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9. ABSTRACT

Nearly every aspect of farming in the semi-arid tropics was examined at the workshop, and it is felt that only through the dissemination of information and an integrated systems approach can the attendant problems be remedied. Toward that end, this report includes the papers presented at the workshop and the discussions following each major group of topics. The first group, Committee I, covered those subjects related to resource assessment and utilization of research on farming systems in the semi-arid tropics. Major attention was given to land, soil, water, climate, and manpower resources for improving production under the rain-fed conditions in this seasonally dry area. Committee II examined the crops and cropping systems research needs for the semi-arid tropics, and Committee III discussed the socio-economic problems related to farming systems research in this area. Finally, Committee IV explored the question of research at the cooperating centers and transfer of technology. The group evaluated various ways for the international institutes to play a productive role in the generation of location-specific technology and its transfer to the different agro-climatic and soil regions in the semi-arid tropics. These focused mainly on off-site activities (farming systems), conceptual models of these systems, operational aspects, and technology.

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INTERNATIONAL WORKSHOP ON FARMING SYSTEMS

November 18-21, 1974

International Crops Research Institute
for the Semi-Arid Tropics
1—11—256, Begumpet
Hyderabad-500016 (A.P.), India

CONTENTS

FOREWORD

In my welcoming message to the participants of this workshop, I made reference to the tremendous diversity of the subjects falling under the term, "Farming Systems." I asked the assembly to go beyond exploration of specific subject areas and develop recommendations based on all available collective knowledge from the myriad disciplines and geographic regions represented in the working sessions.

It was a difficult request to fulfil. But the group had a strong motivation. They were aware that the 500 million people of the semi-arid tropics need immediate assistance to solve their food problem. The farmers of these regions face special problems and the workshop participants recognized that isolated inputs and fragmented policies cannot solve them. Only through an integrated, systems approach can research relate to the real world of the semi-arid tropics and the farmers' complete environment.

I am pleased to report that the group succeeded in their efforts and have provided valuable suggestions and guidance for ICRISAT's Farming Systems program. The purpose of this publication is to make available the information gathered at the conference to a wider audience. We have not attempted an extensive reorganization of material, editing or elaborate presentation in this volume. Our objective is to deliver the information to those who have need of it by the most rapid method available. I am sure this book will achieve that goal and prove useful to a wide range of researchers, students and agriculturists involved in solving a host of problems facing farmers in the semi-arid tropics.

Dr. R.W. Cummings, director
International Crops Research Institute
for the Semi-Arid Tropics
Hyderabad, India. 1975

PREFACE

J.S. Kanwar

The International Workshop on Farming Systems Research organized by ICRISAT was held from 18-21 November 1974 at the Administrative Staff College, Hyderabad, India. Thirty-eight participants and five observers representing 14 countries and 14 organizations attented the workshop. Thirty-five papers were presented.

In his welcome address, Dr. J.S. Kanwar, Associate Director of ICRISAT and Chairman of the workshop organizing committee, outlined the main problems facing farming systems research in semi-arid tropics. Dr. R.W. Cummings, director of ICRISAT, gave an overview of the objectives of the workshop and Dr. B.A. Krantz, ICRISAT agronomist, explained the program details. In the afternoon the participants visited ICRISAT and reviewed the field experiments with the Institute scientists.

The next two days were devoted exclusively to the presentation and discussion of papers in eight sessions. The eighth session consisted of a panel discussion by six experts on the subject of transfer of technology by the international institutes. Representatives from ICRISAT, IRRI, CIAT, IITA, ALAD AND USAID participated.

On 21 November, participants separated into four committees to discuss the observations and suggestions made during the previous sessions and develop recommendations. Committee I discussed topics covered in the first two sessions which related to resource assessment and utilization of research on farming systems in the semi-arid tropics. Major attention focused on land, soil, water, climate and manpower resources for optimising production under the rain-fed conditions in the seasonally dry semi-arid tropics. Dr. Ch. Krishna Moorthy, assistant director general and project director (DF) of the All India Coordinated Research Project for Dryland Agriculture, was the convener of this committee.

Committee II discussed the crops and cropping systems research needs for the semi-arid tropics. It was convened by Dr. I Arnon, director of research, Settlement Study Centre, Israel.

Committee III discussed the socio-economic problems related to farming systems research in semi-arid tropics. Dr. R.R. Harwood, cropping systems agronomist of the International Rice Research Institute was the convener of this committee.

Committee IV examined the question of research at the cooperating centers and transfer of technology. The group evaluated various ways for the international institutes to play a productive role in the generation of location-specific technology and its transfer to the different agro-climatic and soil regions in the semi-arid tropics. Dr. M.B. Russell, University of Illinois, U.S.A., was convener.

The recommendations and suggestions of the committees were discussed in the plenary session under the chairmanship of Dr. M.S. Swaminathan, director general, Indian Council of Agricultural Research.

Part I

Resource Assessment and Utilization of Research for Farming Systems —Land, Water, Climate, Man

SOIL AND WATER CONSERVATION AND MANAGEMENT

IN FARMING SYSTEMS RESEARCH FOR THE SEMI-ARID TROPICS

Jacob Kampen[1] and Associates[2]

INTRODUCTION

Rain-fed agriculture has failed to provide even the minimum food requirements (let alone an acceptable standard of living) for the rapidly increasing populations of many developing countries in the semi-arid tropics. Although the reasons for this are complex, the primary constraint to agricultural development in the seasonally dry tropics is the lack of suitable technology for land and water management and crop production under conditions of relatively low and extremely erratic rainfall. The severity of the constraints is amplified by generally high evaporation conditions and in many areas by soils of shallow depth with limited water-holding capacity. This situation results not only in low general production levels, it also causes great instability and uncertainty from year to year. Therefore, improved resource management which conserves and utilizes the rainfall and the soil more effectively, and new crop production systems which maintain productivity and assure dependable harvests, are urgently required.

Greater demands for food in the seasonally dry tropics have resulted in greater pressure on the land. The intensification of land use in the traditional agricultural setting may become self-defeating. Deforestation, overgrazing and uninterrupted cultivation on sloping lands have caused increased runoff, reduced recharge of the soil profile and the ground-water and also severe soil erosion. These processes in turn have caused soil deterioration, nutrient losses and lower yields of upland crops, downstream flooding of heavily cropped and populated areas, sedimentation of reservoirs and the loss of precious water to the seas.

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[1] International Scientist, Land and Water Management, ICRISAT.

[2] Mr. J. Hari Krishna assisted in writing the paper while Messrs. R.C. Sachan, P.N. Sharma and S.K. Sharma provided valuable comments and suggestions.

Farming Systems Goals

The major goals of the Farming Systems Program are inherent in the primary objectives of the ICRISAT. They include the following:

1. To provide economically viable, labor-intensive technology for improving and utilizing the productive potential of natural resources while maintaining the quality of the environment.

2. To develop superior land and water management systems which can be implemented and maintained during the extended dry seasons thus providing additional employment to people and better utilization of available animal power.

3. To contribute to raising the economic status and the quality of life of the people in the semi-arid tropics by developing farming systems which increase agricultural output and make it more stable from year to year.

The Farming Systems Program at ICRISAT is 'resource centered' and 'development aimed'. This orientation is evident from the ICRISAT's working definition of a farming system: "A farming system involves the entire complex of development, management and allocation of resources as well as all decisions and activities which, within an operational farm unit or a combination of such units, result in agricultural production." The processing and marketing of the products are also directly related to the system that produces them.

Orientation and Purpose

This paper describes a proposed approach to improve land and water management in the semi-arid tropics. It is primarily aimed at technical aspects of resource management and conservation. The development of crop varieties and cropping systems more adapted to the harsh and unpredictable environment and questions of economic and social nature related to resource management are discussed in other papers presented at this workshop. It is well recognized that improved land and water management technology can be of significance only through economically viable systems of production. The problems faced by farmers of the seasonally dry tropics are such that an inter-disciplinary approach is absolutely essential for securing tangible results.

The long term productive potential of land and water can be raised substantially in many regions of the semi-arid tropics. The authors are confident that the returns from improved resource management technology when integrated with contributions of other disciplines aimed at more productive and stable systems of farming, will provide sufficient incentive for widespread adoption. Food shortages are presently experienced in some of the areas of concern, the time required for research has to be minimised. The purpose of this paper is to generate constructive criticism aimed at improving the effectiveness of the research effort and accelerating the attainment of its objectives.

THE SETTING

Substantial diversity exists within the resource environments of different regions in the semi-arid tropics; a generalizing description therefore has inherent dangers. The data collected are not sufficient to arrive at well-defined classifications of similar sub-regions. Most examples referred to in this section have been used as illustrations of specific situations in selected regions rather than descriptions of general characteristics. The consequences of the site-specific nature of environmental factors for the development of applicable land and water management technology are discussed in subsequent sections.

Climate and Precipitation

Definition of semi-aridity. Traditional definitions of semi-aridity were derived with specific attention to temperate regions. These descriptions are inadequate for many tropical regions primarily because the length of time during which precipitation occurs is not considered (Kampen and Krantz, 1973). Troll (1966) distinguished five climatic[1] regions within the tropics and classified the semi-arid zone as follows:

V3: Wet and dry tropical climates with 4-1/2 to 7 humid[2] months.
V4: Dry tropical climates with 2 to 4-1/2 humid months[3].

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[1] The humid climates are indicated as V1 and V2, the semi-arid climates as V3 and V4 and arid climates as V5.

[2] During a 'humid month' precipitation exceeds or equals potential evapotranspiration.

[3] Troll distinguished between a class V4 (rainfall in the warm season) and a class V4a (the tropical dry climate with humid months in the cool season); the area in this latter class is small in the semi-arid tropics, such climates being more common at sub-tropical or temperate latitudes.

Thus the semi-arid tropics are characterized by an arid[1] season which lasts from 5 to 10 months. Climatic characteristics indicate agronomic potentials which are further determined by soils, economics and other factors. Therefore, the description of the area of concern has to be further specified. ICRISAT is giving primary attention to areas in the semi-arid tropics where sorghum and millet occupy important positions in present food production systems and also where these crops could be expected to compete well.

Precipitation. Annual precipitation in the tropical regions as defined above varies from approximately 500 mm to about 1,500 mm (Fig. 1, 2 and 3); cooler tropical areas with rainfall somewhat less than 500 mm may still be considered semi-arid.

Cocheme and Franquin (1967) published a study of the agro-climatology of the semi-arid areas south of the Sahara in West Africa. From these investigations and more fragmentary data for other semi-arid regions, the following characteristics of rainfall in the seasonally dry tropics can be derived (Webster and Wilson, 1966; Arnon, 1972):

1. The beginning of the humid season is uncertain; the monsoon may begin four weeks before or after the mean date of arrival.

2. More than 95 percent of the annual precipitation occurs during the rainy season[2] which generally lasts from 4 to 7 months (Fig. 1, 2 and 3).

3. At least one-third and often more than two-thirds of the annual rainfall occurs in the humid season which in most of the seasonally dry tropics ranges from 2 to 5 months duration (Fig. 1, 2 and 3).

4. Precipitation during the wet season is often extremely variable not only from year to year but also within one single season (Fig. 4 and 5).

5. The mean daily rainfall intensities[3] are two to four times

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[1] During an 'arid month' the potential evapotranspiration exceeds precipitation.

[2] The rainy season here is defined as that period of the year in which monthly rainfall exceeds 1/10 of the monthly potential evapotranspiration.

[3] The mean daily rainfall intensity is computed by dividing the mean annual rainfall by the average number of rainy days per year.

Fig.1: ANNUAL RAINFALL DISTRIBUTION AT 4 LOCATIONS IN THE SEMI-ARID TROPICS OF THE NORTHERN HEMISPHERE (Compiled from "The Climates of the World"; Reid, 1941)

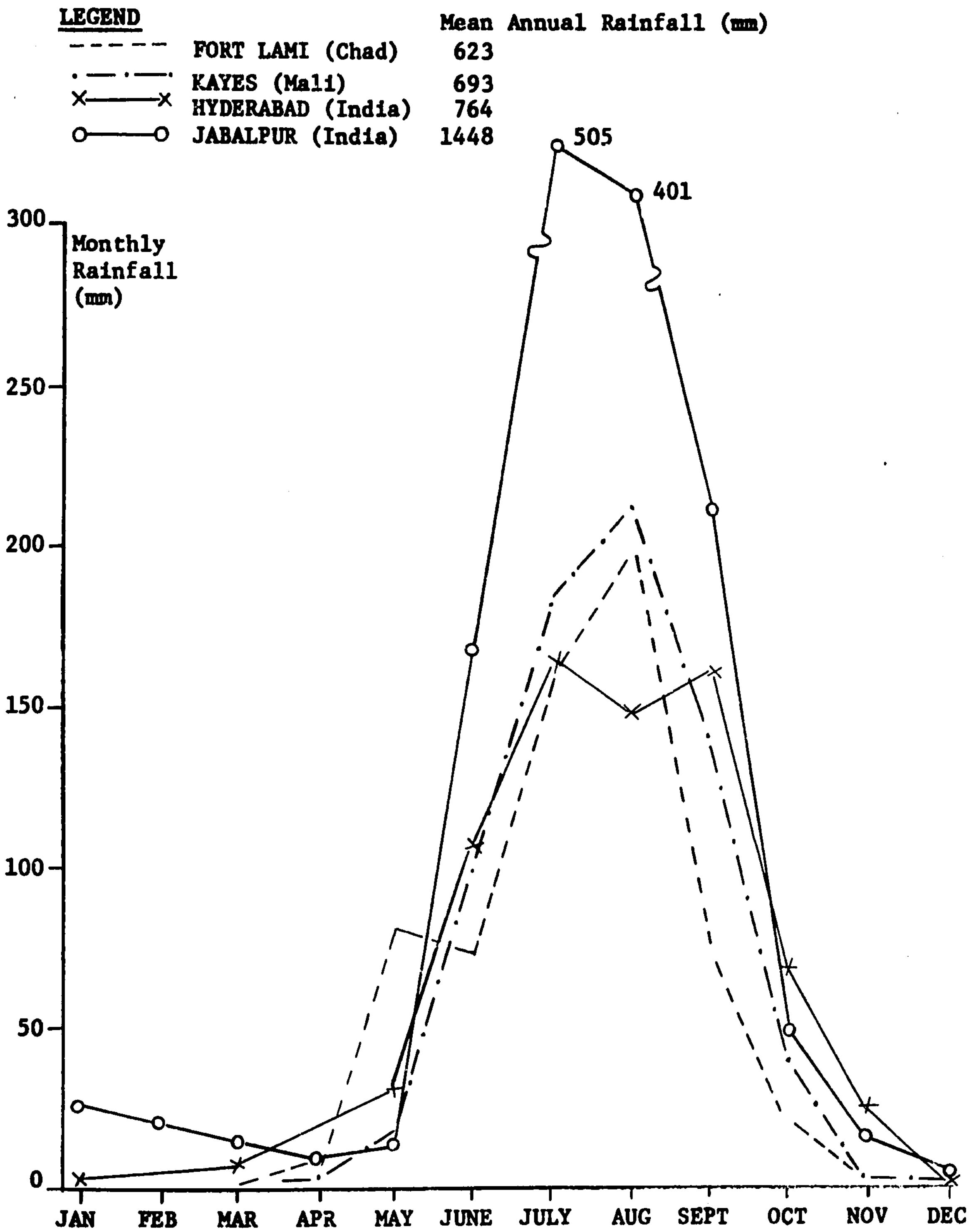


Fig.2: ANNUAL RAINFALL DISTRIBUTION AT 4 LOCATIONS IN THE SEMI-ARID TROPICS OF THE SOUTHERN HEMISPHERE
(Compiled from "The Climates of the World"; Reid, 1941)

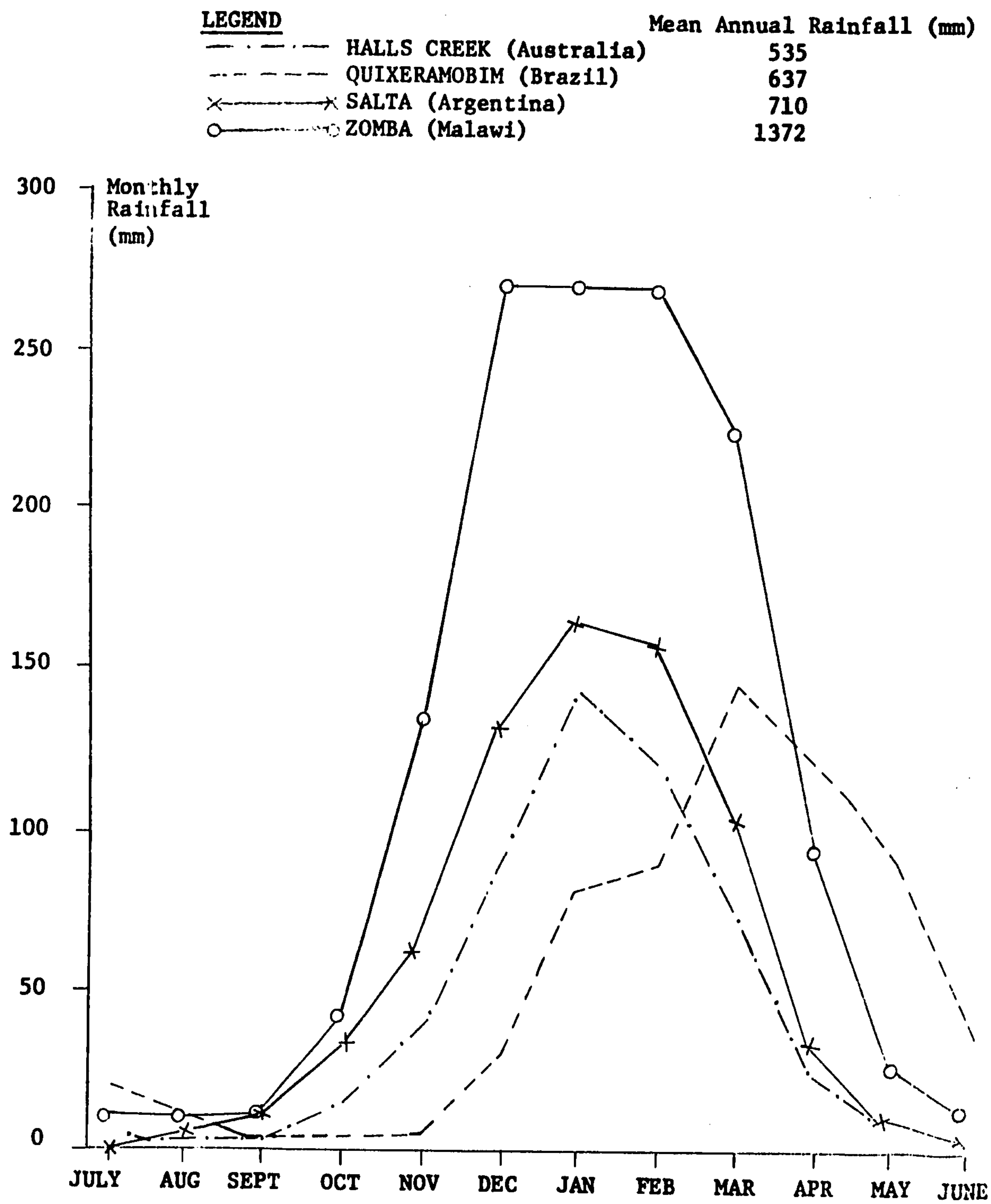
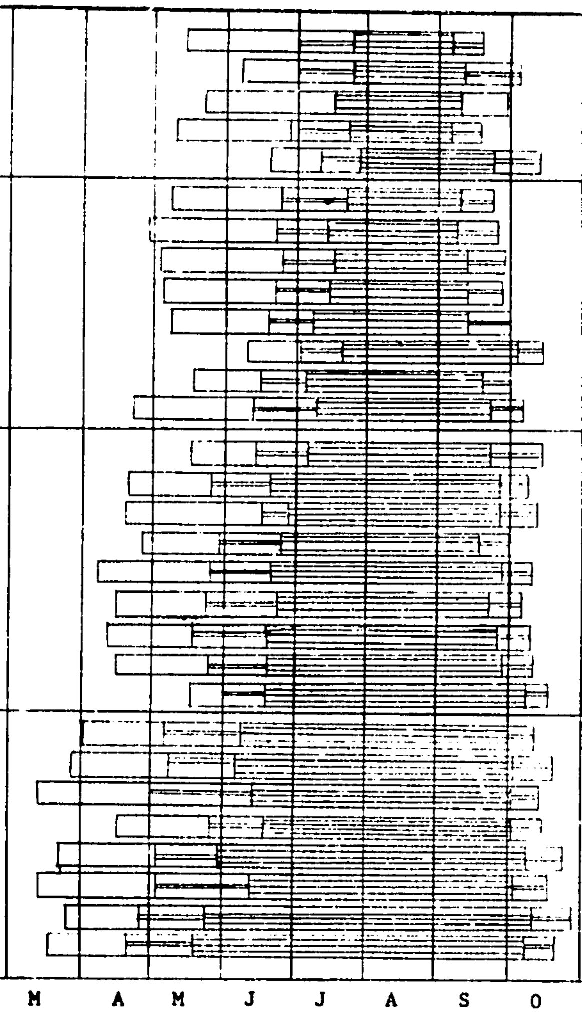
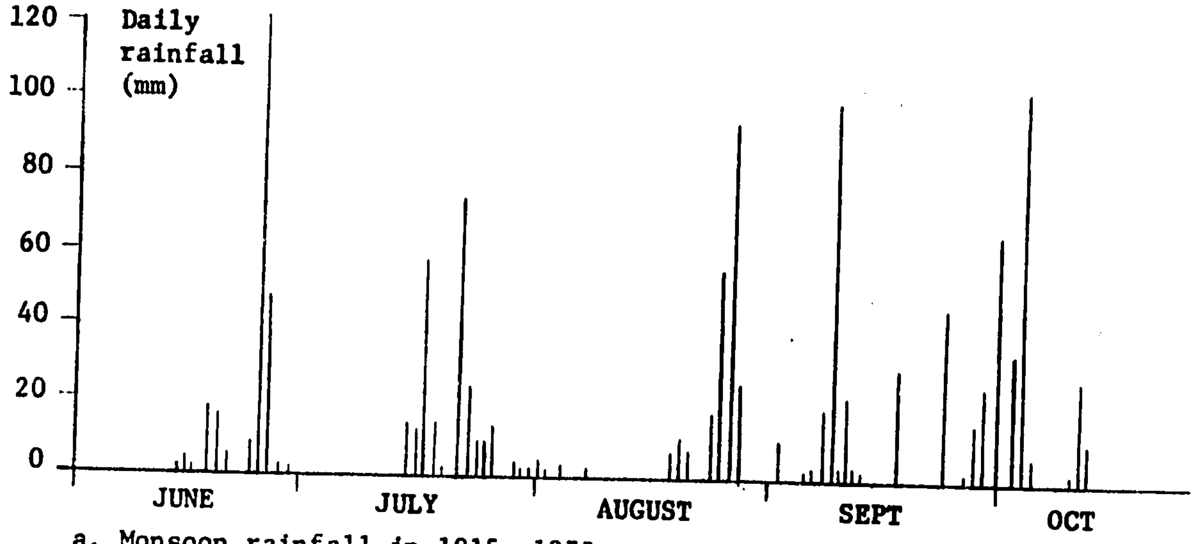


Fig.3: THE MONSOON AT 30 STATIONS IN THE WEST AFRICAN SEMI-ARID TROPICS (The non-shaded bar gives the preparatory season ($P > 1/10$ ET), the light shaded portions the intermediate seasons ($P \geq 1/2$ ET) and the dark shaded par[illegible]e humid season ($P > ET$). Column 'P' gives mean annual rainf[illegible], 'ET' the mean annual potential evapotranspiration, 'ET_4/ET' the relative potential evapotranspiration in the last 4 months of the dry season, and 'EP/P' the ratio of effective precipitation to mean annual rainfall (as adapted from Cocheme and Franquin, 1967)

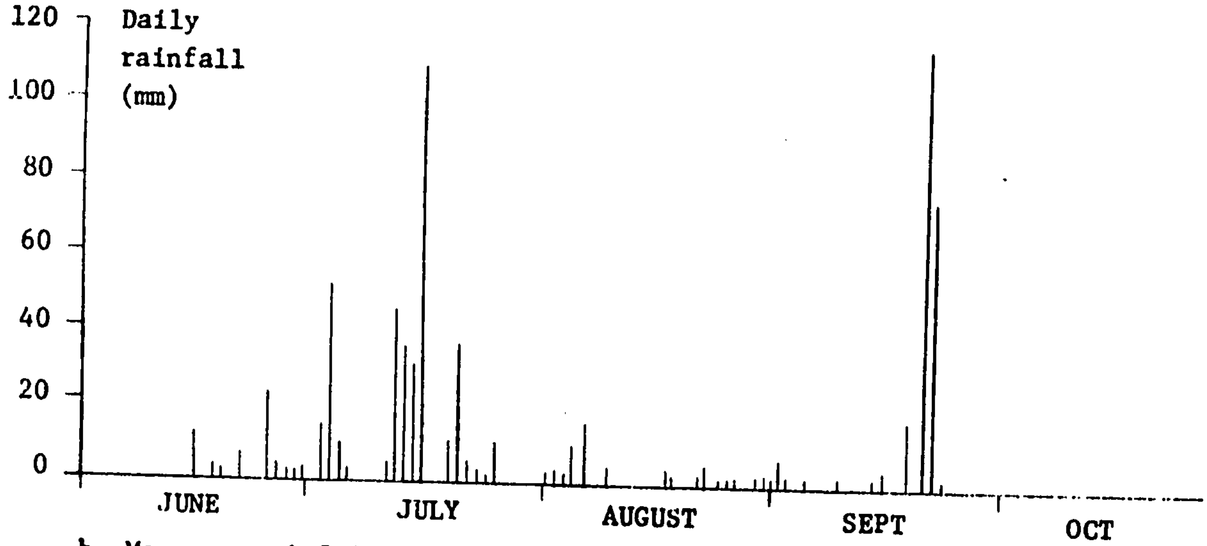


Station	P	ET	ET_4	EP/P
Abeche	505	1927	.40	.86
Matam	535	1619	.40	.83
Mopti	552	1984	.42	.87
Zinder	548	1924	.39	.88
Dakar Yoff 600	578	1825	.36	.83
Birni N Konni	600	1875	.40	.88
Niamey	638	2057	.41	.85
Maradi	642	1674	.41	.81
Fort Lamy	648	1958	.41	.79
Maiduguri	659	1910	.41	.81
Thies	694	1726	.41	.74
Segou	724	1823	.40	.80
Sokoto 800	734	1724	.40	.74
Kayes	821	1820	.43	.75
Maroua	841	1709	.40	.73
Mongo	858	1491	.39	.60
Kano	871	1802	.40	.74
Kaele	878	1807	.40	.73
Ouagadougou	882	1786	.40	.74
Am-Timan	919	1515	.39	.66
Bousso	931	1472	.39	.63
Tambaconda 1000	941	1616	.42	.67
Garoua	1014	1882	.41	.80
Pala	1044	1598	.39	.67
Navrongo	1095	1703	.39	.71
Bamaco	1099	1804	.41	.64
Fort Archambault	1141	1421	.40	.62
Bobo Dioulasso	1185	1712	.40	.66
Moundou	1228	1465	.39	.60
Kaduna	1298	1793	.40	.62

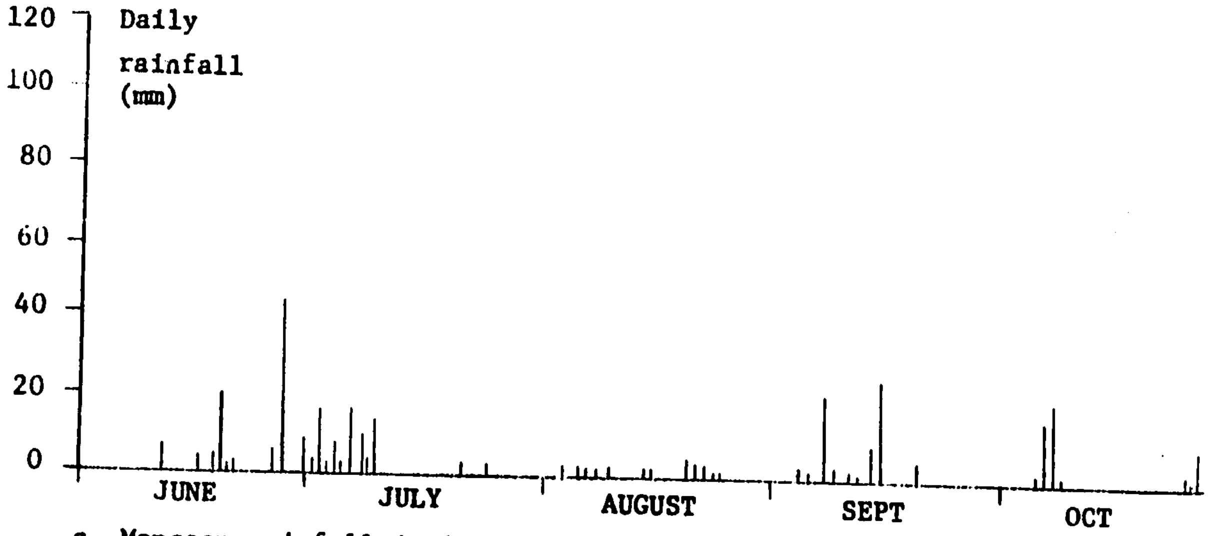
Fig.4: RAINFALL EXTREMES AT HYDERABAD



a. Monsoon rainfall in 1915; 1275 mm

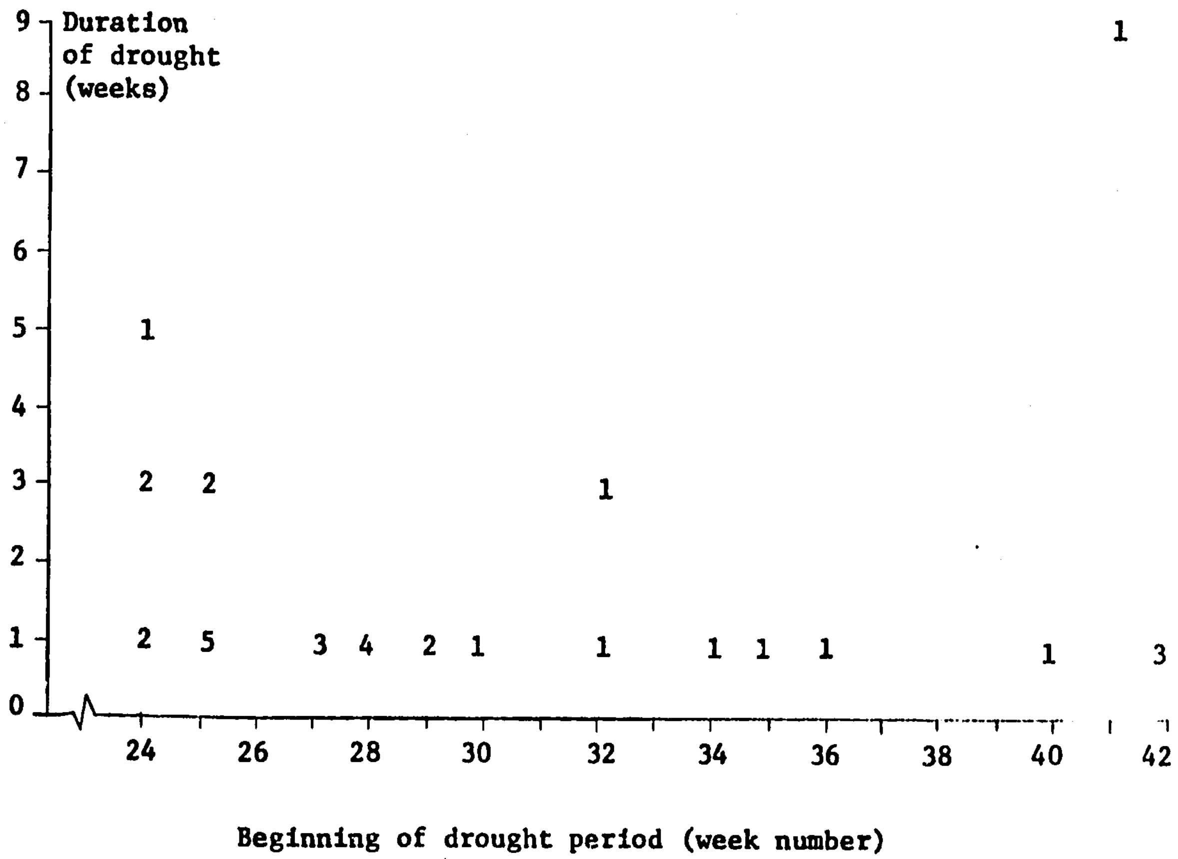


b. Monsoon rainfall in 1965; 776 mm



c. Monsoon rainfall in 1972; 340 mm

Fig.5: OCCURRENCES OF DROUGHT FROM 1901 TO 1970 IN HYDERABAD
(The climatic data of Hyderabad were used for analysis and estimation of soil-moisture regimes. A drought period here is defined as a period during which no significant rain falls while the available moisture in the profile (estimated at 100 mm) has been depleted).
(The assistance of Dr. J.R. Mc Alpine, CSIRO, Canberra, Australia, is gratefully acknowledged.)



greater than in many temperate regions; the short-duration intensities frequently exceed the intake capacity of the soil (Fig. 6).

6. The maximum short duration rainfall intensities increase only marginally with greater annual rainfall. In some areas in West Africa, high rainfall intensity increases with decreasing yearly precipitation.

Evapotranspiration and temperatures. Annual potential evapotranspiration ranges from nearly two to almost four times the average annual rainfall. The evaporation is relatively high during the four months preceding the humid season, potential evapotranspiration during this period often exceeding 40 percent of the annual amount (Fig. 3). The humid season coincides with a minimum in monthly mean potential evapotranspiration values. This minimum is sometimes lower than the minimum rates in the cool season. Monthly mean temperatures are consistently high and their seasonal variation is ordinarily less than 10°C.

The ability of the root profile to store water for crop use may vary from less than 100 mm to over 250 mm. This storage ability partially mitigates the effects of irregular rainfall. However, extended dry periods frequently result in 'droughts' making farming in the seasonally dry tropics a hazardous way of life. The extended dry season during which no crop can be grown except on residual soil moisture or under irrigation represents another factor contributing to instability. During this season there is no work for most of the people and available animal power is not utilized to an appreciable degree.

Rainfall Utilization and Water Resources

A rather low proportion of the average annual rainfall is used for crop production in the semi-arid tropics due to the undependability of rainfall, other climatic factors, soil profile characteristics, technological limitations and economic and social constraints.

Effective rainfall. A recent study on water budgets for 30 stations in the West African semi-arid tropics based on mean monthly rainfall data resulted in a computed long term average 'effective rainfall'[1] of 72 percent, ranging from 60 to 88 percent (Fig. 3).

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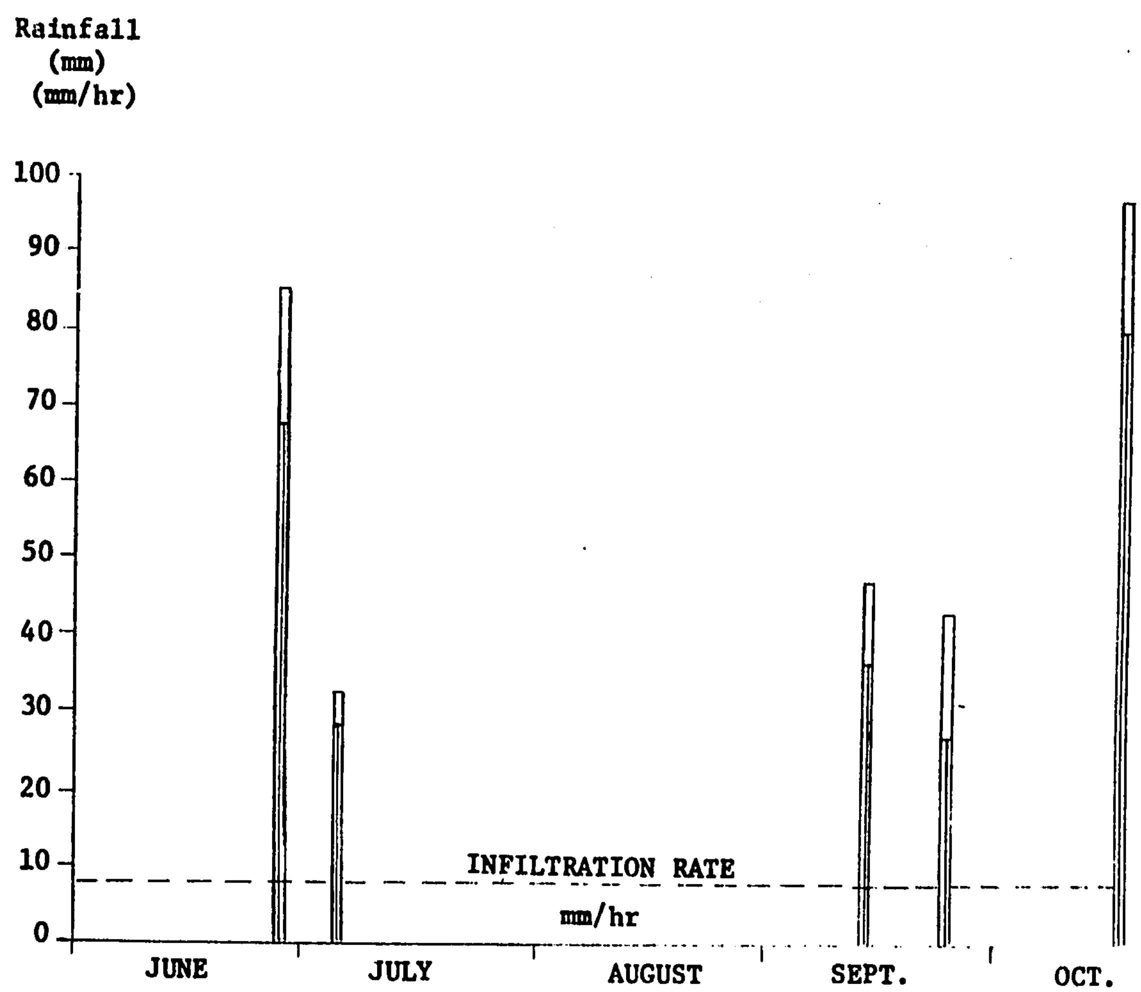
1 'Effective rainfall' for the purposes of this discussion is defined as : 'the quantity of the average annual precipitation which is or could potentially be used for crop evapotranspiration (without recycling of runoff or deep percolation) expressed as a percentage of total annual rainfall'.

Fig.6: RAINFALL INTENSITIES AND TOTAL RAINFALL OF FIVE SELECTED STORMS AT ICRISAT IN 1974
(The total storm rainfall is shaded dark, the maximum intensity observed during a minimum of 30 minutes is represented by the non-shaded bar. An estimate of hourly infiltration rates measured on saturated black soil in ridges and furrows is also given)



Most of the rainfall not used for evapotranspiration in the growing season is lost either through evaporation in the early rainy season, or deep percolation and as runoff. However, long term averages overestimate effective rainfall in areas characterised by variable precipitation. Actual long term effective rainfall may be less than two-thirds and sometimes less than half of the annual precipitation.

Monsoon fallowing. Krantz (1974) states that in India about 15 million ha of land with deep and heavy soils are fallowed during the monsoon. In these areas only a post-monsoon season crop is grown on residual soil moisture. This practice is also common on similar soils in West Africa. In these systems the effective rainfall is primarily determined by the storage capability of the soil profile and the estimated effective rainfall is often less than 50 percent in the low-rainfall areas and as low as 25 percent in high-rainfall areas.

Rainfall use efficiency. Low effective rainfall has severe repercussions on 'rainfall use efficiences'[1]. For example, statistics on regional production indicate that cereals like sorghum and millet, even in the relatively high-rainfall areas of the semi-arid tropics, generally produce less than 750 kg/ha (G.O.I., 1971; F.A.O., 1972). On the basis of an assumed mean annual rainfall, say 100 cm, this amounts to less than 7.5 kg/cm. In lower rainfall areas (mean annual precipitation 500 to 750 mm) average yields of less than 500 kg/ha are not uncommon. Under considerably higher than average levels of land and crop management, demonstrations on farmers' fields have attained rainfall use efficiencies well over 30 kg/cm (Rastogi, 1974). Initial experience at ICRISAT would seem to indicate the technical feasibility of rainfall use efficiencies exceeding 60 kg/cm in some regions (Krantz and Kampen, 1974).

