted from introducing an inappropriate or incomplete technological package before it has been completely tested. For example, the use of the ox plough alone often was not economical.

Moreover, one implication is that over time the growth of a market for trained animals would reduce the learning curve time. This type of market presently exists in Northern Nigeria. Shifts to rapid animal traction require changes in savings behavior and markets. Presently, farmers do their savings principally in goats and sheep. Evolution of farmer savings behavior would be expected over time as it becomes profitable to utilize animal traction.

Table 9. Partial budgets for adoption of ox traction: eight-year budgets under various assumptions.[1]

Annual costs/ Benefits	Year 0	1	2	3	4	5	6	7	8	Internal rate of return
	CFA x 1,000									%
Costs of ox traction										
Animal purchase	100				-100				-100	
Equipment costs	49	5	5	5	5	5	5	5	5	
Feed, medicine, etc.		16	16	16	16	16	16	16	16	
Total costs	149	21	21	21	-80	21	21	21	-189	
Assumed benefits										
Observed farm revenue benefits (FSU), and approximate learning period after adoption:	0	17	34	45	56	67	67	67	67	
Net benefits	-149	-4	13	24	136	46	46	46	256	26
LP estimated benefits for observed u e/learning curve:	0	-15	26	47	64	77	90	98	104	
Net benefits	149	-36	5	26	144	56	69	77	293	25
Benefits when doubling the rate of increased use after adoption:	0	26	64	90	104	109	109	109	109	
Net benefits	149	5	43	69	184	88	88	88	298	41
Benefits with a 50 percent rise in long-term utilization rate:	0	5	60	100	120	143	158	167	173	
Net benefits	149	-16	39	79	200	122	137	146	362	44
Benefits when combining assumptions 3 and 4 above:	0	60	120	158	173	180	180	180	180	
Net benefits	149	39	99	137	253	159	159	159	369	68

1 Source: W. Jaeger (1984) p. 138.

Table 10. Partial budgets for adoption of donkey traction: eight year budgets under various assumptions.[1]

Annual costs/ Benefits	Year 0	1	2	3	4	5	6	7	8	Internal rate of return
	CFA x 1,000									%
Costs of donkey traction										
Animal purchase	25				10				-18	
Equipment costs	48	5	5	5	5	5	5	5		
Feed, medicine, etc.		7	7	7	7	7	7	7	7	
Total costs	73	12	12	12	12	12	12	12	-11	
Assumed benefits										
Observed farm revenue benefits (FSU), and approximate learning period after adoption:	0	17	33	44	55	66	66	66	66	
Net benefits	-73	5	21	32	33	54	54	54	77	35
LP estimated benefits for observed use/learning curve:	0	15	34	52	68	75	85	90	94	
Net benefits	-73	3	22	40	46	63	73	78	105	41
Benefits when doubling the rate of increased use after adoption:	0	34	68	85	94	97	97	97	97	
Net benefits	-73	22	56	73	72	85	85	85	108	67
Benefits with a 50 percent rise in long-term utilization rate:	0	25	65	95	115	128	140	148	153	
Net benefits	-73	13	53	83	93	116	128	136	164	70
Benefits when combining assumptions 3 and 4 above:	0	65	115	140	153	163	163	163	163	
Net benefits	-73	53	103	128	131	151	151	151	174	114

1 Source: W. Jaeger (1984) p. 139.

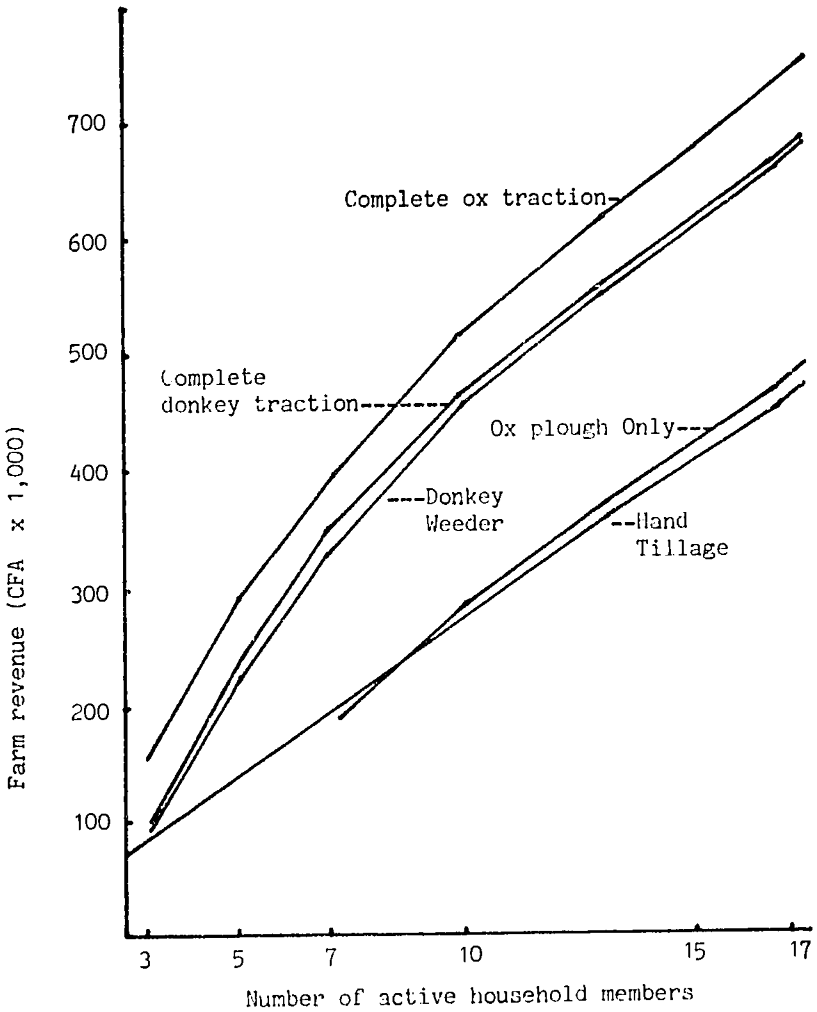

Fig. 2. Increases in farm revenue with animal traction for different farm sizes. Source: W. Jaeger (1984) p. 132.

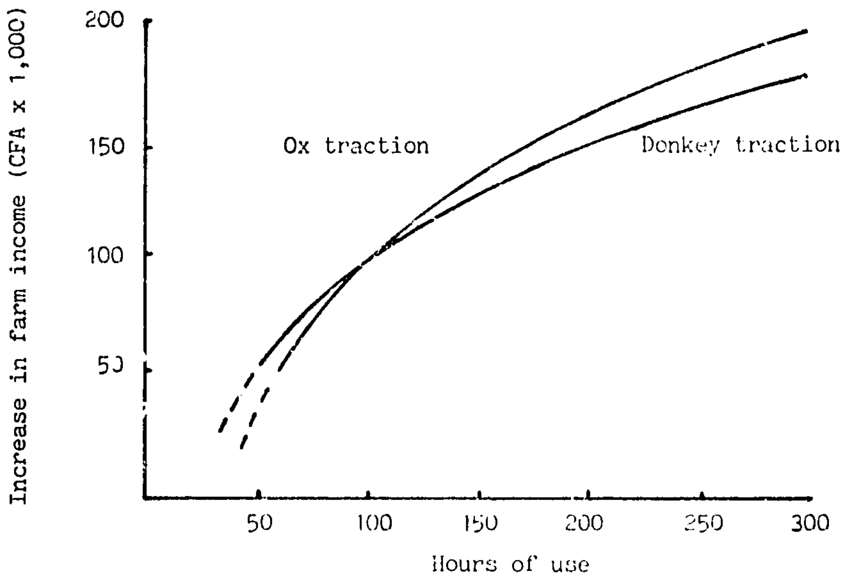

Fig. 3. Increases in farm revenue for different levels of utilization of animal traction. Source: W. Jaeger (1984) p. 129.

In regions of Burkina Faso such as the Central plateau, which is characterized by marginal rainfall and poor soils, yields are declining over time due to the breakdown of the fallow system with population pressure. It may be necessary to first arrest these cereal yield declines with more intensive farming before there will be a payoff to extensification. Otherwise, the extension of animal traction could be just spreading the overty by expanding the area on which yields are steadily declining (Sanders and Roth, 1985).

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A RESEARCH STRATEGY TO DEVELOP APPROPRIATE AGRICULTURAL TECHNOLOGIES FOR SMALL FARM DEVELOPMENT IN SUB-SAHARAN AFRICA

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The dismal record of economic development. The record of economic development in Sub-Saharan Africa (SSA) since the era of independence in the early 1960's has been a dismal one. Between 1960 and 1982 Gross National Product (GNP) per capita is estimated to have increased at an annual rate of only 1.5%, compared to 3.0% for all low income countries, 3.3% for industrial market economies and 4.1% for all upper/middle income countries (World Bank, 1984). SSA countries maintained a reasonable growth rate in the decade immediately after independence. The decline started in the 1970's and accelerated in the 1980's. The rate of growth of Gross Domestic Product (GDP) per capita was 1.3% per annum in the 1960's, dropped to 0.7% in the 1970's, and has averaged-3.7% since 1980 (World Bank, 1984 b).

Agriculture has contributed in no small measure to the poor performance of the African economies. It contributed 47% to GDP in 1960 but only 33% in 1982, and its annual growth rate was about 2.1% in the 1970's compared to 3.0% for GDP as whole. In fact, SSA is the only part of the developing world in which the index of per capita food production has declined during the last two decades. Only Rwanda, Central African Republic, Swaziland, Ivory Coast, Mauritius and Cameroon have shown any positive increase in per capita food production over the last two decades.

Of all the sub-regions of SSA, West Africa has shown the slowest growth rate for total food production. Thus the SSA food problem translates mainly into a West African problem (Paulino, 1983). Furthermore, per capita production of all crops in West Africa has declined, except for rice, which is a minor staple in the region. The poor performance in food production is due mainly to the very low rate of growth (0.5% per year) for the major staples--sorghum and millet, and the absolute decline in the cash crop groundnut. The small increase in total food production has been due almost exclusively to an increase in area under cultivation indicating that technological change has not yet had much impact on food production in West Africa.

The reasons for poor performance in SSA. The economic crisis situation in SSA has many causes: political, technical as well as structural. External factors include the world economic recession, and the declining terms of trade for the commodities traded in Africa. The present world economic recession (or shall we say "part-world" economic recession, since the USA and much of Europe does not appear to have ever been in depression from the point of view of SSA) has significantly reduced the purchasing power of SSA governments. This has been attributed to its effect on the debt burden of the SSA countries (caused by high interest rates), and the reduced demand for SSA exports. Thus their ability to finance the essential capital and recurrent expenditures (e.g., irrigation works and fertilizer imports needed to increase agricultural production) has been reduced (OAU 1980).

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Internal factors have also played an important role in the decrease in SSA purchasing power. They include: poor economic management, inefficient and wasteful parastatals, poor pricing policies which impinge heavily and negatively on agriculture, and neglect of export crop production in which Africa's comparative advantage is said to lie at the moment (World Bank, 1981, 1984).

However, in my opinion, sufficient weight has not yet been given to the part played by environmental constraints and the lack of appropriate technological solutions in bringing about the present crisis, particularly in the agricultural sector. Better internal policies and more favorable external economic climates might have delayed, but would not have prevented the present crisis. It is generally believed that agricultural research has come up with the answers to the environmental and other agricultural development problems, but that the solutions have not been transferred to farmers because of certain bottlenecks highlighted in much of todays agricultural literature (e.g. poor extension systems, inadequate pricing policies, ineffective and inefficient seed multiplication programs or marketing parastatals, etc.). In my view, environmental and other farmer constraints have not been adequately taken into account in research undertaken for, or in SSA. Furthermore, the set of new technologies is often inappropriate, in that they respond poorly to farmers' changing needs and cannot bring about a sustainable growth in aggregate output.

Coverage of the paper. In Section II, the past performance of agricultural research systems is discussed. First of all the type and pattern of agricultural research during the colonial and the post-independence periods are examined. The operational difficulties of existing research systems is then discussed, followed by a critical evaluation of the present stock of technological innovations that have been produced. Finally, factors contributing to successes and failures are highlighted.

In Section III, the elements of an appropriate technological research strategy for SSA are spelled out. The characteristics of new technologies that fit in with an agricultural development strategy which emphasizes small farm development are delineated. The final section contains the conclusions.

PAST PERFORMANCE OF AGRICULTURAL RESEARCH SYSTEMS IN SSA

The colonial period. Agricultural research was not neglected by colonial governments. Between 1900 and 1920, one or more agricultural research stations were established in virtually every country in SSA (Mckelvey, 1965). However, these research stations concentrated almost exclusively on export crops, e.g. oil palm, cocoa, coffee and groundnuts.