Ground and surface water. Water transfers from distant watersheds or water 'mining' from deep aquifers are limited to exceptional cases in the semi-arid tropics. The water balance of most regions must be considered as a closed system in which total withdrawals (evapotranspiration, surface and deep drainage) are eventually balanced by the total input (rainfall). In most areas of the seasonally dry tropics the available quantities of ground-water and surface water are insufficient to provide for conventional irrigation on a very substantial portion of the arable land. However, limited quantities of irrigation water are available at some locations. A potential exists in these regions to harness surface and ground water for 'life-saving' irrigation to break a drought or to extend the post-monsoon season.

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1 'Rainfall use efficiency' is defined as "the agricultural production (in kg or the monetary equivalent) in relation to the annual precipitation (in cm)".

Large scale irrigated agriculture, which is dependent on transport of water over considerable distances is not dealt with in this paper.

Land Ownership and Farm Size

The potential for improved management of land and water is influenced by land tenure, fragmentation of holdings, size of holdings, and other factors. These aspects should be taken into account to develop applicable resource management technology and design criteria. Available data for all of the semi-arid tropics are inadequate at this time. Ryan (1974) discusses social and economic issues related to the development of improved farming systems.

Ownership status. There are indications that in some regions a major portion of the land is cultivated by farmers who fully own their land. Table 1 illustrates that for six selected dryland districts in the Indian semi-arid tropics owner-operated farms generally account for more than 80 percent of the cultivated land. Farmers who own and cultivate their land may be more interested in investments enhancing the productive potential of their farms than absentee landlords.

Fragmentation. Long established cultivation, shortage of land, unrestricted rights of transfer, limited credit facilities and uncertainty, population pressure and living in villages away from the farm land have contributed to serious fragmentation of holdings. Boundaries between fields are often demarcated by small bunds.

Farm size. The average size of farm in rain-fed areas is substantially larger than in regions where a significant proportion of the land is irrigated. As shown in Table 1, often more than 75 percent of all farms in irrigated districts are smaller than two ha while in rain-fed situations frequently more than 60 percent of all farms exceed two ha in size. In the selected districts 50 percent of all farms in primarily rain-fed areas generally fall within the two to ten ha size. In rain-fed districts the land area occupied by farms from 5 to 10 ha usually exceeds 25 percent of the cultivated land. The number of large farms ($>$ 10 ha) and also the area occupied by these is relatively small. Fragmentation and small holdings complicate the development of better resource management technology.

Table 2 shows that entirely irrigated farms in three selected, primarily rain-fed districts in Andhra Pradesh measured on an average less than .9 ha whereas partly irrigated and entirely rain-fed farms on an average ranged from 1.9 to 6.6 ha. It is rather surprising to note that in some districts the average farm size of partly irrigated farms is relatively large. For example, in Adilabad, Mahboobnagar and Medak districts in Andhra Pradesh the irrigated proportion of all cultivated land is 6, 9 and 15 percent respectively. Entirely irrigated farms account for 2, 2 and 3 percent respectively and consequently the irrigated land in partly irrigated farms accounts for only 4, 7 and 12 percent of the cultivated area. However, the cultivated area occupied by partly irrigated farms amounts to 46, 21 and 43 percent (Table 2). This situation may be advantageous when efforts are made to introduce new technology aimed at the optimum use of water resources.

Table 1. Farm Size Distribution, Irrigation and Ownership Status in 12 Districts of India (Source: Bureau of Economics and Statistics)

Size class (ha)	<1 %[1]	1-2 %	2-3 %	3-4 %	4-5 %	5-10 %	> 10 %	Owner operated[2] %	Irrigated area[3] %
'Rain-fed' Districts in Andhra Pradesh									
Adilabad	26	17	19	9	7	15	6	81	5
Mahboobnagar	21	20	16	10	8	17	1	78	8
Medak[4]	43	22	11	6	4	8	5	80	15
'Irrigated' Districts in Andhra Pradesh									
East Godavari	70	16	3	3	2	3	1	84	57
Krishna	64	19	7	4	2	3	1	90	56
West Godavari	62	19	8	4	2	4	1	91	62
'Rain-fed' Districts in Karnataka									
Bellary	16	21	17	11	9	17	9	91	8
Bijapur	10	16	14	11	8	24	17	87	3
Gulbarga	11	15	13	11	9	24	17	84	2
'Irrigated' Districts in Karnataka									
Mandya	55	24	10	5	2	3	-	97	31
Shimoga	33	30	15	7	5	7	2	79	48
South Kanara	47	28	12	5	3	4	1	50	43

[1] Columns 1-7 indicate the number of farms of a particular size expressed as a percentage of the total number of farms in the district.

[2] Column 8 gives the percentage of owner operated, cultivated area.

[3] In column 9 the irrigated area expressed as a percentage of the total cultivated area is given.

[4] Medak District is included because of ICRISAT's location in that area.

Table 2. Relation of Farm Size to Irrigation and the Relation of the Area in Partly Irrigated Holdings to Total Cultivated Area in three Primarily Rain-fed Districts in Andhra Pradesh (Source: Bureau of Economics and Statistics)

District	Average farm size (fully irrigated)	Average farm size (partly irrigated)	Average farm size (entirely rain-fed)	Area in farms which are partly irrigated (Total cultivated area)
Medak	.5	2.8	1.9	46%
Adilabad	.5	3.8	3.1	21%
Mahboobnagar	.9	6.6	3.3	43%

Soils and Soil Erosion

The soils of the semi-arid tropics show great diversity in texture, structure, type of clay, organic matter content and depth. These variations result in significant differences in infiltration rate, erodability, moisture holding capacity, drainage characteristics, aeration, susceptibility to and recovery from compaction and general response to soil management and manipulation. However, particular soil types are widely spread throughout the seasonally dry trppics; this may counteract the adverse effects of environmental variation on the implementation of new management practices. Krantz (1974) discusses the fertility status of the soils of the semi-arid tropics. It is not feasible to describe the soils in detail; the important properties of the major soils are summarily discussed below:

The red and grey soils. The red and grey soils (also called chromic luvisols) are moderately well-drained with a reasonable hydraulic conductivity. The texture of the surface soil ranges from stony to sandy and loamy in the pale yellow light red groups and from loamy to clayey in the deep red and grey groups (Raychaudhuri et al, 1963). The clay in the red soils in predominantly of the kaolinitic, non-swelling type.

The depth of the surface soil may vary from 0 to 30 cms, the underlying subsoil being often clayey. In the dry season, these soils are difficult to cultivate due to surface hardness; particularly on the steeper slopes they are susceptible to sheet erosion. After adequate rainfall, the stored moisture of a red soil profile is generally less than 150 mm and may be sufficient to support a standing crop for only two to four weeks; therefore, normally only a monsoon-season crop is grown (Swaminathan, 1973). These soils cover the largest area of the semi-arid tropics and are found extensively in India (72 million ha) and also in many other semi-arid tropical regions, e.g. in Angola, Northwest Brazil, North Cameroun, Chad, Dahomey, Ghana, Mali, Northern Nigeria, Sudan, Togo, Upper Volta and Zambia (Cocheme and Franquin, 1967; F.A.O. 1974).

The lateritic soils. The lateritic soils (also called ferric luvisols) are well drained with a satisfactory hydraulic conductivity. The texture of the topsoil is loamy or clayey with many concretions, the clay is of the kaolinitic or illitic type. The top soil is of varying depth with underlying subsoil being laterite (ferruginous deposits, hardening on exposure). In some areas the top soils have been eroded leaving behind a slag like mass. Trees and shrubs are often found on these soils; at low elevations monsoon-season crops are also grown. Lateritic soils are generally associated with undulating topography in regions with a relatively high average annual rainfall. They cover 13 million ha in India and fairly extensive areas in Chad, South Mali, Niger, Nigeria, Upper Volta and other countries.

The black soils. The black soils (also called vertisols) are usually poorly drained and possess a low hydraulic conductivity. The texture of the top soil is always clayey (40 to 60 percent), the clay being of the montmorillonitic type characterised by pronounced shrinkage during drying and swelling during wetting. The black soils are hard in the dry season, muddy and sticky in the wet season and difficult to cultivate without perfect water control. Erosion is a serious problem on these soils, particularly under fallow conditions. Russell (1970) stresses their potential for significant increases in production through improved drainage.

The profile is of varying depth (30 to 150 cm). The subsoils are mostly clayey but sometimes sandy (Cocheme and Franquin, 1967). Where as on shallow black soils only a monsoon-season crop is grown, a deep black soil profile may, after adequate rainfall, store more than 250 mm in the root profile and support a post-monsoon season crop. About 64 million ha of black soils are found in India, they also occur in the central delta of the Niger, Chad, Dahomey, Senegal, Upper Volta and Sudan.

The sandy soils. These soils (also called arenosols) are very sandy (often drifting sands) and thus lack the water holding capacity needed to support plant life through dry periods. The sandy soils are easily workable but subject to wind erosion. These soils are found extensively south of the Sahara, for example in Mali, Mauritania, Niger, Sudan and Chad; they also occur in Southwest Africa and Botswana.

The alluvial soils. The alluvial soils are extremely variable in moisture and drainage characteristics. They are found in present or previous river valleys (the latter particularly in semi-arid West Africa). The texture of the surface soils may range from drift sand to loams and from silts to heavy clays. Large scale gravity irrigation and tubewells are often found in the river valleys, which has sometimes resulted in salinity and alkalinity problems.

Erosion and runoff. Anyone familiar with the landscape of the semi-arid tropics, particularly during the rainy season, recognizes the vast damage and the rapid decline in the productive potential of the land caused by soil erosion. Some authors indicate that deforestation and subsequent poor management of the land may reduce long term precipitation averages and bring about changes in climate (Krishnan, 1973). Heseltine (1961) points out a decrease in land and water resources in tropical Africa owing to lack of management. Kanwar (1972) reports that in India alone 6,000 million tonnes of soil are lost annually; a significant portion of this loss occurs in the semi-arid regions of India. As a result, large areas have become shallow and stony and the land in such areas is cut by deep meandering gullies. Vandersypen (1972) estimated that under conditions of about 800 mm annual rainfall, 100 to 300 mm are lost annually as runoff.

In a recent report on improving agriculture in the low-rainfall areas of the world it is stated that in many developing countries increased pressure on the land has resulted in expansion of cultivated agriculture into marginal areas and intensification of agricultural activities on unsuitable lands (F.A.O. 1974). Consequently, there has been increased exposure of land resources to the hazards of wind and water erosion. Over-stocking and over-grazing, deforestation and the cultivation of steep slopes are causing permanent damage to vast areas. The land resource endowment base is shrinking and the productive capacity diminishing. This in turn again increases the quest for more land. To break this vicious circle, more stable forms of land use which preserve and maintain the productive capacity are urgently needed.

Resource Management, Development and Research: The Present State

Four conventional approaches to ameliorate the problems faced by farmers of the rain-fed semi-arid tropics have been:

1. To fallow the land during the rainy season in an attempt to accumulate a moisture reserve in the profile.

2. To implement soil and water conservation programs

3. To meet crises by emergency programs

4. To develop irrigation facilities

Fallowing. Fallowing is practiced for either one or a combination of two primary reasons. In the relatively low-rainfall areas it is mainly a risk evasion measure. Rather than growing a crop during the undependable monsoon rains, crops are grown in the post-monsoon season on residual stored soil moisture, sometimes supplemented by small quantities of winter rains. In the traditional setting this system of farming must have provided a preferred level of stability, although in years with well distributed rainfall, opportunities for significantly higher production are lost.

In the higher rainfall areas the lack of viable alternative technology is the main reason for fallowing. Poor drainage, difficulties in cultivation and weed control as well as inadequate crop technology result in a choice for the post-monsoon season as the main crop season. The land is repeatedly ploughed to eliminate weeds and to enhance infiltration. The result of this system is relative stability at a low general level of production.

In both systems a substantial part of the mean annual rainfall is lost due to the limitations of the storage capacity of the root profile and also because of increased runoff and evaporation losses under fallow conditions. Jacks et al (1955) noted that a few minutes of high intensity rainfall on some bare soils is sufficient to cause surface sealing and a drastic reduction in infiltration. Arnon (1972) stated that frequent cultivations to produce a soil mulch often result in impaired soil structure thus increasing runoff losses and soil erosion. Ellison (1944), Hudson (1957) and others pointed out the serious repercussions of a fallow system on soil erosion and the critical importance of vegetative cover during high intensity rains.

Mulching. Much research has been done on the use of mulches to reduce evaporation, increase infiltration, prevent the soil from blowing and washing away, control weeds, improve soil structure and to increase crop yields. The yield increasing effect of mulches consisting of crop residues has not been clearly established (Kampen, 1974). The results of mulching seem dependent upon climate, season and soil type, and are not universally advantageous, One reason may be the association of mulches with pests and diseases. It is not surprising that the beneficial effects of mulches decrease in relative magnitude under the extreme climatic conditions of the semi-arid tropics. The feasibility of providing organic mulches at the rate of about 5 ton/ha is doubtful when the straw yields are hardly in that order of magnitude and when the straw is generally needed as fodder.

Traditional bunding. In most cases programs to combat erosion and runoff aim at covering large areas by contour or other bunds. The principle involved is to prevent erosion causing runoff water from proceeding down the slope of the land and to increase the quantity of water infiltrated into the soil. In the semi-arid tropical environment, well-maintained systems of bunds have a very definite effect in decreasing soil erosion on a watershed basis. However, unless land levelling is executed as a primary erosion control measure, substantial erosion and sedimentation may occur in fields between bunds. This phenomenon is demonstrated by significant elevation differences frequently observed upslope and downslope from bunds. Although large quantities of runoff water are held back by bunds, increased infiltration often affects only a small proportion of the land.

Unfortunately, the practice of bunding has not provided significant gains in terms of more productive and stable agriculture, although substantial funds have been allocated for it (Swaminathan 1973). This is not surprising, as bunding without levelling or at least complementary cultivation practices cannot be effective. Bunding is aimed primarily at soil conservation - a long term measure. In a fallow system, the monsoon rainfall even in 'drought' years normally exceeds the storage capacity of the root-zone. In a monsoon cropping system bunding may result in drainage problems. Krantz and Kampen (1973) discussed contour bunding on heavy soils and concluded that the practice is not an effective water conservation measure for the semi-arid tropics.

Irrigation

To eliminate the basic cause of uncertainty in semi-arid agriculture, three types of irrigation facilities are being developed: wells, small runoff storage reservoirs (called tanks in India) and large projects. The large schemes were initially envisaged as supplemental water facilities for upland crops. Experience over the last two decades has shown that these projects do not supplement variable natural rainfall due to a lack of flexibility which is inherent to large irrigation schemes. Thus, irrigation in the semi-arid tropics most often consists of providing continuous water on a seasonal basis.

In temperate regions significant gains in sorghum production through timely irrigation have been reported (Hiler, 1974). On black soils at Bellary, Karnataka, sorghum yields of 527 kg/ha were obtained under entirely rain-fed conditions; two supplemental irrigations (of 12 cm each) increased yields to over 2,700 kg/ha (Das and Tejwani, 1974). Crops like sorghum and millet are not normally provided with supplemental water in the seasonally dry tropics. Owing primarily to a lack of sufficient irrigation returns on other cropping systems, paddy cultivation has become most common in both large and small irrigation projects.

Wells are mostly owned by individuals. Although water may be drawn from an area exceeding the individual property boundaries, the benefits from irrigation accrue exclusively to the well owner. Small runoff storage reservoirs are characterised by inefficient use of water and considerable loss of land. The shallow depth of these storage facilities results in large evaporation and seepage losses while substantial areas of otherwise productive land are occupied. The common use of available water for paddy further reduces the quantity of water actually used for crop transpiration. Siltation owing to the lack of erosion control measures has significantly reduced the storage capacity of many reservoirs (Krantz and Kampen, 1973).

Summarizing, one can say that present water resource development in the semi-arid tropics often results in the creation of 'islands of relative wealth' in a 'sea of poverty'. This situation may contribute to social tension at a later stage. The fact that the total water resources are insufficient to cover any substantial portion of all cultivated land thfough conventional irrigation is conveniently neglected. Few serious efforts have been made in exploring the question of how available water resources could be used to stabilize and support large proportions of semi-arid agriculture and benefit a greater number of farmers, rather than to replace a small part of rain-fed farming by irrigated paddy cultivation.

Emergency Measures

During crises large sums of money are often spent for hastily conceived relief programs. Food aid is often provided and 'crash' resource conservation and development schemes are designed and implemented. However, after the calamity is over and life returns to normal, the acute problems may be forgotten until the next crisis occurs. The Sahel region in West Africa provides a good current example of this type of effort. It is self-evident that these types of activities seldom result in substantially improving the stability and long term productive potential of the environment. Only sustained programs of research and development, extension, training and application of improved technology will achieve lasting results.

Research

Agricultural research in the developing countries of the semi-arid tropics has until recently been aimed primarily at increasing production in irrigated areas. Faced with a situation of limited resources and serious food shortage, this appeared to be a logical decision. In recent years there has been an increasing concern about agriculture in unirrigated areas. The awareness of the widening gap between irrigated and rain-fed regions has been growing. Moreover, an increasing number of people have realized that the potential of the semi-arid tropics to produce food for a hungry world far exceeds present production levels.

Fortunately, many countries are launching national research programs for rain-fed agriculture. In India, the All India Co-ordinated Research Project for Dryland Agriculture, initiated in 1970, provides an excellent example of an integrated approach towards research and action on the problems of semi-arid agriculture. The initiation of pilot projects has facilitated the testing and transfer of research results to real farms. On a global basis, the concern about the semi-arid tropics and the new confidence in the productive potential of these areas resulted in the creation of the ICRISAT in 1972.

A PROGRAM FOR RESOURCE MANAGEMENT RESEARCH

Guidelines for Research

The discussion in the preceding pages permits one to derive guidelines for research on resource development and conservation in the semi-arid tropics. It is appatent that sufficient data are presently not available with ICRISAT to permit a well documented and precise determination of priorities for research and development. A program to collect and analyse information from different regions is urgently required.

Those involved in soil and water research at ICRISAT envisage the following immediate needs:

1. To arrive at higher rainfall use efficiencies
2. To increase the effective rainfall available for crop use
3. To decrease runoff and erosion
4. To develop effective drainage systems where needed
5. To improve upon the use of available ground and surface water
6. To generate superior technology for land and water development and management.

Watershed-based development. Since the major constraints to agricultural development in the seasonally dry tropics are related to water, the watershed (i.e. the natural drainage units) should become the focus for resource development in any given region. Technological considerations regarding the conservation of water, erosion and runoff as well as the utilization of ground and surface water necessitate a catchment approach. At ICRISAT, research on agricultural production systems is aimed at the development of "watershed-based" farming systems which have been defined as follows:

'A watershed-based farming system involves the optimum utilization of the catchment precipitation through improved water, soil and crop management, directly through infiltration of monsoon rainfall, after runoff collection and storage or after deep percolation recovery from wells, for the improvement and stabilization of agriculture on the watershed'.

Applicability of technology. The majority of the farms in the semi-arid tropics are of moderate size, new management technology, therefore, should be applicable to small units or mechanisms for people to co-operate in resource management have to be evolved. The undependability of rainfall results in requirements of extreme flexibility for management systems as well as crop production technology. Successful systems must operate satisfactorily under a wide range of conditions. Failure, particularly in the early stages of attempted implementation, may result in serious setbacks. Variability in the moisture holding characteristics of soils may necessitate the implementation of different management systems side by side.

Immediate rewards. It is important to realize that many farmers are living at the subsistence level. They are therefore more concerned about the immediate rather than the long range implications of their actions; the production in the next season is more important for them rather than the productive potential of their resources in the next decade.

Owing to the erratic rainfall patterns and other natural hazards, the semi-arid tropics have for centuries been the scene of intermittent droughts, floods and other forms of natural calamities. The farmer is influenced in his decisions by his experience of a hostile, undependable environment. He feels that he cannot afford the risk which he suspects may be involved in experimenting with new technology.

New land and water management and conservation technology must be associated with an immediate and clearly visible impact on the levels and stability of agricultural production to motivate farmers to take the risk of changing their traditional practices. Long term or small gains will not capture the imagination of farmers and will impede acceptance.

Labor intensive methods. Populations are presently rapidly increasing, resulting in greater pressure on the land and in a large labor force which is only partially employed. Mechanical power and large machinery are not available to farmers of the semi-arid tropics in significant measure. Therefore, to facilitate fast implementation on a large scale, the application of new management technology must be feasible through effective use of available man power and draft animals. The low power inputs of agriculture in some of the African regions (even animal power is not used) poses special problems for development.

Social factors. The social and economic conditions of the farmer and his attitude towards co-operation in resource management are of critical importance for the success of improved land and water management technology. Levels of education and training are generally low, inner motivations and attitudes are often still rooted in religious belief and traditions. Nair (1961) observes that attitudes towards co-operation are often indifferent and sometimes distrusting. Simulation of such constraints and the testing of approaches to overcome them is not feasible within the protective boundaries of a research station. This calls for a second research phase which is executed under real world conditions after satisfactory, technologically and economically sound results have been obtained in the first phase.

Priorities for Research

Research on land and water management at ICRISAT must give primary attention to the farmer's most immediate and important problems. The selected priorities are:

1. To assist in the development of criteria for new cropping systems and crop management technology which increases long-term rainfall use efficiency while contributing to runoff reduction and erosion protection

2. To develop the resource management technology which provides the environmental conditions required for a rational choice between traditional agricultural systems and more remunerative new systems of farming

Under conditions of reasonably adequate moisture, it takes the same amount of water to grow a crop producing only a small quantity of food as it takes to grow a high-yield crop. Therefore, the most direct contribution to higher rainfall use efficiencies can be made by the generation of cropping systems and input and management packages which result in increased production through maximization of the output per unit of available water. In addition, the management level has often a direct bearing on the ability of the plant to withdraw moisture from the soil. Crops grown in the wet season may help to provide storage space in the profile during the late monsoon rains in areas which are now monsoon fallowed. However, constraints related to land, soil and climate and the uncertainty inherent in semi-arid agriculture have so far placed severe restrictions on the feasibility and acceptability of new cropping systems. It is for these reasons that the primary goal of land and water management research should be to quantify and decrease the risk involved in semi-arid agriculture.

2a The development of land management technology which results in reduced runoff and erosion, while increasing infiltration of rainfall without causing drainage problems.

2b The development of surface drainage techniques which result in a better growth environment for plants and improved workability of the soil during the monsoon without resulting in excessive runoff.

Systems of beds or ridges, separated by sloping furrows, draining into graded terraces and waterways (on a watershed basis illustrated in Fig. 7) appear to have the greatest potential to fulfil the partially conflicting requirements. Initial research at ICRISAT supports the contention that ridge and furrow systems can be used to manipulate runoff and reduce erosion. Earlier research established the surface drainage function of ridges and furrows (Choudhury, 1971; Krantz and Kampen, 1973).

The ridges function somewhat as 'mini bunds'. Each furrow runs under a slope which normally less than the maximum slope of the land, the actual value being determined by considerations of erosion and runoff. When runoff occurs, its velocity is reduced and infiltration opportunity time is increased. Instead of allowing runoff to concentrate in large streams, the excess water is conveyed off the land in a large number of small flows. Drainage of the primary root-zone is maintained in the ridges and on soils characterised by low infiltration rates, excess water in furrows is not held back. On light soils the ridges can be 'tied'[1] at certain intervals to further increase infiltration. Important advantages of ridge and furrow systems are:
(a) Only minor earth movement (smoothing) is required;
(b) implementation can be executed by animal power; and (c) no further land development is necessary to facilitate the application of supplemental water, if available. Certain restrictions in terms of row spacing have to be accepted. Technical assistance must be available to the farmer.

Hillel and Rawitz (1972) indicated that soils which crack markedly during the dry season may benefit from tillage because the cracks become secondary evaporation surfaces inside the soil. Johnston and Hill (1944) found that the soil water content decreased substantially near soil cracks. Thus, on heavy soils primary tillage immediately after harvest of the previous crop may contribute to moisture conservation. A rough surface will also result in increased infiltration in the early monsoon season. Early in the dry season draft animals are in optimum physical shape.

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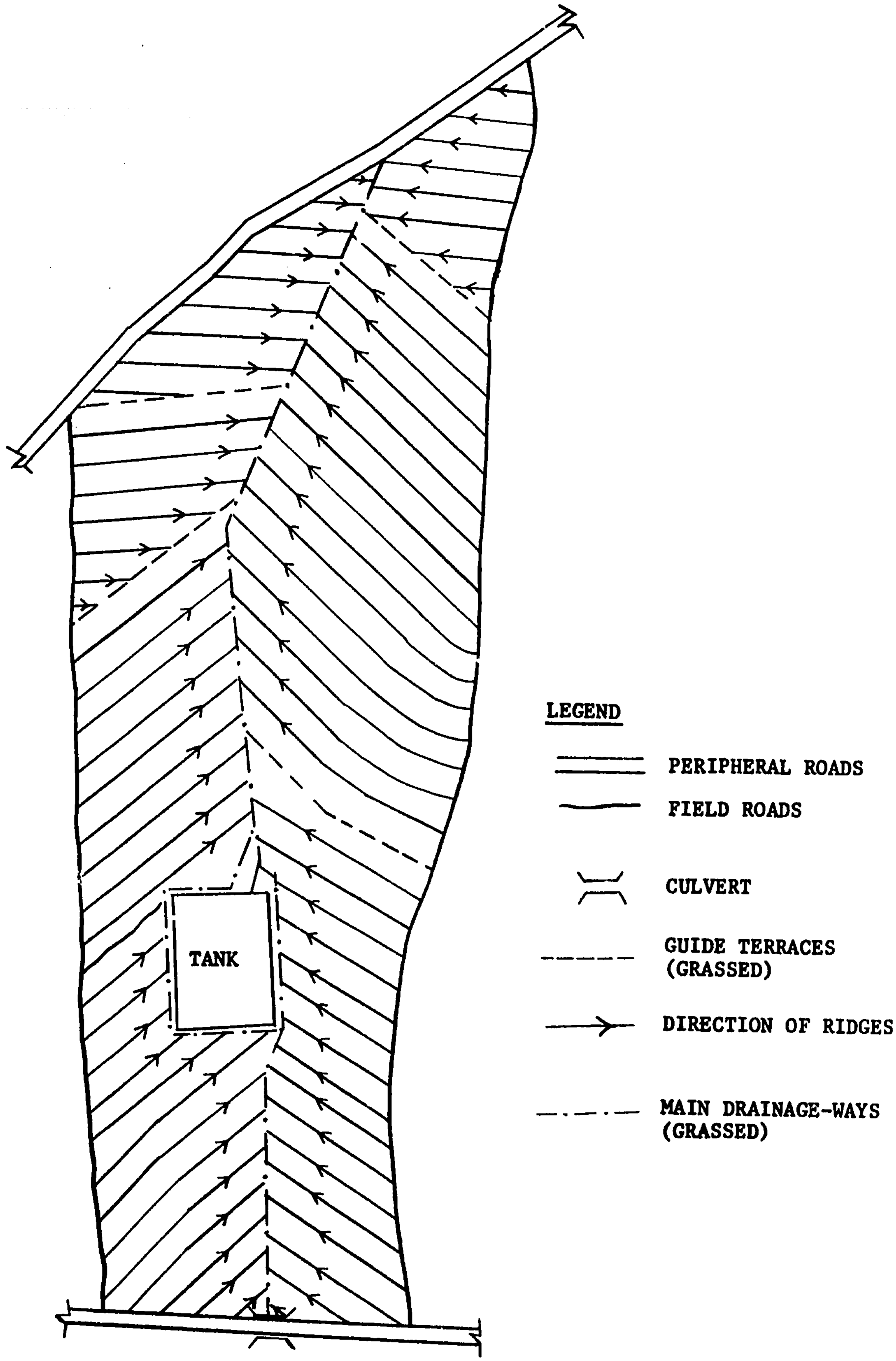
1 'Tied' ridges consist of ridge and furrow systems in which the furrows are blocked at intervals by soil or mulch which hold back water which otherwise would run off.

Fig.7: SCHEMATIC DRAWING OF A WATERSHED IN RIDGES AND FURROWS WITH A RUNOFF STORAGE FACILITY



2c The development of waterway systems which safely convey excess water from the land with minimum interference in agricultural operations and which contribute to the overall productivity of the system of farming.

Waterways are a necessity to cope with runoff which may occur at any time during the rainy season. Fixed systems of field drains (taking out of production only a small area) are preferred over wide meandering drainage ways (reducing production over large areas). At ICRISAT efforts are underway to develop criteria for man-made drains suited to the setting of agriculture in the semi-arid tropics. Grassed waterways, sometimes with drop structures, appear to have potential as safe (i.e. non-erosive) runoff disposal facilities while contributing substantial quantities of forage for animals which are an important component of most present systems of farming.

2d The development of alternative technologies for the use of available ground and surface water for upland crops, resulting in increased benefits through the stabilizing of rain-fed agriculture and the lengthening of the growing season.

2e The development of superior systems for runoff collection and reutilization as well as ground-water development to increase the available water resources on a watershed basis.

Given the present utilization of water resources in much of the semi-arid tropics, the development of improved application methodology and the determination of optimum timings and quantities of supplemental water application to crops other than rice is urgent. The late dry season is, from a general water balance point of view, apparently an inopportune time for growing crops owing to the relatively high evaporation. New technologies in water use which decreases risk and therefore provide the basis for the profitable utilization of other inputs are needed. Individual farm units are often small and may not permit the necessary investments. Therefore, more information is necessary on the potentials for multiple use of required equipments and the feasibility of co-operative arrangements.

In some regions substantial development of ground and surface water resources has taken place whereas in other area agriculture is entirely dependent on rainfall and the quantities of water held by the soil. Therefore, the development of criteria for further development of water resources and their conservation are of utmost importance. In this regard determination of the quantities of runoff and deep percolation under alternative management systems and the optimum depths of storage facilities minimising the land area occupied are important aspects. Investigations on relations between seepage from reservoirs and ground-water recovery are also required. To attain economically acceptable ratios of earth movement to created capacity for runoff storage units, co-operation in construction may be necessary. Particularly on flat land pumping of runoff water into above ground reservoirs will be investigated.

THE PROGRAM AT ICRISAT

The soil properties, depths and slopes have important repercussions with regard to the feasibility of alternate cropping systems, moisture availability, drainage properties, and runoff and erosion characteristics. Fortunately, the ICRISAT main research station is characterised by substantial diversity. Both black soils and red soils are present, varying in depth from 10 cm to 1.5 meters. The land is relatively flat although the slopes vary considerably. This diversity provides valuable opportunities to simulate a wide range of conditions in the semi-arid tropics at the ICRISAT. However, it does not eliminate the need for associated research at other locations in the world. Initially, major attention has been given to the deep black soils and medium-depth red soils. In the following years the program will be extended to cover a larger range of soil and slope conditions. Within the Farming Systems Program, two components of research can be distinguished: research on production factors and research on watershed-based farming systems.

Research on Production Factors

Land and water management research, carried out as a part of production factor investigations, involves studies on development and management methods on small scale experimental plots, detailed investigations of physical phenomena in small field plots and in the laboratory, and the development of better equipment in the workshop tested in field trials. Although some of these experiments will not give complete answers to questions of actual implementation on a farm scale or to the economic issues involved, to find 'leads', it is necessary to work under carefully controlled and manageable conditions.

In most experiments, five basic systems of cropping are distinguished: three of these are traditional; namely, monsoon season cropping, post-monsoon season cropping and intercropping; two are of a more experimental nature, namely double cropping[1] and

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[1] In a double-cropping system, as practiced in Farming Systems Research, a short-duration monsoon season crop is sown and harvested, thereafter a post-monsoon season crop is sown in between the rows of stubble.

relay cropping[1]. The last two cropping systems extend over both seasons. Krantz (1974) discusses the various aspects of different cropping systems in detail.

A brief description of those experiments, which are primarily aimed at evolving better land and water management technology and which are carried out under research on production factors, is given below:

Studies on ridge and furrow systems. As discussed previously, ridges and furrows appear to have considerable potential as a soil and water management and conservation technique. However, the quantitative relationship to yield has to be established. To obtain the required information, systems of beds separated by furrows at 75 cm spacing have been compared to flat planting for two seasons. These investigations will be further intensified by evaluating the yield effects and related factors of ridged planting on several cropping systems under alternate land slopes, under mechanically smoothed and natural conditions and by applying variable furrow spacings. On the red soils, which generally are much less subject to drainage problems than the black soils, investigations on the effect of tied ridges on infiltration, moisture conservation and yield will be initiated.

Studies on timings and methods of land preparation. Tillage and residue management is related to the organic matter status and structure of the soil and may have a pronounced effect on moisture conservation. To obtain detailed information on the long term influences of alternative land management treatments on yield, runoff, moisture and other factors, the following two management techniques will be compared under several cropping systems over a number of years:

a) Traditional practice: After the harvest of the produce (grain or seed and sometimes fodder) of the last crop in the preceding year, the stubble and weeds are grazed during the remaining part of the dry season. After commencement of the early monsoon rains, the land is ploughed and planted or kept fallow.

b) Experimental practice: Immediately after harvest of the last crop of the preceding year, the land will be cultivated to incorporate the stubble and weeds. Following this the land will be ridged leaving a rough cloddy seed-bed during the remaining part of the dry season. At the beginning of the

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[1] In a relay-cropping system, as practiced in Farming Systems Research, a monsoon season crop is sown and a few weeks before harvesting of this first crop, a second or post-monsoon crop is sown. The first crop is harvested at or soon after physiological maturity after the second crop has established.

monsoon the land is ready for planting or fallowing[1].

Comparisons have been initiated for the relay-cropping systems and for the monsoon-season cropping on the black soils. Other cropping systems will be included from the next monsoon season. On the red soils similar experimentation will be started, initially on a monsoon-season cropping system. An important deviation in experiments on the red soil will be that instead of land preparation immediately after harvest of the previous season's crop, the land surface will be left undisturbed until the early monsoon rains have wetted a substantial part of the profile. On the red soil the presence of a significant moisture reserve in the profile is essential to increase chances for crop survival during the seedling stage. At least some of the red soils are subject to wind erosion during the pre-monsoon season (Krantz et al, 1973).

Studies on infiltration characteristics. Observations on factors associated with better land and water management will be made in all farming systems experiments. However, the infiltration characteristics of alternative soil-crop-management complexes appear to be of such critical importance that detailed studies are necessary. The relationships of infiltration rates to the moisture status of the soil, vegetative cover and land treatment have to be investigated. These studies have to be followed by field and laboratory experiments to determine the basic causes of observed differentials. In 1974 a beginning was made comparing ridged, flat, cropped and fallow situations. Considerable expansion of this phase of research is envisaged in subsequent seasons.

Studies on 'life-saving' supplemental irrigation. The question of the optimum use of all available water resources is of critical importance to the stability of semi-arid agriculture. Therefore, the potential effect of supplemental water in decreasing risk and increasing production has to be determined for alternative systems of cropping under varying conditions of rainfall and soils, and at various levels of associated crop management technology. Experiments to obtain preliminary answers to these questions have been conducted in 1973 and 1974 and will be continued and further refined.

Development of improved animal-drawn implements. New land development technology and soil management practices aimed at more efficient rainfall use and resource conservation can in the context of the semi-arid tropics be succeddful only if the implement phase is

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1 Fallowing in this context does not apply to the entire monsoon season; the land is fallowed only until a risk reducing moisture storage has been attained.

developed simultaneously. Within a short time a special division on animal power and animal-drawn equipment will complement the Farming Systems Research Program. During the 1973-74 seasons, a beginning has been made to adapt and develop animal-drawn equipment for land development and crop-related operations.

Research on Watershed-Based Farming Systems

Research on watershed-based farming systems, the second component of the Farming Systems Research Program, is of special importance to the development of improved resource management and conservation technology. Innovations developed with regard to specific production factors have to be integrated into improved systems of farming. Therefore, complete alternative farming systems are being carefully monitored on a realistic scale to evaluate the consequent water utilization patterns, production effects and other requirements.

Animal power will be used in most soil and water management investigations executed on watersheds. This has certain drawbacks, particularly because of the present lack of good animal-drawn farm machinery. However, animal power is and will be the only source of power for land tillage in most of the semi-arid tropics and the use of heavy machinery would therefore be inappropriate.

Water balance studies. Many questions relating to the development of land and water do not lend themselves well to conventional experimental designs, for example comparisons of different bunding systems and studies on the effects of alternative slopes of ridge and furrow systems on water use, erosion and runoff; the optimum development and utilization of ground and surface water resources; and the general yield effects of various development and management inputs. Nevertheless, a better understanding is necessary of the quantitative interrelationships between levels of soil and water management and control, rainfall use efficiency, drainage, runoff collection and recycling for supplementing available soil moisture, soil conservation measures, systems of cropping and yields. At the ICRISAT, a number of natural watersheds have been selected for quantitative research on all components of the water balance under different management systems.

Black-soil watersheds. On the black soils, eight watersheds, subdivided into sixteen sub-units, are presently being used for watershed-based research. These units vary in size from two to eight ha involving a total area of about 90 ha. (Fig. 8). These areas have been farmed by villagers for decades and in some places severe sheet add gully erosion has resulted. Some of the watershed units are being maintained in their original state and will be continued under cropping patterns and resource management systems traditionally followed in some regions of the semi-arid tropics.

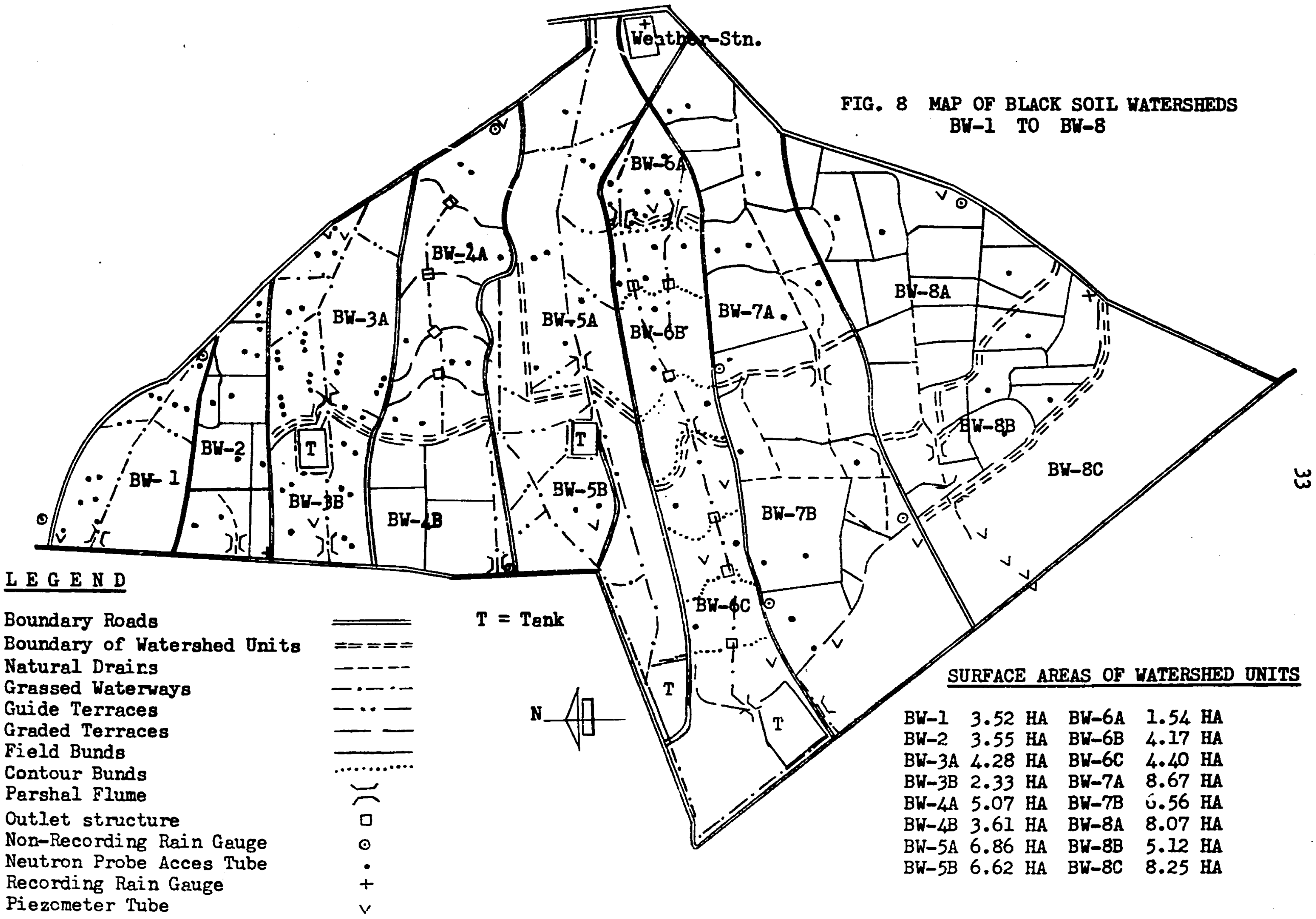

FIG. 8 MAP OF BLACK SOIL WATERSHEDS
BW-1 TO BW-8

SURFACE AREAS OF WATERSHED UNITS

BW-1	3.52 HA	BW-6A	1.54 HA
BW-2	3.55 HA	BW-6B	4.17 HA
BW-3A	4.28 HA	BW-6C	4.40 HA
BW-3B	2.33 HA	BW-7A	8.67 HA
BW-4A	5.07 HA	BW-7B	6.56 HA
BW-4B	3.61 HA	BW-8A	8.07 HA
BW-5A	6.86 HA	BW-8B	5.12 HA
BW-5B	6.62 HA	BW-8C	8.25 HA

In other watershed units all land preparation and planting is being done by bullocks using improved varieties and production practices. In some units eroded gulleys have been reclaimed, existing fields bunds removed and the fields planed in an attempt to restore the land to the topography which existed earlier. In each of the 'developed' watershed units, grassed waterways have been constructed and in some catchments these drain into runoff storage facilities.