The investment did yield rather substantial returns. Hybrid oil palms were developed (Abaelu, 1971) and contributed significantly to agricultural export growth between 1940 and 1960. Hybrid palms outyield local wild palms by 500-700 percent under farm conditions in West Africa (Eicher, 1967). Cotton research started in Uganda around 1904 and spread to Northern Nigeria and the French colonies in the 1920's and 1930's. Substantial yield increases have been obtained under farm conditions by cotton farmers applying the results of this research, e.g. in Burkina Faso, Delgado (1981). Similar successes were obtained with research in cocoa and to a lesser extent with groundnuts, both of which started in West Africa in the 1920's.

Hybrid maize in Kenya and Zimbabwe is the only food staple toward which substantial research efforts were directed during the colonial period. Research was launched in Zimbabwe in 1932 and in Kenya in the mid 1950's. Both programs have been very long term in nature, and have yielded substantial returns (Eicher, 1984). Otherwise, very little research was conducted on the major food staples during that period (Collinson, 1983).

It is also worth noting that most of the colonial export crop research programs relied heavily on the transfer of materials from other developing regions of the world, as well as developed countries. For example, plant breeding materials were successfully transferred from Asia for oil palm, USA for cotton, and South America for coffee. Unfortunately, as we shall see later, this success with technology transfer has not been repeated in food crop research. It must also be stressed that there existed substantial investment into local research and adaptation of the imported technology during the colonial period.

As Judd, Boyce and Evenson (1983) and Oram and Binglish (1984) have shown, SSA countries, in general, invested much less in agricultural research as a percentage of total agricultural production than did other developing countries and the developed world. Thus, although there was substantial investment in export crop research during the colonial era, the quantum of research was probably insufficient to guarantee long run profitability of crop production.

The post independence period. The post independence period has been marked by a large increase in public sector research expenditures. Judd, Boyce and Evenson (1983), estimated that agricultural research expenditures in 1980 constant US dollars, increased from about $57 million in 1959 to $280 million in 1980 in East and West Africa, while manpower increased from 1636 scientist man-years to 4,100. As a percentage of the value of agricultural output, public sector expenditure rose from about 0.37% to about 1.19% in West Africa and from 0.19% to 0.81% in East Africa over the same period.

Commendable as these increases are, the evidence is that they have not produced commensurate increases in research output. In this paper the productivity of post-colonial agricultural research in SSA is operational difficulties encountered by national research systems; and second, in terms of an evaluation of the stock of technologies that have been produced.

Operational difficulties of national research systems. To function effectively, an agricultural research system needs trained personnel and funds for fixed expenditures (e.g. building of laboratories, purchase of equipment, etc.) as well as operating funds (e.g. purchase fuel, fertilizers and chemicals, payment of laborers, etc.).

It has already been pointed out that there has been a substantial increase in agricultural research workers in SSA. The statistics on the number of scientist man-years, of course, says nothing about the level of qualifications or competence of the researchers. In many national research institutions, a substantial number of researchers are people with B.S. level qualifications who, at best, can only be expected to perform routine experiments and analysis. Little wonder that so many trials in SSA are repeated year after year, long after they have lost their meaning. It

Although the above description referred specifically to the Sahel, it accurately describes the situation in many SSA countries.

Evaluation of new technological options.[1] In this section some of the current stock of technological interventions in four areas (land and water management, mechanization, soil fertility management and crop improvement) are examined from the point of view of their appropriateness for small farm development.

Land and water management. The objectives of improved land and water management methods are to protect the soil base over the long-term while at the same time providing an immediate boost to yields. Research on the humid zones has shown that the process of soil degradation under high rainfall conditions usually begins with inappropriate partially mechanized clearing methods, subsequently exacerbated by insufficient soil cover. Improved systems, building on traditional farming practices, are being developed by the International Institute of Tropical Agriculture (IITA). These involve light clearing, *in-situ* burning, and intensive use of surface mulch in combination with herbicides and minimum or zero tillage. How these packages perform under small farmers' management and fit into their systems, however, is only now being determined in on-farm testing. Moreover, the development of economic chemical weed control methods and small scale equipment for use in low tillage systems pose immediate research problems (ter Kuile, 1983).

Within the semi-arid zones, a set of interventions is being examined including mulching, contour bunding, and various watershed based management systems. Although tied ridges have been shown to dramatically reduce runoff and increase yields in on-station trials in both East and West Africa (Ruthenberg, 1980; ICRISAT, 1981), substantial labor costs and yield gaps observed under farmers' conditions throw doubt on the extensive use of this approach. Due to increasing demands for crop residues as livestock feed, fuel etc., the potential for extensive use of mulches in sorghum and millet production is probably equally limited.

On the other hand farmers' tests conducted in Burkina Faso over several years have found very significant short-term yield increases from the introduction of dirt anti-erosion dikes constructed on the contours of farmers' fields (ICRISAT, 1983). Small scale rock-based water harvesting systems have also been shown to be attractive to farmers as a means of reclaiming highly eroded fields in high population pressure regions of Burkina Faso.

Mechanization. Improved equipment (internal combustion, animal or human powered) have not yet made an important contribution to agricultural production except in a limited number of cash-cropping areas in the semi-arid tropics of Africa. Within the humid-tropics, tsetse fly infestation prohibits the development of animal based systems. Mechanization schemes based on the use of tractors (two- or four-wheeled) have met with limited success in the humid tropics due to high capital costs relative to the capital resources and scale of operation of farmers. This is also attributed to the lack of know-how in equipment use and maintenance. Work in the humid tropics is now concentrating on light manual powered equipment for use in minimum tillage and alley cropping systems (ter Kuile, 1983).

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[1]This section is based on Matlon and Spencer (1984).

often takes a team of outside consultants to suggest new areas of research for such programs. There is much need to raise the level of qualifications of the researchers in many national programs.

The tendency to staff national research systems with unqualified people is sometimes encouraged by donor agencies insisting on having and training counterparts in externally funded short-term research projects. Counterparts with B.S. level qualifications work with expatriate Ph. D. researchers for one to three years, then are left on their own and expected to carry on and modify the new research programs as necessary. Is it surprising that it usually requires an entirely new project preparation mission, years later, to suggest new lines of research.

More importantly however, than the quality of staff, is the lack of sufficient operational funds and the abundance of poor financial and research management. The situation has recently been described as follows:

> "The effectiveness of research, extension and training institutions is impaired by the lack of operating resources needed to function as they should. Yet, all too frequently, governments continue to expand programs, hiring more personnel instead of providing necessary resources to those already on the payroll. Poor performance and effectiveness, thus, go beyond the simple lack of resources. They arise from poor development administration and financial management. Poor personnel management and work discipline, lack of performance incentives and professional advancement, and inadequate operating funds to do a good job; all discourage highly motivated researchers, trainees and extension agents. The resulting high staff turnover disrupts research programs and institution building efforts so necessary for creating effective indigenous national research and extension systems. Until these problems are addressed, zonal research and networking programs will not achieve their full potential.
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> Untimely budgetary allocations frequently disrupt production campaigns, agricultural experiments and data collection activities throughout the Sahel. Experiments sometimes must be abandoned or curtailed half-way through the season, or are not properly tended to because of a lack of gasoline, vehicles or other resources, or because of the inability to control implementing staff, partly these problems arise from unpredictable budgeting exercises over which research and extension institutions have little control. Partly they arise from legal structures that severely constrain the institutions' ability to control and allocate resources put at their disposal. Partly they arise from poor internal planning and management of resources in the face of what is obviously a highly unstable and unreliable resource situation. Unless these kinds of institutional constraints are appropriately indentified, analyzed and resolved, we risk spending another ten years making little progress toward increasing agricultural production..." (LeBeau et al., 1984, pp.5-6)

Whether these tools are economical under farmers' conditions has yet to be demonstrated.

Despite efforts to introduce animal traction in the semi-arid tropics dating to the early 1900's, the current use of animal traction systems is limited to less than 15% of cultivated area. The potential yield and labor savings benefits of animal powered cultivation practices, repeatedly measured under experiment station conditions (Sargeant et al, 1981), have rarely been confirmed under farmers' management.

A set of common institutional and technical constraints, acting both on the demand and supply sides of animal traction systems, have limited the attainment of the potential benefits. On the supply side, poorly developed extension and support systems result in the lack of medium-term credit for equipment and animals, as well as inadequate training, veterinary, and equipment maintenance systems. Moreover, there is an absence of assured channels for complementary inputs and products.[1]

Several limiting factors are present on the demand side. First, due to the limited range of mechanized operations, power constraints are often simply shifted between operations resulting in a gross under-utilization of animals and little area expansion. Second, except for the Guinean zones where the rainy season is longer, there is a conflict between the time needed for plowing after the onset of rains and the need to plant on time in order to make use of early rains. This limits the area that can be plowed, and reduces the time animals can be used for custom work for other farmers (Jaegar, 1984). Similarly, due to the rapid drying and hardening of soils following the rains, farmers face a conflict between harvest and end-of-season plowing, which means that crop residues are almost never completely incorporated. Finally, numerous studies suggest that at least six to eight years are required to achieve full economic benefits, causing net incremental benefits to be negative during the early years of adoption.

Soil fertility improvement. Despite the generally poor chemical status of most African soils and its rapid depletion under continuous cultivation, the consumption of chemical fertilizers is very low in SSA. This is due, in part, to the absence of well developed petro-chemical industries in most African states so that fertilizer use entails substantial foreign exchange costs, exacerbated by high transport costs to and within landlocked countries. Furthermore, technical response rates are low and highly variable, particularly on local varieties of rainfed food crops and in the more arid areas, resulting in marginal or negative economic returns (IFDC, 1976; ICRISAT, 1983). Finally, complementary applications of large quantities of organic matter are required to achieve and maintain the potential response to chemical fertilizers over the long run (Pichot et al., 1981).

For all of these reasons, greater basic and applied research needs to

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[1]In part, these factors help explain the successful extension of animal traction systems in the Sine-Saloum area in Senegal, in southern Mali and in southwestern Burkina Faso, where vertically integrated cash crop marketing organizations have actively promoted adoption through comprehensive support (Matlon, 1985).

be directed to developing and using locally available sources of chemical fertilizers, such as rock phosphate, as well as organic sources of soil nutrients. A particularly promising area is a more efficient integration of crops and livestock. The inter or relay-cropping of leguminous fodder crops with food or cash crops holds some promise. For the longer-term, nitrogen fixation by non-leguminous crops and blue-green algae may also become feasible. Finally, the integration of tree and crop production may hold future potential, not only to provide windbreaks and a source of organic matter, but also as a means of recovering nutrients from soil depths below crop rooting zones.

Crop improvement. With few exceptions (e.g. hybrid maize in Zimbabwe and Kenya) major programs for the genetic improvement of food staples are relatively recent and have had little success. Despite frequently promising on-stations results, yield gaps of up to 60% are consistently observed when most new varieties are cultivated by farmers (ICRISAT, 1980/83). Unacceptable taste, as well as processing and storage problems, are also commonly encountered. As a result, probably less than 2% of total sorghum, millet and upland rice area in West Africa is sown to cultivars developed through modern genetic research.

Experience suggests that this poor record is due to a complex set of factors. This includes excessive emphasis given to the development of high-yielding but input-dependent crop varieties in view of the regions' soils, level of infrastructural development, and limited farm-level capital. New materials have also been developed and selected exclusively under research station conditions, which are generally a typical of prevailing farmers' conditions. The situation is often made worse by the lack of early, systematic, and critical feed-back from farmers to breeders (Matlon, 1983).

Reasons for failure to produce appropriate new technologies. From the above review we can conclude that the current set of new production technologies responds inadequately to the continent's evolving needs. In areas of lowest population pressure in the semi-arid tropics, marginally profitable animal powered mechanized systems permit some expansion of cultivated area. But methods by which these systems can evolve to more intensive, ecologically sustainable systems are generally lacking. Improved labor augmenting mechanized systems are even less well developed in the humid tropics.

Research to develop yield increasing, land-augmenting technologies has received increasing emphasis recently but gains have been modest. Contrasted with often impressive on-station yields, new technologies usually perform poorly under farmers conditions and demand a level of management small farmers are usually unable to provide.

These failures stem to a large extent from two causes. First of all, there is an inadequate understanding of small farmer goals and resource limitations. Research objectives are therefore often very different from those of the potential clientele, the small farmer. One glaring example is the case of intercropping. Numerous studies have shown that except for some small areas in East and Southern Africa, intercropping is vastly more important than sole crop systems, occupying over 90% of cropped area in most countries. Although there was some work done in the 1930's (Belshaw, 1979), it was not until very recently that there was any serious research on intercropping in SSA[1]. It was not until the 1970's over 50 years after agricultural research started in SSA, that intercropping started to receive any attention. Even today, less that 20% of all agronomic research in SSA addresses the issue of intercropping, a level of emphasis for below what is required. Yet, what little research has been done shows that intercropping is often much more efficient than sole cropping, even from the agronomic point of view, not to mention its other advantages to small scale farmers, for example, risk reduction.