In some watersheds, the development work was executed with mechanical power and machinery to facilitate the early completion of a limited number of research facilities. In other units development is now under way using animal power and human labor. This situation will give many gradations in development from traditional practice to intermediate technologies to technically optimum development using heavy machinery. Comparisons are made between flat planting versus ridge and furrow planting with and without contour bunds or graded terraces. A comparison is also made between average ridge and furrow slopes of .4, .6 and .8 percent and of systems with and without runoff water storage facilities for 'life-saving' supplemental irrigation. Table 3 gives a brief outline of the land and water management treatments which will be applied to different watershed units. Krantz (1974) discusses the cropping systems superimposed on the watershed units.

Red soil watersheds. On the red soils, two watersheds, subdivided into several separate units varying in size from about one to approximately eight ha are presently being developed for watershed-based research. Some preliminary data have been collected on two of the sub-units. The red soil watersheds will also be utilized to test various land and water management practices under alternative cropping systems. On the red soils the cropping systems will in addition to cereals and other crops include grasses and trees. The water balance of each sub-unit will be closely monitored to obtain data on the system rainfall use efficiency. Some units will be farmed according to traditional practice whereas in others varying degrees of development will be tested. Several types of ridge and furrow systems and 'tied' ridges will be tried and compared to contour planting, contour bunding and mulching techniques. Recycling of runoff water is even more critical on the red soils; the research will include efforts at more efficient storage and utilization techniques in such situations.

Monitoring the water regime. An effort is made to monitor continually the water regime on each watershed unit with the objective of selecting optimum systems for agricultural production. A number of recording and non-recording rain gauges have been installed. Runoff data are obtained from Parshall flumes with continual recorders. Samples of eroded material are collected regularly. Soil moisture measurements are made both gravimetrically and by means of a neutron probe at least once every two weeks. Ground-water levels are observed frequently and the installation of tensiometers for quantitative

Table 3. Soil and Water Management and Conservation Practices on Black Soil Watersheds.

Unit No.	Crop system technology[1]	Power source Implements	Cropping season(s)[2]	Land and water management technology under testing	Runoff storage Application method	Means of development[3]
(1)	(2)	(3)	(4)	(5)	(6)	(7)
BW1	North Optimum South Medium	Bullocks Improved	Monsoon and Post-monsoon	Ridges and furrows at .6% and graded terraces[4]	None	Mechanical
BW2	North Optimum South Medium	Bullocks Improved	Monsoon and Post-monsoon	Ridges and furrows at .6% and field bunds remain	None	Animal power Human labor
BW3A	North Optimum South Medium	Bullocks Improved	Monsoon and Post-monsoon	Ridges and furrows at .4% and graded terraces	Deep storage tank[5] Piped recycling[6]	Mechanical
BW3B	Medium	Bullocks Improved	Monsoon and Post-monsoon	Replicated trial of ridges and furrows at .4%	None	Mechanical
BW4A	North Optimum South Medium	Bullocks Improved	Monsoon and Post-monsoon	Flat planting at .4% along .4% graded terraces	Deep storage tank(BW3) Piped recycling	Mechanical
BW4B	Traditional[7]	Bullocks Traditional	Post-monsoon	Flat planting and field bunds remain	None	None
BW5A	North Optimum	Bullocks Improved	Monsoon and Post-monsoon	Ridges and furrows at .8% and graded terraces	Deep storage tank Piped to circle[9]	Mechanical
	South Optimum	Tractor Improved[8]				
BW5B	Medium	Bullocks Improved	Monsoon and Post-monsoon	Replicated trial of ridges and furrows at .8%	Medium depth tank Piped recycling	Mechanical
BW6A	Medium	Bullocks Improved	Monsoon and Post-monsoon	Flat planting in vertical mulch along contour bunds	None	Animal power Human labor
BW6B	North Optimum South Medium	Bullocks Improved	Post-monsoon	Flat planting along contour bunds	None	Animal power Human labor

(Contd...)

Table 3 (Contd...)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
BW6C	North Optimum South Medium	Bullocks Improved	Monsoon and Post-monsoon	Flat planting along contour bunds	Medium depth tank Piped recycling	Animal power Human labor
BW7A	North Optimum South Medium	Bullocks Improved	Monsoon and Post-monsoon	Ridges and furrows at .6% and graded terraces	Medium depth tank Piped to circle	Animal power Human labor
BW7B	North Optimum South Medium	Bullocks Improved	Monsoon and Post-monsoon	Ridges and furrows at .4% and graded terraces	Medium depth tank Gravity supply below[10]	Animal power Human labor
BW8A	Traditional	Bullocks Traditional	Monsoon	Flat planting and field bunds remain	None	None
BW8B	Medium	Bullocks Improved	Monsoon	Flat contour planting field bunds remain	Small field tanks Gravity supply below	Animal power Human labor
BW8C	Medium	Bullocks Improved	Monsoon paddy[11] and grasses	Flat planting in levelled fields	Pump storage tanks[12] Gravity supply below	Mechanical

1. Crop system technology defines primarily the level of fertilizers applied.
2. Cropping in a second season each year will depend on the soil moisture status and on the availability of supplemental water.
3. For development either heavy machinery or non-mechanically powered means are used.
4. The average slope of ridges and furrows to the drainage ways is specified.
5. Deep storage tanks are more than 3M deep, medium depth tanks are 1.5-3M deep.
6. Piped recycling; stored runoff water is supplied back entirely on the donor watershed.
7. Traditional technology simulates local production techniques.
8. On half of each cropping system area, tractors will be used exclusively.
9. Piped to circle; stored runoff water is supplied to area around the tank.
10. Gravity supply below; After lifting water is provided to the area below the tank.
11. The area in BW8C is saline, a paddy and grass crop will be applied for sometime to reclaim the area.
12. At times of drainage flow, water will be pumped into a storage tank.

determinations of deep percolation has been started. A few large lysimeters are being installed to obtain more precise information on evapotranspiration. Precise data on runoff water storage and recycling are also being collected.

Future studies. On both the red and black soils a substantial area has been reserved for later use. Once technically viable system have been developed, they will have to be adapted to fit the other constraints faced by the farmer of the semi-arid tropics. Questions like the use of machinery for land development and the sequence and timing of the necessary activities will be further investigated. The constraint of limited financial resources will be taken into account more stringently. The replication of the most promising technologies under these conditions will provide valuable additional data.

The feasibility of realistic simulation of entire farms (including, e.g. labor resources, draft animals, livestock, etc.) is being explored. Such simulation would have to be based on quantitative investigations of representative systems of farming which will be initiated soon (Ryan, 1974).

THE INTERNATIONAL PROGRAM

The third and fourth components of the Farming Systems Program are: Co-operative Research with national and regional organizations, and Extension and Outreach through national programs.

These phases are of special relevance to the soil and water management and conservation programs because of the site specificness of many problems. The agro-climatic environment at the ICRISAT is being used for the generation of principles which will assist in the development of integrated approaches to better resource management systems in different regions of the semi-arid tropics. These principles then must be translated into technology applicable to the requirements and constraints of different regions.

Simulation techniques. Simulation techniques based on mathematical modelling and using digital computers appear to have considerable potential in quantifying and predicting the hydrologic behaviour of different environments. Attempts will be made to calibrate and test such models on the basis of precise data collected at a limited number of locations. These simulation models can then be used to forecast the hydrologic consequences of the implementation of alternative resource management technologies in similar environments using only a limited number of data inputs. This technique may considerably reduce the need for detailed water balance research at a large number of locations.

<u>Selection of bench marks.</u> Despite simulation techniques, it will still be necessary to identify a limited number of 'bench mark' locations. The diversity of the resource base (climate and soil, people and livestock) encountered in the seasonally dry tropics dictates associated research efforts in a number of areas characterised by widely divergent agro-climatic oonditions, in addition to a 'base program'. This calls for additional data on climate, soils and other factors to classify the semi-arid tropics into regions with common characteristics so that priorities can be determined. In a simplified phsical classification it is, within the general environment of the seasonally dry tropics, possible to distinguish between regions of high and low average rainfall, between areas with soil profiles having good or poor moisture holding characteristics and between locations with a flat or a steep topography[1].

As illustrated in Table 4 this very preliminary and simple classification would result in eight regional descriptions with distant resource management and conservation requirements and with considerably varying ultimate agricultural production potential. To be a useful tool, a regional characterisation must include social and economic considerations in addition to physical determinants.

Table 4: Suggested Physical Characteristics for a Regional Classification of the Semi-Arid Tropics.

Class	Monsoon rainfall	Soil moisture characteristics	Topography
1	High	Good	Flat
2	High	Good	Steep
3	High	Poor	Flat
4	High	Poor	Steep
5	Low	Good	Flat
6	Low	Good	Steep
7	Low	Poor	Flat
8	Low	Poor	Steep

The development of associated research programs at representative locations is urgent, particularly in view of the critical food problems

1 A precise definition of the boundary limits of each situation will not be attempted until additional data have been collected and analyzed. For illustrative purposes 750 mm might be thought of as the dividing line between high and low average annual rainfall; good soils might be defined as those having more than 150 mm of available water in the root profile; in regions of flat topography average land slopes might not exceed 4 percent.

in some areas of the semi-arid tropics. Since the number of such locations must be limited, opportunities for simulation of different environments at ICRISAT must be explored first. It would appear that religions in classes 1 and 3 (Table 4) would provide opportunities in this regard.

To arrive at superior land and water management technology under conditions basically different from those at the ICRISAT, it is suggested that associated research be first initiated in regions where average rainfall is relatively low, the topography is flat, and the soils vary from good to poor in terms of moisture-holding characteristics (classes 5 and 7 in Table 4). A second 'bench mark' location might be selected in regions of high rainfall, good soils and steep topography (class 2 in Table 4) and a third in areas with low annual rainfall, good soils and steep topography (class 6 in Table 4).

Testing of technology. The testing of new resource management and conservation systems under real world conditions is visualised under cooperative research programs. Opportunities for "operational research" projects will be explored with national research organizations. The All India Coordinated Research Project on Dryland Agriculture might provide ideal opportunities for the development of a "Model of National Co-operation".

Improved resource management will required competent technical assistance at the farm level. It is expected that the concepts developed will often be substantially different from conventional thinking. Training of those involved in the actual implementation of new action programs is therefore essential.

SUMMARY AND CONCLUSIONS

Resource management and utilization, specifically soil and water management and conservation, are presently at a low level in the semi-arid tropics. This is primarily due to the limitations of traditional agricultural production systems.

Only a relatively small portion of the total annual precipitation is being actually used for crop production whereas ongoing soil erosion continues to reduce the productive potential of the land.

The evolving new crop production technology creates greater potential as well as a greater need for improved land and water management resulting in increased and more dependable production of food, feed and fiber.

Improved soil and water management and conservation practices must be extremely flexible and have an immediate and visible effect on production to be acceptable to the farmer.

Implementation of better resource management and utilization of technology will be facilitated if human labor and animal power can be effectively used.

Research on improved land and water management should be aimed at generating basic principles for resource management in the semi-arid tropics and at the integration of these in complete systems of farming.

The presence of vegetative cover and the prevention of concentrated runoff streams on the land to increase infiltration as well as the creation of adequate drainage are of great importance in the development of sound soil and water management and conservation practices.

Economically viable technology for the exploitation and utilization of surface and ground water resources for upland crops may make a significant contribution to increasing and stabilizing agricultural production.

Substantially improved resource management must be executed on a watershed basis and mechanisms have to be evolved for people to work together for the solution of common problems; therefore research on the human and social aspects of new technology is imperative for successful implementation.

Better soil and water management technology is to be tested not only under experimental conditions; research on the requirements of this technology under real world conditions is essential.

Resource management is only one component of systems of farming; its full potential can be attained only if the entire farming system is aimed at optimum utilization and conservation of soil and water.

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APPLICATION OF AGROMETEOROLOGY

TO THE FARMING SYSTEMS IN THE SEMI-ARID TROPICS

Derk Rijks*

Agrometeorology is an applied science that is concerned with the relationships between weather and agricultural production. It has two major parts, namely descriptive and analytical.

The first part contains the description of the weather, and specifically of those weather parameters that affect agricultural production, and a knowledge of the variability of these parameters in time and space. In semi-arid zones, perhaps more than elsewhere, large variations in the values of these parameters exist, and will continue to exist; these variations should be taken into account while designing the farming systems.

The second part concerns the analysis of the effect of the weather on vegetation, soil, open water and animals, as well as the reciprocal effects of these 'surfaces' on their atmospheric environment. It seeks to formulate the laws that relate agricultural production to the weather parameters and then to apply this knowledge both to increase the benefits that can be derived from natural resources and to minimize the disadvantages caused by adverse meteorological conditions.

These two parts are intimately related and the differences between them are not at all strict. A description of the weather for application in agricultural practices is usually made against the background of some weather-production relationship known or supposed to exist. On the other hand, analytical studies are often undertaken against the reference of a more or less well defined set of climatic conditions, often by preference one where as many parameters as possible are thought to be non-limiting.

Agrometeorological knowledge can be applied in two ways:

1. By selecting crops or varieties or cultural practices to suit the weather; these cultural practices may include selection of methods of land layout, pre-sowing soil preparation, selection of sowing dates and methods of sowing, spacing, mode of fertilizer application, weeding, water management practices,

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degree of mechanisation and type of equipment used, harvesting and post-harvest technology.

2. By modifying the climate on a meso-scale to suit the crop, e.g. by the implant of wind-breaks, shade arrangements or land-layout arrangements.

The first of the two methods is the most widely used, although the distinction between the two is not always very rigid.

The application of agrometeorological knowledge becomes more profitable as more is understood of the dynamics of agricultural production as a function of the weather. To achieve this objective, efforts will have to be made both in the disciplines of agriculture as well as in that of meteorology. In the first case, one can analyze the actual agricultural process, pinpoint the weak links of the production cycle and improve production conditions for this link. In the second case, one can analyze the meteorological conditions of a region, calculate the maximum production that could be arrived at and then try to define the agricultural system that realizes this production potential as much as possible.

The most effective strategy of work would probably combine the two approaches, not only to promote a better understanding of the basic processes, but also to produce results at short term, while further work goes on.

Agrometeorology is the science of the contact zone between the airmass on the one hand and water, soil, crops and animals on the other. It can and does make use of the existing knowledge of synoptic meteorology, plant physiology and soil science. Unfortunately, one can observe that much of the crop physiological and micrometeorological work carried out is not always easy to interpret and apply in agrometeorological terms. The problem is often one of scale and type of meteorological parameters used. Meteorological parameters on a field scale change gradually throughout the day as well as continuously from day to day, unlike the more rigidly imposed conditions in greenhouses and growth chambers. Also, the reference parameters used in micrometeorological studies are often different from those available to an applied meteorologist, working on a field or even on a regional scale.

In other words, the 'input language' of crop physiology and micrometeorology is often different from that used in applied agrometeorology.

Reference to the general synoptic meteorological situation is essential for a good understanding of the scope for effective application of agrometeorological knowledge, although the interactions of the many disciplines that ultimately influence agricultural production prevents an easy extrapolation of agrometeorological conclusions on the basis of similar synoptic meteorological situations only.

The undeniable relation between applied agrometeorology and soil physics is evident to agronomists, but often unsufficiently clear to synoptic meteorologists as well as policymakers and administrators.

For understandable reasons fair progress has already been made in the analysis of the influence of weather on the production of irrigated crops, but less is known in respect to the non-irrigated farming systems of the semi-arid tropics, i.e. rain-grown crops, crops in low lying lands or flood-plain crops.

The two major characteristics that distinguish these farming systems are:

1. The frequency and the reliability of the water supply (frequent but often unreliable for rain-grown crops; more reliable but only once towards the beginning of the growing season for flood-plain crops).

2. The temperature regime during the growing cycle (crops grown during summer rains vs. winter rains; crop grown after the retreat of the water from flood-plains or low lying lands at the end of the rainy season).

Apart from these two major characteristics, special climatic conditions may be encountered in some cases : hot or cold winds that interfere with the process of flowering, high humidity favouring the outbreak of diseases or hindering harvest procedure, or low solar radiation regimes that are associated with certain sowing periods.

Application of Agrometeorological Knowledge

The rainfall regime was among the first aspects of agroclimate to be studied not only in semi-arid zones, but also elsewhere, such as under the semi-arid crop production conditions that occur at the beginning and at the end of crop seasons in bi-modal rainfall areas in equatorial regions. Apart from studies on total rainfall and intensities, reliable techniques for the calculation of rainfall probabilities for different time intervals have been developed, and applied with advantage to the selection of suitable crops and varieties and optimum sowing dates for a given location.

As a further development, such rainfall probability calculations have been superimposed on independent calculations of potential evaporation. By a judicious choice of crop factors (relating crop water requirement to potential evaporation) and soil water storage capacities, acceptably accurate water balance evaluations have become feasible.

A next step, necessary and possible, now that computers have become readily available tools, is to calculate the water balance at key centers for the main crops of a region from a run of actual rainfall and evaporation figures and soil water characteristics over a series of years, rather than from separately calculated probability distributions of rainfall and evaporation.

The knowledge of this type can be applied to select the length of the growing season, and the earliest practical sowing date with a pre-established frequency. It may help to plan the farming system so that the peak water requirement of a crop occurs at a time of optimum water availability. It may also bring to light the need for erosion control and/or water storage measures. Such measures can perhaps be as simple as the farming operation of 'tie-ridging', to be advised in part of a season but not necessarily throughout the season. They can take more permanent forms, such as the construction of farm or communal storage facilities. As the water balance data are strictly quantitative, the waste involved in adopting too small or too big size solutions may be largely avoided. The knowledge of the expected water balance may effect decisions on all cultural operations on the crop, such as were enumerated in the introduction.

For the regions touched by the movements of the Inter-Tropical Convergence Zone in its most northerly positions, we may eventually be able to distinguish the different water balance regimes in early or late starting rainy seasons that are associated with the different rain-bearing mechanisms of the equatorial airmasses, and advise farmers in these regions accordingly.

Accurate water balance knowledge will also provide information on the probability of occurrence of an after-sowing or mid-season drought. This can have an effect on farming practices as well as on the selection of suitable varieties. Where an early-season drought is a regular feature, one may select a variety with a slow early-leaf development, whereas, if erosion control is desirable, the opposite may be looked for.

From the water conservation point of view, knowledge of the expected water balance helps in planning to retain and collect the water required, to evacuate the excess water in an orderly way and to use water where, when and how it could be most profitable.

The accurate evaluation of potential and actual evaporation constitutes an essential part of water balance calculations.

The sunshine and radiation regimes are those where modification is virtually impossible, so that in these fields adaptation of crops and cultural practices is required. Crop physiology work on photoperiodism has been more readily transposable to agrometeorological application than most other facets of crop physiology. Solar radiation measurements have been collected and analyzed not only to be used for the calculation of potential evaporation, but also to estimate rates of potential photosynthesis. The knowledge or rates of potential photosynthesis can be used in the choice of sowing dates (so that the stages of growth when the sink for photosynthetic products is greatest may coincide with peak photosynthesis), for determining crop spacing, for the selection of systems of intercropping and perhaps even for the timing of the release of water from small storage tanks.

It has sometimes been assumed that the temperature regime is of relatively minor importance in semi-arid zone agriculture. This is perhaps because mean temperatures may seem to be non-limiting, while extremes of temperature may actually interfere with plant development or growth. Examples are the effects of either very high temperatures (in regions with sporadic summer rains) or very low temperatures (as may occur in winter for flood-plain crops) on flowering, during periods when mean temperatures may be misleadingly within the acceptable range. A great deal of crop physiology work is available on this subject, but some of it needs to be translated into agrometeorological terms. Temperature regimes may thus become important in particular when water storage, either in the soil profile, as for flood-plain crops, or in tanks, for later release has become a part of the agricultural system.

Little systematic work has been done on soil temperatures in semi-arid zones, although specific adapted agronomic practices may be required in different conditions. This is especially so at sowing, when the biological activity of the crops is limited to the very upper layers of soil, where temperature variations are greatest. Warm moist soils, for instance, may favour a rapid attack by soil microbes on germinating seed, and a fungicide treatment of seed may be required or seedling establishement may be much slower for crops sown in a cool period of the year, necessitating perhaps more elaborate precautions against damage by seedling-eating cricket.

Further application of the knowledge of the sunshine, radiation, temperature and humidity regimes may be made in post-harvest technology where agrometeorology may help to reduce post-harvest losses in agricultural production.

The wind regime in semi-arid zones has not often been studied in a quantitative manner. This is perhaps so partly because the measurement of wind force and direction is relatively costly, and partly because its direct effects on crop production are not always eminently visible, whereas its effect on evaporation has usually a low power-of-modulation character. The possible beneficial effects of windbreaks on basic crop production are still disputed while in many cases side-effects have been negative in semi-arid zones.

The advances in the technology of the utilization of wind power may make applications feasible under certain conditions; hereto a better evaluation of the wind regimes will be required.

An almost open field for the application of agrometeorology exists in the study of the release and availability of nitrogen in soils. Little is known about the effects of climatological factors on the nitrogen producing micro-organisms in the root zone. Water balance, light competitions and soil temperature regimes may be prime considerations in the selection of intercropping or rotation practices that could give new solutions to the nitrogen supply problems that may become as acute as water supply problems in certain parts of the semi-arid zone.

All those familiar with the practice of applying agrometeorology to agriculture, know that there are interactions among the effects of the different climatic parameters on crop production, the existence of which has more or less been pointed out, but seldom quantitatively described. For example, it is known that interrelationships and feed-backs exist among the effects on crop growth of water, temperature regime affecting the rate of crop growth, rates of potential photo-systhesis during this stage, N availability, soil temperature and farming practices, such as spacing. But no quantitative answer can as yet be given as to the effect on crop production of a variation in one or more of these input parameters. Development of such a multiple input model (even if it covered only establishment and early growth, which are so very important in tropical agriculture) may be some way off, even though at present agrometeorologists, when applying the results obtained from a simple model, e.g. a water balance model, to a new area or crop, do in fact use their experience and intuition to allow for variation in other agro-climatic parameters.

Weather Forecasting

Weather forecasting for agriculture is an aspect of applied agro-meteorology that has been remarkedly neglected in many semi-arid zones, contrary to the situation in temperate climates. This is perhaps partly because the phenomena and dynamics of tropical meteorology are not fully understood, and partly because the demand for such forecasts has not been adequately voiced. But forecasts relating to the date of onset of the rains, or on the incidence of an after-sowing or mid-season drought, or on the possibility of attacks by crickets, even if made on a 3 to 7 day term, can be of immense value for the timing of cultural operations, the establishing of an intercrop or the adherence to the crop calendar, and thus for the realization of higher yields.

The 1984-type goal of agrometeorology is to obtain complete knowledge of the crop production potential of all climates, and complete knowledge of the agrometeorological requirements for maximum production of all crops, followed by the ability to use these two sets of information to combine selected production factors into one production system.

Until the time that such a goal is achieved, major benefits for the traditional farming systems for the semi-arid tropics can be derived from the selection of crops and varieties and farming techniques to suit the water balance of the area, especially for crops grown during summer rains. A complete set of water balance calculations for key centers in the semi-arid zone must therefore be made. The techniques and criteria for such calculations are now fairly well known. Similarly benefits can be derived from the selection of varieties to suit the temperature and radiation balance of winter-grown flood-plain crops. Benefits can also be derived from the institution of meteorological forecasts for farmers, especially as regards short-term rainfall expectations during the rainy season and the chances of outbreaks of pests.

The basic meteorological data for such work have in many places been collected and need only be worked up. Where necessary, the collection of additional data needs to be undertaken.

On the research side, there is an evident and recognised need for the better understanding of the dynamics of crop production as a function of weather. Perhaps, the first priority is an appreciation of the reduction in yield associated with water shortage for the existing and for the new crops and varieties that are being developed, and the second the definition of a farming system that exploits the agro-climatic potential of a region to supply an increasing part of the requirements of nitrogen for its traditional crops.

SOME CLIMATOLOGICAL FEATURES OF THE SEMI-ARID TROPICAL REGIONS OF THE WORLD

A. Krishnan*

The semi-arid tropical regions are agriculturally potential areas; hence detailed agroclimatic surveys of these regions would help in evolving newer varieties suited to particular regions and in improving the agronomic practices for getting better yields. Especially with the alarming increase in world population and consequent threat of shortage of food, intensified research for the improvement of agricultural production in the semi-arid tropics is extremely important. The object of this paper is to study in detail the distribution of semi-arid regions in the tropical zones of the world and analyze some of their climatological features with relevance to agriculture.

Average climatic water balance data of the continents published by the Laboratory of Climatology, Centerton, New Jersey, U.S.A. in 1963 for the continents of Africa, Asia and Australia, and 'Monthly climatic data for the world' published by the World Meteorological Organization have been utilized in this analysis.

Moisture Detention in 10° Zones of Latitude and Longitude in the Tropics

Krishnan (1968) pointed out the climatic paradox in respect of the latitude zone 20° to 30° N which covers mostly desert regions except in the case of Indian sub-continent where the arid zone covers only limited portions of the States of Rajasthan, Gujarat, Punjab and Haryana. Further, in this subcontinent, the wettest region of the world also occurs in this same latitude belt. This analysis was done by making use of the data of moisture detention in or on the surface of the earth computed by Van Hylckama (1956). This analysis has now been extended to the tropical belts in the northern and southern hemisphere. Table 1 shows the annual moisture detention in every 10° latitude in respect of each 10° longitude zone of the land regions of the world. The unit used is 10^{16} cubic centimeters.

Table 1 clearly reveals the widespread desert conditions in 20° to 30° latitude belt in the northern hemisphere except east of 70°E longitude and a small portion of 80° to 110°W, viz. Central American

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region which is semi-arid. It is also noticed that low detention corresponding to semi-arid conditions prevail mostly in latitude belts 0° to 20° N in Indian subcontinent and in 10° to 20° N in North African and North American continents. However, in southern hemisphere, semi-arid conditions prevail in the outer fringes of the deserts in 10° to 30°S latitude belt in Australia and 20° to 30°S latitude belt in South Africa. However, in view of the averaging over large latitude belts in such analysis, the picture is only rough and approximate.

Table 1: Moisture Detained in or on Surface of Land in Each 10° Longitude Belt of Tropical Zone in Units of 10^{16} Cu. cm.

Long. belt	20° - 30°N	10° - 20°N	0° - 10°N	0° - 0°S	10° - 20°S	20° - 30°S
120-110°W	0	-	-	-	-	-
110-100	103	21	-	-	-	-
100-90	64	127	-	-	-	-
90-80	57	156	34	-	-	-
80-70	23	42	502	496	96	-
70-60	-	29	524	526	323	93
60-50	-	-	266	479	311	423
50-40	-	-	-	311	332	173
40-30	-	-	-	85	37	-
30-20	-	-	-	-	-	-
20-10	2	59	61	-	-	-
10-0°W	0	94	17	-	-	-
0-10°E	0.1	74	162	-	-	-
10-20	0,4	62	331	255	97	0
20-30	0	19	336	412	204	72
30-40	0	78	221	232	237	77
40-50	0	27	55	-	129	46
50-60	31	2	-	-	-	-
60-70	19	-	-	-	-	-
70-80	115	89	11	-	-	-
80-90	518	29	17	-	-	-
90-100	259	171	68	7	-	-
100-110	425	262	134	181	-	-
110-120	327	7	216	190	-	9
120-130	39	74	97	97	24	2
130-140	-	-	-	180	64	0
140-150	-	-	-	230	54	35
150-160	-	-	-	37	6	35
160-170	-	-	-	-	-	-
170-180°E	-	-	-	-	9	-

NOTE: The dashed regions are mainly ocean portions except for a few islands.

Detailed Delineation of Semi-Arid Tropical Regions of the World

The semi-arid zones are delineated by Thornthwaite's moisture indices varying from -20 to -40. These indices are defined by (100S-60D) ÷ n where S is the mean annual water surplus, D is the mean annual water deficiency and n is the mean annual water need (Thornthwaite, 1948). Using the water balance book keeping procedure, it is possible to obtain quantitative values of climatic factors such as water deficiency defined as potential evapotranspiration(PE) minus actual evapotranspiration(AE) and water surplus as precipitation(P) minus AE values. Since the available soil moisture storage can vary from just a few millimeters to well over 300 mm depending on the vegetation cover and soil type, detailed knowledge of these factors is required. AE or water loss from soil will equal PE as long as the soil moisture content is at field capacity level. When the storage drops below the water holding capacity of the soil, the actual loss of water from the soil drops below the potential rate proportionally. In the 1955 revision of Thornthwaite's method, the aridity index, viz. 100 x (P-PE) ÷ P is itself suggested as the criterion for classying the climatic zones (Thornthwaite and Mather,1957). Accordingly, the limit for semi-arid climates is given by the values of the aridity index varying from -33.3 to -66.7. In this present analysis both the above mentioned moisture indices and aridity indices have been computed for different stations in the semi-arid tropical regions of the world. These data are presented in Table 2. The computations have been done for conditions of soil and plant cover which correspond to a soil moisture storage of 300 mm so that even tree vegetation and horticultural crops could be covered. Except in cases where the soil is very sandy and shallow, this storage would be applicable.

It is seen from Table 2 that there are the following five main semi-arid regions in the tropical zones of the world (roughly extending from 25°N to 25°S latitude).

A. Semi-arid tropical zone in North Africa. This zone covers twelve countries in the North African continent. It covers small portions of Uganda, Kenya, Somalia and Ethiopia and the entire southern half of Sudan. Thereafter it extends as a strip covering 10 to 14°N latitude through Chad, Niger, Nigeria, Togo, Ghana, Upper Volta, Mali and Senegal. This strip is known as Sahel region also. As can be seen from Table 2, the aridity increases from lower latitude to higher latitude in each country of this zone. In the major portion, moisture index is between -30 and -40. It is interesting to find that the entire Northern African continent becomes desert beyond 12 to 14° North latitude.

B. Semi-arid tropical zone in east and south Africa. This zone is in a U-shaped form commencing from Kenya in the east to Angola and small portions of Congo in the west. This zone covers major portions of Tanzania, Mozambique, Rhodesia, Zambia, Nyasaland, Botswana land and

Table 2. Moisture, Aridity Indices and Seasonal Distribution of Rainfall in Semi-Arid Regions of the Tropics of Various Continents

Station	Latitude	Longitude	Moisture Index	Aridity index	Annual rain-fall (mm.)	Percentage: Winter	Percentage: Summer	Percentage: Monsoon	Percentage: Post-monsoon	Percentage: April to October
1	2	3	4	5	6	7	8	9	10	11
		(A) Semi-Arid Tropical Zone in North Africa								
I. UGANDA										
Butiaba	1.8°N	31.3°E	-27.5	-45.8	794	9	34	37	20	74
II. KENYA										
Isiolo	0.3°N	37.6°E	-31.9	-53.1	563	2	33	39	26	92
Moyale	3.5°N	39.1°E	-23.4	-39.0	653	8	30	19	43	70
III. SUDAN										
Torit	4.4°N	32.5°E	-23.6	-39.3	987	4	28	54	14	87
Juba	4.9°N	31.6°E	-25.7	-42.9	971	3	31	53	13	91
B o r	6.2°N	31.7°E	-29.9	-49.9	859	2	27	59	13	93
Shambe	7.1°N	30.8°E	-31.9	-53.1						
W a u	7.7°N	28.0°E	-21.5	-35.8	1128	-	20	68	12	96
Akoba	7.8°N	33.0°E	-28.3	-47.2	942	1	22	68	9	96
Awerl	8.6°N	27.4°E	-25.7	-42.8	968	-	19	74	6	98
Rumbek	8.6°N	29.9°E	-24.5	-40.8	993	0.5	26	65	8	96
Nasir	8.6°N	33.1°E	-32.0	-53.3						
Dobib Hill	9.3°N	31.6°E	-33.3	-55.5	812	-	15	74	11	97

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Malakal	9.7°N	31.7°E	-32.1	-53.5	818	-	15	75	10	98
Kurmuk	10.5°N	34.3°E	-26.7	-44.5	943	-	15	72	13	98
Kadugli	11.0°N	29.7°E	-32.7	-54.5	764	-	13	75	12	99
Er Ro-seires	11.9°N	34.4°E	-32.8	-54.7	802	-	9	86	5	99
Zalingei	12.9°N	23.5°E	-29.1	-48.5	629	-	7	90	3	100
Gedareg	14.0°N	35.4°E	-37.5	-62.6	680	-	6	89	5	99
IV. ETHIOPIA										
Negelli	5.3°N	39.6°E	-29.9	-49.8	483	5	63	7	25	81
Direddarva	9.6°N	41.9°E	-37.3	-62.2	623	9	38	49	4	67
Diotia	11.2°N	41.8°E	-34.8	-58.0	710	10	72	15	3	72
V. CHAD										
Fort Lamy	12.1°N	15.0°E	-38.7	-64.4	620	-	6	89	5	100
VI. SOMALIA										
Villagia	2.8°N	45.5°E	-39.8	-66.3	572	5	35	17	42	72
Iscia Baidog	3.1°N	43.7°E	-33.6	-56.0	689	4	35	11	47	75
VII. NIGERIA										
Yola	9.2°N	12.5°E	-27.2	-45.3	990	0	18	73	9	99
Zungeru	9.8°N	6.2°E	-21.6	-36.0	1124	0	16	75	9	99

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Yelwa	10.6°N	4.7°E	-25.3	-42.2	977	0	13	78	9	100
Maiduguri	11.9°N	13.1°E	-36.0	-60.0	634	0	8	89	3	100
Ngum	12.9°N	10.5°E	-39.5	-65.8	544	0	5	94	1	100
Sokoto	13.0°N	5.3°E	-36.3	-60.5	688	0	8	90	2	100
VIII. TOGO										
Lome	6.1°N	1.2°E	-31.8	-53.0	755	7	37	40	16	83
Kpeme	6.2°N	1.5°E	-31.1	-51.8	780	6	41	42	11	84
Nautja	6.9°N	1.2°E	-22.9	-38.2	1068	9	33	41	17	78
IX. GHANA										
Sekondi	4.9°N	1.7°W	-23.3	-38.8	1016	9	36	41	14	78
Capecoast	5.1°N	1.2°W	-26.6	-44.3	863	10	45	31	14	75
Saltpond	5.2°N	1.1°W	-27.7	-46.2	858	7	38	38	16	76
Accra	5.6°N	0.2°W	-32.7	-54.5	725	10	36	40	14	77
Keta	5.9°N	1.0°W	-31.9	-53.2	828	7	39	37	17	81
Tamale	9.4°N	0.9°W	-23.1	-38.4	1080	1	23	65	11	92
Akuse	6.1°N	0.1°W	-22.6	-37.7	1096	10	35	35	20	71
Navrongo	10.9°N	1.1°W	-23.8	-39.6	1101	1	16	76	7	97
X. MALI										
Segou	13.4°N	6.1°W	-37.0	-61.7	678	0	7	91	2	100

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Mopti	14.5°N	4.1°W.	-39.9	-66.5	551	0	8	90	2	99
Kayes	14.6°N	11.6°W	-37.6	-62.7	697	0	3	90	7	99
XI. UPPER VOLTA										
Bobo Dioulasso	11.3°N	4.3°W	-21.5	-35.8	1038	0	19	75	6	94
Ougadougou	12.4°N	1.5°W	-29.8	-49.7	892	0	15	80	5	99
XII. SENEGAL										
Tamba Counda	13.8°N	13.6°W	-33.4	-55.7	794	0	4	88	8	99
Kaolack	14.0°N	16.1°W	-25.6	-42.7	945	0	0	93	7	99
Dakar	14.7°N	17.4°W	-36.9	-61.5	528	1	0	90	9	98
St. Louis	16.0°N	16.5°W	-37.9	-63.2	473	1	1	91	7	98
(B) Semi-Arid Tropical Zone in South Africa										
I. KENYA										
Malindi	3.2°S	40.1°E	-21.4	-35.6	1023	30	15	7	48	33
V o i	3.4°S	38.6°E	-35.8	-59.7	553	4	24	49	23	88
Mwatate	3.5°S	38.4°E	-24.8	-41.3	629	8	21	40	31	81
II. CONGO										
Boma	5.9°S	13.1°E	-24.6	-41.0	902	0	27	46	27	91
Banana	6.0°S	12.5°E	-27.8	-46.3	810	0	19	52	29	92

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
III. TANZANIA										
Misoma	1.5°S	33.8°E	-21.1	-35.2	752	7	18	40	35	76
Kondoa	4.9°S	35.8°E	-21.1	-35.2	644	0	7	73	20	94
Dadoma	6.2°S	35.8°E	-27.9	-46.4	587	0	6	85	8	99
Mpwapwa	6.3°S	36.5°E	-20.3	-33.8	665	1	1	83	15	95
Kasanga	8.5°S	31.1°E	-22.3	-37.2	900	0	11	81	7	99
Kalawaki-vinje	8.7°S	39.4°E	-25.7	-42.8	946	3	9	57	30	87
Lindi	10.0°S	39.7°E	-23.4	-39.0	937	3	9	65	23	92
IV. RHODESIA, GAMBIA AND NYASALAND										
Fortjohnston	14.4°S	35.3°E	-24.8	-41.3	771	1	9	85	5	98
Luangwa	15.0°S	30.2°E	-27.3	-45.6	801	0	14	84	2	100
Brodge Chirundu	16.0°S	28.9°E	-35.4	-59.1	606	0	15	82	3	99
Port Herald	16.9°S	35.3°E	-25.1	-41.9	863	5	14	73	8	92
Livingstone	17.8°S	25.8°E	-24.1	-40.1	676	0	14	81	5	99
Wankle	18.4°S	20.5°E	-34.3	-57.1	591	0	13	83	4	99
Gwaisiding	19.3°S	27.7°E	-25.4	-42.3	609	0	11	82	7	98
Bulawayo	20.1°S	28.6°E	-20.5	-34.2	582	1	20	75	4	97

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Fort Victoria	20.1°S	30.8°E	-21.6	-36.1	583	2	16	78	4	95
Shabani	20.3°S	30.1°E	-27.8	-46.3	540	2	17	75	7	95
Plumtree	20.5°S	27.8°E	-24.0	-40.0	555	1	17	77	5	97
Kazi	20.9°S	28.5°E	-29.7	-49.5	505	1	17	77	5	97
Gwanda	20.9°S	29.0°E	-30.0	-49.9	494	2	18	75	5	96
Triangle	21.0°S	31.6°E	-31.0	-51.7	571	3	21	69	7	96
Sugar estate Nuanetx	21.4°S	30.7°E	-35.5	-59.2	466	2	16	76	6	95
V. MOZAMBIQUE										
Palma	10.8°S	40.5°E	-22.9	-38.2	980	4	7	57	32	84
Mocimboa Dapria	11.3°S	40.4°E	-22.6	-37.7	934	3	7	68	22	78
Quissanga	12.4°S	40.5°E	-20.9	-34.7	1014	5	6	69	20	90
Porto Amelia	13.0°S	40.5°E	-28.6	-47.7	791	4	7	70	20	91
Mecufi	13.3°S	40.5°E	-30.6	-51.0	798	2	4	83	12	90
Namapa	13.7°S	39.8°E	-24.8	-41.3	888	1	7	83	9	98
Muite	14.0°S	39.0°E	-26.3	-43.8	849	1	6	86	7	93
Memba	14.2°S	40.5°E	-29.2	-48.7	770	3	5	83	9	89
Novafreixo	14.8°S	36.5°E	-22.4	-37.4	861	3	7	87	3	94
Mossunil	14.9°S	40.7°E	-20.7	-34.4	943	6	5	76	13	80

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Zumbo	15.6°S	30.5°E	-28.8	-48.0	796	0	11	87	2	99
Chicoa	15.6°S	32.3°E	-32.1	-53.5	732	0	9	88	2	92
Mogovelaz	15.7°S	39.3°E	-20.3	-33.8	1023	5	8	77	10	81
Chemba	17.2°S	34.9°E	-32.7	-54.5	714	4	15	75	6	99
Mungari	17.2°S	33.5°E	-31.5	-52.5	608	0	11	85	3	92
Muyarara	17.4°S	36.1°E	-29.9	-49.8	750	7	10	78	5	91
Villa Fontes	17.8°S	35.4°E	-20.4	-34.0	963	6	10	76	8	90
Mopeahvelah	18.0°S	35.8°E	-22.1	-36.9	974	5	18	67	10	89
Manomeu	18.3°S	35.9°E	-20.1	-33.4	971	7	11	71	11	83
Nova Mambone	20.9°S	35.0°E	-20.3	-33.9	910	7	18	68	7	86
Mabote	22.1°S	34.1°E	-33.6	-56.1	571	2	16	74	8	92
Funnaloud	23.1°S	34.4°E	-37.9	-63.2	524	5	20	67	8	89
Panda	24.1°S	34.7°E	-28.0	-46.6	705	8	13	67	12	84
Canicado	24.3°S	33.1°E	-32.6	-54.4	611	7	18	63	12	86
Mocumbi	24.5°S	34.6°E	-26.6	-44.3	749	13	19	53	16	76
Innarime	24.5°S	35.0°E	-20.4	-34.1	838	16	18	51	15	72
Chibato	24.7°S	33.5°E	-29.3	-48.9	694	9	18	61	12	81
Manjacaze	24.7°S	33.9°E	-27.8	-46.4	704	11	19	59	11	79
Chobela	25.0°S	32.2°E	-28.9	-48.2	649	8	23	60	9	85

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
VI. ANGOLA										
Cabinda	5.5°S	12.2°E	-30.1	-50.2	670	0	23	51	26	91
Noqui	5.9°S	13.4°E	-21.5	-35.9	1059	0	22	47	31	88
San Antonio	6.1°S	12.3°E	-28.6	-47.7	801	0	15	57	27	91
Do Zaire Caxito	8.5°S	13.6°E	-28.1	-46.8	783	0	15	51	34	92
Cafu	16.3°S	15.3°E	-22.9	-38.1	743	1	10	81	9	98
Villa Pereira D'Ela	17.1°S	15.7°E	-27.1	-45.1	637	0	11	79	10	99
VII. BECHUNANLAND										
Kasana	17.8°S	25.1°E	-26.2	-43.7	660	0	14	79	7	98
Maun	20.0°S	23.4°E	-38.8	-64.7	401	0	14	79	7	98
Khomo	21.0°S	24.5°E	-37.9	-63.1	418	0	11	76	13	98
Francis Town	21.1°S	27.6°E	-31.9	-53.1	461	0	19	74	7	97
Khanzi	21.5°S	21.8°E	-34.7	-57.9	438	1	16	76	7	98
Serowe	22.4°S	26.8°E	-35.9	-59.8	379	1	22	75	2	95
Mahalapye	23.1°S	26.8°E	-33.7	-56.1	446	1	22	71	6	95
Dikgalton	23.5°S	27.3°E	-34.5	-57.5	448	1	22	68	9	93
Molepolole	24.4°S	25.5°E	-29.7	-49.5	495	1	21	69	9	95
Gaberones	24.6°S	25.9°E	-27.8	-46.4	518	3	21	69	7	94
Lababi	25.2°S	25.7°E	-25.3	-42.2	522	2	22	65	11	94

(Contd...)