The second major cause of the failure of research systems in SSA to develop a large enough stock of appropriate technology for farmers is, in my opinion, the over reliance on the "diffusion" or "technology transfer" model of development. Following the successes with the direct transfer of export crop plant materials from other developing and some developed countries into SSA during the colonial period, and the green revolution success with the spread of wheat and rice varieties developed by the International Maize Improvement Centre (CIMMYT) and the International Rice Research Institute (IRRI) in Latin America and Asia, the technology transfer model of agricultural research took firm root in SSA. Not only was the model adopted by national research systems, which probably had few alternatives since shortage of staff and funds prevented them from doing more fundamental research, but regional and international research centers also adopted it as a modus operandi. Thus the West Africa Rice Development Association (WARDA) was founded to conduct rice research, development and training activities in West Africa on the principle that all it needed to do in terms of varietal research was to import varieties from other parts of the world, test them for adaptability and select the suitable ones (Lewis, et. al., 1982). ICRISAT's African program at first relied very heavily on material transfer from Asia, with scientific staff placed in one-man or two-man teams in national programs (CGIAR, 1971).

Unfortunately, because the rate of demographic change is higher and the physical conditions which determine technical potential are often more difficult in SSA compared to other continents, the extent to which technical solutions developed elsewhere can be imported into Africa is quite limited. There has therefore been a lack of success to date in the direct introduction of exotic high yielding cultivars, except for irrigated rice where the environment can be modified to suit the crop. For example, ICRISAT has had little success in introdroducing Indian sorghum and millet varieties to West Africa (Matlon, 1983). And after 10 years of variety trials in which over 2000 varieties were imported for trials in the mangove swamps of West Africa, WARDA found only two varieties that perform as well as the best local varieties (WARDA, 1984).

The lessons seem to have been learned by the international and re-

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[1]Three researchers played an important role in regenerating interest in intercropping research in SSA. David Norman's farm surveys in Northern Nigeria in the 1960's demonstrated the importance of the system (Norman 1984), while agronomic research also in Nigeria, by Bede Okigbo and D.J. Andrews, gave professional prominence to intercropping research (Andrews, 1972, 1974; Okigbo and Greenland, 1977).

gional centers[1] and some national programs are concentrating on the development of local materials, to the extent that their resources permit.

ELEMENTS OF AN APPROPRIATE, TECHNOLOGICAL RESEARCH STRATEGY FOR SSA

Implications of agricultural development strategies. Elsewhere I have provided a detailed review of various agricultural development models (Ruttan, 1980) with regard to their relevance within the contemporary context and their implications for a modern agricultural research strategy (Spencer, 1984).

We can summarize the main implications as follows:

(1) Meaningful agricultural development in SSA will only result from technological and institutional innovations which are appropriate to the continents' resource endowments. This calls for research to provide us with a thorough understanding of the natural resource, institutional and socio-economic constraints facing agriculture in SSA.

(2) There is still great potential, particularly in semi-arid zones, to increase agricultural productivity by conservation of natural resources, especially land and water resources. There is thus a need for research to develop soil conservation, irrigation and reforestation technologies.

(3) Because of the high population growth rates, poor quality of the relatively abundant land resource, emphasis should be on a development strategy and research that concentrates on small scale farming.

(4) Although attention should be given to increased export crop production, particularly where there is clear evidence of a large comparative advantage, major emphasis should be on food crop production and research.

Research with a farming systems perspective. It has already been pointed out that one of the basic flaws in agricultural research in SSA in the past three decades has been that it has not taken sufficiently into account the resource and other constraints of small scale farmers who form the clientele for the research. To overcome this problem, agricultural research must be conducted with a farming systems perspective.

Farming systems research is research that views the farm in a holistic manner and considers interactions in the system (CGIAR, 1978). Its major objective is to increase the productivity of farming systems by generating appropriate new technology. It includes location specific on-farm research which has a short-run objective of developing improved technologies for target groups of farmers and experiment station research which has a longer term perspective aiming at overcoming major limitations in farming systems (Byerlee, Harrington and Winkelman 1983; Gilbert, Norman and Winch, 1980).

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[1]For example ICRISAT has reorganized its SSA research program into one regional center in Niamey, Niger, three sub-regional teams in Zimbabwe, Burkina Faso/Mali, and Malawi and one bilateral program in Mali (ICRISAT, 1984) and WARDA has established special research projects to do more fundamental research (WARDA, 1984).

It should be stressed that on-station research should be regarded as an integral part of research with a farming systems perspective.[1] At that stage new technological components are developed and screened (e.g. varieties, herbicides, etc) and parts of, or even whole new cropping systems, are tested at the pilot scale.

Of course, the major contribution of the current emphasis on farming systems research is the higlighting of the role of on-farm research and the delimitation of homogenous target groups of small scale farmers in what are called "recommendation domains." Unfortunately, most of the literature, emphasizes the crucial role of on-farm research and, therefore gives the impression that such research can stand on its own and that experiment station research only has at best, a rather unimportant role to play.[2]

During the past five years, a large number of farming systems research teams have been set up all over Africa with financial and technical assistance from external donors. National research programs are also being urged and assisted to launch large farming systems research, in other words-on-farm research efforts.[3] Given the lack of adequate recognition of small farmers' constraints in the past, this effort will bring to the attention of researchers and policy makers alike the true problems faced by farmers. It will also highlight the fact that we have no ready solutions to many problems, in that there is limited technology on the shelf ready to be modified to suit farmers' needs. But there is a grave danger that we might not be able to move beyond that point if equal emphasis is not put on necessary experiment station research. Having been given a bad name in the past many research stations now run the grave risk of being starved of necessary funding and staffing.

Characteristics of new technologies needed in SSA. In order to increase agricultural productively in SSA, new biological, chemical and mechanical technologies are needed to allow for intensification of agriculture. In addition, new soil and water conservation techniques must be developed.

Biological technology that is adaptable to local conditions is needed. There are now very clear indications that there are limits to the wide adaptability of crop varieties displayed originally by sugar cane, wheat and rice in Latin America and Asia. Varieties are therefore needed which are adaptable to "recommendation domains" of limited spread.

Given the limited capital resource of small scale farmers the input distribution problems in many SSA countries, recommended varieties should be highly responsive to low levels of inputs such as fertilizers. Varieties are needed that perform as well or are slightly better than farmers traditional varieties under traditional levels of management, but yield substantially more under slightly improved management (e.g. Variety B in Figure 1). Too many improved varieties are like Variety C in Figure 1.

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[1]Referred to as "upstream research" by Gilbert, Norman and Winch, 1980.
[2]See for example the manual by Shaner, Philip and Schmehl (1981) which gives an otherwise excellent treatise on the methods and modalities of on-farm research.
[3]See for example the large US funded Senegalese program with ISRA and the planned Malian program.

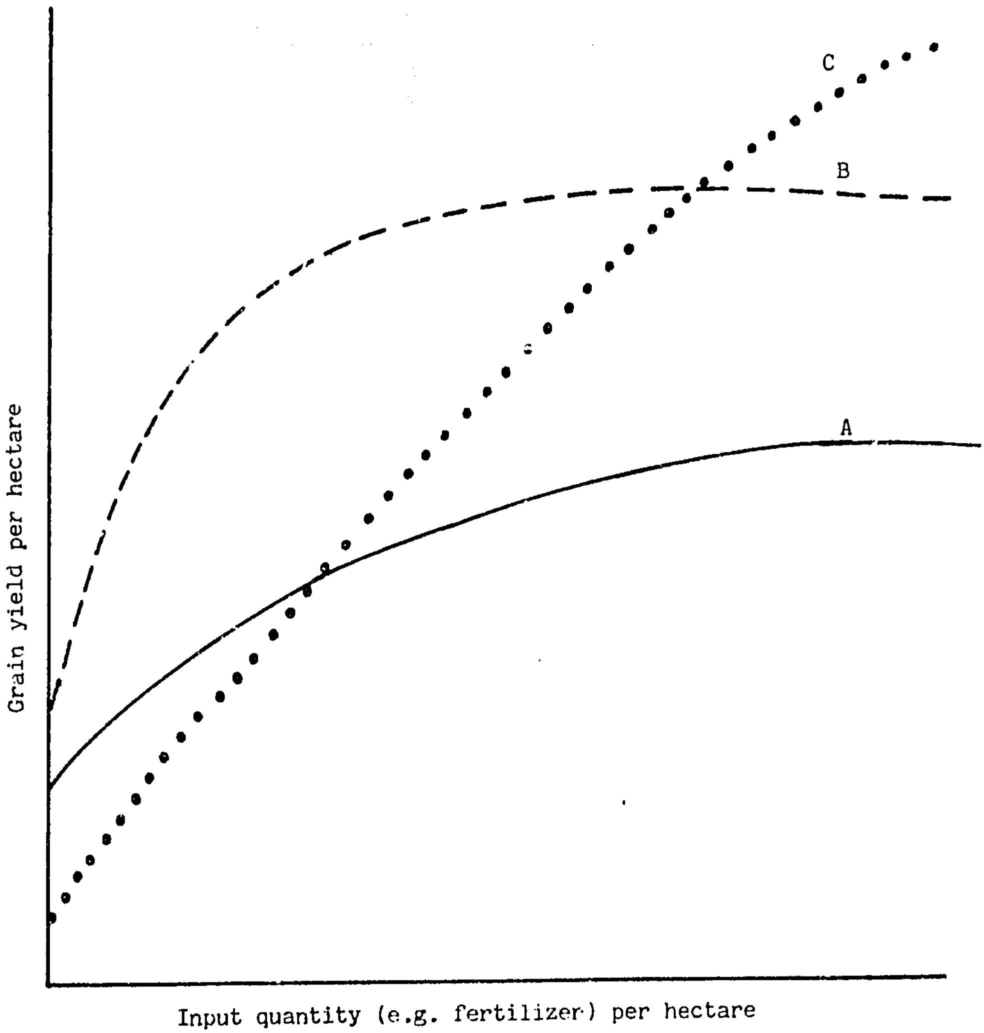

Fig. 1. Hypothetical response of varietal types to increased input levels. A = local cultivar, B = desirable improved cultivars, C = most existing improved cultivars.

They require levels of management that are greatly above farmers' existing capabilities before they express their superior potential.

Several corrective prescriptions can be suggested. In the semi-arid tropics, for example moderate yield increases and a substantially greater stability could be achieved through breeding for improved seedling vigor, drought resistance, and resistance to the most common pests and diseases. The development of varieties with different agronomic characteristics, such as shorter crop cycle or modified plant structure, could also increase farmers' management options for example in intercropping or permitting late planting without yield loss (Stoop et al., 1981).

With regards to new chemical technology, material inputs such as fertilizers should be derived as much as possible from local sources in order to reduce transportation costs. This calls for substantial research efforts on new plant design and processes that would make the production of phosphate fertilizers from domestic rock phosphate economical.

Given the labor bottleneck at weeding time in many SSA countries and the demonstrated yield reducing effects of weeds in many farming systems, there is a need for cheap, effective and easily applied herbicides.

With regards to mechanical technology, we know that, although SSA can be defined as having a land surplus, capital cannot substantially substitute for labor. Most available processing machines cannot economically replace hand labor (Timmer, 1973; Byerlee, Eicher, Liedholm and Spencer, 1983). Furthermore, as indicated earlier, there has been limited success with animal traction or mechanized land cultivation. Yet, labor productivity in SSA is quite low, being generally lower than in much of Asia (Mellor and Johnston, 1984) and there are often severe labor bottlenecks. There is therefore a need for research on appropriate mechanization technology.

As is the case with biological technology, we need mechanical technology that is within the farmer's reach. Cooperative ownership and management of agricultural machinery has not worked in SSA. Neither have government tractor hire schemes. It seems to me that the only open avenue is research on the improvement of farmers' existing tools and equipment. A hand weeder that allows a farmer to weed twice as fast as existing weeders would have a big impact on labor productivity. The animal yoke newly designed by the International Livestock Center for Africa (ILCA) which allows the traditional Ethiopian plow to be pulled by one instead of two oxen is likely to have more impact on agricultural productivity in the Ethiopian highlands than all the mechanization research over the last 30 years. These efforts concentrated on replacing traditional cultivation methods with mechanized methods rather than on improving the existing methods.

There is much need for research on improvement of farmers' hand tools and equipment, unglamorous as that type of research might be. For example, hand held equipment is needed for minimum tillage in the humid zones, not scaled down models of equipment used in developed countries.[1]

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[1]Perhaps a good example of the inappropriateness of this scaling down approach to machinery development is the recent series of equipment developed for zero tillage in the humid tropics. To use the equipment requires land clearing techniques not found on small farms. The equipment can thus only be used by large farmers, yet it is billed as small farm equipment.