Table 2. (Contd..)

1	2	3	4	5	6	7	8	9	10	11
VIII. <u>MALAGASY REPUBLIC</u>										
Diegosquareg	12.3°S	49.3°E	-27.9	-46.4	888	2	4	87	7	97
Tombohorane	17.5°S	44.0°E	-22.4	-37.3	946	1	6	90	3	
Maintirano	18.1°S	44.1°E	-23.6	-39.3	906	2	8	85	5	97
Morondova	20.3°S	44.3°E	-28.3	-47.2	726	2	5	90	3	96
Morombe	21.7°S	43.4°E	-38.7	-64.6	486	3	6	89	2	95
Beroroha	21.7°S	45.2°E	-30.4	-50.7	740	1	13	84	2	96
Benenitra	23.5°S	45.1°E	-29.5	-49.1	735	3	13	80	4	94
Ampininy Quest	24.7°S	44.7°E	-35.0	-58.3	572	4	14	73	9	91
Tshiombe	25.3°S	45.4°E	-37.6	-62.6	489	9	12	70	9	83
(C) <u>Semi-Arid Tropical Zone in Australia</u>										
I. <u>NORTHERN TERRITORY</u>										
Dalywaters	16.3°S	133.4°E	-36.7	-61.2	625	1	13	81	5	98
II. <u>QUEENSLAND</u>										
Fariview	15.5°S	144.3°E	-21.6	-36.1	980	2	7	86	5	97
Burketown	17.7°S	139.5°E	-31.6	-52.7	718	1	7	88	4	98
Normanton	17.7°S	141.1°E	-25.2	-42.1	975	1	7	87	5	97
Mt. Surprise	18.1°S	144.3°E	-23.2	-38.7	780	4	9	81	7	93
Croydon	18.3°S	142.2°E	-33.6	-56.1	727	2	9	81	5	96
George Town	18.4°S	143.5°E	-27.3	-45.5	806	3	8	84	5	95

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Donors' Hill	18.7°S	140.6°E	-34.3	-57.3	655	3	9	82	5	95
Charters Towers	20.1°S	146.1°E	-30.7	-51.3	636	10	11	69	9	84
Hughenden	20.9°S	144.2°E	-38.6	-64.4	485	8	14	69	9	86
Clermont	22.8°S	147.6°E	-34.3	-57.3	693	12	16	61	11	79
Emerald	23.5°S	148.1°E	-28.8	-48.1	632	15	18	57	10	76
Barcaldine	23.6°S	145.3°E	-36.4	-60.7	497	13	16	57	14	77
Blackall	24.4°S	145.5°E	-34.6	-57.8	532	14	17	55	14	75
III. WEST AUSTRALIA										
Wyndham	15.5°S	128.1°E	-37.5	-62.6	692	1	9	86	4	98
Derby	17.3°S	123.7°E	-36.3	-60.5	653	3	4	85	9	95
Broome	17.9°S	122.3°E	-37.3	-62.3	582	6	3	83	7	92
Hallsbreek	18.2°S	127.8°E	-37.9	-63.2	528	2	11	81	6	95
IV. NEW GUINEA										
Port Morsebey	9.5°S	147.1°E	-23.2	-38.8	1015	8	11	64	17	82
(D) Semi-Arid Tropical Zones in India										April to October
Deesa	24.2°N	72.2°E	-37.3	-62.2		0	0	97	3	99
Neemuch	24.5°N	74.9°E	-28.7	-47.8	895	2	1	93	4	97
Ahmedabad	23.1°N	72.6°E	-33.2	-55.3	823	1	1	96	2	99
Dohad	22.8°N	74.3°E	-31.7	-52.9	788	1	2	92	5	98

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Indore	22.7°N	75.8°E	-21.2	-35.4	1053	1	2	90	7	96
Baroda	22.3°N	73.3°E	-24.0	-40.1		1	1	94	4	99
Bhavnagar	21.7°N	72.2°E	-31.9	-53.3	587	1	4	88	7	98
Rajkot	22.3°N	70.8°E	-34.5	-59.5	674	1	2	93	4	98
Khandwa	21.8°N	76.4°E	-29.5	-49.3	961	2	2	89	7	95
Akola	20.7°N	77.0°E	-35.8	-48.5	877	3	3	86	8	93
Veraval	20.9°N	70.4°E	-36.8	-61.3	702	1	1	93	5	98
Amaravati	20.9°N	77.8°E	-28.3	-47.1	975	3	4	85	8	93
Malegaon	20.5°N	74.5°E	-37.7	-62.9	579	2	3	79	16	92
Jalgaon	21.1°N	75.6°E	-33.6	-56.0	840	2	2	88	8	95
Aurangabad	19.9°N	75.3°E	-30.0	-50.0	792	2	4	82	12	94
Nizamabad	18.7°N	78.1°E	-21.2	-35.4	1086	2	5	86	7	95
Ahmednagar	19.1°N	74.0°E	-33.7	-56.2	677	2	6	75	17	93
Poona	18.5°N	73.9°E	-30.9	-51.5	715	1	8	73	18	93
Bidar	17.9°N	77.5°E	-25.7	-42.9	977	1	7	81	11	94
Calingapatam	18.3°N	84.1°E	-22.9	-38.3	986	3	7	62	28	90
Vizagapatam	17.7°N	83.2°E	-22.6	-37.7	974	4	8	52	36	86
Hanamkonda	18.0°N	79.6°E	-25.1	-43.1	945	2	7	79	12	94
Sholapur	17.7°N	75.9°E	-34.5	-57.5	742	2	7	75	16	94
Kakinada	16.9°N	82.2°E	-23.6	-39.3	1172	2	7	56	35	88

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Gulbarga	17.3°N	76.9°E	-32.7	-54.5	753	1	9	77	13	94
Hyderabad	17.5°N	78.5°E	-28.9	-48.1	764	2	9	76	13	93
Rentachintala	16.5°N	79.5°E	-36.1	-60.2	717	3	9	65	23	90
Miraj	16.8°N	74.7°E	-32.1	-53.5	639	1	14	61	24	92
Raichur	16.2°N	77.3°E	-36.1	-60.2	717	1	6	76	17	95
Kurnool	15.8°N	78.1°E	-38.3	-63.8	674	1	11	73	15	94
Masulipatam	16.2°N	81.1°E	-24.6	-41.0	1075	3	6	57	34	86
Gadag	15.4°N	75.6°E	-34.7	-57.8	664	2	19	54	25	92
Cuddapah	14.5°N	78.8°E	-35.8	-59.7	743	3	10	61	26	85
Nellore	14.5°N	80.0°E	-27.3	-35.4	1032	10	7	29	54	61
Chitradurg	14.2°N	76.4°E	-32.9	-54.9	655	3	18	51	28	89
Vellore	12.9°N	79.1°E	-22.1	-36.8	969	11	12	43	34	72
Salem	11.7°N	78.2°E	-26.0	-43.3	965	6	17	49	28	84
Mysore	12.3°N	76.7°E	-24.5	-40.8	835	3	28	39	30	88
Coimbatore	11.0°N	77.0°E	-37.8	-63.0	612	9	22	24	45	70
Tiruchira-palli	10.8°N	78.7°E	-32.9	-54.8	868	11	18	33	38	70
Madurai	9.9°N	78.1°E	-31.8	-52.9	905	9	18	35	38	70
Pambaur	9.3°N	79.3°E	-28.8	-48.0	923	30	13	5	52	34

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
	(E) Some Stations in Semi-Arid Tropical Zone in American Continent									
MEXICO										
Tacubaya	19.4°N	99.2°W	-	-	725	3	12	76	9	94
Merida	21.0°N	89.5°W	-	-	934	9	13	63	15	85
Guana Juato	21.0°N	101.3°W	-	-	681	4	7	79	10	92
Tampico	22.2°N	97.9°W	-	-	1093	8	7	66	19	86
VENEZUELA										
Ciudad Bolivar	8.1°N	63.5°W	-	-	972	9	14	59	18	82
Barcelona	10.1°N	64.7°W	-	-	611	5	8	70	17	85
Maracay	10.3°N	67.7°W	-	-	994	4	13	62	21	84
Maracaibo	10.7°N	71.6°W	-	-	703	1	15	22	62	50
PARAGUAY										
Mcal Esti Ganiba	22.0°S	60.6°W	-	-	754	7	26	53	14	October to April 84
Puerto Casada	22.3°S	57.9°W	-	-	1202	11	29	45	15	76
ARGENTINA										
Laslomitas	24.7°S	60.6°W	-	-	793	5	26	54	15	85

(Contd...)

Table 2. (Contd...)

1	2	3	4	5	6	7	8	9	10	11
Salta	24.9°S	65.5°W	-	-	668	1	12	82	5	97

For "E" - Note: Due to nonavailability of normal data, moisture and aridity indices could not be computed and rainfall analysis of Peru and Bolivia could not be done. However, only a small portion of Peru West of Andes can be classified as semi-arid.

Note: The months of seasons are:

	Winter	Summer	Monsoon	Post-monsoon
Northern Hemi sphere	December to February	March to May	June to September	October to November
Southern Hemi sphere	June to August	September to November	December to March	April to May

Angola. Considerable areas in Malagasy Republic from Diegosquarez (12°S) to Tshiombe (25°S) also come under the semi-arid zone.

The moisture indices are generally between -20 and -30 in this zone except for the latitude zone 16° to 24°S, where the values lie between -30 and -40, indicating increased aridity in the latter zone. These comparatively drier regions in the southern portions of the zone are adjoining to the Kalahari desert in South West Africa.

C. Semi-arid tropical zone in Australia. In the tropical zone in Northern Australia, the semi-arid zone just surrounds the central desert region of the continent as a ring of width equal to about 5° latitude belt. For instance, in the Northern territory and western Australia, it covers roughly 14° to 19°S latitude. In Queensland, it extends from the Gulf of Carpanteria to 22°S latitude along 145°E longitude line and from 18°S to 24°S latitude along 150°E longitude line. The general aridity in this zone decreases from the interior towards the coastal areas. The stations of this zone in Western Australia have generally moisture index of -37 indicating much higher aridity conditions that are prevalent there.

D. Semi-arid tropical zone in India. The semi-arid tropical zone in India covers the central portion of Gujarat, South West sector of Madhya Pradesh and most of the interior portions of the Peninsular India. Krishnan (1969) delineated the arid and semi-arid zones of India, utilizing standard normals of not only meteorological observatories but also those of the considerable number of raingauge stations maintained by the State Governments. On the basis of this classification, out of the total semi-arid zone of 956,750 sq.km. in India, nearly 70 percent lie in the tropical zone. Statewise distribution is as follows :

State	Area of semi-arid zone (sq km)	Percentage of total semi-arid zone in India
Gujarat	90,520	9
Madhya Pradesh	19,820	2
Maharashtra	189,580	19
Karnataka	139,360	15
Andhra Pradesh	138,670	15
Tamil Nadu	95,250	10
	673,200	70

Most of the interior portions of Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and the Central Gujarat have moisture indices varying from -30 to -40, showing higher aridity in these places compared to coastal areas, north-west Andhra Pradesh and portions of Madhya Pradesh, where moisture indices vary from -20 to -30.

E. <u>Semi-arid pockets in the tropical zone of American continent.</u> There are only a few pockets of semi-arid tropical zone in the American continent. In the northern hemisphere, the areas are southern and central Mexico, covering 19 to 22°N latitude, portions of Venezuela covering 8 to 12°N latitude and portions of North East Brazil, the plain lands of western Paraguay and adjoining North Argentina from the main semi-arid tropical zone in the southern hemisphere in addition to a narrow coastal strip in Peru west of the Andes mountains. Due to non-availability of normal climatic data, moisture and aridity indices could not be completed in this study. However, annual and seasonal rainfall distribution for a few stations in these regions are presented in Table 2.

Seasonal Rainfall Distribution of Semi-Arid Tropical Regions

The rainfall in these regions mostly occur during April to October in the northern hemisphere and October to April in the southern hemisphere. The percentage of this period's rainfall to the annual total exceeds 90 and in many cases the same is well over 95. The percentage values however vary from 70 to 90 in the following specific areas.

The percentage values fall below 90 percent in Ethiopia, Somalia, Togo and Ghana in the North African semi-arid zone and at a few scattered places in South African zone owing to occurrence of more rainfall during November. In Indian semi-arid zone, April to October values fall below 90 percent only in north-east monsoon region of Karnataka and Tamil Nadu, where November and winter rainfall are also important. For Australian zone, October to April values go below 90 percent in north-east Queensland owing to winter rainfall. In American continent, the semi-arid zone has rainfall varying from 80 to 90 percent during the above period. One point brought out clearly from the table is that winter rainfall is very less (less than 5 percent) in the semi-arid tropical regions. It increases to only 10-15 percent in a very few regions in India, Australia and South Africa referred to above, the only exceptions being Malindi region in Kenya and Pamban region in India, where the winter rainfall percentage is 30.

Figures 1 to 4 present the pattern of variations in the percentage of monsoon rainfall (June to September) to annual rainfall, with respect to latitude in semi-arid tropical regions in North Africa, South Africa, Australia and India.

In the North African semi-arid zone (Fig.1), the percentage contribution of monsoon rainfall to annual rainfall increases linearly from 50 percent in 5°N latitude to about 95 percent in 15°N latitude, the exceptions being Somalia, Togo and Ghana, as mentioned earlier.

Fig.1: NORTH AFRICAN SEMI-ARID TROPICAL ZONE

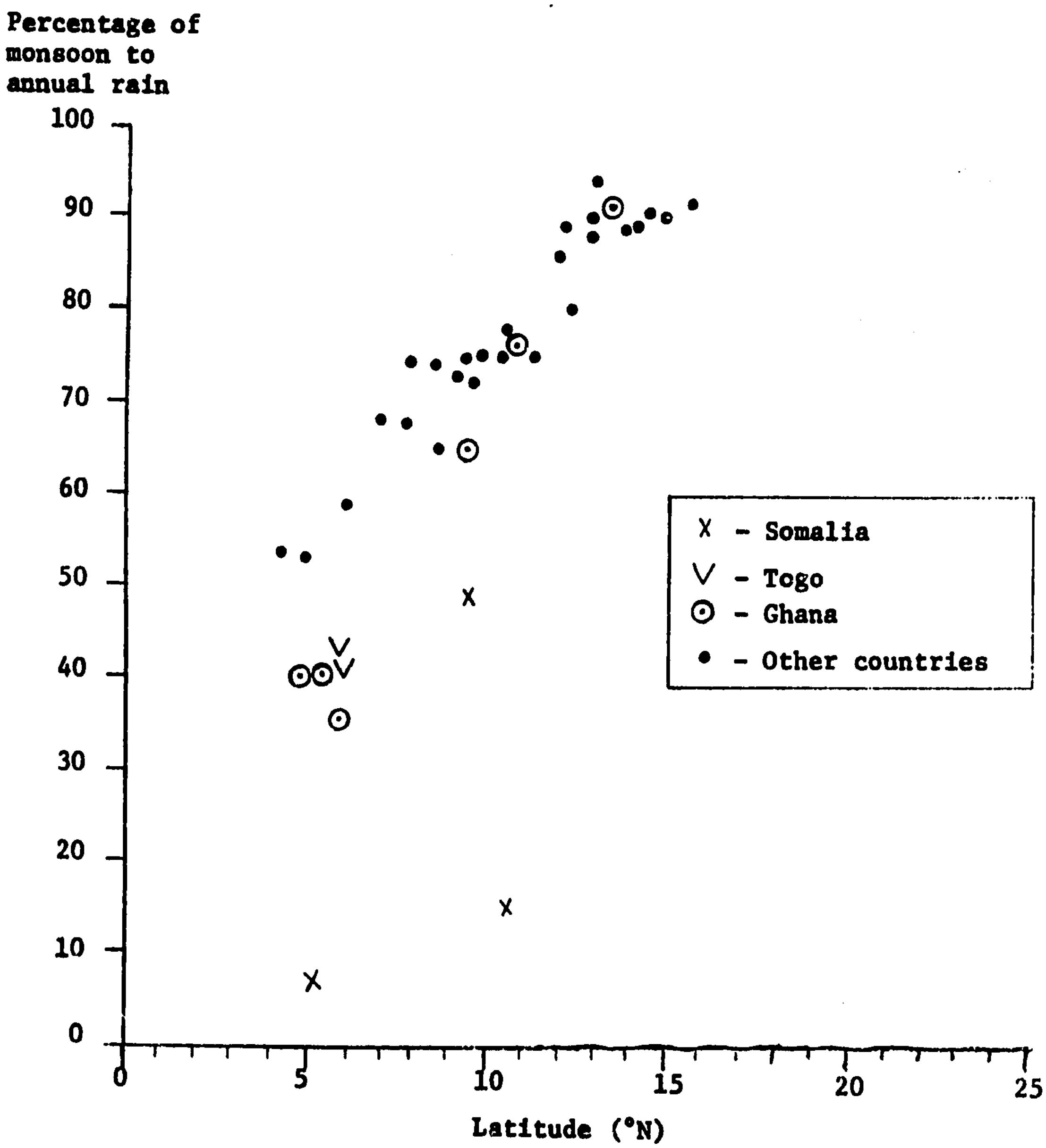


Fig.2: SEMI ARID TROPICAL ZONE IN EAST AND SOUTH AFRICA

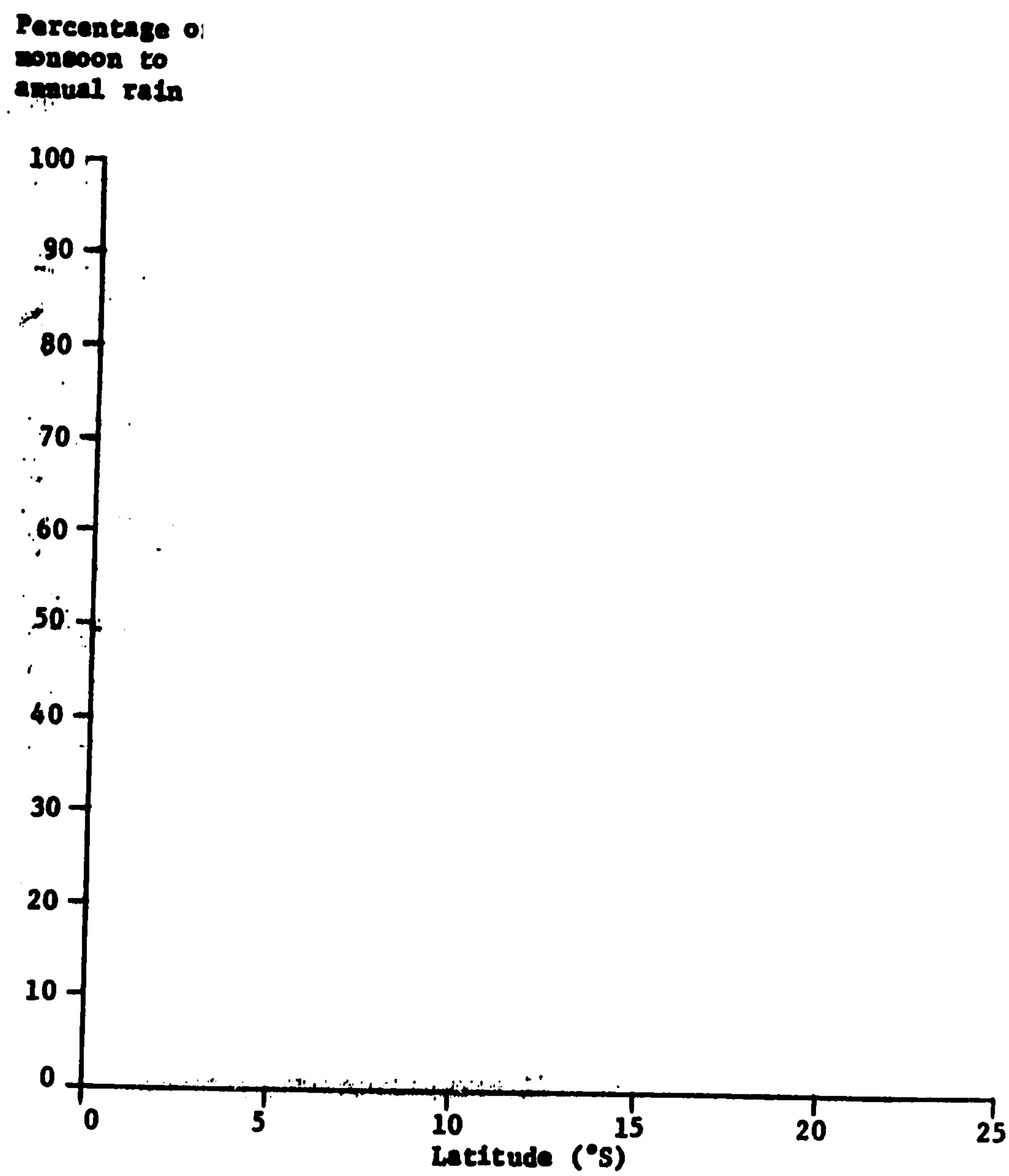


Fig.3: AUSTRALIAN SEMI-ARID TROPICAL ZONE

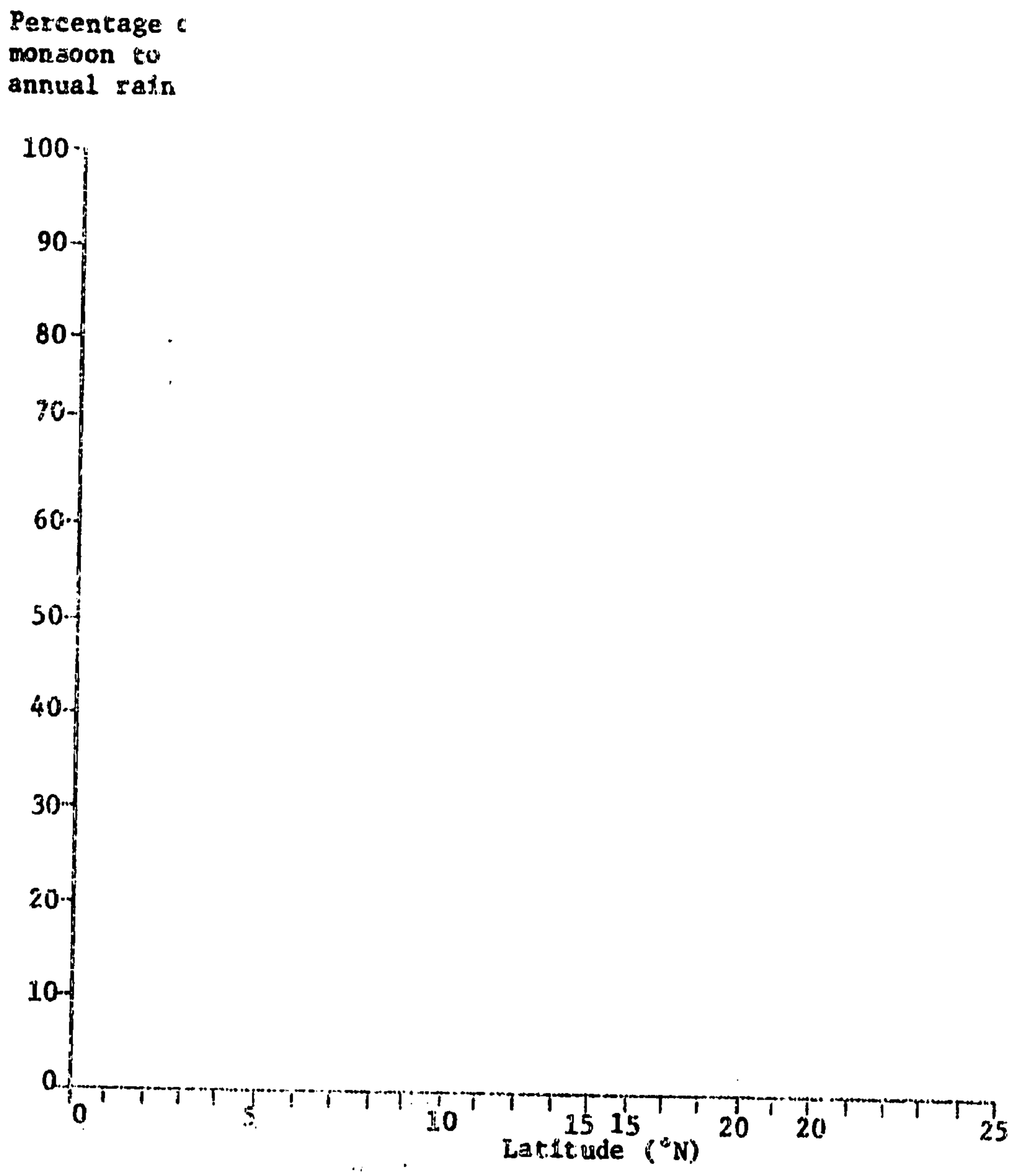
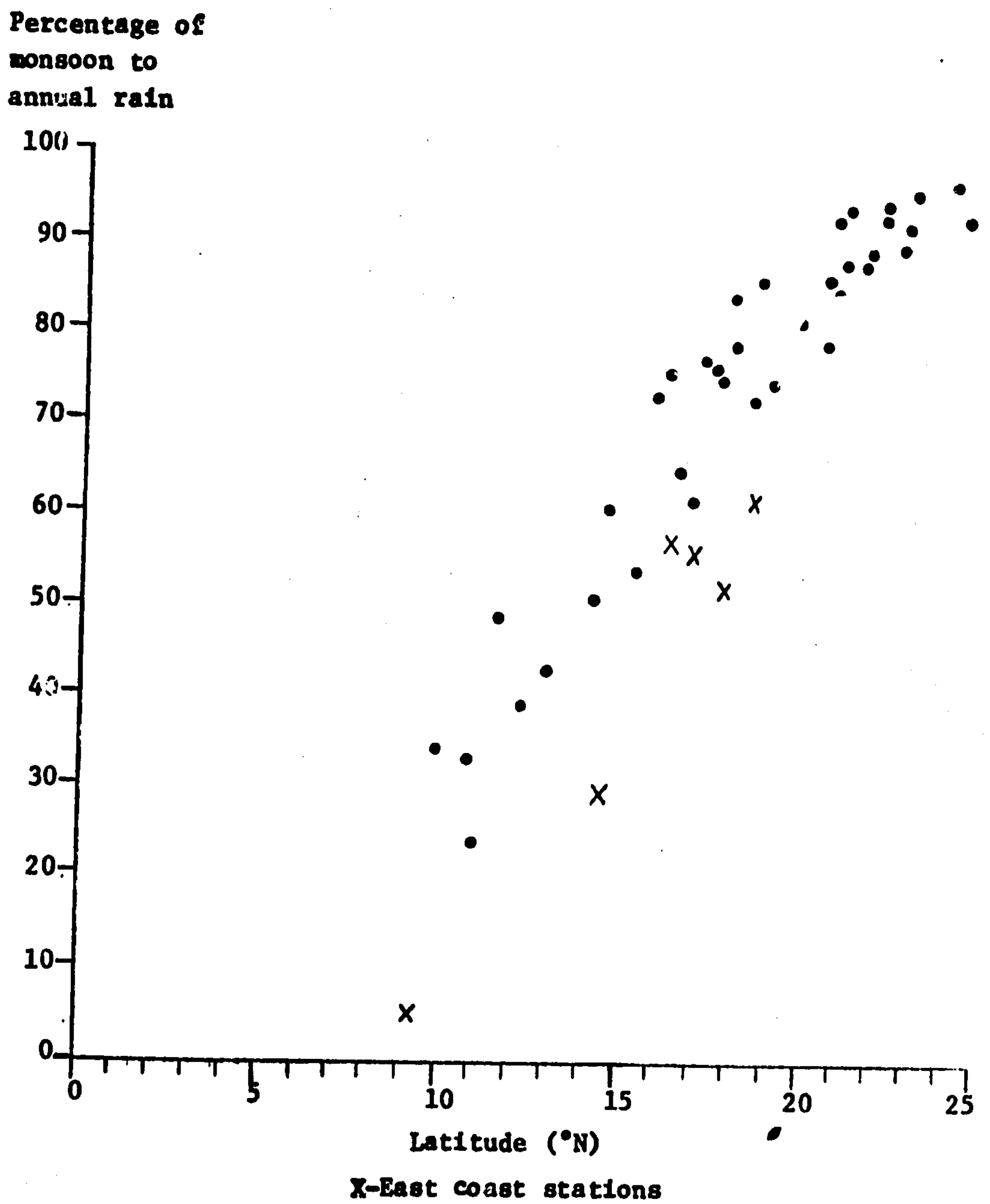


Fig.4: INDIAN SEMI-ARID TROPICAL ZONE



In the South African semi-arid zone (Fig. 2), a bell-shaped curve is obtained, the contribution increasing upto 15°S latitude and decreasing thereafter. Such a feature is not noticed in the Indian semi-arid zone, where the contribution increases from 50 percent corresponding to 15° latitude to 95 percent corresponding to 25° latitude. Stations between 10° and 15° have values ranging from 30 to 50 percent, since they receive considerable rainfall during North-east monsoon season (October to December). The east coast stations do not fit in with the general linear relationship. The Australian stations conform to the southern hemispheric pattern as revealed by the South African semi-arid zone, the contribution during December to March decreasing with latitude in the 15° to 25° South latitude range.

Synoptic Features Governing the Distribution of Rainfall

The significant features in the general air circulation affecting the rainfall distribution in semi-arid tropics of the world are the subtropical anti-cyclones, which form two belts encircling the earth on either side of the equator. In these anti-cyclones, air subsides and arrives hot and dry at the surface. The zone in which the convergence of trade winds emerging from these anti-cyclones occurs is known as the inter-tropical convergence zone (ITCZ). This zone receives much heat from the sun so that the air, as it converges and grows warmer, begins to rise. When the air rises over ITCZ, decreasing pressure causes it to expand and grow cooler, its moisture condenses resulting in rains. The ITCZ and sub tropical anti-cyclones move north and south with seasons. In summer, the relatively low pressure of the ITCZ is far north of equator to develop anti-clockwise circulation. The oceanic trade winds of southern hemisphere cross the equator and move towards these low pressures as south west monsoon. In Africa, this monsoon is opposed by the dry north easterly trade winds, commonly known as 'Harmattan', emerging from the anti-cyclones over North Africa. There are usually many individual anti-cyclonic cells in North Africa including Azores - the most intense one of these types. The meeting line between monsoon and 'Harmattan' is called either inter-tropical discontinuity or ITCZ. The position of this front plays a significant role in the rainfall distribution of this region.

The comparatively little coverage of deserts in 20° -30°N latitude belt and the occurrence of arid zone right in the region of the lowest pressure during the main rainy season are peculiar to the Indian subcontinent. This may be mainly ascribed to the large circulation changes caused by Asiatic monsoon which is the best known monsoon of the world. Ramanathan (1960) indicated that there are no monsoon westerlies in American continent and Pacific. The African monsoon produces only westerlies of about 2.5 km thickness over west Africa and Sudan, whereas the Indian monsoon is the deepest (about 6 km. in 10-15°N). Further, ITCZ lies only a little north of Equator, say within 5 to 10° latitude in Pacific and Atlantic oceans; however, in the continental areas the picture is different. The southern hemisphere air stream penetrates well into India and south east Asia as southwest monsoon upto 30° North latitude whereas it extends only upto 18°N in African continent. In Australia also the summer rainfall occurs in association with the occurrance of North-west monsoon, though the winter rainfall associated with south-east trade winds also occurs to a certain extent in the semi-arid zones in eastern Queensland. (C.S.I.R.O, 1960).

Agroclimatological Features of the Semi-Arid Tropical Regions

For any farm systems analysis, the knowledge of the values of the driving variables, processes and control functions is required. In view of the large complexity of various processes involved, modelling approach should be used. The major reason for adopting modelling approach is to provide a frame-work for bringing together the parts of the systems which are too complex to be comprehended otherwise. The collections of crop production data along with concurrent weather and climatic data, such as atmospheric temperature, humidity, total radiation and available soil moisture period obtained by climatic water budgeting procedures, etc is, therefore important. Most of the semi-arid zones in the world grow subsistence crops, such as millet, sorghum, maize and cowpea and cash crops like cotton, groundnut, etc. Crops in these regions, more particularly those which are indigenous, show a multitude of forms adapted to the whole range of climatic conditions. A comprehensive agroclimatic analysis would therefore enable one to subdivide these crops into ecotypes with a narrower range of climatic requirements, which can then be defined with sufficient accuracy for planning.

Table 3 shows the mean temperature (°C), relative humidity (%) and vapour pressure (mm of Hg) in respect of different stations in the semi-arid tropical zones. For Indian stations, these data are based on standard normals published by the India Meteorological Department for the period 1931-1960, whereas for other countries these are computed from monthly normals of these climatic elements, as published in Monthly Climatic Data for the world. The vapor pressure values in respect of these countries have been computed from the normals of temperature and relative humidity. Table 4 shows the summary of these data in respect of different zones. In case of India, mean vapor pressure values, as computed from normal temperature and relative humidity data are also included in the table in brackets.

The seasonal variation in temperature in the semi-arid tropical regions is very little. The south African semi-arid zone is cooler than such zones of other countries. However, variations between the different zones are not much. In north African zone, there is little difference between winter and summer temperatures. Vapor pressure values computed from the mean temperature and relative humidity differ from the normals

Table 3. Seasonal Climatic Parameters of World's Semi-Arid Tropics

Station	Winter (Dec-Feb)*			Summer (Mar-May)*			Monsoon (Jun-Sept)			Post-Monsoon (Oct-Nov)		
	Temp. °C.	Relative Humidity	Vapor pressure (mm Hg)	Temp. °C	Relative Humidity	Vapor pressure (mm Hg)	Temp. °C	Relative Humidity	Vapor pressure (mm HG	Temp. °C	Relative Humidity	Vapor pressure (mm Hg)
1	2	3	4	5	6	7	8	9	10	11	12	13
		%			%			%			%	
(A) Semi-Arid Tropical Zone in North Africa												
SUDAN												
Wau	26.0	37	9.3	28.5	48	14.0	25.3	77	18.6	25.2	63	15.2
Malakal	27.6	30	8.3	28.1	41	11.7	25.1	79	18.9	25.3	63	15.2
Juba	27.5	46	12.7	27.4	66	18.1	24.6	80	18.6	25.2	67	16.1
CHAD												
Fortlamy	24.4	30	6.9	31.6	30	10.5	28.1	69	19.7	27.5	45	12.4
NIGERIA												
Maiduguri	22.8	27	5.6	30,6	30	9.9	27.4	70	19.2	26.5	42	10.9
Yola	23.3	28	6.0	31.1	41	13.9	26.6	77	20.1	27.5	59	16.2
TOGO												
Lome	27.1	82	22.1	27.5	83	22.8	25.1	86	20.5	26.3	85	21.8
GHANA												
Accra	27.4	78	21.4	27.5	80	22.0	25.0	84	20.0	26.6	81	21.1
Tamale	28.5	36	10.5	29.7	59	17.5	25.9	78	19.6	27.3	69	18.8
UPPER VOLTA												
Bobodioulasso	25.8	31	7.7	29.5	50	15.5	25.7	78	19.3	26.9	63	16.8
Ouagadougou	26.2	26	6.6	31.5	37	12.8	26.6	73	19.1	27.7	51	14.2

Table 3 contd.

1	2	3	4	5	6	7	8	9	10	11	12	13
MALI												
Kayes	26.4	23	5.9	33.6	22	8.6	29.1	71	21.4	29.1	56	16.9
Segou	25.0	29	6.9	30.0	32	10.2	27.8	72	20.2	27.9	57	16.1
Mopti	23.7	36	7.9	31.2	29	9.9	28.6	69	20.2	27.5	57	15.7
SENEGAL												
St.Louis	22.5	60	12.2	28.8	72	21.4	27.5	82	22.5	26.8	71	18.7
Dakar	21.6	68	13.1	21.8	77		27.0	77	20.6	27.1	77	20.7
Kaolack	25.2	36	8.7	29.1	40	12.1	28.6	74	21.7	28.3	64	18.5
Tambacounda	25.5	27	6.6	31.5	31	10.8	27.1	75	20.2	26.9	68	18.1
(B) Semi-Arid Tropical Zone in South Africa												
RHODESIA												
Bulawayo	14.3	50	6.1	21.7	49	9.5	20.7	73	13.4	17.4	60	8.9
GAMBIA												
Livingstone	17.4	44	6.6	25.3	42	10.2	23.1	73	15.5	22.1	57	11.3
MALAGASY REPUBLIC												
Diegosquarez	24.5	66	15.2	25.6	69	17.0	27.0	81	21.6	26.7	73	19.2
PORTUGUESE EAST AFRICA												
Porto Amelia	24.0	72	16.1	26.1	74	18.8	27.2	80	21.7	26.2	77	19.6

Table 3 contd.

1	2	3	4	5	6	7	8	9	10	11	12	13
			(C) Semi-Arid Tropical Zone in Australia									
NORTHERN TERRITORY												
Dalywaters	21.5	39	7.5	28.2	40	11.5	30.0	59	18.8	25.2	41	9.9
WESTERN AUSTRALIA												
Broome	22.0	47	9.3	27.2	58	15.7	30.0	66	21.0	26.8	54	14.3
Hallscreek	19.0	43	7.1	28.0	37	10.5	28.4	54	15.7	23.5	41	8.9
			(D) Semi-Arid Tropical Zone in India									
Deesa	20.6	41	7.0	30.1	37	12.0	29.8	70	21.4	25.5	43	11.1
Neemuch	18.3	39	6.1	29.1	29	8.9	27.8	71	19.1	23.4	40	8.9
Ahmedabad	21.3	41	7.5	30.7	37	12.3	29.7	71	21.9	26.5	45	13.8
Dohad	20.9	40	7.3	30.3	31	9.7	27.6	74	20.1	25.0	48	11.5
Indore	18.7	41	7.0	28.6	26	8.6	26.6	75	19.0	22.3	47	10.7
Baroda	21.4	52	9.5	30.2	41	13.3	29.4	76	22.7	25.7	61	15.4
Bhavnagar	21.1	36	7.4	30.2	37	13.6	29.5	69	21.3	26.6	44	12.7
Rajkot	20.7	37	6.5	31.3	44	12.7	30.4	71	20.9	26.7	44	11.2
Khandwa	21.3	40	7.6	31.4	25	8.9	28.1	71	19.6	24.3	49	11.6
Akola	22.3	41	7.9	32.1	26	9.3	28.5	69	19.3	24.9	50	9.1
Veraval	22.3	57	12.8	26.7	75	20.1	27.9	87	24.5	26.7	65	17.4
Amravati	22.8	37	10.0	32.0	28	10.7	27.8	70	18.9	25.1	47	11.8
Malegaon	21.4	38	7.3	29.9	28	9.5	27.5	67	18.2	24.2	49	11.3
Jalgaon	22.1	40	7.7	31.9	29	9.9	28.7	71	20.1	24.9	50	12.0
Aurangabad	22.4	39	7.8	30.4	29	9.7	26.3	74	18.2	24.4	51	11.9
Nizamabad	23.0	46	9.7	31.8	31	10.8	27.7	70	19.1	24.5	58	14.2
Ahmednagar	21.5	43	7.8	29.3	28	8.9	26.0	69	17.0	23.8	53	12.1

Table 3 contd.

1	2	3	4	5	6	7	8	9	10	11	12	13
Poona	21.8	50	8.8	28.5	40	11.3	25.5	77	19.0	24.3	61	12.8
Bidar	23.0	46	9.5	30.4	39	12.4	25.7	74	17.6	24.0	57	13.0
Calingapatam	23.1	74	15.9	29.1	76	23.2	29.2	81	24.3	26.0	77	19.7
Visakhapatnam	23.3	75	17.7	29.1	76	24.5	29.3	82	26.0	26.5	74	20.6
Hanamkonda	23.9	54	11.8	31.8	42	13.9	28.6	68	19.6	25.5	62	15.5
Sholapur	23.8	38	8.5	31.3	32	10.7	27.3	67	17.7	25.3	52	12.7
Kakinada	23.8	70	16.5	30.3	68	22.4	29.4	75	22.6	26.4	73	19.9
Gulbarga	23.8	39	8.9	31.5	32	10.5	27.4	68	17.8	25.2	52	13.0
Hyderabad	22.1	55	11.4	30.1	41	14.0	26.7	73	18.9	23.7	62	15.1
Rentachintala	24.9	53	12.7	32.7	44	16.2	30.3	61	19.6	26.6	64	16.7
Miraj	22.9	47	10.0	29.1	48	13.9	25.3	78	18.3	24.6	59	13.9
Raichur	24.9	46	10.9	31.9	43	15.0	27.9	66	17.3	26.1	56	14.2
Kurnool	24.8	49	11.2	32.1	37	12.8	28.5	64	17.3	26.3	61	15.7
Masulipatam	24.1	74	17.3	29.9	71	22.7	29.7	73	22.6	26.7	77	20.6
Gadag	24.0	47	10.6	29.3	55	15.7	25.3	77	17.6	24.8	61	14.3
Cuddapah	25.7	60	15.5	33.0	47	18.2	30.2	62	20.0	27.0	71	19.1
Nellore	25.3	73	17.5	31.3	63	20.9	33.0	59	19.8	29.0	77	20.8
Chitradurga	23.7	48	10.7	28.8	48	13.6	24.9	74	16.5	24.2	64	14.5
Vellore	24.1	67	14.8	30.5	57	17.0	29.9	59	18.4	26.2	73	18.4
Salem	25.7	58	13.9	30.5	55	17.2	28.7	65	18.5	26.6	70	17.9
Mysore	22.9	53	10.9	27.1	55	14.1	23.9	75	16.4	23.4	70	15.1
Coimbatore	25.0	57	13.4	30.1	57	16.6	26.1	71	17.8	25.7	71	17.6
Tiruchirapalli	25.9	66	16.7	30.7	56	18.7	30.5	55	17.9	27.2	73	19.8
Madurai	26.1	64	16.1	30.7	55	18.1	30.6	53	17.3	27.7	70	19.3
Pamban	26.2	81	20.6	29.1	77	23.6	29.1	79	23.6	27.6	82	22.7

* Months of seasons pertaining to southern hemisphere stations will be different as mentioned in earlier note.

Table 4. Seasonal climatic parameters of world's semi-arid tropics

	Temperature (^oC)				Relative humidity (%)				Vapor pressure (mm Hg)			
	Winter	Summer	Monsoon	Post-monsoon	Winter	Summer	Monsoon	Post-monsoon	Winter	Summer	Monsoon	Post monsoon
North Africa	25.3	29.4	26.7	26.9	40	48	76	63	9.9	14.2	20.0	16.8
South Africa	20.1	24.7	24.5	23.1	58	59	77	67	10.7	13.9	18.1	14.7
Australia	20.8	27.8	29.5	25.2	43	45	60	39	8.0	12.6	18.5	11.0
India 15^o – 25^oN	22.4	30.4	27.9	25.2	48	41	72	56	10.5 (9.7)	13.9 (13.4)	19.3 (20.3)	13.8 (13.5)
9^o – 15^oN	25.6	30.2	28.6	26.5	63	57	65	72	15.0 (15.5)	17.8 (18.3)	18.6 (19.0)	18.5 (18.7)

computed by averaging the individual mean monthly vapor pressure values only by 0.5 to 1.0 mm of Hg. Seasonal variations are similar in different regions of the world. Regions affected both by south-west and north-east monsoon reveal high humidity in monsoon, post monsoon seasons and to a certain extent in winter also.

Though the normals of different regions indicate fairly uniform pattern in temperature and humidity, there is considerable variation from year to year and within the year itself.

It is well known that plants require a fixed amount of heat (accumulated degree days) or photo-thermal units. A number of studies have been undertaken in the past for relating the length of time for a crop to reach maturity to its thermal and photo-period environment. This equation can be written in the following form as suggested by Robertson (1968)

$$\mathcal{M} = (dM) \div dt = F_1(L)\ F_2(T)$$

$\mathcal{M}$ = is the average rate of maturity per unit time of t
M = is the degree of maturity
$F_1(L)$ - Curvilinear function of photo-period
$F_2(T)$ - Curvilinear function of day and night temperatures

Integration of this equation over time leads to an expression for the degree or development M of the crop over a phenological period from one phenological stage S_1 to another S_2. There should be improvement in such methods for estimating various phenological dates from environmental factors. The solar energy affects the rate of crop development through two processes by contributing to the effective crop temperature and by contributing to the photoperiodic response. Robertson (1953) indicated that crop temperature can be estimated from atmospheric temperature, wind, sunshine and vapor pressure. Thus studies on effective crop temperature and energy balance factors are important in semi-arid tropical zones for agricultural development.

Crop Growing Season

Moisture is the main limiting factor affecting crop yields in the semi-arid tropics. For planning the cropping patterns and for arranging different crop sequences, information on the possible crop growing seasons at different stations in these regions is extremely important. The main climatic needs for millet and sorghum varieties in these regions are the synchronizing of the crop growing season with the optimum moist period as determined by climatic water budgeting approach and in case of late varieties matching of the end of humid period with photoperiodically controlled date of heading. Similar to the procedure followed by Cocheme and Franquin (1967), the crop growing season with 'nil' or slight water stress under rain-fed farming can be defined as the period for which actual evapotranspiration(AE), estimated by water balance book keeping procedure taking into account both the rainfall and the stored soil moisture, exceeds half the value of potential evapotranspiration(PE) viz., AE $\geqslant$ (PE) ÷ 2.

These data in respect of different semi-arid tropical regions in India along with annual mean rainfall and PE values computed by Penman's method are given in the Table 5. The stations are arranged in four subregions with different ranges of annual rainfall.

It would be interesting to compare the same with values given by Cocheme and Franquin (1967) in respect of Sahel region of Africa which is presented in Table 6. Since north-east monsoon rainfall regime stations in India form a special category with regard to commencement, end and duration, means in respect of them are given separately.

It is seen that the mean duration of crop growing season is higher in India than Sahel in all the subregions, probably due to higher rainfall less potential evapotranspiration and generally larger water-holding capacity of the soil. In the north-east monsoon region in India, there are two types of growing seasons. One in Salem-Mysore region with longer growing season extending from April to December and another with shorter growing season from mid-August to mid-January. But the latter areas also have some actual evapotranspiration values though the same do not exceed (PE) ÷ 2. Some suitable legume and

Table 5. Crop growing season in semi-arid tropical regions of India

Station	Normal annual rainfall (mm)	Normal annual potential evapotra-nspiration (mm)	Crop Growing Season	
			Actual duration	No. of days
1	2	3	4	5
Region I (Mean annual rainfall 500-600 mm)				
Melegaon	579	1659	10 Jun to 12 Oct	125
Bhavnagar	587	1815	1 Jul to 30 Oct	122
Region II (Mean annual rainfall 600-800 mm)				
Coimbatore	612	1622	27 Sep to 11 Dec	76
Miraj	639	1688	16 Jun to 5 Nov	143
Chitradurga	655	1606	15 May to 13 Oct	152
Gadag	664	1664	15 Jun to 8 Nov	147
Kurnool	674	1827	17 Jun to 26 Oct	132
Rajkot	674	2145	21 Jun to 10 Oct	112
Ahmednagar	677	1605	2 Jun to 8 Nov	160
Veraval	702	1685	3 Jun to 23 Oct	143
Poona	715	1474	4 Jun to 21 Nov	171
Rentachintala	717	1775	22 Jun to 12 Nov	144
Raichur	717	1951	12 Jun to 28 Oct	139
Sholapur	742	1802	8 Jun to 2 Nov	148
Cuddapah	743	1834	14 Jun to 30 Nov	170
Gulbarga	753	1913	9 Jun to 21 Oct	135
Hyderabad	764	1757	12 Jun to 8 Nov	130
Aurangabad	792	1774	5 Jun to 20 Nov	169
Region III (with mean annual rainfall 800-1000 mm)				
Ahmedabad	823	1677	14 Jun to 20 Nov	160
Mysore	835	1534	18 Apr to 2 Dec	229
Jalgaon	840	1912	9 Jun to 21 Nov	166
Tiruchirapalli	868	2091	21 Aug to 2 Jan	135
Akola	877	1730	5 Jun to 4 Dec	183
Neemuch	895	1601	14 Jun to 15 Jan	216
Madurai	905	1684	(11 Apr to 29 Apr 28 Jul to 9 Jan)	185
Pamban	923	1825	30 Sep to 15 Feb	139
Hanamkonda	945	1787	4 Jun to 8 Dec	188
Khandwa	961	1729	7 Jun to 30 Dec	207

contd.

Table 5. contd.

1	2	3	4	5
Salem	965	1728	8 May to 15 Dec	222
Vellore	969	1686	19 Jun to 22 Jan	218
Visakhapatnam	974	1482	1 Jun to 11 Jan	225
Amravati	975	1769	4 Jun to 22 Dec	202
Bidar	977	1754	1 Jun to 13 Dec	196
Baroda	985	1575	9 Jun to 12 Dec	187
Calingapatnam	986	1540	31 May to 25 Dec	209
Region IV (with mean annual rainfall 1000-1200 mm)				
Nellore	1032	1728	23 Jul to 9 Feb	202
Indore	1053	1813	5 Jun to 27 Dec	206
Masulipatnam	1075	1704	9 Jun to 6 Jan	212
Nizamabad	1086	1591	31 May to 28 Dec	212
Kakinada	1172	1689	1 Jun to 2 Jan	216

pasture crops with low water requirements can be profitably grown during the period April to August. Typical diagrams representing the march of PE and rain in the above mentioned subregions are presented in Figures 5 to 8.

Synchronization of the water requirement and growth cycle of crops sown with occurrence of moist and humid periods as obtained by water budgeting method will be useful in delineating optimum yield zones for different crops.

Acknowledgement

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Table 6. Comparison of semi-arid tropical regions in India & Sahel.

	No. of sta-tion	Mean annual rainfall (mm)	Mean annual P.E. (mm)	Mean crop growing season		
				Commencement date	End date	Duration (days)
Subregion I (with 500-600 mm annual rain)						
India	2	583	1737	21 Jun	21 Oct	123
Sahel	5	544	1856	30 Jun	11 Oct	104
Subregion II (with 600-800 mm annual rain)						
India	15	749	1767	10 Jun	2 Nov	146
Sahel	8	667	1843	19 Jun	20 Oct	124
Subregion III (with 800-1000 mm annual rain)						
India	12	933	1687	7 Jun	18 Dec	195
Sahel	9	882	1669	30 May	28 Oct	152
Subregion IV (with 1000-1200 mm annual rain)						
India	4	1097	1699	4 Jun	1 Jan	212
Sahel	6	1096	1687	8 May	6 Nov	183
Subregion V (Northeast monsoon regime stations)						
India: Salem-Mysore	2	900	1631	28 Apr	8 Dec	225
Rest of region	5	868	1790	26 Aug	19 Jan	147

Fig. 5: SHOLAPUR

REGION II

ANNUAL RAINFALL - 742 mm.

CROP GROWING SEASON 8th JUN TO 2nd NOV.

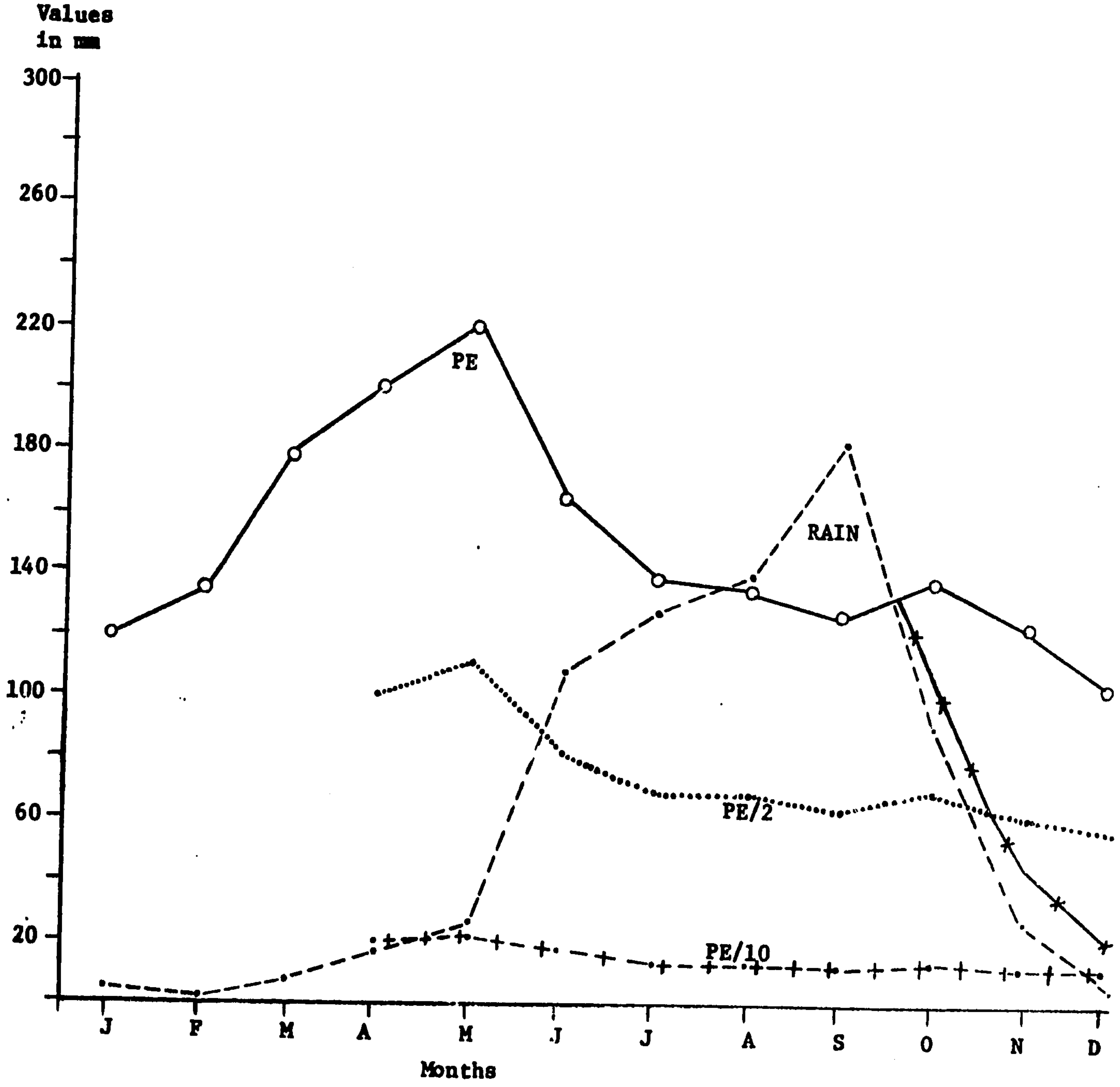


Fig. 6: AKOLA

REGION III

ANNUAL RAINFALL 877 mm

CROP GROWING SEASON 5th JUN TO 4th DEC

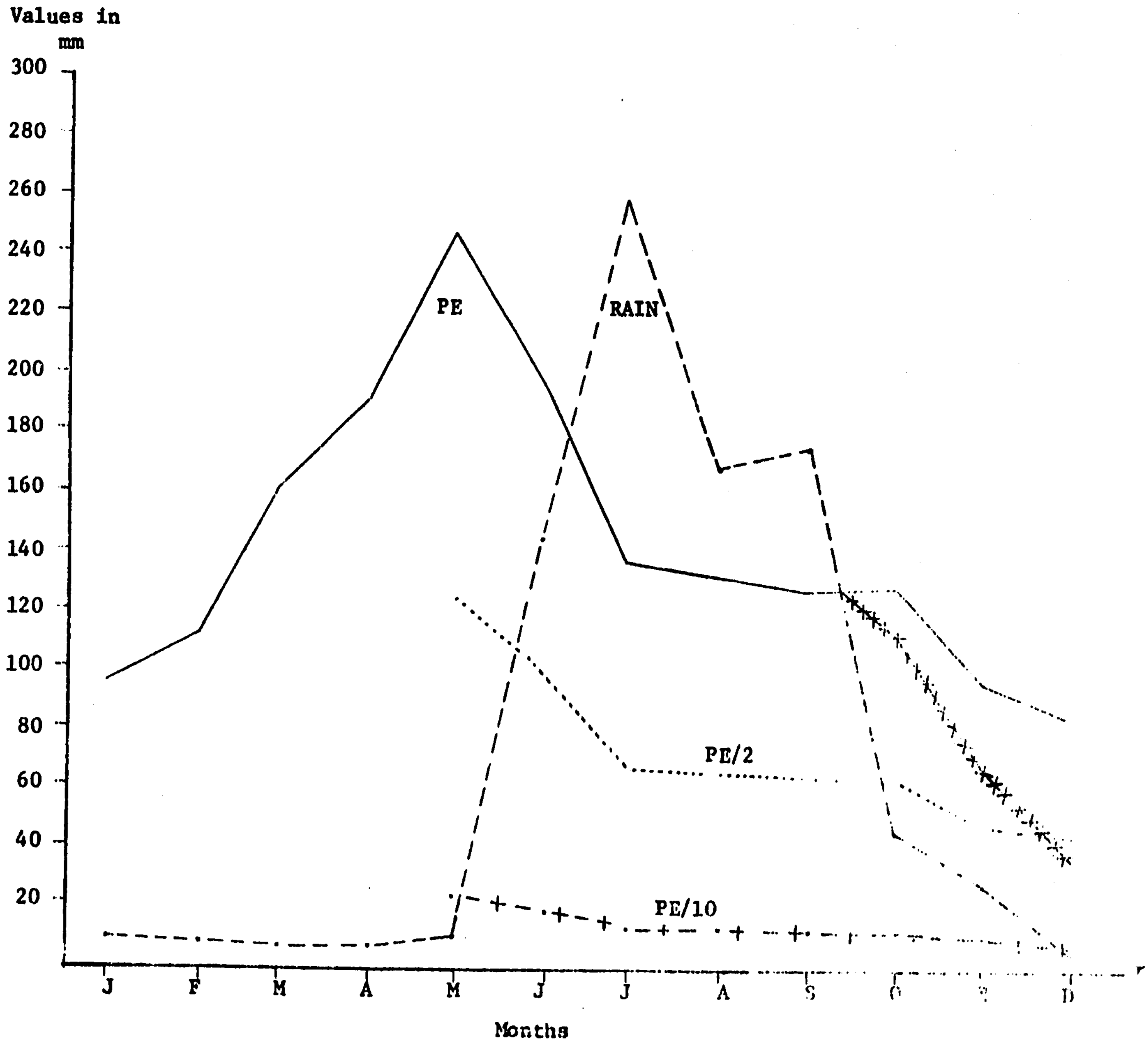
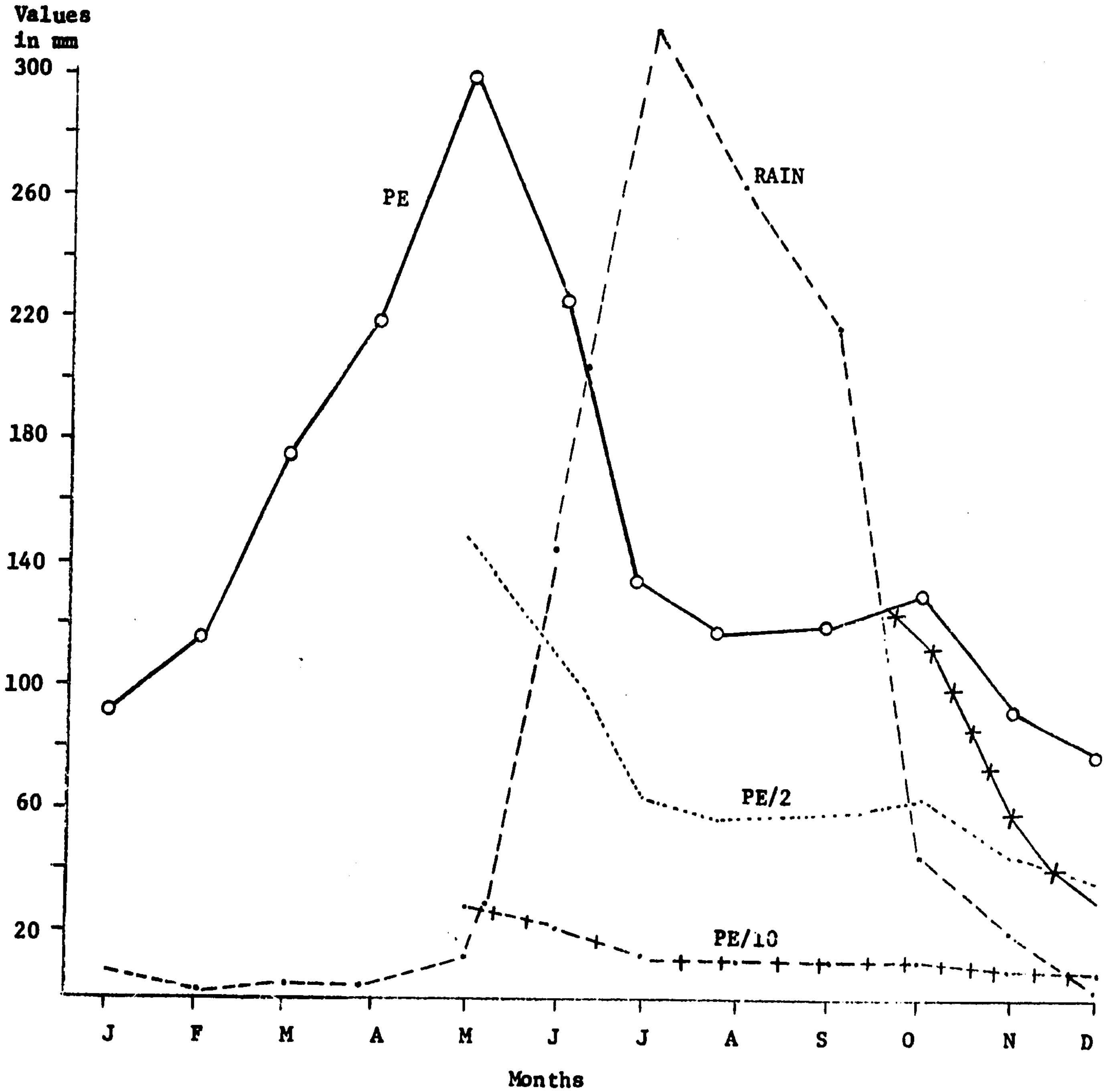


Fig. 7: INDORE

REGION IV

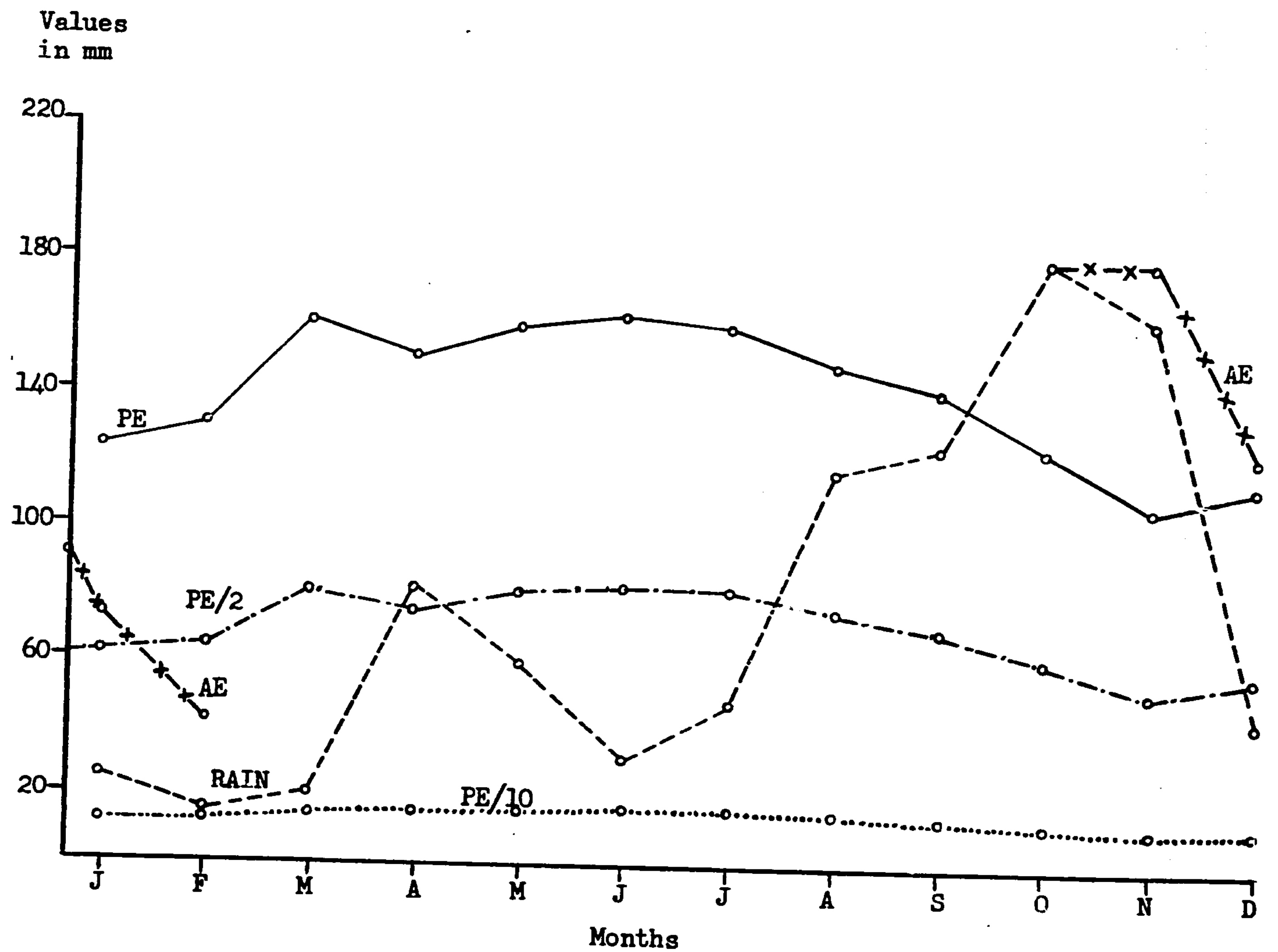
ANNUAL RAINFALL - 1053 mm

CROP GROWING SEASON 5th JUN - 27th DEC.



MADURAI

Fig. 8: REGION V - N.E. MONSOON TYPE, ANNUAL RAINFALL - 905 mm
CROP GROWING SEASON (28 JUL. to 9 JAN.)



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ASSESSMENT OF CLIMATIC RESOURCES IN RELATION TO FARMING SYSTEMS IN THE SEMI-ARID TROPICS

J. Elston and M.D. Dennett*

A farming system is an abstraction that relates the crops, that can be grown at a place, to its physical, biological and social environment (Duckham and Masefield, 1971). There are some characteristic features of the physical environment that can be analysed more simply than the biological or social features. The amount of solar energy received at the crop defines the ultimate limit of production. Often climatic factors may limit the duration of crop growth through the year or affect the efficiency with which solar radiation is used. The variation of climatic factors affects the yield from year to year. The expectation of an extreme value helps determine the distribution of particular types of farming systems. Any analysis must account for both the mean and the variability of climatic factors.

There is no _a priori_ basis to the classification and assessment of climate. Any assessment of agricultural climates must be based upon the responses of crops and animals to climatic factors.

Climates help determine possible farming systems because crops and animals respond to environmental factors. Any complete analysis of climatic control would have to account for the operations of climatic factors upon biological processes. At present, sufficient knowledge is not available about these operations to make it possible to predict the consequence of climate in any but the most general form.

Solar Radiation

Daily total of solar radiation generally vary from about 15 to about 24 MJ m^{-2} day^{-1} at low altitudes within the tropics (Huxley, 1963). In general, there is no great seasonal pattern (Fig. 1, 2, and 3) though cloudiness may affect radiation receipt (Fig. 4). Outside the tropics solar radiation varies more seasonally (Fig. 5).

Solar radiation does not vary as much as rainfall from year to year. The basic geometry which controls the partition of the Solar constant is fixed, though the turbibity of the atmosphere and reflection and

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Fig.1: SOLAR RADIATION

KABANYOLA (0°28'N, 32°37'E)

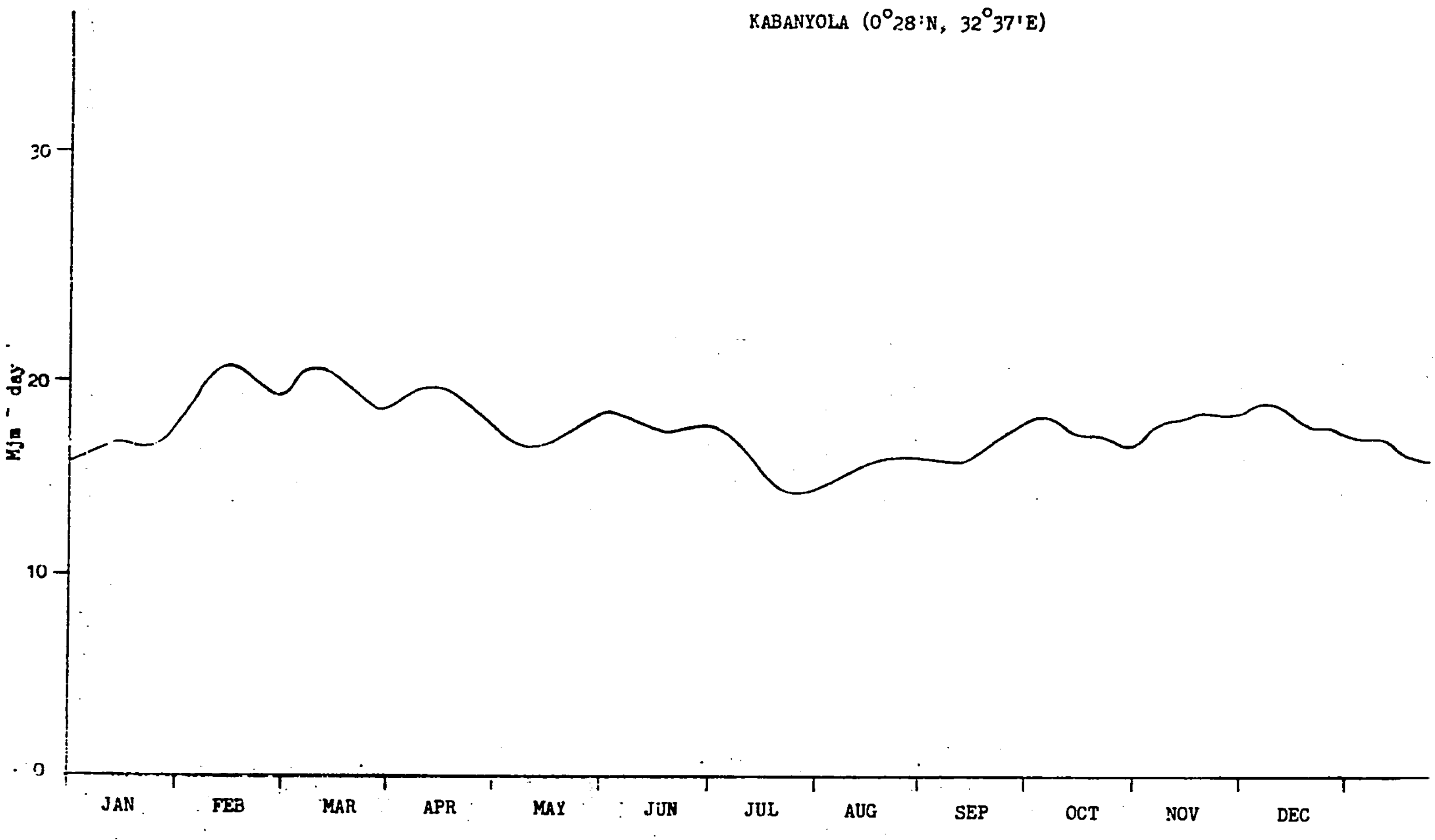


Fig.2: SOLAR RADIATION, BENIN (06°17N 05°42'E)

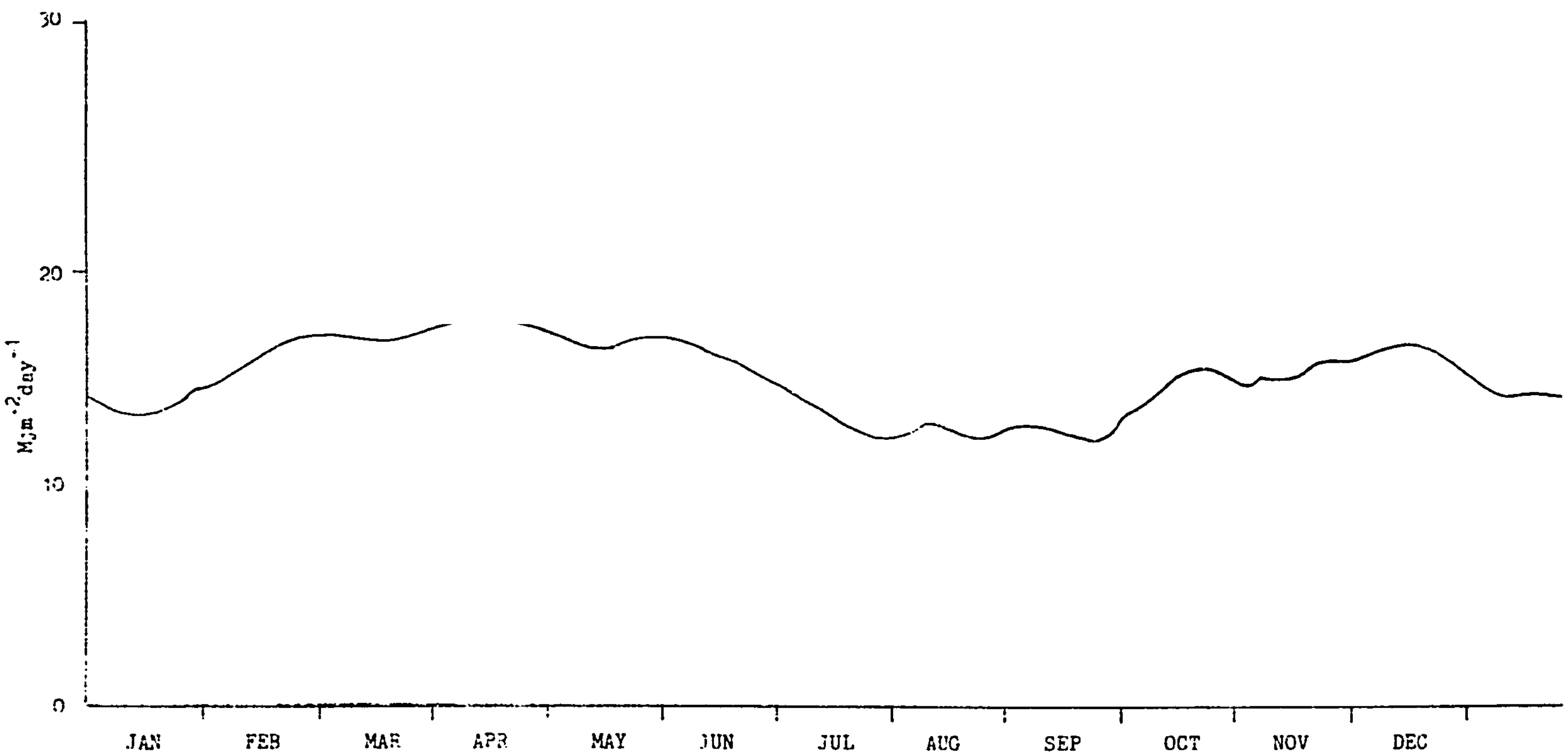


Fig.3: SOLAR RADIATION, SAMARU (11°N, 8°E)