The characteristics of desirable technology spelled out above implies a research strategy which gives major emphasis to in situ development of new plant materials, local sources of chemical and biological fertilizers and improved hand tools and animal traction. These should be combined into simple technological packages which could be adapted in stages by small scale farmers and which would substantially increase their incomes.

Soil, water and forest conservation research. As pointed out earlier, soil, water and forest conservation provide avenues through which many productivity gains can be achieved in SSA. Research is needed on improved conservation practices which could be profitably adopted by small farmers.

In semi-arid zones, immediate attention should be given to research aimed at improving the management of existing large scale irrigation schemes. Soils research is also needed to develop economical ways of maintaining or increasing soil fertility and of increasing water infiltration and reducing run-off in semi-arid areas. In this regard, research in developing economical crop rotations including tree crops, leguminous species and mixed farming should be given high priority.

Under the general heading of conservation research, I include reforestation. The forest cover is being lost at alarming rates in both the arid zones where desertification is increasing and in humid zones where climatic changes might be occurring. In my opinion, there is not much hope of reducing firewood demand either by substitution with other fuels or by police actions or taxation. Efforts must be made to increase fuel wood supplies while maintaining the forest cover.

As is the case of other areas, reforestation programs in the past have relied too heavily on imported tree species and techniques, which have rendered projects hopelessly uneconomic (Taylor and Somare, 1983). Research is needed on improvement of traditional forest species, on the identification of fast growing trees for humid areas, and trees capable of being established under harsh semi-arid conditons. Research into the incorporation of trees into crop as well as animal production systems should be given high priority.

Livestock research. Livestock are an important part of farming systems, particularly in semi-arid zones where crop production interfaces with rangelands. Consequently attention needs to be given to livestock production, particularly to control of livestock diseases.

From the research point of view, we should note that livestock research in SSA during colonial periods was mainly veterinary research. This, together with recent work by international organizations like the International Laboratory for Research into Animal Diseases (ILRAD), has produced economical control measures for most of the important diseases, the major exception being trypanasomiasis. The available literature on livestock production and productivity[1] shows that the lack of reliable feed supply is probably the most limiting factor on animal production. It is probable that possibilities are li... d.

[1]See Eicher and Baker (1982), Chapter VI, for a review of social science research in this area.

CONCLUSIONS

By its dismal performance in the post independence period, agriculture has contributed greatly to the poor economic performance of sub-saharan countries. Agricultural research systems, domestic as well as international, must take a share of the blame since they have not produced a large enough stock of technological innovations capable of ensuring a large and sustainable growth in aggregate agricultural output.

Researchers had an inadequate understanding of small farmer goals and resource limitations such that research objectives were often different from those of their potential clientele. There was also an over-reliance on the technology transfer model in which researchers attempted to introduce new technology from other developing and developed regions of the world rather than working to improve on locally available plant materials and farming systems.

To improve the situation and lay the groundwork for future agricultural growth and development there has to be an increase in investment in agricultural research as well as a change in the direction of research. Major increases in agricultural productivity can only be expected from investment in agricultural research capacity needed to develop technologies appropriate to the regions' natural and institutional environment.

Since agricultural development can only be brought about by widespread, yet gradual, increases in productivity by small farmers adopting innovations appropriate to their proportions, research must concentrate on developing technologies for them. Varieties are needed that are adaptable to limited areas, and respond well to low doses of inputs such as fertilizers. Material inputs should be derived mainly from local sources and mechanization research should concentrate on improving hand tools and animal traction.

Major emphasis should be put on soil, water and forest conservation, especially on research to develop economical crop rotations including tree crops, leguminous species and mixed farming. First priority should be given to food crop research, especially research on sorghum and millet. Although an increase in export crop research may be justified in some countries, present levels of investment in livestock research need not be increased since much increase in livestock production can only be expected after substantial increases in crop productivity.

Major emphasis will need to be put on developing and increasing the efficiency of national research systems. But in the short to medium-term, regional and international research centers must continue to play an important role in agricultural research in SSA. Substantial external donor assistance will be required in the short to medium-term to ensure that these centers, as well as national research systems, receive adequate funding.

Investment in research must be of course be cast within a longer time-frame (10-20 years) than has been common in the past, cast within a farming systems perspective and should include investment in human capital development.

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THE DEVELOPMENT AND EVALUATION OF NEW SYSTEMS OF AGRICULTURAL PRODUCTION: SOME FIELD AND MODEL RESULTS FROM BURKINA FASO FOR TIED RIDGES AND FERTILIZATION

J.H. SANDERS and M. ROTH[1]

One crucial aspect of developing new technology is the combination of different component parts from the experiment station for their testing under farm level conditions. For farm level testing, it is necessary to identify the constraints that will be considered and to combine a number of component parts to obtain a sufficiently large combined effect to be noticed by farmers. Then from farm fields yield effects and profitability can be estimated. The final stage of the analysis is the fit of the new technology into the whole farm context. This paper illustrates the type of insights gained from the whole farm modeling. The technologies studied are agronomic improvements, tied ridges and fertilization.

STAGES OF TECHNOLOGY EVALUATION

The basic research problem is to identify a new technology, which farmers could adopt. The conditional form of the verb indicates that new inputs may not be available presently or that changes in governmental policy may be necessary but that the technology is technically and economically feasible. Specifically, farm level tests of technology are evaluated with the following three criteria:

(1) Does the new technology yield significantly more than farmers' practices?

(2) Is it profitable?

(3) Does it fit into the farmers' production system?

The customary method of analyzing (1) is some form of analysis of variance and this is the traditional tool of the agronomist and the first step in the evaluation procedure. However, farmers are not yield maximizers. Clearly, farmers need to make money from the new activities and the next step is some variation of budgeting activities to consider profitability.[2]

Even if new technology increases yields and is profitable, it may not fit into a farmer's production system. The seasonal labor requirements may be high and competing with other farmer activities. It may require very large scale use of non-farm inputs such as credit. Hence, the evaluation technique needs to consider all the farm activities including the on-farm and off-farm resource availabilities. The simplest approach to whole farm

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[2]Farmers in developed and developing countries have many other objectives besides profits. Risk avoidance, subsistence objectives, social standing and various institutional constraints, undoubtedly enter into the farmers' decision making process. However, this evaluation is a normative analysis based upon the assumption that some of the farmers some of the time will be concerned with earning more money rather than an attempt to describe all the factors acting on the farmers' decision making process. Once the diffusion process begins, other farmers will follow. The subjective riskiness of adopting new practices will decrease as other farmers observe innovators' experiences under conditions similar to their own.

analysis is linear programming. This is the principal analytical tool utilized here. It is not as data intensive as much econometric modeling. It responds to the fit question (3) above. With modifications institutional constraints and different farmers' objectives besides profit maximization can be added.

In the division of effort, agronomists are principally concerned with the accuracy of their data and with verifying the quality of their experiments with the analysis of variance. The economists, after interacting with the agronomists in the identification of the constraints and the experimental design, then follow through on (2) and (3) with the simple budgeting and the modeling.[1] Clearly, the interaction should continue throughout the process of identifying farm level constraints, designing experiments, and evaluation.

CONSTRAINTS, YIELDS AND SIMPLE BUDGETING: SOME 1984 RESULTS

Much confusion has been introduced in the agricultural economics literature by treating the constraints problem as if there were only two factors of production, land and labor. Following this type of analysis seasonal labor shortages are conventionally defined in some of the African literature as the most pressing constraint and animal traction as an appropriate technological innovation. This is not terribly helpful in a semi-arid environment such as the Central (Mossi) Plateau of Burkina Faso where in many regions the increasing man-land pressure has been causing a decrease in the fallow periods. Hence, cereal yields have been falling and soil fertility deteriorating.

A broader definition of the constraints would make constraint identification obvious from the geographic description. Much of Burkina Faso is semi-arid so the most pressing constraint is water. Improved water conservation techniques have been developed in many regions of the world. Unfortunately, on the Mossi Plateau when there is water available, soil fertility quickly becomes limiting. In the absence of water, fertilizer utilization is risky in semi-arid regions.

The above is the simple agronomic rationale for the development and testing of systems of tied ridges combined with fertilization of sorghum, maize, and millet during the last three crop seasons, 1982-1984. Different levels and types of fertilization and various times for establishing the tied ridges have been tested in these farm trials.

The individual and combined effects of moderate fertilization and tied ridges are illustrated in results from the 1984 farm level trials of the FSU/SAFGRAD program. In Table 1 the mean values for the trials on farmers' fields indicate that yield increases were obtained for either tied ridges or fertilization alone but that these yield increases were doubled with the combination of tied ridges and fertilization. Similarly, in Fig. 1 the data from two villages with fertilization alone or tied ridges alone

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[1]One test of these assumptions about farmer decision making and the validity of our evaluation is whether farmers adopt new technology passing these three evaluation criteria. A systematic analysis of the use of these criteria and the adoption of new technologies is reported by Sanders and Lynam (1983) from four years of farm trials for field beans and cassava.

Table 1. Mean sorghum yields in four villages with fertilization and tied ridges, Burkina, 1984.[1]

Treatment	Sorghum yield			
	Nedogo	Bangasse	Dissankuy	Diapangou
	kg/ha			
Control	186	293	447	433
Tied ridges	446	456	588	655
Fertilization	441	616	681	806
Tied ridges and fertilization	751	944	855	1106

[1] Source: Ohm, Nagy and Pardy (1985).

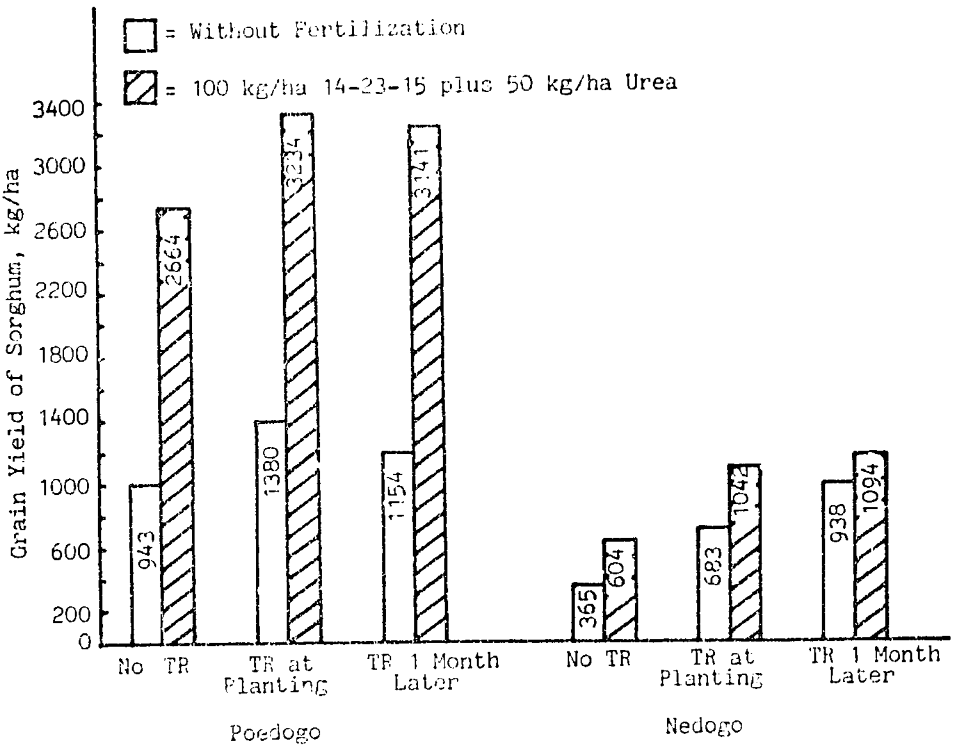

Fig. 1. Interaction effects of fertilization and tied ridging on grain yield of sorghum grown at two villages in Burkina in 1984. The standard errors of the difference between any two treatment means are, respectively 297 and 108 kg/ha for Poedogo and Nedogo.

Source: Ohm, et al. (1985).

demonstrates that substaintial yield increases were obtained. In both villages, the largest gains of an approximate tripling of yields were obtained from the combination of tied ridges and moderate fertilization.

Even more dramatic results for the combined effects of tied ridges and moderate fertilization were reported in the researcher managed trials of different fertilization levels with tied ridges in four villages in Burkina Faso (Table 2). Only in Dissankuy was there a significant yield increase from tied ridges alone but those yields were tripled with the combination.

Table 2. Mean sorghum yields for different treatments in the Burkina villages.

Treatment	Sorghum yield[1] Nedogo	Bangasse	Dissankuy	Diapangou
	kg/ha			
Control	135a	266a	1010a	677a
Tied ridges	146a	229a	1844b	708a
100 kg cotton fertilizer (14-23-15)	813cd	1083bc	3156c	865ab
Tied ridges, 200 kg cotton fertilizer (14-23-15)	1000d	1472c	3167c	1000b

[1]Means followed by the same letters are not significantly different at the 5% level. Source: Ohm, et al., (1985).