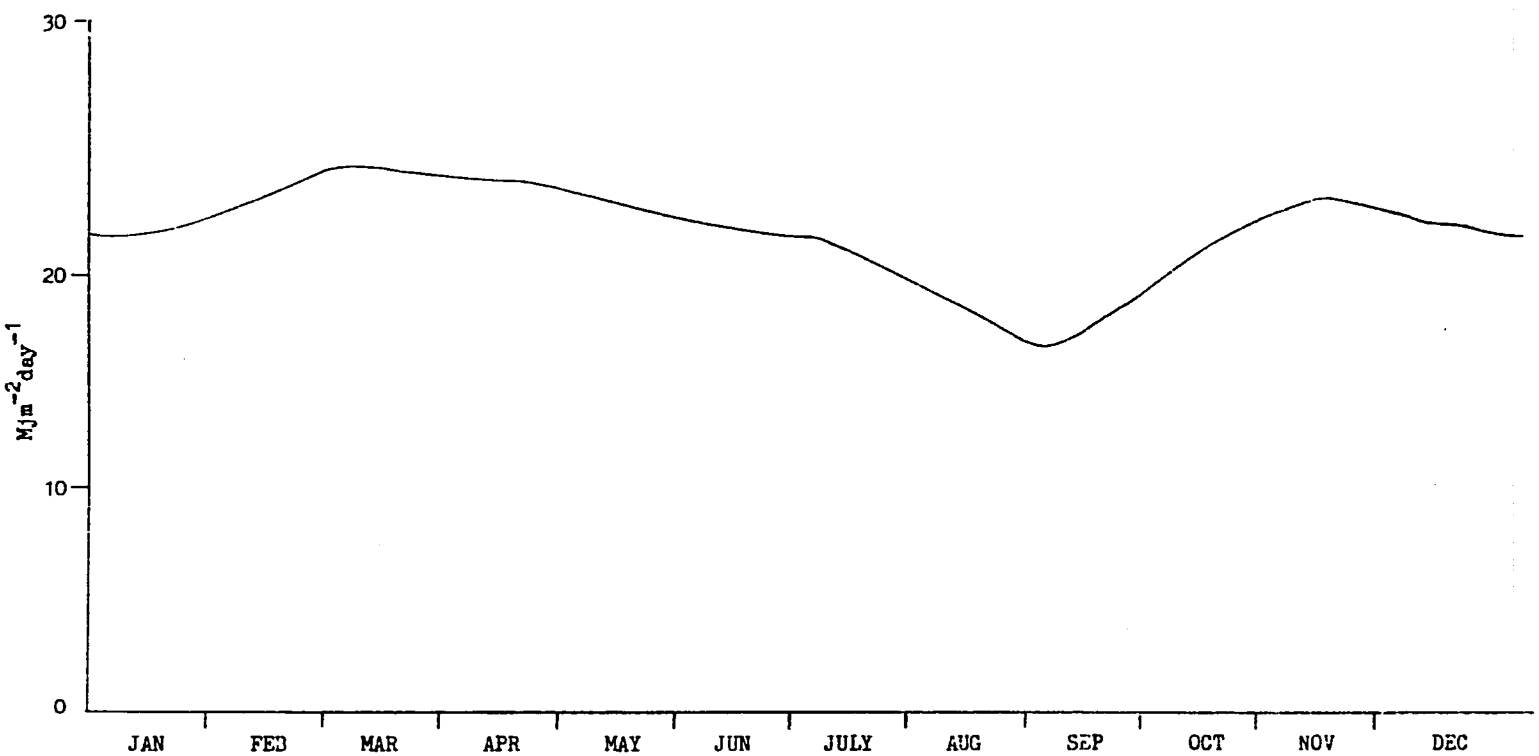


Fig.4: SOLAR RADIATION, POONA (18°34'N 73°58'E)

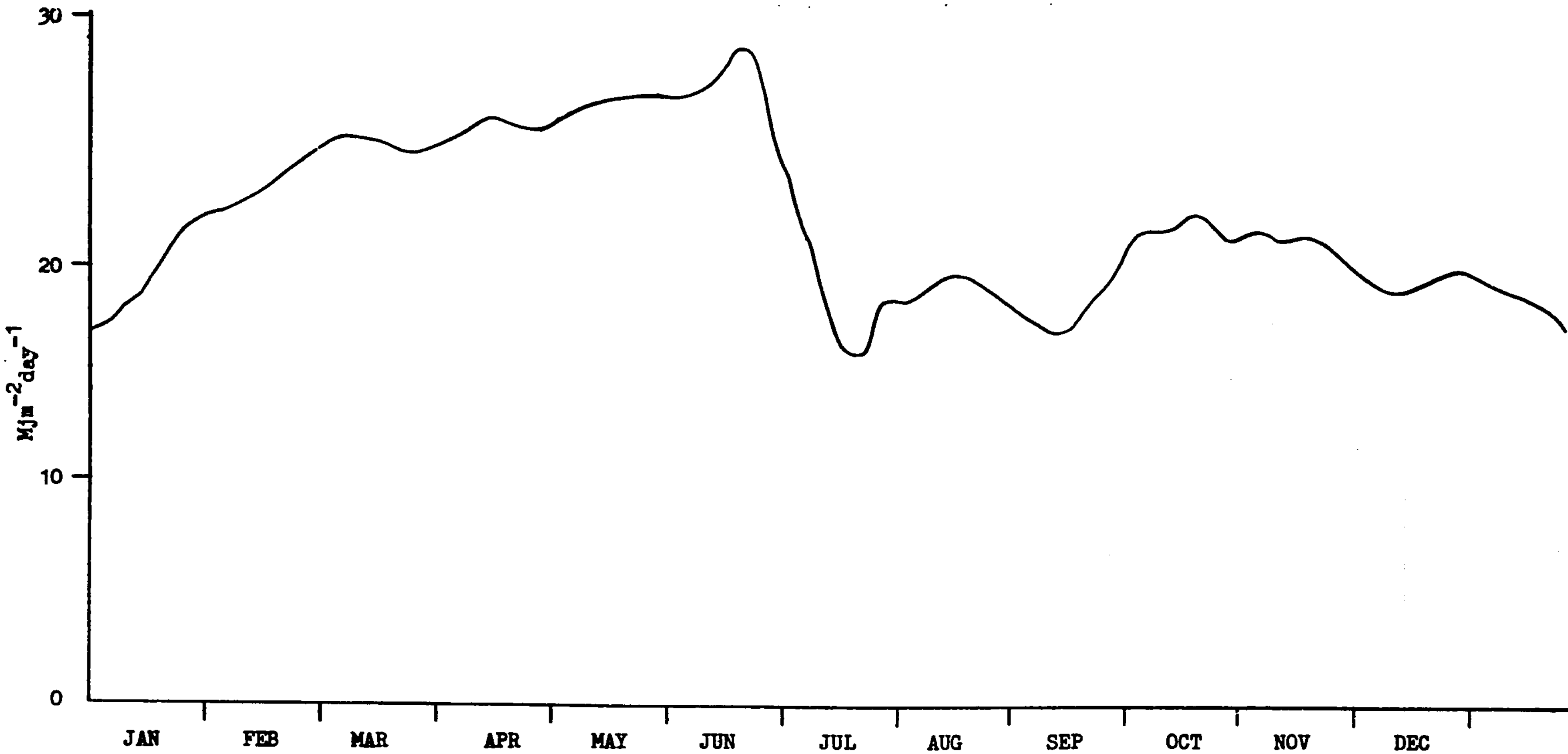
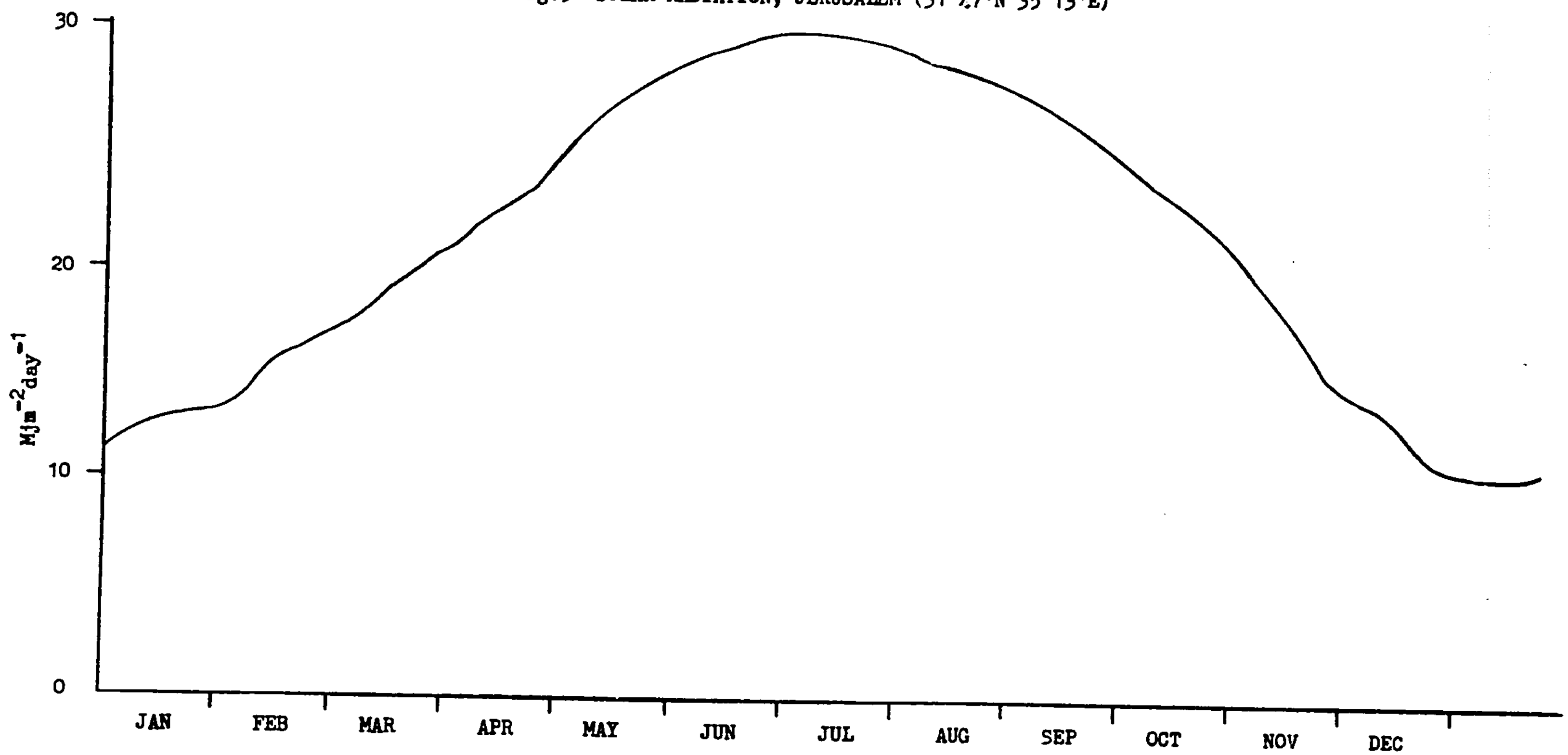


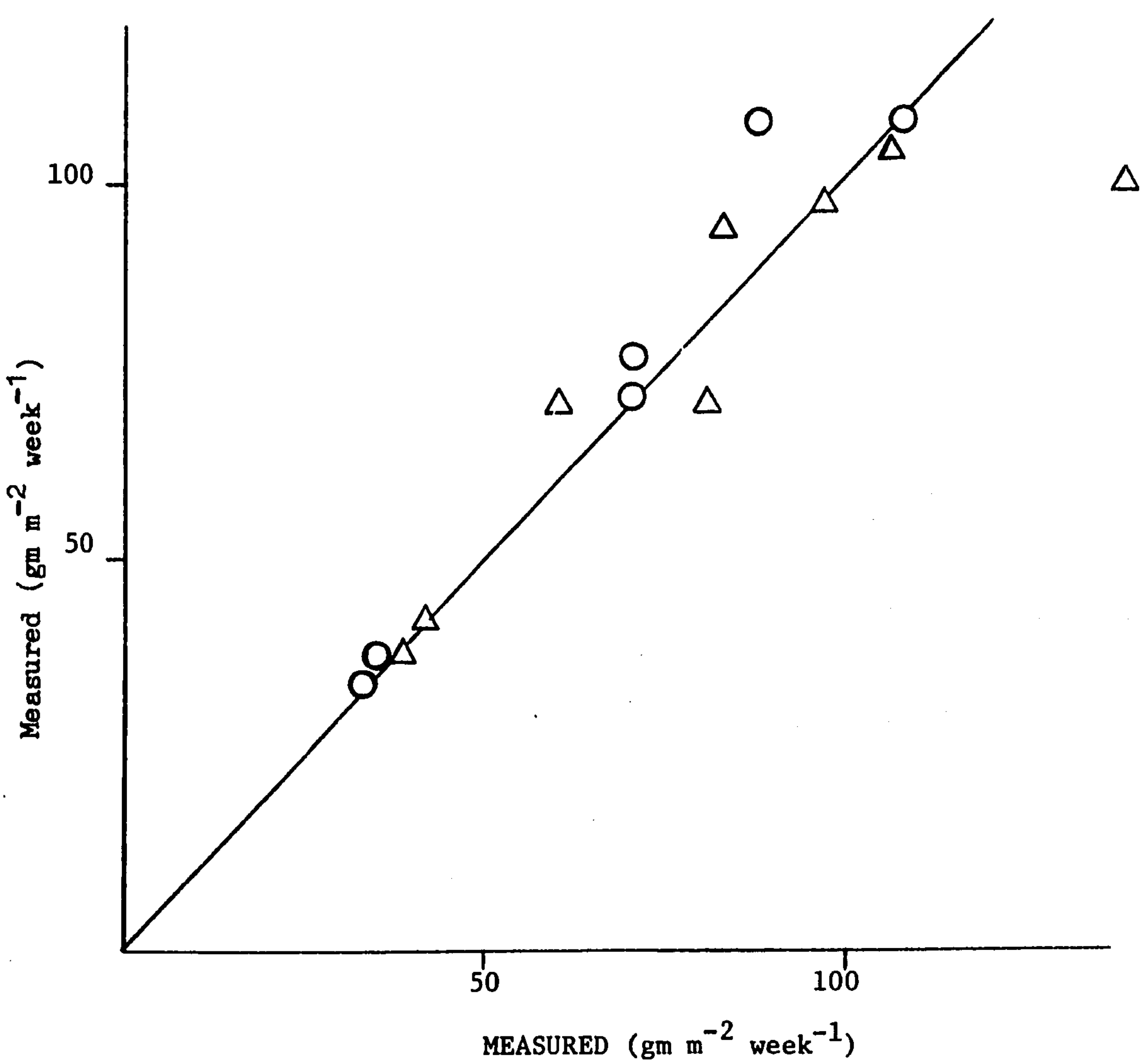
Fig.5: SOLAR RADIATION, JERUSALEM (31°47'N 35°13'E)



absorption by clouds may vary. Solar radiation has not been measured directly at many places for long periods of time. However, regressions of solar radiation upon cloudiness and upon hours of bright sunshine can be used to provide estimates for other stations. Such regressions should be tested against measurement wherever possible.

The growth rate of a crop during vegetative growth is proportional to the intercepted radiation (Monteith, 1972), and the agronomy of a crop can be seen as the manipulation of leaf area to intercept radiation. Models of dry matter production are surprisingly accurate (Fig.6).

Fig.6: PREDICTED VS ACTUAL CROP GROWTH RATES FOR SEVERAL CROPS OF GROUNDNUT AT SAMARU (TAKEN FROM 3).



The prediction of total dry matter production during the vegetative phase, where leaf area index is known, from measurements of solar radiation is straight-forward. The partition of this dry matter into economic yield can be made using measured harvest indexes. The calculations can be used to define the maximum production that can be expected from a particular farming system.

The Water Balance

The water balance limits the length of the growing season through most of the tropics. Water stress by affecting leaf area, may limit the interception of radiation and by altering stomatal resistance may decrease the efficiency with which solar radiation is used. The water balance is the balance between the supply of water to the crop surface and the demand for water from the crop surface. Rain water may run off along the soil surface, drain beyond the root zone or be stored in the soil. Evaporation may occur from the soil surface or through the crop. Rainfall is the easiest component of the water balance to measure. Evaporation is a complex process, combining the effects of a number of simpler environmental variables in the supply of energy for evaporation and in the transport of water vapor from the surface.

The length of the growing season at a place within the tropics depends upon the length of the period when water supply equals or exceeds demand. This period varies in length from year to year. Near the equator (Fig.7), there are short periods of drought with small deficits. The natural vegetation is rain forest and the crops are mostly perennial. The cash crops are often high technology crops like rubber, cocoa and coffee. Further from the equator (Fig.8), there is a single period of drought, which gradually lengthens with increasing distance from the equator (Fig.9). These climates are only seasonally humid and are usually called seasonally arid. The natural vegetation is savanna and the crops are annuals. The seasonally arid climates grade into the semi-arid and arid climates where demand always exceeds supply (Fig.10).

Variability

Climates vary from year to year. The data used to define the water balances shown here are for means. Two places may have the same mean monthly rainfall but very different ranges for the month. In general evaporation is more conservative than rainfall. In all analysis of farming systems the variability as well as the mean of a climate factor must be considered.

Rainfall

There are more measurements of rainfall than of any other climatic factor. The measurements are of variable and uncertain reliability. There are errors that come from an unrepresentative location, from the exposure of the instrument above the ground and from the observer. These errors are of varying importance in different analysis. The errors on account of exposure of the instrument above ground is not usually great (High and Oguntoyinbo, 1974). There are rules for the siting of gauges, which if followed should minimize errors. There is no obvious method of locating and describing observer errors.

Rainfall varies more sharply with distance than other climatic factors. Though rain may be accurately measured at a site, the measurements may not represent the region around. A large part of rain in the tropics comes from local storms. There is therefore usually a considerable increase in reliability when rainfalls are averaged over a meteorologically homogenous region rather than when single stations are analysed.

Fig.7: ESTIMATED WATER BALANCE, KABANYOLO ($0^{o}28'N$, $32^{o}37'E$)

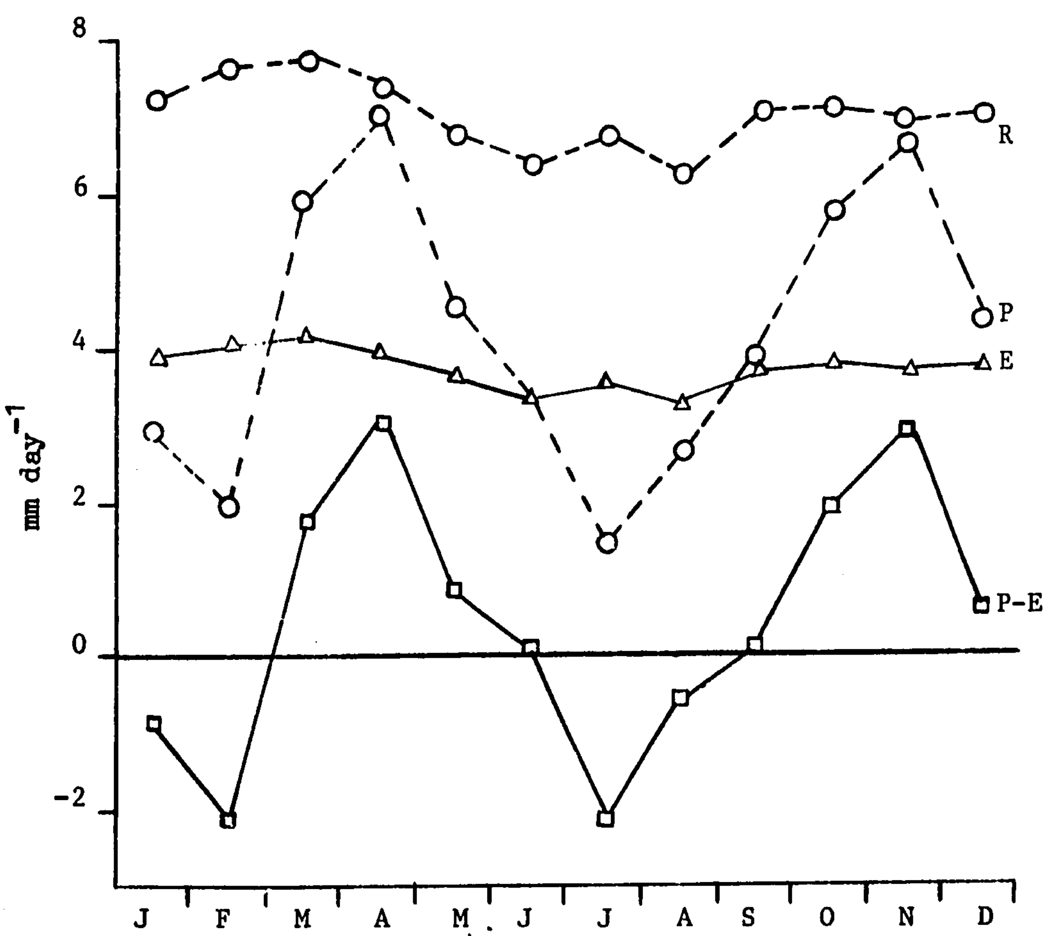


Fig.8: ESTIMATED WATER BALANCE

BENIN (6° N, 5°30' E)

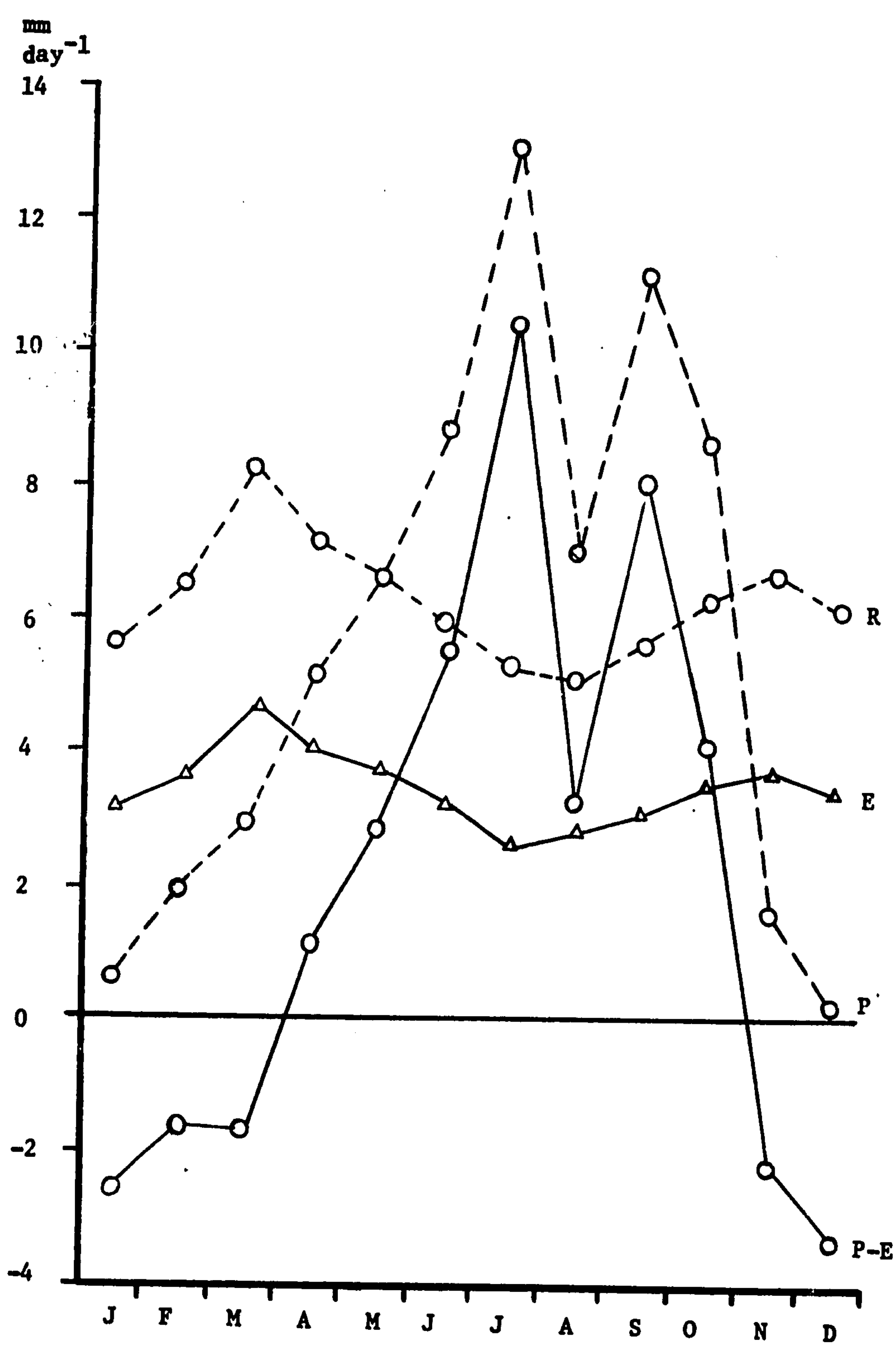


Fig.9: EXTIMATED WATER BALANCE

SAMARU (11 °N, 8°E)

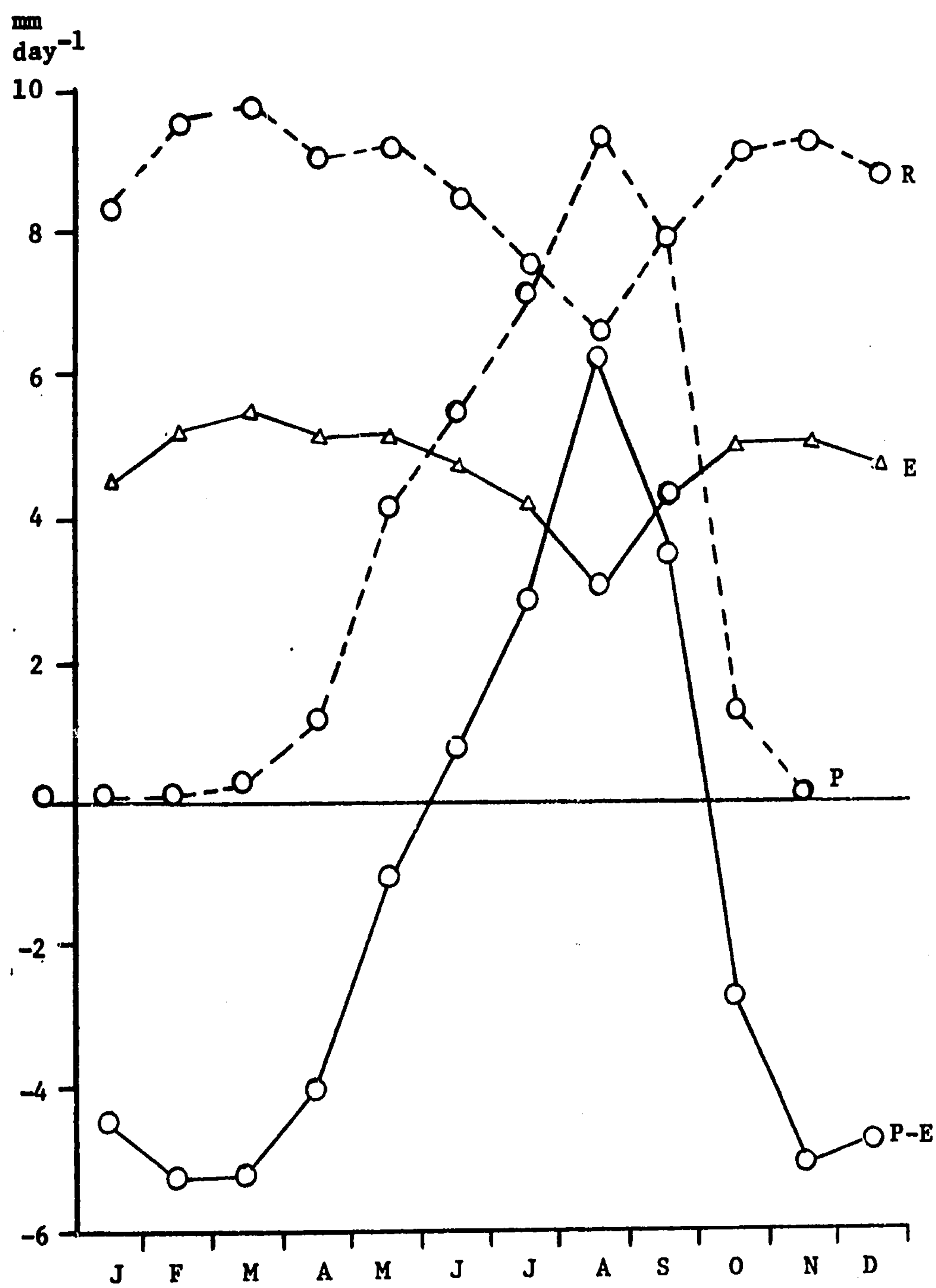
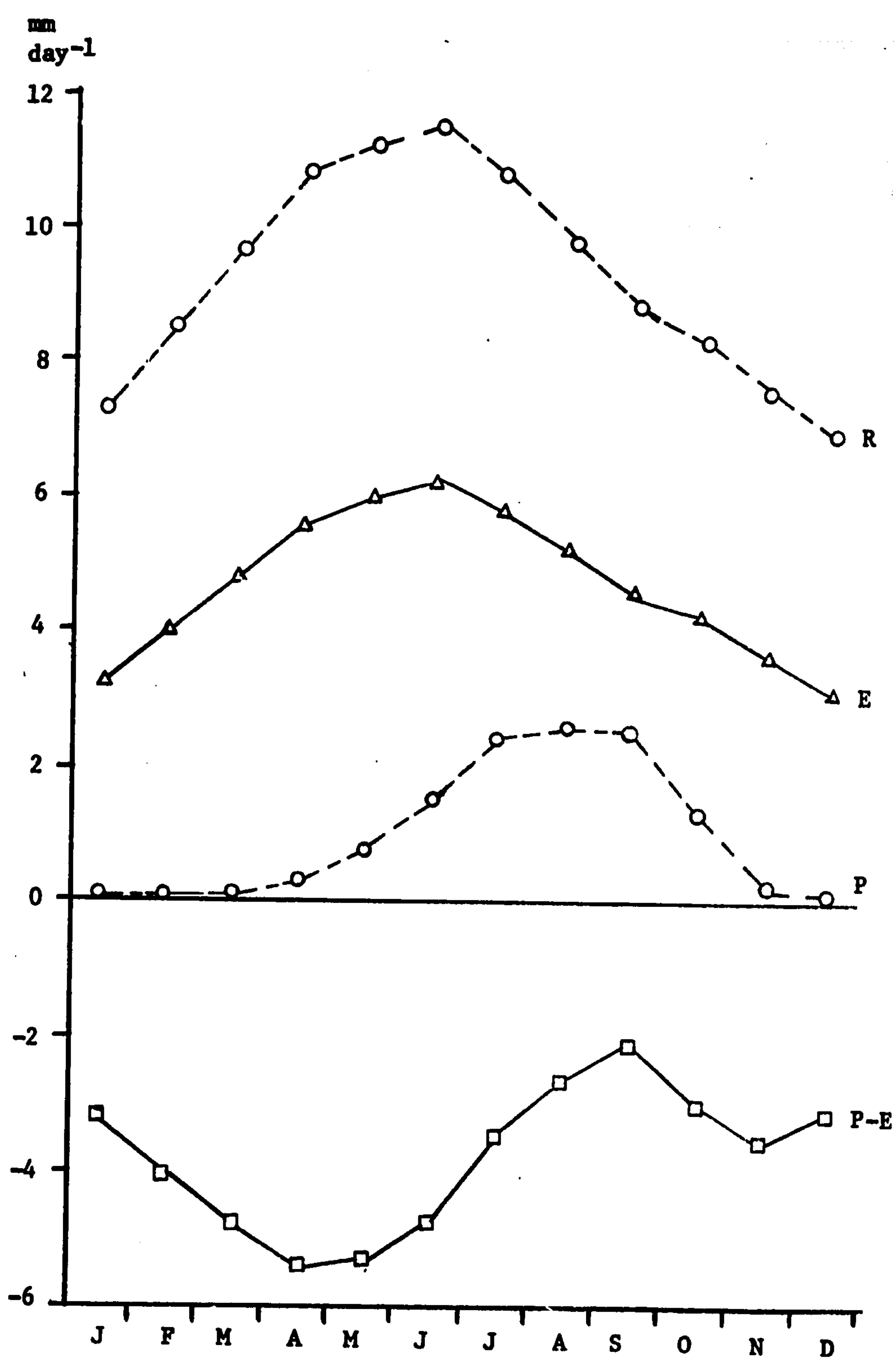


Fig.10: ESTIMATED WATER BALANCE

WINDHOEK (23°S, 17°E)



The Analysis of Rainfall

The simple statistical calculations generally used by agriculturalists, such as the 'F' test or a linear regression, assume that the variate is drawn from a normal distribution. Daily and pentad rainfall values are not normally distributed (Fig.11) but are strongly skewed. The longer the period for which data are bulked, the more the distribution tends to be normal (Godske, 1966). This is the Central Limit Theorem.

In agriculture we must consider variation in short periods of time. For example, water stress may be important only after five days without rain in some parts of the tropics. Information will be disguised if monthly averages are used. Measurements must be transformed to normal distributions or to other distributions whose parameters are known, otherwise non-parametric tests must be used. The statistics of normal distributions are simple and well known. Generally daily and pentad data can be transformed to a normal distribution using logarithms or square roots.

The transformed data must be tested for closeness to a normal distribution. The transformed data, ignoring days without rain, should give a straight line when plotted on probability paper against the percentage cumulative frequency (Fig.12). There are also simple statistical tests for skewness and kurtosis. Confidence limits can be calculated, using the standard deviation, for appropriate probabilities. This is a convenient way of presenting measurements in terms of the expectation of particular rainfalls.

Rainfall varies from month to month through the year and from year to year. Within the tropics rainfalls are less variable in areas of high rainfall (Fig.13). Rainfalls within the tropics are more variable than comparable quantities in temperate regions (Manning, 1955). The variance in the observations rises steeply as rainfall decreases below a mean rainfall of about 1 m/year.

Trends and Fluctuations in Rainfall

Climates change. Climates in the savanna of northern Africa have changed substantially over the past few millenia (Jackson, 1957). Climatic changes over shorter periods have been identified in other parts of the world (Lamb, 1972). Long runs of measurements can be tested for trends (which are monotonic), for discontinuities (which are abrupt) and for fluctuations (which are any other systematic changes).*

Trends

Because trends are monotonic, they can be described by either linear

* See 'Climatic Change', W.M.O. Tech.Note 79, W.M.O. 1966.

Fig.11: FREQUENCY DISTRIBUTION OF PENTAD RAINFALL FOR MAHALAPYE, JANUARY 1911-1972 (23°S, 27°E)

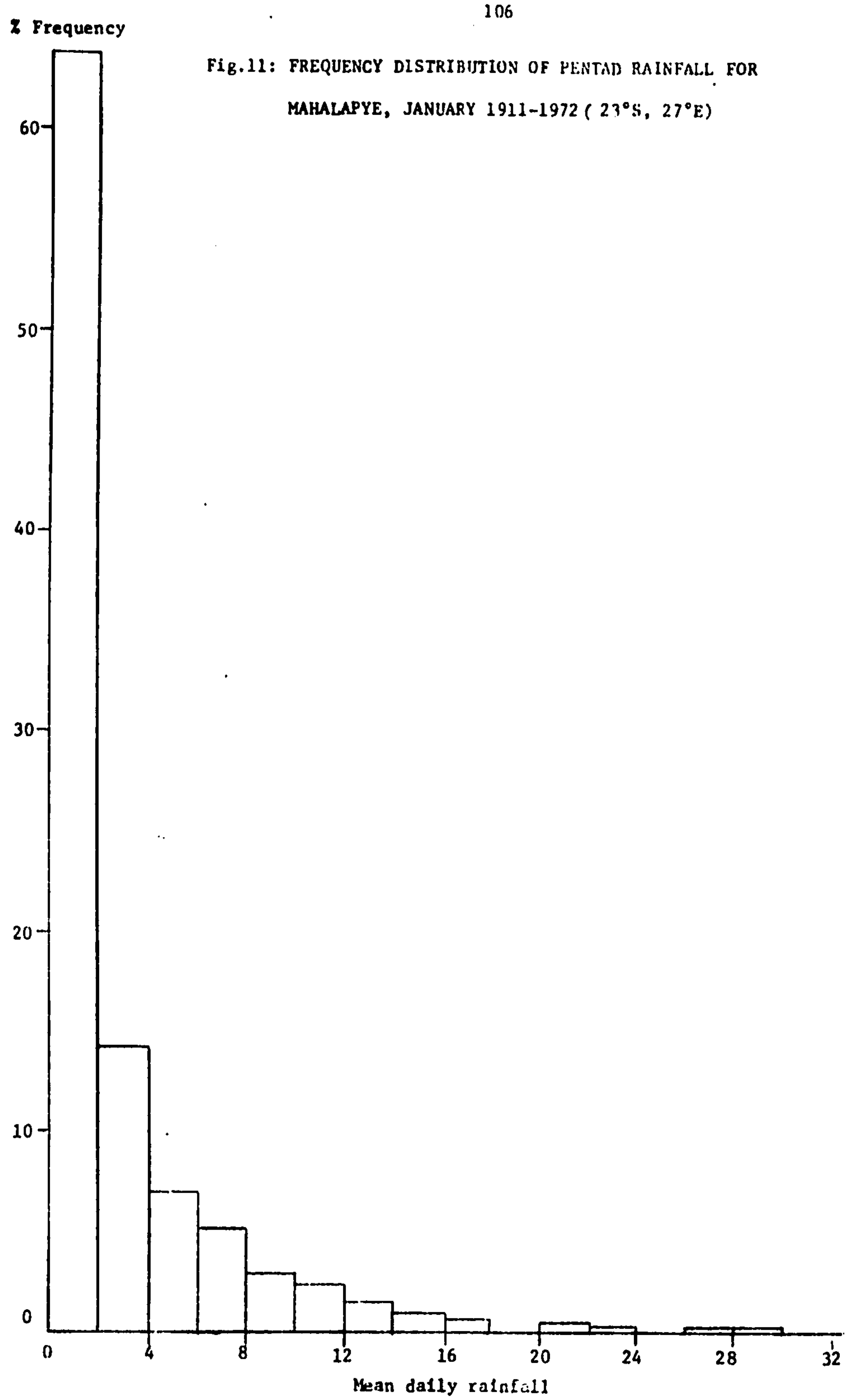


Fig.12: MAHALAPYE PENTAD DISTRIBUTION, SHOWING LOG-NORMAL DISTRIBUTION OF DAYS WITH RAIN

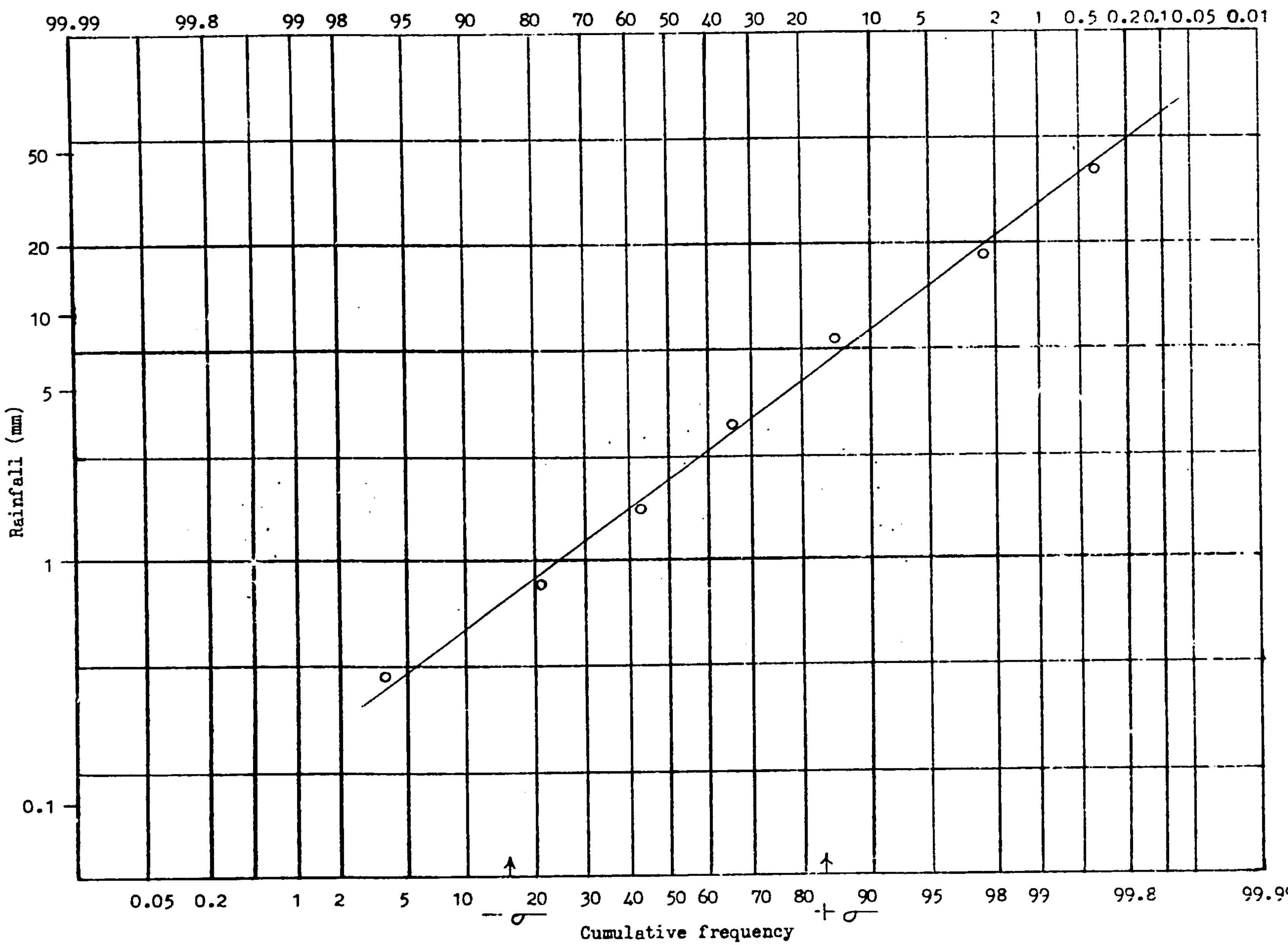
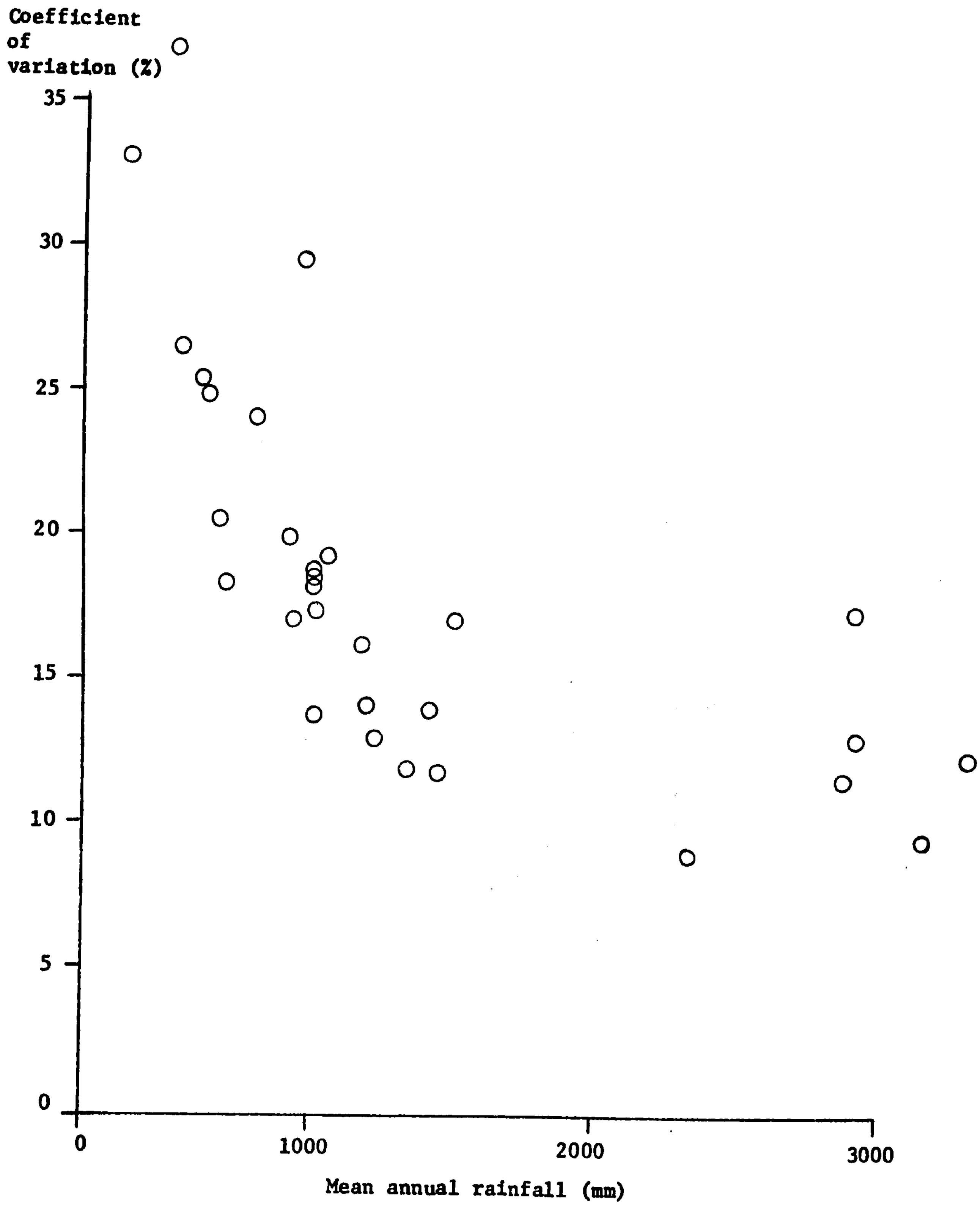


Fig.13: COEFFICIENT OF VARIATION VS ANNUAL MEAN RAINFALL FOR THE METEOROLOGICAL SUBDIVISIONS OF INDIA (DATA FROM PARTHASARATHY B, AND DHAR, O.N., 1974 Q. Jl.R. Met. Soc. 100: 245)



or quadratic regressions. The conventional assumption of the normal distribution is made. If there are large random variations about the trend, then statistical analysis will not attribute much of the variance to the regression. A relatively small section of a low frequency fluctuation may appear, statistically, to be a trend.

Rank statistic analysis can be used to find trends*. Here data are ordered by time and by quantity of rainfall and the two orders compared. No assumptions are made about the distribution or changes in the trend with time. There are two principal tests: the Mann - Kendall rank statistic and the Spearman rank statistic. As regards rainfall studies, there is some advantage in the Spearman statistic, where two occasions may have the same rainfall or where the mean value may be entered for missing values a number of times.

Trends of both increasing and decreasing rainfall have been found at some places in the tropics. A random series of numbers may show a trend. The longer the period for which a trend is apparent, the more likely is the trend to be real with a real physical explanation. The longer a series of random numbers the less likely is a spurious trend to be detected.

Discontinuities

An abrupt change of any scale will show in a graph. A 't' test can be used on the two limbs. We have never detected any discontinuities. Abrupt changes are unlikely because of the 'time-constant' of the atmosphere. Perhaps any change found is more likely to be instrumental rather than to be real.

Fluctuations

Fluctuations are changes that are repeated in time. There is a series of tests that give increasing amounts of information. A run test, which assesses the lengths of period continuously above or below the median value, can be used to detect the existence of fluctuations (Thom, 1966). Spectral analysis can then be used to attribute the variance of the measurements to changes of different frequency (Blackman and Tukey, 1958).

Differences in the amount of the variance attributed to different frequencies can be tested statistically. Fluctuations have been detected for some places in the tropics (Table 1) and the probability of the fluctuations being due to chance tested. A very long run of random

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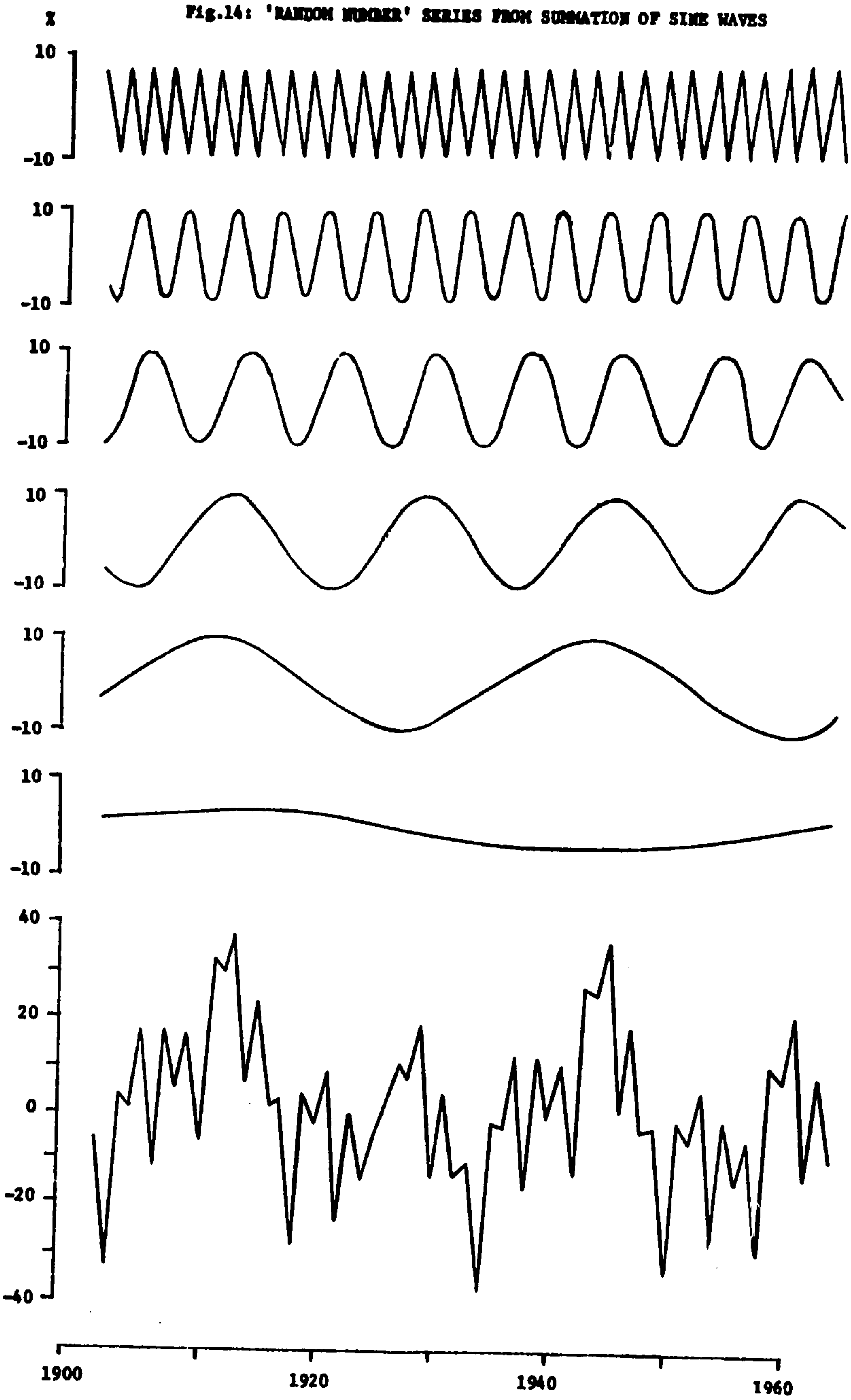
* See 'Climatic Change', W.M.O. Tech.Note 79, W.M.O. 1966.

Fig.14: 'RANDOM NUMBER' SERIES FROM SUMMATION OF SINE WAVES



numbers will give equal variance in each frequency band, this is called 'white noise'. This is the usual basis for comparison, though it is not always meteorologically appropriate.

Spectral analysis smooths amplitude changes and cannot locate phase changes. Filters can be used to define both sorts of changes (Craddock, 1968). Every curve can be considered as the outcome of a series of smaller constituent curves - the Fourier analysis (Fig.14). Craddock has designed a series of filters to suppress variation outside specified wave bands (Fig.15). When a particular filter is applied to a time series, the form of fluctuations in the appropriate wave band is shown. At Addis Ababa (Fig.16), spectral analysis indicates a fluctuation with a period of about 10 years. A filter showing periods longer than about

Fig.15: UNITARY FILTERS OF ORDER 5

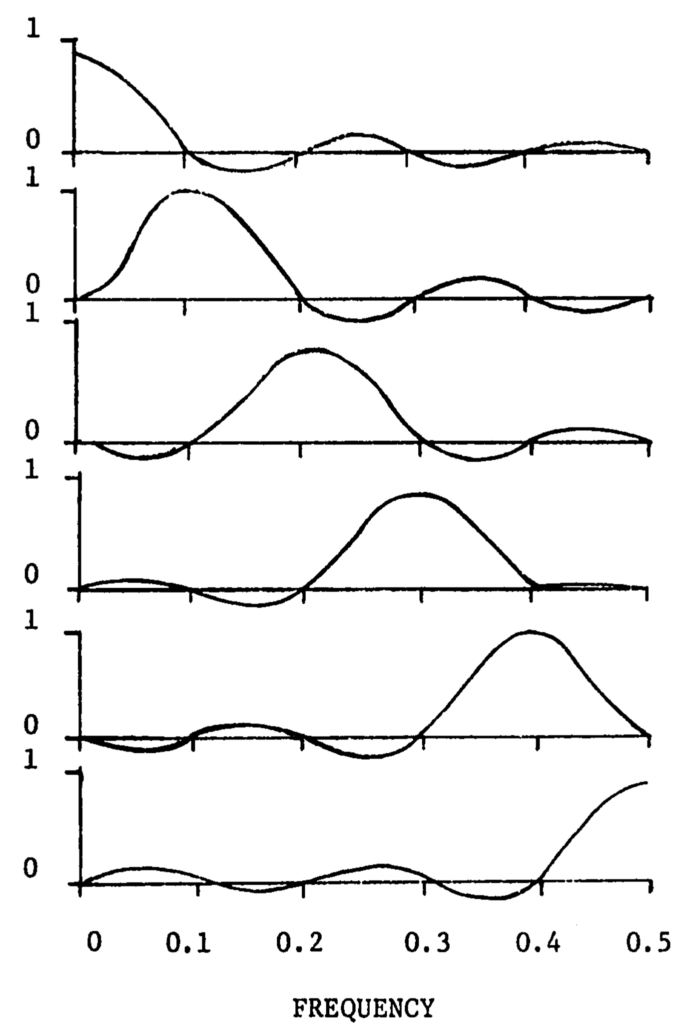
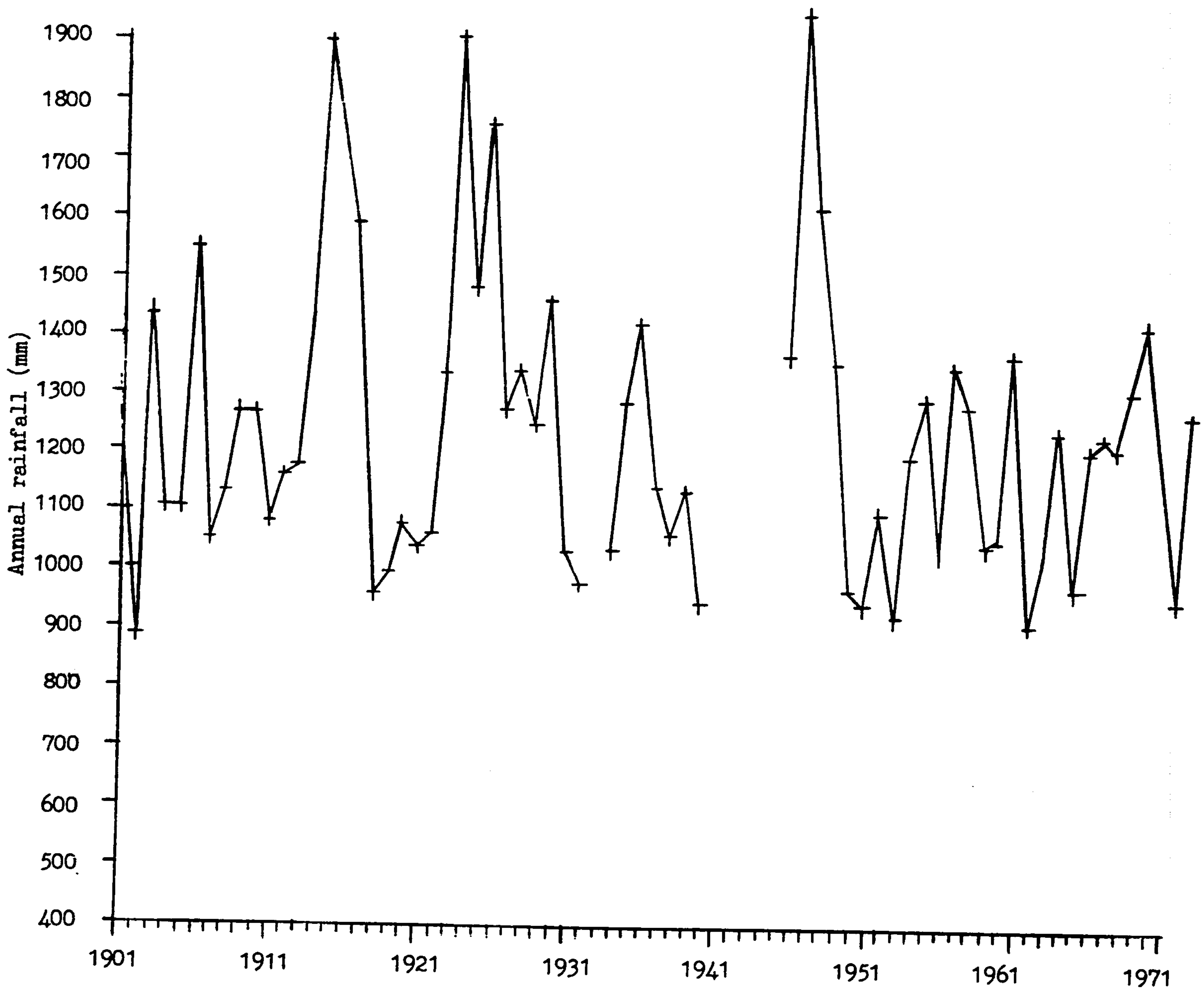


Fig.16: ANNUAL RAINFALL TOTALS FOR ADDIS ABABA



8 years has given the phase of this oscillation for Addis Ababa (Fig.17), while at Hyderabad (Fig.18) the filtered output is much more variable and has the characteristics of a random series (Fig.19 and 20).

Running averages are filters, suppressing variation except at a wavelength of more than twice the period of the running average (Fig.21). Their use can be very misleading (Pittock, 1974).

PREDICTION

Reliable predictions of the amount and distribution of rainfall in a season would be useful. Such predictions are not yet possible. However, predictions of the general character of a season can be made from the early rainfall of the season in some places (Table 2).

Table 2: Contingency table for June and for total rainfall for 69 years in the Sahel zone of West Africa.

		Annual Rainfall		
		Dry	Normal	Wet
	dry	12	8	3
June	normal	8	8	7
rainfall	wet	3	7	13

Run-off and Drainage

There is no general theory that predicts run-off as a function of rainfall total. Empirical studies sometimes show a linear relation between run-off and rainfall, but the regression constant varies with place. For the moment run-off has to be estimated from the best available measurements of such a constant.

During the rains, in a seasonally arid climate, considerable quantities of water may drain through the soil. Again, this is difficult to estimate.

Evaporation

The actual rate of evaporation from a crop depends upon climatic and plant variables that are difficult to define and analyze. Micro-meteorological measurements of actual evaporation have been made in the

Fig.17: ANNUAL RAINFALL TOTALS FOR ADDIS ABABA TREATED WITH LOW PASS FILTER

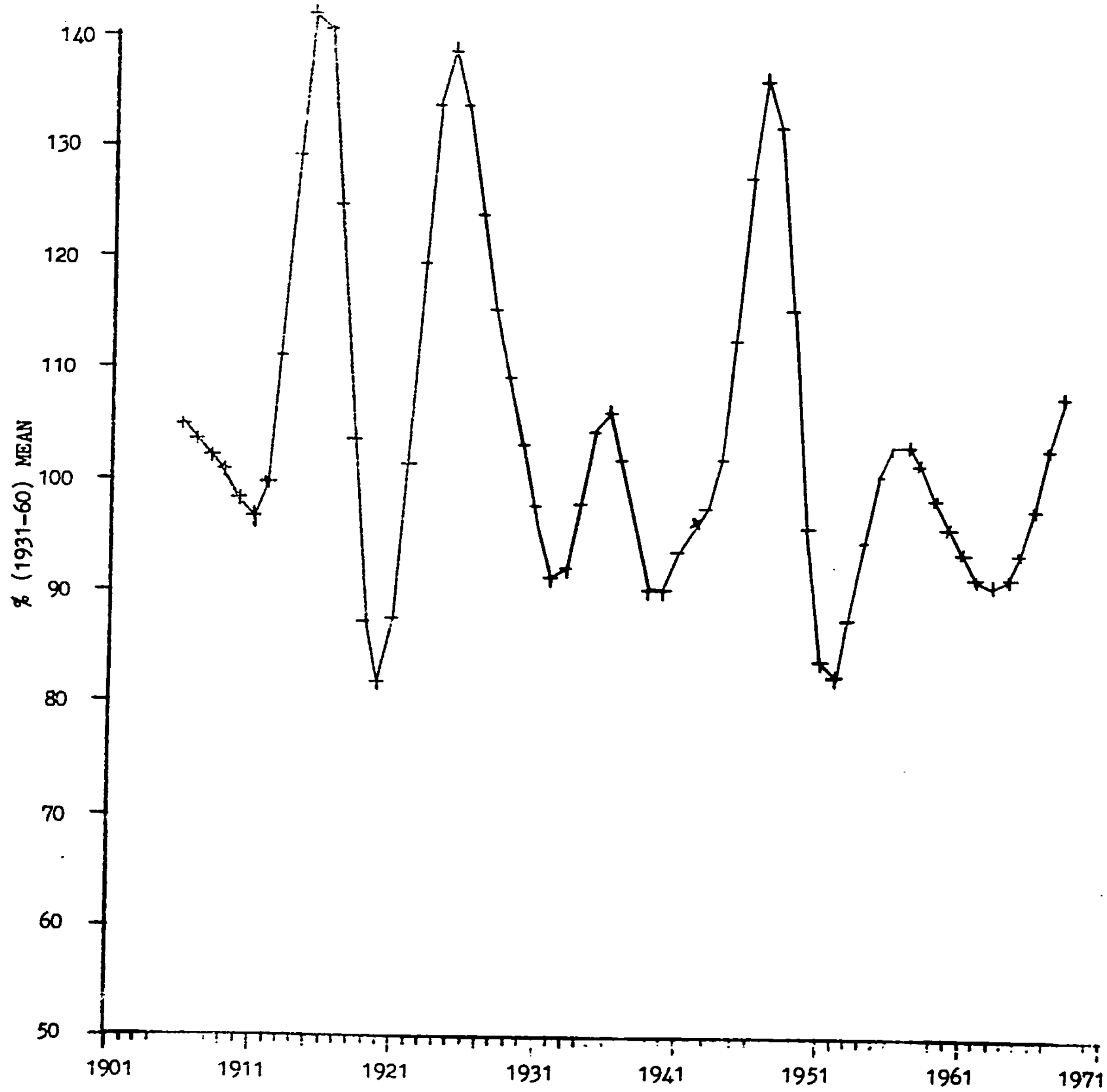


Fig.18: ANNUAL RAINFALL TOTALS FOR HYDERABAD, TREATED WITH LOW PASS FILTER

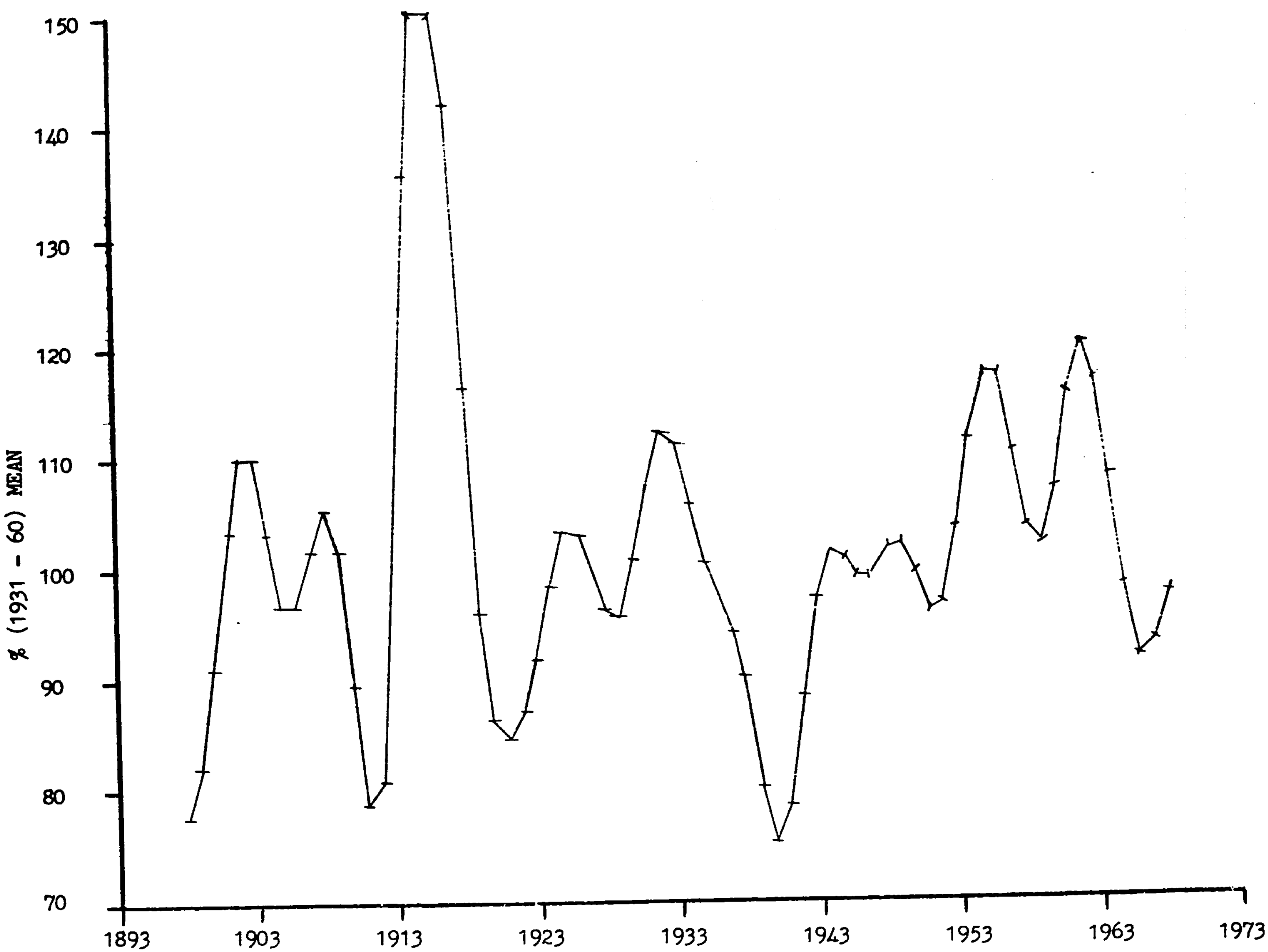


Fig.19: FISHER AND YATES RANDOM NUMBER SERIES

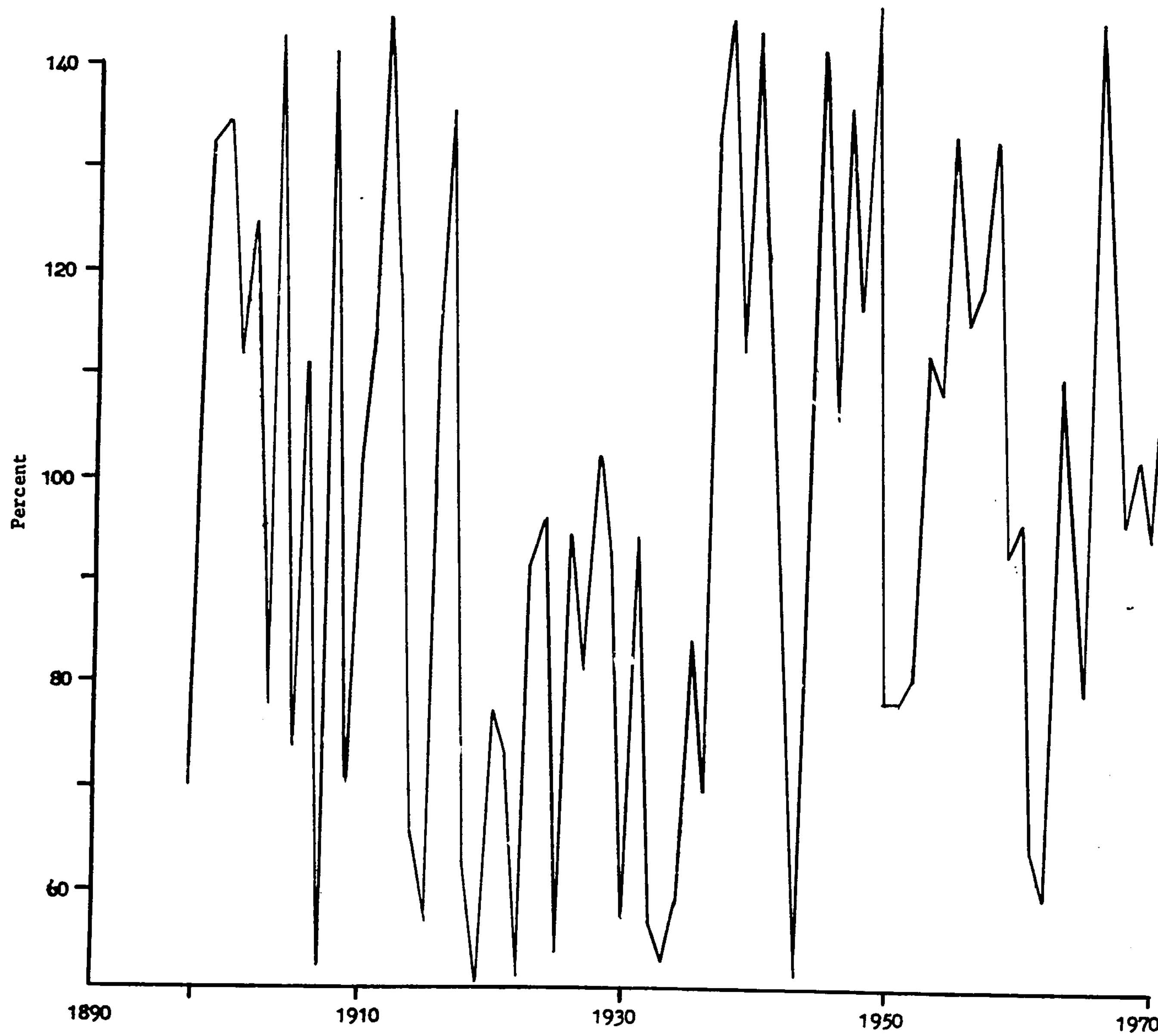


Fig.20: FISHER AND YATES RANDOM NUMBER SERIES TREATED WITH LOW PASS FILTER

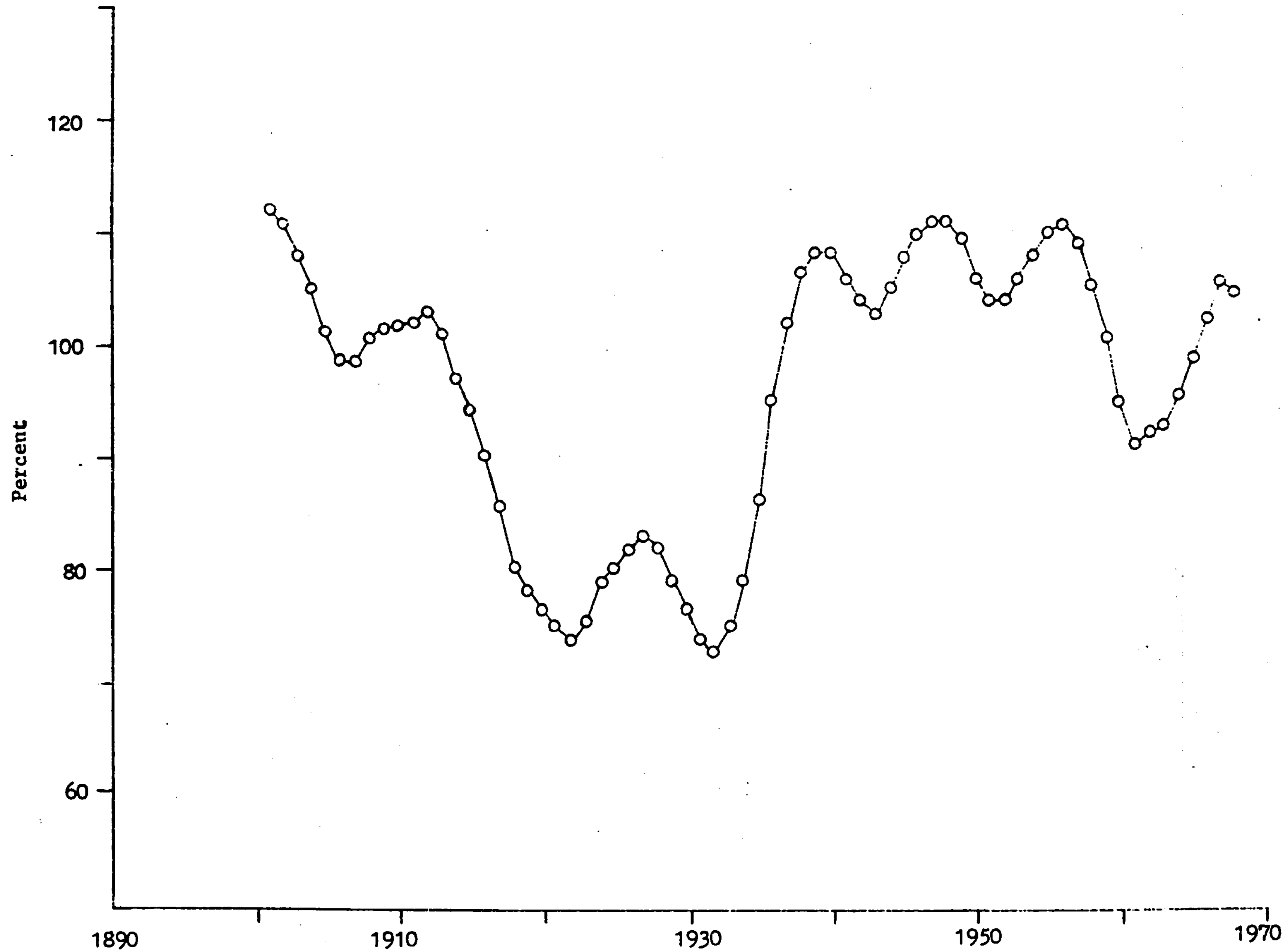
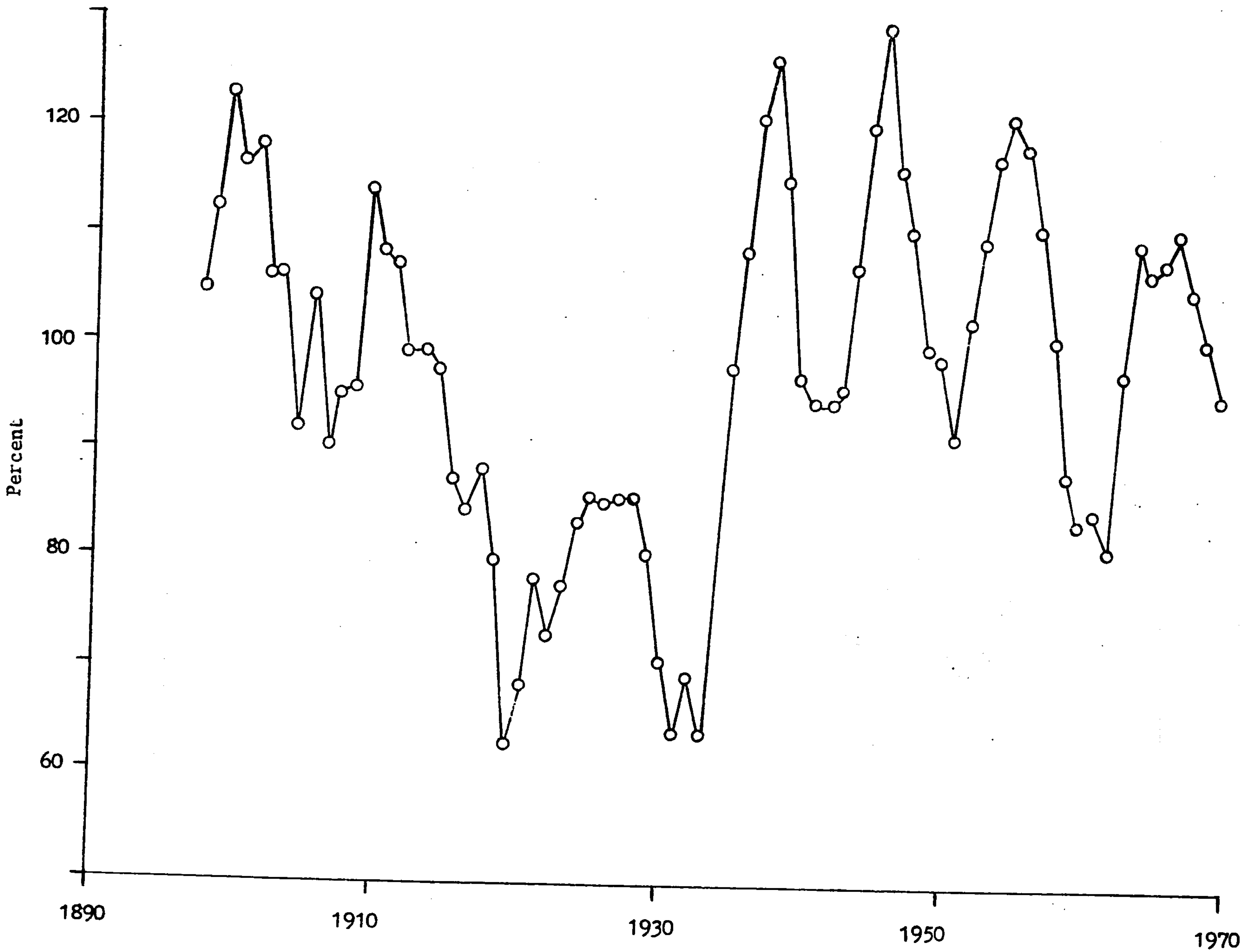


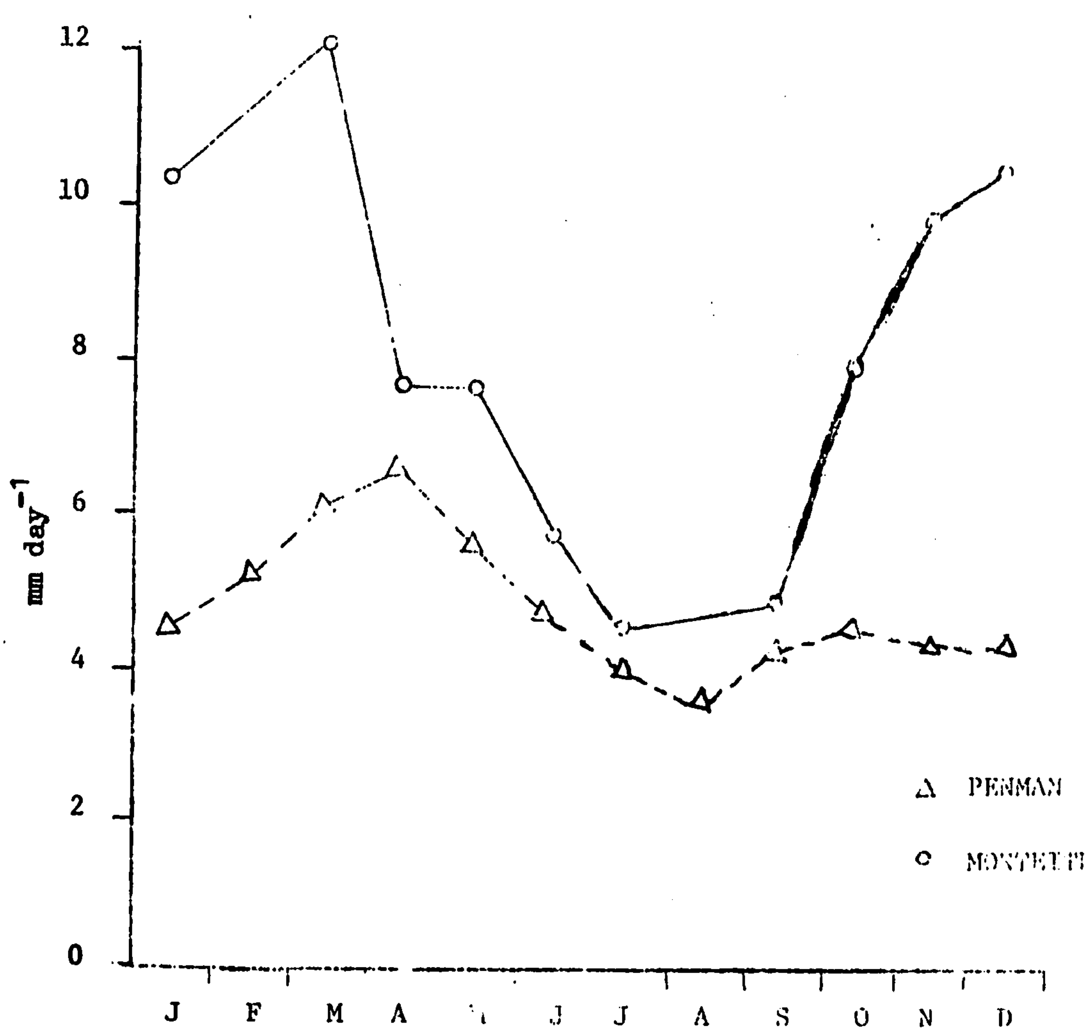
Fig.21: 5-YEAR RUNNING MEANS OF FISHER AND YATES RANDOM NUMBER SERIES



tropics (Rijks, 1971). Such measurements are difficult and uncommon. Instead, estimates of potential evaporation are often used. In arid climates there is considerable horizontal transfer of heat energy. The formula used should allow for this. There are now analysis that treat the crop as a surface with a resistance to the transfer of water vapor (Monteith, 1965) and which allow for the horizontal transfer of heat, at least in part (Fig.22).