Are these technologies profitable? Simple budgeting of costs and returns has been reported elsewhere (Ohm, et al., 1985; Ohm, Nagy, and Sawadogo, 1985). To summarize, both fertilization and tied ridges alone were profitable in almost all cases. Profit levels were substantially increased with the combination of these activities (Ohm, et al., 1985).

WHOLE FARM MODELING

The critical question in the evaluation is whether the technology fits into the farmers' production systems. Simple profitability is not by itself a sufficient criterion. There may be other constraints or even other measurements that have to be made to evaluate the feasibility of the new technology.

Based upon various farm surveys representative form models utilizing linear programming were constructed for the Central Plateau and the Eastern Region (Table 3). The objective function was profit maximization with a constraint for a minimum maize production.

Estimates of the yield effects of tied ridges with moderate fertilization for sorghum alone on the type of land in which sorghum is typically cultivated, and for tied ridges alone for maize on compound land, were estimated based upon FSU/SAFGRAD data. Before the 1984 farm trials only these two activities were shown to be profitable using simple budgeting analysis. In 1984 the FSU/SAFGRAD program also showed profitable results for millet with improved agronomy and even further increased yield advantages for the two above new technologies.[1]

The research questions then for the model are:
(1) whether the new technologies would be adopted on the model farms,
(2) what would be their income effect, and
(3) what are the most pressing constraints preventing adoption?

Table 3. Yield response to tied ridging plus fertilizer technology used in the whole farm analysis.[1]

Region		Maize	Sorghum
		kg/ha	kg/ha
Central Plateau	Highly manured compound soils	650 (60)	
	High quality village soils	600 (90)	550 (60)
	High quality permanently cultivated bush soils		425 (90)
	Low quality permanently cultivated bush soils		325 (100)
Eastern	Highly manured compound soils	700 (55)	
	High quality village soils	650 (75)	
	High quality-fallowed bush soils	520 (90)	
	Low quality-fallowed bush soils	420 (100)	

[1]Figures are yields achieved under donkey traction technology; yields for oxen were estimated to be 10 percent higher. Figures in parentheses are the percentage increase over yields estimated for donkey traction alone (i.e., without tied ridging or fertilization treatments). Source: Roth and Sanders (1985).

Extensive comparisons of many different alternatives are summarized in Roth and Sanders (1985). The basic information is in Tables 4-7 and Fig. 2. The tied ridges come into the profit maximizing farm plan on both the compound land and on the land conventionally planted to sorghum (Stoop, et al., 1982). They do increase income, but not very much compared with the introduction of donkey and oxen traction due to the small area on each farm on which the new technology is used.

The data were limited on the labor requirements for constructing the tied ridges. A value of 100 man-hours/ha was utilized. Fig. 2 indicates that farm profits are very sensitive to reduction of the labor requirements.

[1]These marginally profitable results were for millet fertilized with volta phosphate over a three year period; hence, some residual effects of the fairly insoluble rock phosphate were apparently obtained.

Table 4. Effect of tied ridging technology plus animal traction on area cultivated, production and net farm income estimates, Central Plateau, Burkina.

Variable		Traditional management: Hand tillage only	Tied-ridging technology[1]: With donkey traction	Tied-ridging technology[1]: With oxen traction
Total area cultivated, ha		4.8	6.96	7.67
Maize:	Traditional	.15		
	With tied ridges		.20	.20
Red Sorghum:	Traditonal	.60	.07	
	With tied ridges		.53	.60
White Sorghum:	Traditional	.80	.80	.65
	With tied ridges			.15
Millet		3.15	4.39	4.61
Rice		.03	.03	.03
Peanuts		.07	.94	1.43
Fertilizer used: (kg/farm)	Urea		37	49
	Cotton fertilizer		73	98
Total cereals production, kg				
Per household		1987	2975	3381
Per resident		199	213	225
Total oilseeds production, kg		219	618	835
Net farm income (000 CFA):				
Per household		131.8	189.8	229.3
Per worker		26.4	29.2	32.8
No. of workers per household		5.0	6.5	7.0

[1]Based on 50 kg urea and 100 kg cotton fertilizer per hectare; labor time of 100 hours per hectare and yield estimates given in Table 10.
Source: Roth and Sanders (1985).

Table 5. Effect of tied ridging technology plus animal traction on area cultivated, production and net farm income estimates, Eastern Region, Burkina.

Variable	Traditional management: Hand tillage Only	Tied ridging technology[1]: With donkey traction	Tied ridging technology[1]: With oxen traction
Total area cultivated, ha	4.10	6.14	6.78
Maize: Traditional	.16	.16	.02
With tied ridges			.14
Sorghum: Traditional	.77	.66	.83
With tied ridges		.43	.54
Sorghum/millet (75/25)	.77	.77	.77
Millet	.77	.61	.77
Millet/sorghum (75/25)	1.36	3.16	3.46
Rice	.05	.05	.05
Peanuts	.23	.29	.20
Fertilizer used: Urea		21.7	28.2
(kg/farm) Cotton fertilizer		43.3	56.5
Total cereals production, kg			
Per household	1961	3153	3733
Per resident	269	269	261
Total oilseeds production, kg	269	422	456
Net farm income (000 CFA):			
Per household	103.9	136.4	155.4
Per worker	29.7	27.3	26.0
No. of workers per household	3.5	5.0	6.0

[1]Based on 50 kg urea and 100 kg cotton fertilizer per hectare; labor time of 100 hours per hectare and yield estimates given in Table 10. Source: Roth and Sanders, (1985).

Table 6. Summary of various productivity measures estimated from sole and combined impacts of animal traction, fertilization, and tied ridging technologies, Central Plateau, Burkina.

Alternative power source	Traditional technologies	Tied ridges plus fertilization[1]
Hand tillage		
Total area cultivated, ha	4.82	2
Active workers/household	5.0	
Area cultivated/worker	0.96	
Income/household (000 CFA)	131.8	
Income /ha	27.5	
Income/worker	26.4	
Donkey households		
Total area cultivated, ha	7.29	6.96
Active workers/household	6.5	6.5
Area cultivated/worker	1.12	1.07
Income/household (000 CFA)	178.4	189.8
Income/ha	24.4	27.3
Income/worker	27.5	29.2
Oxen households		
Total area cultivated, ha	8.13	7.67
Active workers/household	7	7
Area cultivated/worker	1.16	1.10
Income/household (000 CFA)	211.3	229.3
Income/ha	26.0	29.9
Income/worker	30.2	32.8

[1]The unsubsidized price of fertilizer was utilized: 122 CFA/kg urea and 125 CFA/kg cotton fertilizer.

[2]Since the tied ridging is a very labor intensive operation, it was assumed that animal traction would be necessary to assist in the construction of the ridges. Source: Roth and Sanders, (1985).

Table 7. Summary of various productivity measures estimated from sole and combined impacts of animal traction, fertilization, and tied ridging technologies, Eastern Region, Burkina.

Alternative power source	Traditional technologies	Tied ridges plus fertilization[1]
Hand tillage		
Total area cultivated, ha	4.10	2
Active workers/household	3.5	
Area cultivated/worker	1.17	
Income/household (000 CFA)	103.9	
Income/ha	25.3	
Income/worker	29.7	
Donkey households		
Total area cultivated, ha	6.39	6.14
Active workers/household	5.0	5.0
Area cultivated/worker	1.28	1.23
Income/household (000 CFA)	135.8	136.4
Income/ha	21.3	22.2
Income/worker	27.2	27.3
Oxen households		
Total area cultivated, ha	7.10	6.78
Active workers/household	6.0	6.0
Area cultivated/worker	1.18	1.13
Income/household (000 CFA)	152.9	155.4
Income/ha	21.5	22.9
Income/worker	25.5	26.0

[1]The unsubsidized price of fertilizer was utilized: 122 CFA/kg urea and 125 CFA/kg cotton fertilizer.
[2]Since the tied ridging is a very labor intensive operation, it was assumed that animal traction would be necessary to assist in the construction of the ridges. Source: Roth and Sanders, (1985).

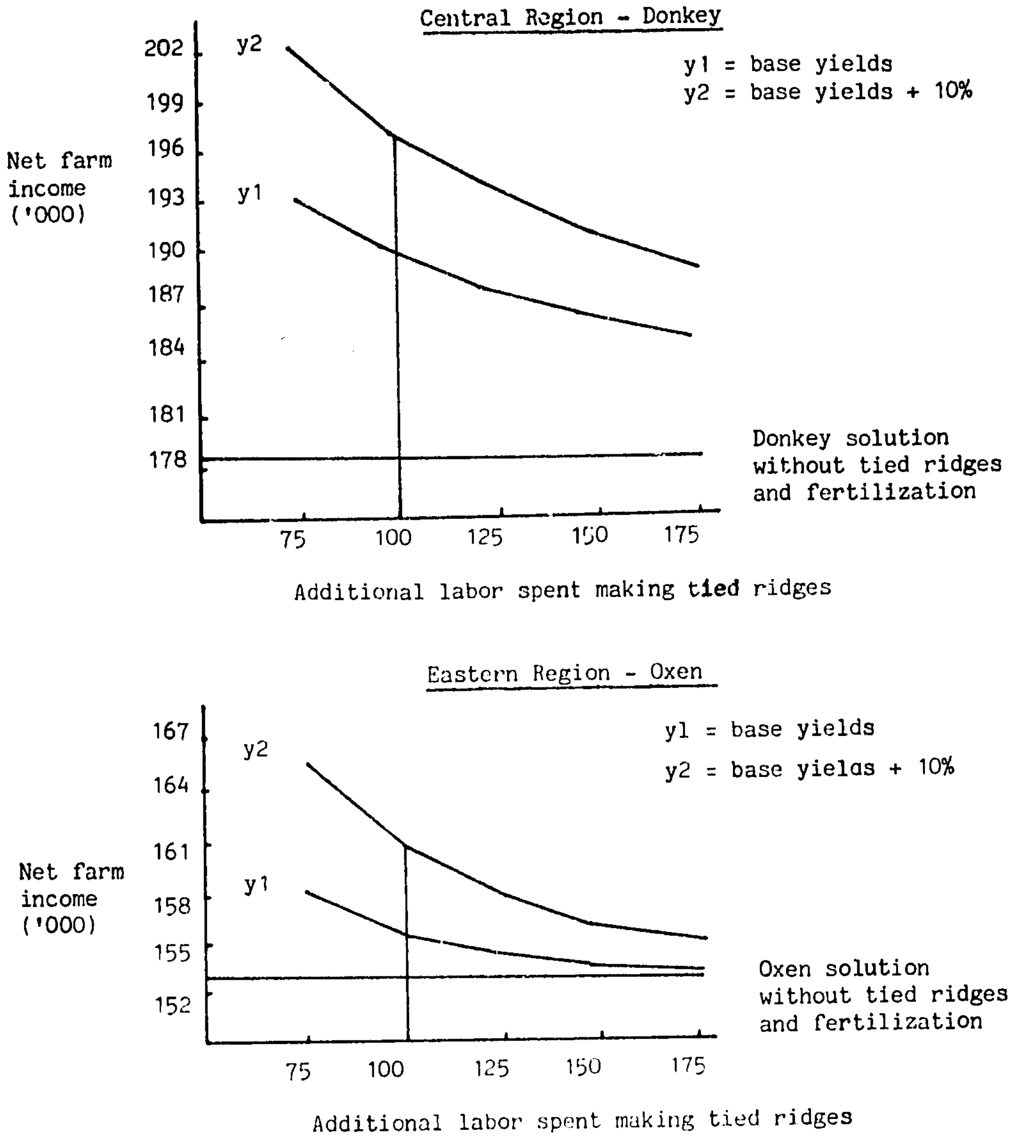

Fig. 2. Effect of various yields and labor spent tying ridges on total net revenue of the farm. Source: Roth and Sanders (1985).

A further reduction in labor requirements would enable an expansion of the combination of tied ridges-fertilization into the rest of the compound and sorghum land. The modeling results indicated the sensitivity of farm income to this labor requirement. Since then, the FSU/SAFGRAD project has improved these estimates with 55 to 75 man-hours/ha now estimated as necessary after a donkey or ox has done the ridging. Presently, in Burkina, 100 prototype animal drawn ridgers will be farm tested in the coming crop season. So the farm research is attempting to resolve this seasonal labor constraint. If the animal traction ridger can successfully further reduce the seasonal labor requirements of doing the tied ridges, then the next big gain would be from the extension of this tied ridge-fertilizaton technology into the millet area.

Given the present land use indicated by these representative farms, increased efforts need to be put into adapting the tied ridge-fertilization combination to the lower quality millet land. In 1983 solubility problems with the volta phosphate were apparently responsible for the lack of economic response to the tied ridge-fertilization activities with millet. The 1984 FSU/SAFGRAD report does show a profitable return to this combination of tied ridges and voltaphosphate on millet in the 1984 trials; however, absolute millet yields were still extremely low in the 1984 trials and a more efficient, low cost fertilizer source still remains to be identified.

CONCLUSIONS

One important aspect of whole farm modeling is that it forces an identification of the system interactions and helps identify constraints. In this case the improved water retention makes higher fertilization less risky but the introduction of the tied ridges is constrained by large labor requirements. Putting the three together will not be easy because farmers tend to adopt things one at a time in a sequencing operation. However, the large yield and profit gains appear to result from the combined innovations. Once the combined technology is introduced, the next step will be introduing new varieties of maize, sorghum, and millet into this improved agronomic environment. The most important point may be that with the irregular rainfall and fragile and low fertility soils characterizing semi-arid Burkina, agronomic innovations, involving water retention and soil fertility improvements, may need to precede varietal development. For overall reviews of agricultural technology developments in West Africa see Matlon, 1985; Spencer, 1985; Matlon, 1983; Matlon and Spencer, 1984.

Tied ridges is a labor intensive technique, which needs to be performed at one of two peak seasonal labor demand periods either first weeding or planting. The animal traction ridger may increase the profitability of animal traction as well as making this more intensive land use possible. Improved tillage prior to planting is another alternative attaining some of the same objectives of better water retention thus increasing the probability of a profitable return to fertilization. Further modeling could consider other variations of water conservation, soil fertility, and animal traction.

There is an emerging consensus from researchers and some empirical evidence here that the complementary effects of the combined technologies are very large. Some farmers may adopt one at a time but low cost methods to attain combinations seem to be a high return agronomic and economic research activity.

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FOOD CONSUMPTION ANALYSIS AND RELATED PARAMETERS FOR OUAGADOUGOU, BURKINA.

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Consumption sets the stage for production. When consumption trends change, there can be an effect on the level and types of goods that are produced. Thus when designing new agricultural technologies and food policy, a view of the long term consumption patterns and their likely impact on production must be taken into consideration. For example, if in five to ten years through technology intervention sorghum production is increased, will the increase be absorbed by consumers, at what price, and what are the effects on sorghum and other staple food production? The results from consumption analysis can be used as one of the indicators as to where research resources should or should not be targeted. This paper reviews the consumption, production and impacts of staple foods in Burkina. An analysis of various consumption parameters is undertaken and conclusions drawn with respect to future consumption patterns.

Food consumption analysis may be seen as a two step process. The first step concerns the understanding of the patterns of consumption of different food items by specific consuming units, for example individual households, nations or groups of nations, and how these patterns evolve in time and space in response to changing economic and non-economic conditions. Economic variables usually thought to affect consumption behavior include the purchasing power of and the prices faced by the consuming unit. Non-economic variables that determine household consumption patterns include population, household size, education, and ethnic group make up. This first step in analysing consumption leads to the derivation of various consumption parameters -- e.g., income and price elasticities -- which characterize the consumption decision process of the consuming unit.

The second step consists in using the parameters estimated in the first step to address micro or macro level food or agricultural policies. In the specific case of Burkina Faso, the major issue is that of food sufficiency. Alleviating this problem means that enough food must be supplied through an increase in either domestic production or imports. The question is thus raised of which commodities to promote. In approaching such a question, one must bear in mind the dichotomic nature of food consumption habits between urban and rural populations. The rural population's diet is sorghum and millet based and these crops are all grown locally. In contrast, the urban diet includes a high proportion of rice and wheat products, which are mainly imported.

In absolute terms, the quantities consumed nationwide of sorghum

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and millet outweigh by far those of rice and wheat (compare Tables 1, 2, and 3). However the recent phonomena of rising incomes combined with increased imports of wheat and rice under foreign aid programs have caused an increase in the proportion of wheat and rice consumed (Table 4). Foreign aid increased in response to the agricultural crisis that shook Burkina Faso starting in the late sixties and early seventies. It is generally believed that these relatively new products have reshaped consumers' preferences. To what extent such a preference shift has occurred towards rice and wheat is not known.

Table 1. Production, inports, and consumption of sorghum, millet, and maize in Burkina Faso, 1978-81.[1]

Agricul. years	Domestic Production				Imports[2] (M)	Consumption[3] (C)	M/C
	Sorghum	Millet	Maize	Total			
	metric tons (X1000)						%
1978/79	635.0	377.9	107.7	1,120.6	11.6	988.4	1.2
1979/80	635.2	377.7	99.5	1,130.4	20.4	981.2	2.1
1980/81	546.9	350.7	104.5	1,002.1	19.8	871.6	2.3
1981/82	658.8	442.8	118.6	1,220.1	12.2	1,049.4	3.6

[1]The data on domestic production and imports are taken from MDR-DEP (1983).
[2]Combines sorghum-millet-maize.
[3]Consumption was computed as imports + production upon adjusting for seeds and waste for the latter. The usual 15% of wastes and seeds was applied to total production.

Table 4 shows clearly an increase in the relative importance of wheat/rice; however the paucity of the number of observations does not allow one to draw conclusions with great confidence.

The assessment of these preference changes is however of great importance for agricultural macro policy planning. Indeed the knowledge of who consumes what and how patterns of consumption are likely to evolve are as of primary importance for commodity planning. In more concrete terms, the response of agricultural scientists to the food deficit situation in Burkina has been to develop new technologies to increase pro duction of sorghum and millet. What is the future of sorghum and millet in the human diet? Are sorghum and millet likely to remain the preferred cereals in the future?

Appropriate answers to these questions again require taking into account the dualistic nature of consumption patterns in Burkina Faso, i.e., urban vs rural. Extended time series data are required for tracking the possible change in the structure of consumers' preferences within each of the two sectors. Such data are however not available. To date, the only large scale household budget and consumption studies that encompassed both rural and urban areas were conducted

Tableau 2. Domestic production, imports, and consumption of rice in Burkina Faso, 1978-81.[1]

Agricul. years	Domestic production[2]	Private Imports[3] (M)	Foreign Aid (A)	Total Consumption[4] (C)	(A+M)/C	A/C	A/(A+M)
	metric tons (x 100)						
1978/79	25,565	7,981	2,270	31,981	32.1	7.1	22.1
1979/80	30,499	21,158	4,422	51,504	49.7	8.6	17.3
1980/81	26,138	24,832	5.505	52,552	57.7	10.5	18.1
1981/82	29,405	11,520	3,552	40,072	37.6	8.9	23.6

[1]Data on domestic production, private imports, and foreign aid are taken from MDR-DEP statistics publication (1983).
[2]Original data were in terms of paddy rice. A factor of conversion of 0.65 has been applied to arrive at the shelled rice equivalent .
[3]Private imports means imports by the private sector which requires foreign exchange.
[4]Total consumption is obtained as the sum of imported rice and domestic production, after a correction for seeds and wastes for the latter. It is usually assumed that 15% of local production is accounted for by seeds and wastes.

Table 3. Imports of wheat, Burkina Faso, 1976-80.[1]

Year	Imports
	metric tons
1976/77	15,500
1977/78	28,100
1978/79	23,100
1979/80	36,040
1980/81	50,391

[1]Source: Morris (1982).

Table 4. Relative importance of sorghum-millet and rice-wheat in consumption.[1]

Year	Ratio wheat-rice/millet-sorghum
1978/79	5.6
1979/80	8.9
1980/81	11.8

[1]Source: Combining Tables 1-3.

in 1950-52 and 1963-64.[1] Extensive research in consumer behavior regained attention with the urban consumer study which generated the data used in this paper, and with the on-going studies of the International Food Policy Research Institute (IFPRI) and the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT).

The data for the consumption analysis of this study were collected over the period of September 1982 to August 1983. The objectives of the study are:

(1) examine the patterns of consumption of the urban household, and
(2) evaluate the direction of change of these patterns of consumption over time.

The information generated, though referring only to the urban population, which accounts for a small proportion of total population, is useful for policy planners. The urban center is situated at a crossroads between the domestic agricultural sector of which it constitutes an important market for locally produced millet and sorghum, and a foreign sector which supplies it with part of its rice needs and its entire wheat consumption requirements. A knowledge of urban consumption parameters therefore permits inferences on their demand for sorghum and millet, which directly affects the farmers' willingness to produce these crops above subsistence levels. The significance of this for the development of new technology for millet and sorghum is that for such technology to be adopted by the farmer it must be profitable, which implies that the product must be at least marketable. Were the estimated demand parameters to indicate some tendency to consume more rice and wheat products in the future, this would signify a greater dependence of the country on the foreign market, given the current situation. This would also imply a lesser likelihood of farmers to increase millet and sorghum production above subsistence level through technological innovation.

The organization of the paper is as follows. The theoretical background on which the expose draws is first presented. Then follows a section on the methodology utilized, including a brief description of the data employed. Finally, an analysis of the results follows, with emphasis on their implications and the conclusions that can be drawn.

BRIEF THEORETICAL BACKGROUND

The following analysis takes the household as the unit of analysis, as opposed to the individual consumer in traditional consumer theory. The basic assumption of the analysis is that a household purchases goods in optimal quantities, meaning that these quantities are generated from the household's attempt to maximize its satisfaction of consuming such goods, given its environmental conditions, its income and the prices of the goods. This results in an allocation of the total budget among goods such that the expenditure on each good is a function of its own price, the prices of other goods, income and household characteristics including size and consumption by age and sex, education, and social status.

The importance of such functions imbedding household preferences is that they permit the prediction of a household's future behavior when

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[1] See MDR-DEP, 1983 for a tabular analysis of the results of these surveys.

confronted with changing prices and income. This assumes that the preference structure itself remains unchanged during the process. However such predictions become feasible only if the exact nature of the function is known (i.e., the mathematical form and the values of the parameters characterizing such form) which in theory is possible if we have already observed the household's patterns of purchasing when confronted with varying income and prices. That is, data on quantities purchased are needed either for the same household(s) over many time periods. or for different households at the same point in time.

The system of functions representing the household's preferences becomes quickly large and unmanageable if one considers each good individually. For practical reasons there is a need to scale down the problem by combining goods into broader categories. For instance the entire set of a household's goods may be divided into food and nonfood; food in turn may be subdivided into cereals, meat, vegetables, etc. The actual grouping depends upon empirical issues such as the data available and the objective of the study.

Even by aggregating goods, the resulting number of subsets may still be too large for the data at hand. An assumption commonly made in order to empirically identify the parameters of the system is that budget allocation is a sequential process whereby the household first allocates income among very broad categories (e.g., food and nonfood); the portion of income accruing to each group is then allocated among goods that compose the group, without further reference to goods not belonging in the group. In order for such a multi-stage budgeting to be legitimate, the household's preferences must be separable into the categories. That is, in generating household's utility, the trade-off between any two goods in a category so as to keep utility unchanged is independent of marginal changes in goods not belonging in that category. When this assumption is invoked, the number of parameters to estimate is drastically reduced (see Phlips, 1974; Johnson, Hassan, and Green, 1984; and Barewal and Goddard, 1985 for more development on separability and sequential budgeting).

METHODOLOGY OF STUDY

The data that are used in the analysis are a time series of cross-sections generated by a survey conducted in Ouagadougou from September 1982 to August 1983. A total of 73 households were interviewed; the data gathered included the weekly expenditures on each of 63 products, the sources and amount of household monthly income, and a set of household characteristics including household size and composition by age and sex, formal education, occupation, urbanization, religion, and ethnic group of the head of household. The expenditure data were complemented by price data generated through a market survey over the same period. For a more thorough description of the survey procedure, see Sawadogo, 1985.

Data are aggregated in two ways to facilitate the analysis. First, weekly data are collapsed into 12 montly observations. Then the 63 original products are combined into five food groups and one non-food group. The five food groups are:

(1) the traditional cereals, i.e., sorghum, millet, and maize;
(2) the new type cereals, i.e., rice and wheat products;
(3) meat;
(4) vegetables and sauce products; and

(5) other foods.

To allow for the comparison among different income categories, the sample has been subdivided into three subsamples based on income. The first subsample is made of the lowest income people and is the first quartile of the income distribution (less than 30,000 CFA/month). The second subsample represents the second and third quartiles (30,000 to 85,000 CFA/month). The third subsample represents the upper income households, i.e., the fourth quartile (above 85,000 CFA/month).

A preliminary analysis of the data was performed by computing average expenditures and average expenditure shares, by income group and for each commodity group (Tables 5 and 6).

Table 5. Sample monthly average expenditures and prices, by income stratum.

Category	Income stratum			
	Entire sample	Lower income	Medium income	Upper income
	FCFA/month			
Total expenditure	33,699	23,258	35,389	42,483
Food	21,700	17,309	22,538	25,217
Nonfood	11,939	5,949	12,851	17,266
Traditional cereals (sorghum-millet-maize)	3,011	2,915	3,772	1,821
New-type cereals (wheat-rice)	4,138	3,483	4,459	1,821
Meat	3,874	2,728	3,551	[illegible]
Vegetables	4,630	3,937	4,500	[illegible]
Other food	6,057	4,246	6,256	7,743
Prices	FCFA/kg			
Traditional cereals	81	82	80	82
Price of new cereals	142	143	141	141
Price of meat	647	635	659	640
Price of other food	446	444	446	445
Aggregate price of food	456	447	436	502

On average upper income people spend more than lower income households (Table 5). With regard to food, the same observation is made. The upper income stratum spends on average 25,000 CFA/month for food, vs 22,000 for the middle income, and 17,000 for the lowest income strata. Also, the low and mid-income classes spend more on cereals than the upper income class. In particular the average lower income household spends 2,915 CFA on sorghum, millet, and maize monthly, compared to 3,772 for the middle and 1,821 for the upper income households. This pattern is reversed regarding more expensive foods such as meat and vegetables for which the higher income families spend on average significantly more than the lower income households. The conclusion is that there are indeed differences in consumption patterns between upper income and lower income households. The latter tend to consume more of the less expensive foods (cereals) while the former spend considerable amounts on more expensive foods (meat and vegetables).

These conclusions are corroborated by the results in Table 6 which contains the average shares of individual products out of the total expenditure. For the entire sample, the average household allocates 73 percent of its expenditure to food and 27 percent to nonfood. By income stratum, the share of food declines from 79 percent for the low income household to 72 percent and 68 percent for the mid and upper income households. The share of cereals decreases significantly from the low income (24%) to the mid income (21%) and high income households (12%). One notes that the share of the new type cereals exceeds that of the traditional cereals for all income strata. The difference appears more significant for the upper income households who spend on average three percent of their income on sorghum, millet, and corn vs nine percent on rice and wheat.

Table 6. Monthly average expenditure shares [1] by income stratum.

Category	Income Stratum			
	Entire sample	Low income	Medium income	Upper income
Food	.73	.79	.72	.68
Nonfood	.27	.21	.28	.32
Traditional cereals	.08	.10	.09	.03
New cereals	.12	.14	.12	.09
Meat	.15	.13	.13	.18
Vegetables	.18	.21	.17	.18
Other food	.20	.21	.21	.20

[1]Computed by dividing the expenditure of the commodity by total expenditure.

The two tables suggest that there is some relationship between consumption and income (total expenditure)[1]. It is the purpose of the following section to investigate the nature of this relationship.

ANALYSIS OF RESULTS

The Linear Expenditure System (LES) was used to estimate the income and price parameters. Estimates of the LES basic parameters that are

[1]Similar tabular analysis has been performed using education and household size as independent variables. In both cases no clearcut correlation was evident between consumption and these variables. It was then decided not to pursue further investigation and these two variables.

used to compute the marginal budget shares, the income and price elasticities are found in Sawadogo, 1985.

Effect of income. Marginal budget shares, which refer to the portion of additional income that is spent on a particular commodity, are shown in Table 7. While the average budget shares shown in Table 5 represent an actual situation (the household spends X percent of its income on commodity Y), the marginal budget shares represent a tendency and hence suggest what the future is likely to be. For example, while the average budget shares indicate that the average household in the sample allocates 73 percent of its budget to food, the marginal budget shares suggest that of an additional 100 CFA, the household allocates only 32.6 CFA to food, the remainder being allocated to nonfood. The marginal share of food decreases as one moves from the lower to the upper income strata, from a high 48.9 percent to a low 28.3 percent.

Table 7. Marginal budget shares estimates using nonlinear least squares on LES.

Budget category	Entire sample	Lower 25%	Middle 25%	Upper 25%
	%			
Food	32.6	48.9	30.6	28.3
Nonfood	67.4	51.1	69.4	71.7
Tradcer	8.3	16.8	8.7	5.4
Newcer	10.5	18.0	10.2	8.8
Meat	3.7	3.9	2.9	3.4
Vegetable	2.5	2.9	2.2	2.5
Other Food	7.6	7.4	6.6	8.2

It is important to note that the cereals, wheat and rice have consistently a higher marginal share than the traditional cereals. Of any additional 100 CFA, households on average allocate about 10 CFA to wheat and rice against eight CFA to sorghum, millet, and corn. Low income households would allocate 18 CFA to wheat and rice and 16 CFA to the traditional cereals, mid income households 10.2 CFA and 8.7 CFA and upper income households 8.8 and 5.4 CFA. For all income groups, the combined share of cereals equals or outweighs the combined share of all other foods. This suggests that at the margin cereals still appear as a major contributor to the urban household diet.

Another income parameter that combines marginal and average budget shares is the income elasticity defined as the ratio of marginal budget share to average budget share at constant prices. This measure has the advantage of being dimensionless, i.e., it is not affected by a change in the units of measurement (eg. from 1 FCFA to 1,000 CFA). Income (or expenditures) elasticities are shown in Table 8, by income stratum. The income elasticity of food is .45, meaning that for a 1% increase in total income, expenditure on food will increase by 4.5%. It is usually expected that income elasticities for food are high in developing as compared with developed countries. The numbers found here are comparable to the results of other studies in developing countries[1].

Table 8. Income elasticities computed from LES parameter estimates.

Budget category	Entire sample	Lower 25%	Middle 25%	Upper 25%
	%			
Food	.45	.62	.43	.42
Nonfood	2.50	2.43	2.48	2.24
Tradcer (sorghum, millet, maize)	.75	1.29	.67	1.08
Newcer (wheat, rice)	.66	1.06	.64	.68
Meat	.19	.23	.17	.13
Vegetable	.10	.11	.09	.10
Other food	.27	.28	.22	.27

One notes the high values of income elasticities for cereals. When total expenditure is increased by 10 percent, consumption of sorghum, millet, and maize increases by 7.5% for the average household in the sample. An increase of total income by 10 percent is accompanied with an increase of 6.8 percent in the consumption of wheat and rice. These elasticity values are even higher for the lower income class, respectively, 1.29 and 1.06. Thus cereals appear as "superior" goods for the lowest income class. The empirical implication of these results is that cereal consumption by the lower class can be promoted through policies tending to raise the level of income in this class. A transfer of income from the very rich to the poor would increase aggregate consumption of wheat and rice because the income elasticity of the rich (.68) is significantly lower than that of the poor (1.06). The higher than expected income elasticity of the traditional cereals for the upper income class (1.08) can be explained by a very low average expenditure share on these cereals. (Recall that the income elasticity is the ratio of the marginal to the average budget share).

Effect of prices . In the short run, prices play an important role in the allocation of resources among goods. A price increase has two effects. The first effect is that, everything else constant, the household's purchasing power decreases. The second effect is that the good whose price has increased becomes relatively more expensive than other goods, and as a consequence, a rational household will substitute away from this good. These two types of effects are combined into a single measure which is the cross price elasticity. The latter measures the relative change in consumption of a good following a relative change in the price of the same good or of another good. In the first case the elasticity is referred to as own price elasticity, and in the second case as cross-price elasticity.

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[1]Sigma One Corporation, 1983 finds the following numbers for urban Sudan: 73 for overall sample, .092 for lower income, .755 for mid-income, and .514 for higher income households.

Own Price elasticity estimates are shown in Table 9. All price elasticities are negative as theoretically expected. When aggregate food price index increases (decreases) by 10%, the average household's food consumption decreases (increases) 5.6%. The lower income households have a higher response to price changes than the higher income households. An interesting result is the price elasticity of cereals, which is very high at all income levels, with an absolute value greater than one in all cases. A one percent decrease (increase) of the price of traditional cereals will cause an increase (a decrease) of 2.58 percent in consumption for the average household. For these cereals, the magnitude of the price response increases as income increases. Economic theory does not provide any answer to whether this is the "normal" pattern or not. The response of wheat and rice to a price change is also very high. It is again to be noted that the higher income households have a higher response than lower income households.

Table 9. Estimates of own price elasticities using nonlinear least squares on LES.

Budget category	Entire sample	Lower 25%	Middle 25%	Upper 25%
	%			
Food	-.56	-.71	-.55	.53
Tradcer (sorghum, millet, maize)	-2.58	-2.04	-2.58	-3.23
Newcer (wheat, rice)	-2.37	-1.83	-2.54	-2.22
Vegetables	-.57	-.34	-.60	-.52
Other food	-1.23	-.71	-1.24	-1.20

Cross price elasticity estimates are shown in Table 10. Their magnitude is significantly smaller than the own price elasticities in Table 9, meaning that the change in the price of good affects in the first place the good and then other goods. The importance of crop price elasticities is that they show the nature of the relationship, substitutability or complementarity, between two goods. When the cross price elasticity is negative, the goods are (gross) complements; when it is positive, they are (gross) substitutes. Hence the table suggests that traditional and new type cereals are complementary in consumption. This is not what was expected. One would expect wheat and rice on one hand and sorghum, millet, and maize, on the other hand to be substitutes. The results may be attributed to a low price variation: if prices did not change "enough" during the period of observation, reactions of households toward substitution cannot be observed. New type cereals and traditional cereals appear to be "balanced" in the sense that their respective responses are of similar magnitudes. Such is not the case for meat and traditional cereals, for example. A change in the price of meat has little impact on consumption of traditional cereals, whereas a change in the price of the latter drastically affects the consumption of meat, particularly for the middle income households.

Table 10. Estimated cross price elasticities using nonlinear least squares on LES.

Category	Entire sample	Lower 25%	Middle 25%	Upper 25%
	%			
Tradcer/newcer[1]	-.10	-.16	-.10	-.07
Newcer/tradcer	-.09	-.18	-.09	-.07
Tradcer/meat	.003	.06	.001	.02
Meat/tradcer	1.01	.12	3.89	.89
Tradcer/vegetables	.03	.12	.02	.03
Vegetables tradcer	.06	.04	.08	.04
Tradcer/other food	-.02	.06	.02	-.02
Other food/tradcer	-.25	.20	-.27	-.21
Newcer/meat	.003	.06	.001	.03
Meat/newcer	1.23	.11	4.58	.11
Newcer/vegetables	.04	.14	.02	.04
Vegetables/newcer	.08	.04	.09	.05
Newcer/other food	-.03	.07	-.02	.03
Other food/newcer	-.32	.20	-.32	-.29
Meat/vegetables	-.41	.09	-1.10	-.05
Vegetables/meat	-.002	-.01	-.001	-.02
Meat/other food	.61	-.04	.94	.03
Other food/meat	.01	-.07	.002	.09
Vegetables/other food	.02	-.01	.02	.01
Other food/vegetables	.11	-.15	.08	.14

[1] $A/B = \frac{\partial A}{\partial P_B} \cdot \frac{P_B}{A}$ = elasticity of A with respect to price of B.

SUMMARY AND CONCLUSIONS

The major finding of this study is that both traditional cereals (millet-sorghum) and new type cereals (wheat-rice) are very responsive to income and to their own prices. These high response values are observed at all income levels. For every 100 FCFA of additional income received by the households, both types of cereals claim an important part. The findings suggest that sorghum is far from becoming an inferior good (i.e., one whose demand decreases as income increases) for the average urban household in Burkina Faso. This conclusion is also expected to prevail at the rural household's level, since it usually has less income.

The findings suggest the following conclusions:

(1) It appears that the demand for sorghum and millet can still be made greater in urban centers by raising consumers' incomes or by lowering cereal prices. New technology in sorghum and millet production is expected to bring lower prices by increasing productivity. In that case, the price elasticities found by the analysis suggest that the farm level excess supply is potentially absorbable by urban consumers. Hence the problem of a market for increased production of sorghum and millet seems not to be an accute one in the near future. In any case a combination of lower prices and a transfer of income to the lower income households would increase demand for millet and sorghum.

(2) This analysis is limited to the urban consumer: one expects however to find even greater responses of consumption to income and prices in rural sectors for those categories of households who are not farmers or who do not produce enough for their consumption requirement. The possibilities of substitution are limited in rural areas so that any increase in income or a price decrease of sorghum/millet will be first and foremost felt on these crops.

A limitation of these findings is their time span (one year) which may not be long enough to allow for significant changes in prices and households' adjustment to these new prices. This insufficient relative price variability may explain the very low values found for the cross price elasticities. A more exhaustive analysis (encompassing both rural and urban areas and for longer time periods than one year) is needed to more accurately assess the dynamics of preference changes of consumers over time and what this implies.

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WORKSHOP SUMMARY

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The Workshop on Appropriate Technologies for Farmers in Semi-Arid West Africa brought together biological scientists, social-scientists and others involved in new technology design and dissemination. Papers were presented in four sessions. Session I included two general papers on soil and water management and soil fertility outlining research experiences to date. Each general paper was followed by case study papers. Two general papers were presented in Session II on plant improvement and crop associations and were followed by case studies in each area. Papers on livestock were presented in Session III. Session IV focused on technology needs and promising avenues of research, technology evaluation, and the broader aspect of the interface between production and future consumption patterns and the implications for new technology design. Each session was followed by in-depth group discussions. The discussions of the first three sessions focused mainly on the micro issues involved in technology design and dissemination while the discussion in Session IV focused on macro policy issues.

The papers presented in Session I under Soil and Water Management and Soil Fertility demonstrated that significant yield increases can be obtained by on-station and on-farm research with technologies such as ploughing, diguettes, tied ridges and fertilization in the West African Semi-Arid Tropics (WASAT). However there are persistent problems of adoption by farmers. Factors explaining the low rates of adoption of soil tillage by farmers include: limitations in draft power, short growing season and soil characteristics. Non-mechanized construction of tied ridges requires high labor inputs at times when labor is most needed for planting and weeding operations. To offset the high labor demand in peak periods in the agricultural season, there is a need for inexpensive, mechanically simple equipment to decrease labor inputs for tied ridging, seeding, weeding and fertilizer application. Diguettes have been adopted in certain areas and have the advantage that they can be constructed during the non-agricultural season which minimizes competition with crop culture for labor. However, applicability and transferability across regions must be investigated. The adoption of fertilizer has been limited by its low availability and cash/credit availability. However, commercial fertilizer use alone without support from water retention technologies presents the farmer with a high risk of losing his cash outlay. The use of manures and mulching are both beneficial, however there is a limited supply.

The discussion in Session I pointed out the need to target the research of soil, water and fertility management across soil types, agroclimatic zones and crops. Each of the soil and water management technologies must be applied under specific soil type, toposequence, climate and other environmental conditions. Although the increase demonstrated by the use of fertilizers can be substantial, there is a need to look at the problem of soil nutrients in their totality rather than as a single nutrient. There is a need to look at the effects of using fertilizer and water retention/erosion reduction methods both in terms of the long run effect on the soil resource base and their long term effects on costs and returns. In general, research is required in understanding the interface between crop production, livestock production and agro-forestry so as to design technologies that benefit from the integration of all three areas; a theme that was carried through to the other sessions of the workshop

The papers presented in Session II indicated significant yield increases for on-station research but there is a significant yield gap between on-station and on-farm yields especially for the principle food grains of millet and sorghum. In many cases, this yield gap is less for the local variety then for the experiment-station-developed variety. The adoption of new varieties by farmers in the WASAT region is very low. Part of the problem stems from the present goals of the crop development strategy in the WASAT. Crop improvement programs have looked to the "green revolution" model for their goals and objectives and have stressed the goal of yield potential under high management conditions relying largely on the use of plant material transfer from other parts of the world rather than on local materials. However, the environment of the WASAT region is very different from Asia where the green revolution took place. The WASAT region exhibits soils that are structurally inferior and less fertile with a lower water holding capacity. Little irrigation exists, rainfall is generally lower and its distribution more eratic in the WASAT than in areas where the green revolution has been highly successful. The less than desirable physical environment makes new technology adoption in the WASAT more risky. In general, the infrastructure to support new technology adoption and dissemination is at a lower level in the WASAT. Population pressures for the most part are much higher in Asia and consequently the economic incentives for new technology adoption are much stronger. Given the physical environment, agricultural production in the WASAT region is characterized by a "low to moderate input" cropping system and any new technology design especially in the area of new crop development must bear this in mind.

Gains in production from genetic improvements are usually maximized under high management conditions. Thus, major gains from crop development in the WASAT will only come about by improving the existing physical and management environment. This improvement however, will not take place in the short run. Thus crop improvement programs in the WASAT should concentrate on developing varieties that show stability and exhibit a response curve that exploits moderate management levels while maintaining to a high degree the ability to exploit higher management levels. Selection must be focused on resistance to important pests and diseases as well as production superiority under varying levels of soil productivity and available soil moisture - all of which are factors which contribute to production stability. This strategy for improved crop development will give the best chance for higher adoption rates, increases in aggregate production, reduced production variability and income distribution equality. This change in crop development goals requires new screening and selection procedures and an increased interdisciplinary effort between on-station and on-farm research as well as increased interactions with the farmer.

Crop associations as indicated by the papers in the second part of Session II have and continue to play an important role in the farming systems of the WASAT. The reasons given for intercropping vary but in general they are; insurance against biological and economic risk, increased soil fertility and prevention of erosion, possible higher aggregate yield and economic returns and possible gains because of a better distribution of labor over the agricultural season. While there was research on intercropping in the 1930's in the WASAT, there has been a discontinuity in research programs and only within the last fifteen years has research again focused on this area.

More on-farm research including socio-economic research and farmer participation is required to appraise on-station research results. Important insights have been gained from on-farm research such as farmers indicating that they judge a cropping association system by the yield of the principle food crop and how the secondary crop fits into of the overall labor availability pattern and consumption needs. Crop association varieties must also be developed with an aim of use in mind. Farmers may want only the seed or the top growth for hay or both. In the case of cowpeas, there is a need to work on both photosensitive and non-photosensitive varieties. Further research needs are in the areas of; development of adapted genotypes, soil fertility management, maximizing spatial and temporal advantages, nitrogen fixation and yield stability. In the WASAT, there are many types of crop associations employed by farmers and for researchers to work on all of them is an impossibility. A strategy for research should be the identification of several major crop association systems across the different ecological zones of the WASAT in which major research investments would be made. The new crop development strategy as outlined in the "Relevant Crop Variety Development" section of Session II should also be adhered to.

Session III focused on the importance of livestock production systems and animal traction within the farming system. The papers presented gave an overview of livestock production in agropastoral systems of the WASAT, their socio-economic significance, the maintenance and conditioning of cattle during the dry season and the profitability and effect of animal traction. It was made clear that technology intervention in livestock systems be done within the context of the total farming systems.

The use of animal traction can lead to significant area expansion effects through increased weeding capability especially at the first weeding - late planting, peak labor demand period. Increased yields from the use of animal traction have been observed but are usually small and it is a debated issue in the literature. To be profitable, animal traction utilization rates must be high (at least 30 days per year). There is a learning curve for both animal and farmer and it may take three to five years to achieve the full benefits from animal traction. High internal rates of return can be achieved especially with high usage and shorter learning curves. However, in spite of possible high internal rates of return, animal traction adoption rates are low in the WASAT primarily because of low utilization rates and long learning curves. Problems of obtaining high utilization rates stem from; small size farms, inappropriate and/or incomplete set of implements, poor animal health and poor management skills. Shorter learning curves are not obtained because there is little farmer or animal training through extension and there is not a well developed market for trained draft animals. To date, animal traction useage in the WASAT can be characterized as land using (extensive). However, in those areas of high population pressure where the traditional fallow system is breaking down, area expansion is taking place on more marginal land with declining yields making animal traction farmers no better off.

What is required is land saving technologies (intensive) to increase yields through new crop development, soil and water management and soil fertility practices. On-station and on-farm research have a role to play in finding ways to use animal traction in a more intensive mode especially in the soil and water management areas. Such implements as a mechanical tied ridger can be used as a land augmenting tool.

Papers in Session IV were presented on methods of evaluating new technologies, the role of consumption analysis in technology design and evaluation and technology needs and promising avenues of research.

Technology evaluation of on-farm level tests use the following citeria:
(1) technical feasibility (Is the technology superior to existing farmer practices?),
(2) profitability, and
(3) appropriateness of the technology (Does the technology "fit" the farmers' production system and constraints?)
The first critera involves the biological scientists, ie, agronomists using analysis of variance and their technical skills in identifying diseases, pests and the like. The second and third criteria are primarly undertaken by socio-economic personnel. Simple budgeting analysis can be used to show the profitability of a technology. However, even if a technology is technically and economically feasible, it may not fit into the overall production system of the farmer. Whole farm modeling can facilitate in answering this question. Whole farm modeling techniques such as linear programming (LP) can be used to model land endowments and labor requirements and availability of a representative farm. Technical aspects of the new technology from the on-farm research are modeled into the LP and evaluated with respect to the available resources of the farm. The model indicates the extent to which the new technology is adopted and indicates the constraints within the production system that hold the technology from further adoption. The results from the whole farm modeling exercise can be used as feedback to scientists designing the technologies. The approriateness of the technology also includes a social soundness evaluation of the impact of the technology on intra-household and inter-household relationships.

Consumption analysis is important because consumption sets the stage for production. Over time, consumption trends change in response to increases in income and education. As a society becomes more affluent, preferences turn toward increased rice and wheat consumption which are mainly imported in the WASAT and away from such locally grown staples as sorghum and millet. Such changes in consumption patterns combined with increased production of sorghum and millet through the use of new technology can change farm gate prices and the relative profitability of different crops. Thus when designing new technologies, a view of the long term consumption patterns and their impact on producer prices should be taken into consideration. Grain imports under aid programs also can change relative prices and change consumer preferences.

The paper on technology needs and promising avenues of research started with a critique of agricultural research policy. Since the independence era, economic development of the WASAT has stagnated. The agricultural sector has contributed to the stagnation with very low growth rates especially in principle food crop production. The small increase in total food production, however, has come about through land area expansion rather than from yield increases per unit of land demonstrating that land augmenting technologies are not being used. This is in spite of increased funding of principle food crops research in the post independence era. However, the increased funding was accompanied by management inefficiencies, unqualified staffing and limited operating funds. Two reasons for the failure to produce appropriate technologies are firstly, the failure to understand farmer goals and their resource limitations and secondly, the adoption of the technology transfer model development, i.e., the green revolution model.

Future research must consider the given resource base of the WASAT and concentrate on soil conservation, water management and reforestation within a small scale farming context. Research should concentrate on principle food crops and on export crops only to the extent that they have a clear competitive advantage. The research must have a farming systems perspective which includes interaction among on-station research, on-farm research and the socio-economic environment of the farmer. A promising avenue of research for the future in the biological area is developing varieties with stability and an increased response to moderate management levels. An increased use of local plant materials in research programs may have a higher payoff than imported materials. Chemical technologies such as fertilizers require research on the utilization of local materials where possible such as local rock phosphate to decrease transportation costs and foreign exchange requirements. Since the first weeding-late planting period is a peak labor demand period, research on low cost effective herbicides could also have substantial payoffs. Another area of research is that of increasing labor productivity by improved mechanical means. Simple improvements in existing hand tools and animal traction equipment is the first step. Livestock research to date has been in the area of animal diseases. An important constraint now appears to be the availability and quality of feed for animal maintenance especially during the dry season. Future research on native pasture improvement and the growing of forages on fallow land are avenues of research. However, the only real effect on the feed supply will come with increased crop production.

The ending discussions of the workshop concentrated on the issues of; what is appropriate technology, problems of the adoption of technology packages and the problems of long term planning of agricultural research. There was a discussion on what input and product pricing regime should be used to define appropriate technology. Prices of fertilizers and grains are often subsidized. Are technologies that are only profitable under subsidized prices appropriate technologies? Further, should researchers develop new technologies using subsidized price ratios as a guide? Two reasons as to why subsidized prices should not be used as a guide for technology design are:

(1) government policies can change leaving the once appropriate technology an inappropriate technology, and
(2) there is a real resource cost to the subsidization of input and product prices.

Thus, there is a cost to society in terms of the money spent on subsidization that may be spent elsewhere in the economy which may give society greater benefits. However, with this in mind, it is important to continue to develop a range of technologies for specific recommendation domains to ensure that at each stage of development farmers have a choice of technologies.

Given the current food production situation, a quantum jump in production is required. The adoption of a total package of technologies is needed to obtain the quantum jump however, total packages are adopted more slowly than single technologies or parts of a package of technologies. Farmers will adopt those parts of the package that are easiest and most profitable. To attain total technology package adoption, the most profitable components in the package may need to be extended to the farmer first and over time, all the technology in the package may be adopted. To do this, a long term perspective is required to chart a course that will take agricultural production to desired levels in a reasonable period of time, i.e., five years.

Given that a quantum jump in production is required and that each institutional organization within the agricultural system has its own direction and agenda, will their combined effort lead in the long run to incremental changes that will increase production to desired levels? The answer at present is probably not. Many if not most countries in the WASAT do not have well-defined agricultural policies or agricultural research policies. Crisis planning is at the root of current policy direction and has led to short term goals. With respect to agricultural research, the funding in total is very low and most WASAT countries contribute little to their own research efforts. Donor agencies also tend to plan in a crisis environment which results in short term planning and inappropriate research. The impact of donor agency funding from sending in two to three expatriates or increasing the budgets of International Centers is often marginal because National research systems are very weak. Strong National research organizations are important to develop location-specific technologies over wideranging agroclimatic zones and are the only institutions that can carry out research that maintains a long term perspective. Crisis planning can only be avoided by strong National research institutions that identify long term research needs and goals and present them to policymarkers.

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