Unlike rainfall which can be zero, potential evaporation has a positive figure for every day. The assumptions in the calculation of potential evaporation generally limit the calculations to periods of 5 days or longer. The distribution tends, therefore, to be more nearly

Fig.22: COMPARISON OF PENMAN AND MONTEITH ESTIMATES OF POTENTIAL EVAPORATION FOR SAMARU, NIGERIA.



normal, and statistical comparison more straight-forward. However, the complexity of the calculations has limited its use.

Water Deficit

Evaporation on its own is not of profound importance in the analysis of farming systems, but the deficit of water is. Many measurements have been made of the change of water content in the soil and the development of water deficits has been described. The relation between the deficit calculated from potential evaporation and the real deficit has been examined (Smith, 1959). Climates have been compared (Fitzpatrick, Slayter and Krishnan).

However, we need to know the expectation of particular deficits throughout the growing season and the effect of particular deficits on growth. Moreover, because a crop can adapt to water stress (Kassam and Elston, 1974), the interpretation of the meteorology will be complicated. We do not know enough about water deficits or their consequences within the growing season. The control of the length of the growing season is more clearly understood (Bunting, 1961 and Curtis, 1968).

Temperature

Within the seasonally arid and arid tropics the water balance is the most important factor controlling agricultural production. However, temperatures do vary and we are uncertain of their significance. Run tests and rank statistics can be used to test for homogeneity. Distributions of monthly temperatures may be normal (Alice Springs, Australia) or skewed (Turiaco, Brazil). More are normal than are skewed. After transforming and testing for a normal distribution, confidence limits may be calculated. Because the temperature on a particular day may be related to the temperature on the previous day, Markov Chains may have to be used.

Again, mean data hide variation and the expectation of extreme values must be considered (Hashemi, 1969).

Effects of Topography

Meteorological measurements do not represent the climate of a crop exactly. The microclimate is a modification of the prevailing climate due to features of the surface, producing differences in the radiation and energy balances. These local differences may be of great importance in special, marginal situations.

Hydrological studies of catchments have a special use where there is either too much or too little rain. Then calculations of the water balance can be used to assess the possibility of flooding, the need for drainage works or the possibilities of various techniques for water conservation.

Conclusions

The analysis of long runs of measurements of climatic ractors for reliability is relatively straightforward. Where long runs of measurements are not available, the means calculated may be misleading (Bunting, Dennet, Elston and Milford, 1974).

The mean length of the growing season can be calculated easily and the agricultural consequences of season length are well understood. Where water does not limit vegetative growth, the total dry matter production is related to solar radiation and can be predicted from measurements of solar radiation. These predictions can be used to help assess the productive possibilities of different farming systems.

In arid regions or in seasonally arid regions during the dry season, water stress may limit the rate of production of dry matter while a crop is growing. The intensity and duration of such effects can be defined empirically and assessed experimentally. However, sufficient knowledge is not yet available to model the consequences of water stress realistically.

Acknowledgements

Dr. A. H. Kassam and Dr. P.C.Prasad made valuable suggestions and helped in calculations. Mr. J. Sankla helped in making the diagrams. Mr. J. Diphaha and Mr. M. Coughlan have supplied information. Professor J.L.Monteith F.R.S. allowed the reproduction of Fig. 6.

Table 1. Spectral Analysis of Annual, or Seasonal (*), Totals

	Frequency	0.025	0.05	0.10	0.15	0.21	0.25	0.30	0.35	0.40	0.45	0.475
	Period	40	20	10	6.7	5.0	4.0	3.3	2.9	2.5	2.2	2.1
*Mahalapye	1911 - 1972	6.2	11.7	11.4	9.6	7.4	7.4	10.0	9.8	9.0	9.0	9.0
Hyderabad	1893 - 1973	4.7	10.8	15.3	13.1	8.7	8.2	9.4	11.4	10.8	5.9	3.0
*Leon	1878 - 1960	9.4	15.6	15.6	11.1	10.6	12.6	8.9	4.7	5.4	4.3	2.5
Tehran	1869 - 1967	<u>10.4</u>	14.1	16.2	10.9	6.8	8.2	9.1	9.1	7.7	4.6	3.2
Addis Ababa	1901 - 1973	6.8	17.1	<u>23.6</u>	15.8	7.1	4.5	6.3	7.2	5.3	4.3	3.8
Sahel, Zoned	1905 - 1973	9.1	10.8	12.5	10.6	6.3	5.7	8.3	9.2	12.6	12.7	9.4
Fisher and Yates	1897 - 1973	9.6	13.2	16.1	11.1	8.3	9.4	6.9	5.0	5.4	6.8	7.6
Random Series	Very Long period	5	10	10	10	10	10	10	10	10	10	5

____ indicates statistically significantly different from random at 95% probability.

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A GEO-CLIMATOLOGICAL APPROACH FOR

FARMING SYSTEMS RESEARCH

S.M. Virmani*

Increased and stabilized agricultural production in the semi-arid tropics are the two major aims of the farming systems research program of the International Crops Research Institute for the Semi-Arid Tropics (Kampen and Krantz, 1973). Optimal farming systems to meet these primary objectives need to be worked out with a view to verifying the suitability of the present farming/cropping systems and suggesting modifications.

Owing to great spatial variability of rainfall and soils, optimal cropping systems within a farming system net-work are highly location specific. That this is universally accepted is demonstrated by the wide use of field trials as basis for both the project design and for the extension-type information in both the initial developments or in changing agricultural patterns. However, a consideration of transferable information using a systematic model based on soil and climatic resources should permit greater efficiency in the selection of both the applied and the basic research as well as in the transfer of technology on optimal farming systems in agricultural development programs in drylands.

Presently, both the design of programs of research and of the agricultural development with regard to the farming systems in drylands are primarily based on expert opinion and judgement, which are based on physical and biological information and experience. Quality of the judgements made would depend upon the accessibility to information and on the skill with which the information is evaluated and synthesized. This paper suggests a systems approach which could assist in selecting cropping patterns for changing environmental conditions and in giving an approximate idea bout the relative area that may be apportioned to different crops, to meet the aims of the farming systems research program. This could greatly enhance the efficiency of the expert judgement and could help guide the processes of characterizing the agricultural environment.

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Keller et al. (1973) have considered disaggregating the agricultural environment into four general frame-work vectors: intimate plant environment (climate, soil and pests); external environment (human, energy, institutional, economic); plant material; and husbandry programs. Except for climate and soil, which are basic factors, most of the other vectors can be modified or controlled. Water is the major constraint in agricultural production in the semi-arid tropics. Allevation of the effects of this barrier is the ultimate aim of the farming systems research program. The overall dovetailing of the external environmental factors, plant material and husbandry programs revolve around the central focal point - increased use of rainfall water for production.

In following the natural cycle of water as regards its uses, three main levels of effort can be recognized: 1. Observation and descriptive organization of the data; 2. physical interpretation and formulation; and 3. application or intervention by man to change conditions to his benefit. The system can, however, be curtailed into three parts (a) data collection, (b) physical reasoning, and (c) practical considerations (Zeslavsky, 1970).

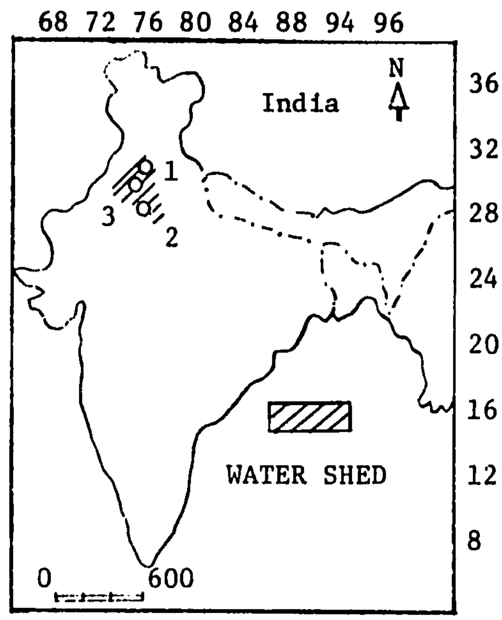
In the context of the present discussion, it will be appropriate to reduce the complexity of the system by considering the practical applications. In the watershed hydrology in drylands, we are interested primarily in: (a) when and how much water will be available with say about 70 percent reliance (b) how much and when shall be the runoff in bare soil or cropped conditions on a given soil, (c) what are likely to be the periods of soil moisture/atmospheric stress under varying rainfall conditions, and (d) what crop/crops can be successfully grown. These are marginal problems. But a thorough understanding of the most intricate physical phenomenon with a sense for practical application can produce most fruitful results in the shortest time even without a comprehensive quantitative formulation. There is also a trial and error in engineering that is often cheaper than research. An actual breakthrough by this simplying device of the application of new technology can be achieved as far as decision making process is concerned.

In the following pages, an analysis of the geo-climatic characteristics of a watershed located in the north-west of India is presented so as to define its intimate plant environment. Based on these, a schedule of cropping for three selected areas is presented.

Watershed Studied

Three locations in a contiguous watershed generally comprising the Haryana State of Indian Union were selected (Fig.1).

Fig.1: LOCATION OF THE WATERSHED STUDIED



1.AMBALA 2.NARNAUL 3.HISSAR

In all cases south-west summer monsoon supplied more than 70 percent of the total annual precipitation during July to September. Some pre-monsoon and post-monsoon showers were also received. The total amount of rainfall received from year to year was highly variable at all the locations (Table 1). Ambala received on an average 131 percent seasonal rainfall compared with its PE for the same period; Narnaul 101 percent and Hissar about 60 percent respectively. Accordingly, precipitation for Ambala has been designated as relatively high, Narnaul as medium and Hissar as low.

Table 1. Rainfall characteristics of the selected locations in the watershed

Station	Seasonal rainfall* (mm)	S.D.	CV (%)	Seasonal PE (mm)	Altitude (m)	Data for period studied
1. Ambala	582	163	28	445	275	1944-70
2. Narnaul	456	192	42	452**	422	1950-70
3. Hissar	328	128	39	516	208	1915-70

*July to September ** For New Delhi

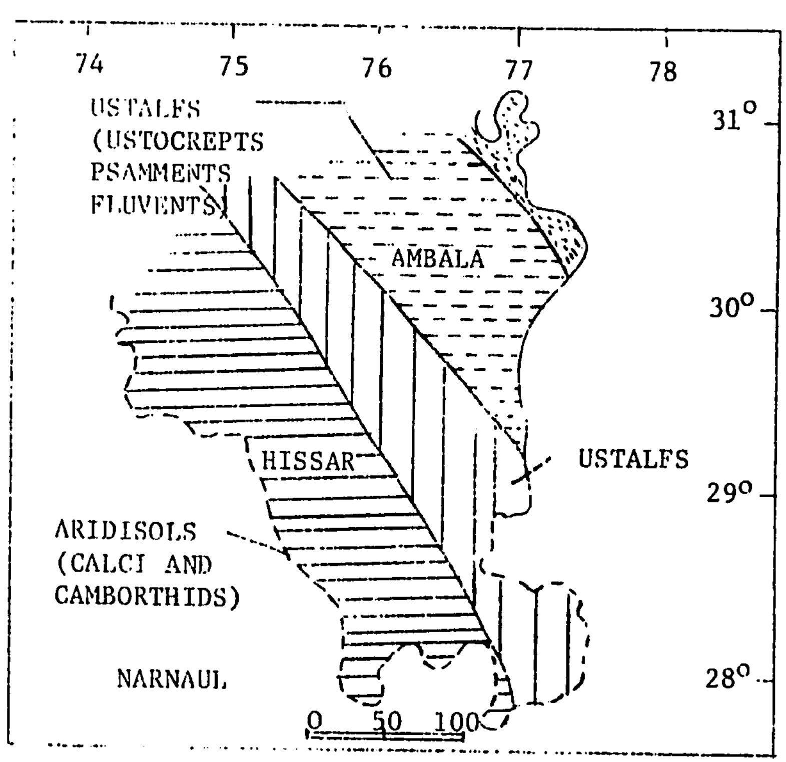
Soils and Land Form

The soils of the watershed are developed from recent alluvium. A generalized soil map (Rao, George and Ramasastri, 1971) is shown in Fig.2. Soils vary considerably with regard to their water storage capacity from 100-300 mm/meter depth of the profile. A land form map is shown in the Fig.3.

Dependable Precipitation*

Dependable precipitation assumes great importance for crop planning in the tropical semi-arid areas for two reasons: first, that there exists a great variability in the quantum and the distribution of summer rainfall, and secondly, that the atmospheric humidity sharply declines with the recession/stoppage of rains and temperatures rise above the normal values.

Fig.2: SOILS OF THE WATERSHED



(After Sehgal, SYS, and Bhumbla 1968)

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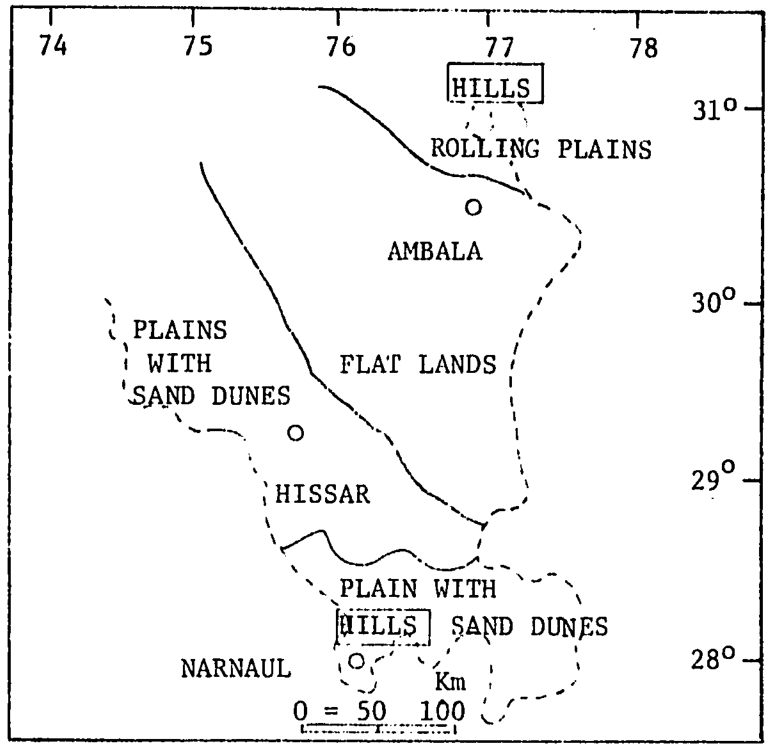
* Probability of occurrence at ≠ 70 percent.

Fig.3: LAND FORM OF THE WATERSHED



Adapted from Duggal (1966)

An in-depth analysis of the rainfall distribution from long term weekly precipitation records of the three locations showed the following three types of precipitation-time scale sub-systems: (Fig.4, Table 2).

(a) Seasons with 4-5 rainy weeks of dependable precipitation receiving 70-80 percent of the total seasonal cumulative rainfall after onset, the total not exceeding 250 mm;

(b) Seasons with 6-8 rainy weeks of dependable precipitation receiving 70-80 percent of the total seasonal cumulative rainfall ranging between 200/250-450 mm; and

(c) Seasons with 8-10 rainy weeks of dependable precipitation receiving 70-80 percent the total seasonal cumulative rainfall, the total being invariably more than 400-450 mm.

The slope of the curves in Fig.4 also show that the general trend of the rainfall in different seasons follows one of these three basic classes irrespective of the location. The high, medium or low average rainfall stations are a consequence of the differential frequencies of occurrence of these precipitation-time scale sub-systems.

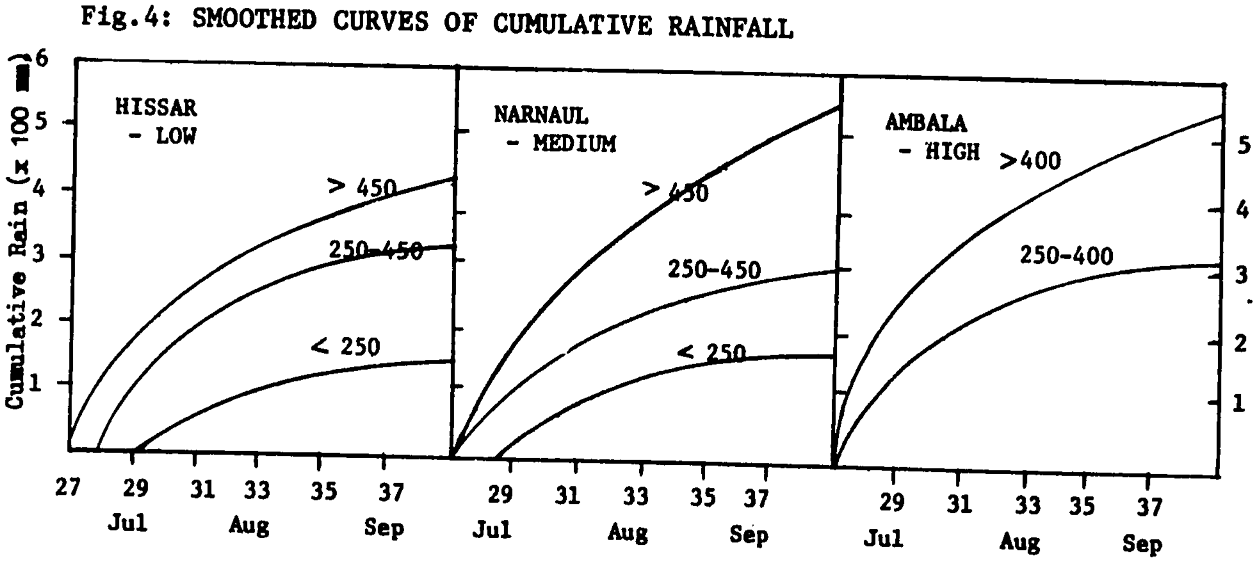
Table 2. Percent Probability of Precipitation in Different Seasons at Three Locations

Month	Week	Seasonal rainfall class (mm)								
		250*			250 - 400/450			400/450		
		1	2	3	1	2	3	1	2	3
July	27		67	60	25	75	64	82	77	83
	28		67	50	100	50	73	77	85	83
	29		33	70	75	75	68	86	69	75
	30		67	75	100	75	77	90	61	67
	31		67	70	100	62	73	81	46	83
Aug	32		67	70	75	75	82	91	92	92
	33		100	45	75	62	73	86	100	83
	34		67	50	100	87	68	77	90	83
	35		0	25	50	50	73	63	90	75
Sep	36		0	40	100	87	36	77	96	58
	37		0	35	45	50	45	68	80	57
	38		33	25	25	37	36	41	23	58
	39		0	25	25	50	27	50	31	50

* No such season was recorded at Ambala, while three years data was available for Narnaul.

1 ≠ Ambala, 2 ≠ Narnaul, 3 ≠ Hissar

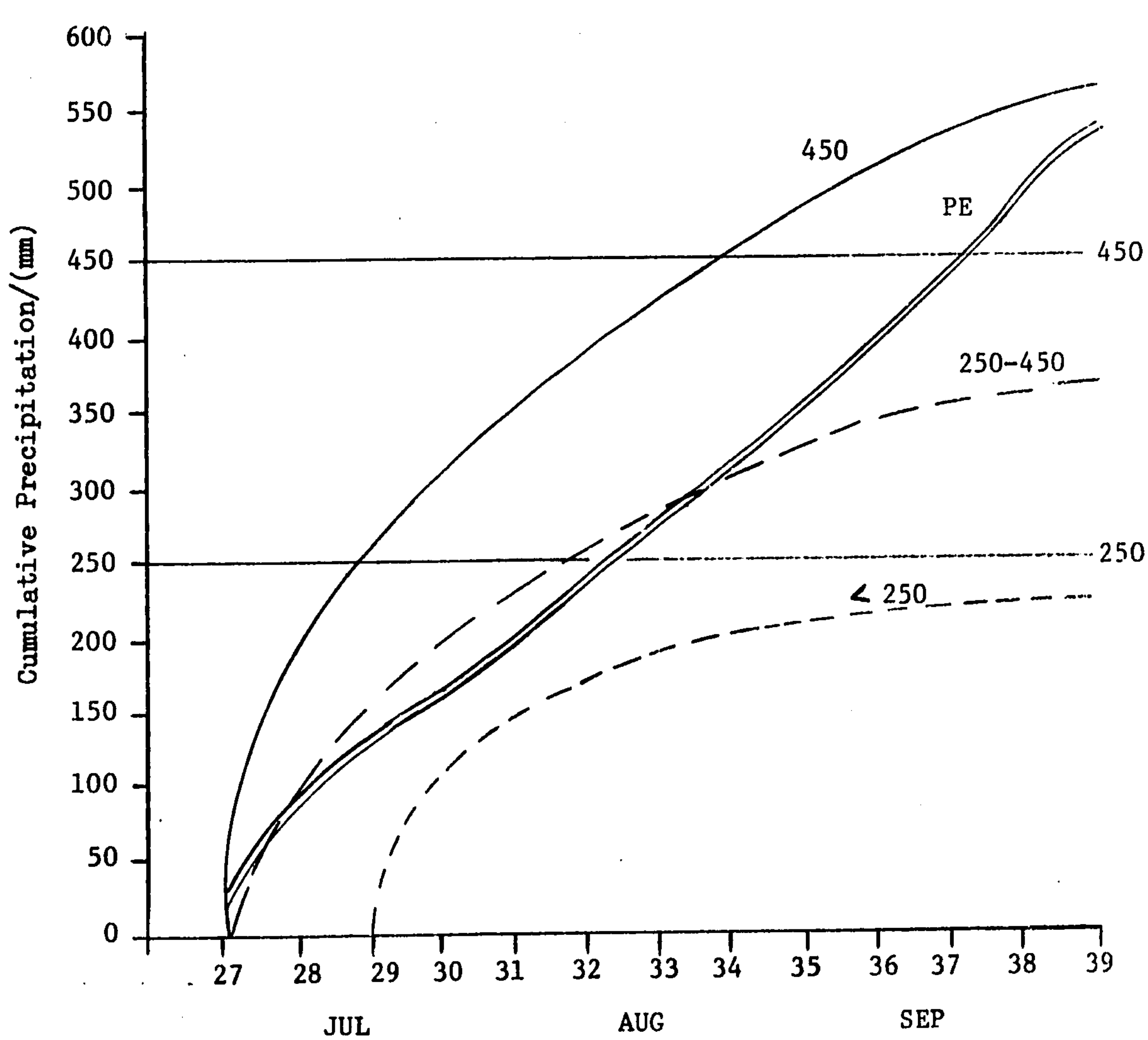
Fig.4: SMOOTHED CURVES OF CUMULATIVE RAINFALL



Relationship of Precipitation-Time Scale Sub-systems to PE

A schematic cumulative precipitation against time-scale after onset is shown in Fig.5. The cumulative PE is also plotted therein. It shows, in general, that in seasons receiving less than 250 mm rainfall, there would be water deficit compared to the climatic demand all through the rainy crop season; seasons ranging in rainfall from 250-450 mm shall have rainfall ≫ PE upto about the middle of August and a climatic water deficit afterwards; and seasons receiving more than 450 mm rainfall are likely to show a climatic water surplus throughout the rainy crop season (kharif).

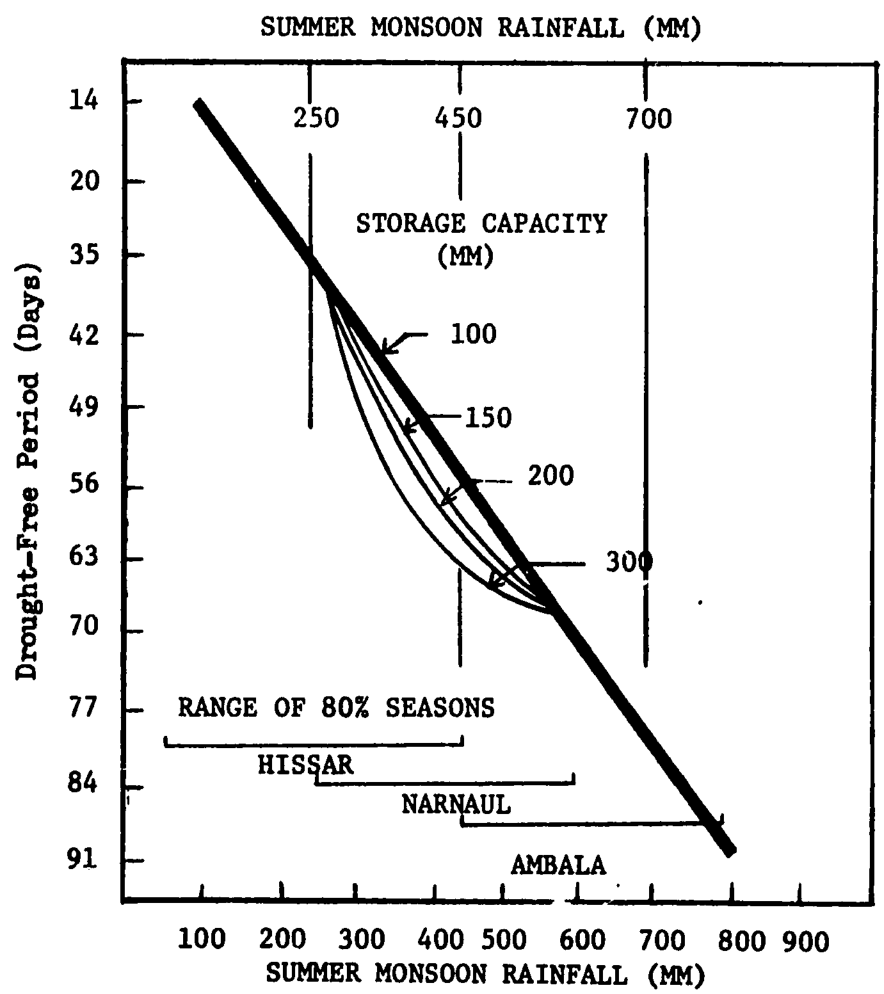
Fig.5: A GENERALIZED RELATIONSHIP OF CUMULATIVE PRECIPITATION AND TIME-SCALE FOR THREE SUB-SYSTEMS TO PE



Effect of Soil-Moisture Storage Capacity and Summer Rainfall on Stress-Free Periods

A general topo-sequence of the soils of the watershed showed that their moisture storage capacity ranged between 100-300 mm. This was taken as the upper limit of the total water stored and 20-80 mm as the lower limit of water availability (volume of soil water at wilting point). The relationship of the total summer monsoon rainfall to the stress-free periods and soil types is shown in Fig.6. It is evident that climatic water availability is independent of the soil in low rainfall conditions (< 250 mm). In the medium rainfall seasons ranging from 250 mm to about 500 mm, the soil type plays a definite role, and in relatively high rainfall seasons ($>$ 500-550 mm) again stress-free periods for crop growth are independent of the soil.

Fig.6: RELATIONSHIP BETWEEN DROUGHT-FREE PERIODS, SOIL MOISTURE STORAGE CAPACITY AND SUMMER MONSOON RAINFALL



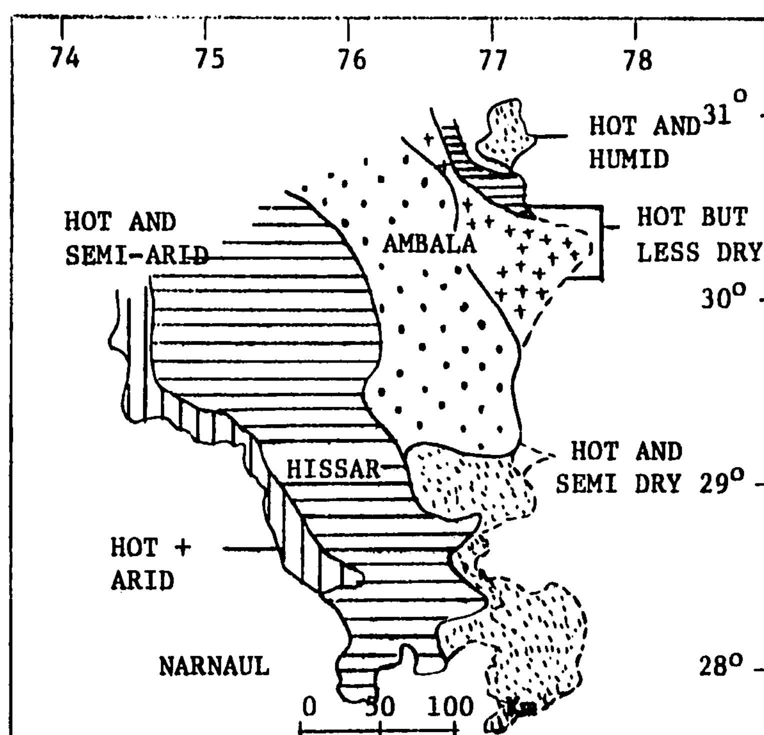
Bioclimatic Regions in the Watershed

The bioclimatic regions in the watershed are shown in Fig.7.

Potential Water Supplies*

Bare soil conditions. Based on actual evaporation for Hissar, a computer program for evaluating weekly soil moisture changes was developed. Under bare soil conditions, evaporation for a rainy week was computed at .8 of weekly PE and for rainless week as 0.7 (0.8 PE storage/storage capacity). A minimum of storage at wilting point and upper limit of storage capacity from 100-300 mm were taken to represent a cross-section of the soils of the watershed. Separate computations for each of the seasons for the three locations at four soil water storage capacities (100, 150, 200, 300 mm) were carried out. The regressions of the amount of surplus water in relation to soil type and

Fig.7: BIOCLIMATIC ZONES OF THE WATERSHED



(Adapted from Duggal, 1966)

* Water available for storage outside the profile.

summer monsoon rainfall are shown in Table 3.

Table 3. Relationship Between Potential Water Surplus, Soil Type and Summer Rainfall (Bare soil conditions).

Location	Regression	f value for moisture storage capacity (mm)				Threshold Value (mm)
		100	150	200	300	
Hissar	Y = f (-108.9+.37x)	1.76	0.98	0.24	-	300
Narnaul	Y = f (-102.4+.38x)	1.55	1.02	0.70	0.28	300
Ambala	Y = f (-132.6+.44x)	1.65	1.15	0.84	0.27	300

Y is the amount of surplus water in mm, and x is the total summer monsoon rainfall in mm.

It is apparent from Table 3 that the values of f in the regression equation progressively decrease with an increase in the soil moisture storage capacity. In years when seasonal rainfall is $<$ 300 mm, there is likely to be little surplus water at any of the locations tested. The probability analysis of the time of run-off showed that 80 percent chances of its occurrence lie in weeks 33-36.

Cropped conditions. An analysis of the AE/PE showed that the actual water loss from a cropped soil at Hissar was 0.8 PE in a rainy week at any time of the grop growth during kharif. However, in a rainless week it was 0.5 PE during vegetative stage of crop growth, 0.8 PE during the grand-growth and flowering stages and 0.7 PE at maturity. The phenological stages of pearl millet crop were considered as a basis for these calculations. The amount of potential water surplus for soils of different storage capacities was correlated with the total summer monsoon rainfall (Table 4).

Table 4. Regression Equations for Predicting Potential Water Surplus in Cropped Conditions.

Location	Regression	f value for different soil storage capacity(mm)				Threshold value (mm)
		100	150	200	300	
Hissar	Y = f (-33.2+0.16x)	2.28	0.78	0.58	-	400
Narnaul	Y = f (-93.6+0.34x)	1.65	1.08	0.70	0.27	400
Ambala	Y = f (-153.5+0.46x)	1.63	1.10	0.78	0.34	400

Y = surplus water in mm, x = total monsoon rainfall in mm.

A comparison of data in Tables 3 and 4 shows that the threshold value for water surplus increased from 300 mm rainfall observed under bare soil conditions to 400 mm in the cropped conditions. A plot of potential water surplus response curves in relation to rainfall for the two cases further revealed that the slope of the curves was almost of the same order, showing thereby that the amount of potential water surplus would be independent of the soil cover in seasons receiving > 400-450 mm rainfall.

From the regression equations (Table 3 and 4), the amount of water surplus under variable rainfall conditions for an acceptable length of time can be calculated from climatic data. The mean, median, maxima and minima can be obtained for various soil types. Several decisions on the construction of water storage devices can be made and their economics projected. The validity of the climatological regressions presented needs to be verified by field experiments.

Amount of Water Present in the Profile after Summer Fallowing or Rainy Season Crops

So far, the conditions obtainable during the summer monsoon period from July to September were considered. The period from October to April is the growing season for winter crops. The probability of rainfall during this period is less than 30-40 percent in any of the weeks. Thus rainfall is highly erratic. At Hissar, with 70 percent reliance, only 2 cm of winter rainfall can be expected, whereas at Narnaul it is 4 cm and at Ambala 6 cm. Winter _(rabi)_ season crops are raised on either summer-fallowed soils or in moisture available in the profile after cropping.

(a) _Prediction of the amount of conserved moisture in the soil under summer fallow conditions._ From the data computed for potential surplus water, the amount of residual profile moisture was correlated against the total summer rainfall (Table 5).

Table 5. Regressions for predicting conserved moisture under summer fallowing*.

Station	Regression equation	r	S.D.
Hissar	WSTR = -53.7 + .46 RNTL	0.87	37.6
	= -45.3 + .20 RJUL + 0.54 RAUG + 0.73RSEP	0.96	20.4
Narnaul	WSTR = -39.0 + .40 RNTL	0.96	36.2
	= -36.9 + .16 RJUL + 0.50 RAUG + 0.64RSEP	0.95	27.2
Ambala	WSTR = -19.5 + .40 RNTL	0.77	55.8
	= -15.8 + .25 RJUL + 0.40 RAUG + 0.58RSEP	0.92	36.5

* Soil storage capacity 300 mm. WSTR = Water stored at the end of week 39. RNTL = Total summer monsoon rainfall, RJUL, RAUG, RSEP are rainfalls received in July, August, September, respectively.

(b) Cropped conditions. The residual profile moisture from the computer program used for surplus water evaluation at the end of the rainy crop season was correlated with the total amount of monsoon rainfall received. The regressions are shown in Table 6.

Table 6. Relationship of Summer Monsoon Rainfall and Soil Storage Capacity with the amount of Soil Moisture at the Commencement of Winter Crop Season in Summer-Cropped Conditions.

Station	Regression	Value of f for different storage capacities				Threshold value (mm)
		100	150	200	300	
Hissar	Y = f(-3.0 + 0.168x)	0.81	0.94	1.08	1.16	400
Narnaul	Y = f(-13.8+ 0.162x)	0.83	0.99	1.31	1.72	400
Ambala	Y = f(-21.9+ 0.214x)	0.58	0.82	1.08	1.53	400

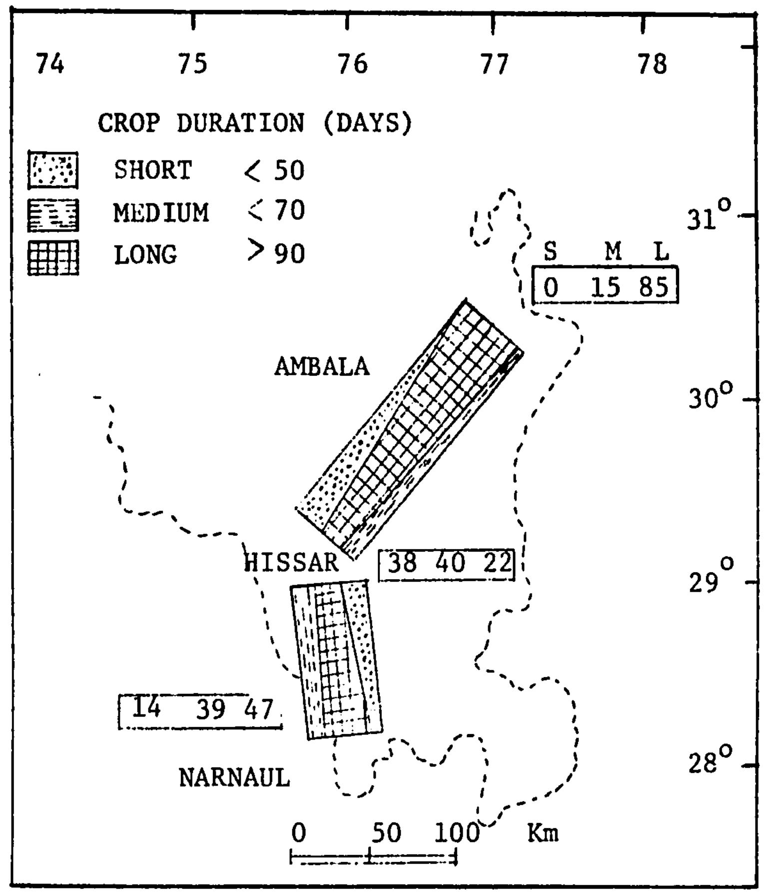
Y = amount of profile moisture in mm, x = seasonal rainfall in mm.

From the regression equations (Table 6), it is evident that even for achieving a residual moisture of about 10 cm in a soil profile under cropped conditions, the total summer rainfall should exceed 600 mm. In Hissar such an eventoccurred once in the last 30 years (1941-70), while at Narnaul its frequency of occurrence was 4 in 21 years (1950-70), and at Ambala 12 in 26 years (1944-70). Obviously, one crop either in kharif or in rabi can be normally raised on a piece of land at Hissar. At Narnaul, once in every five years, two crops can be raised successively on same piece of land, whereas at Ambala almost every alternative year, double cropping should be possible. A threshold of 10-15 cm water is required in case of oilseeds, such as rape, mustard and Eurica sativa, 15-20 cm for chickpeas (Cicer arietinum), 20-25 cm for barley and 25-30 cm for tall and dwarf wheats respectively. A forecasting of soil moisture based on summer monsoon rainfall and soil type can be made on this basis after field verifications. Planting of suitable crops based on assured soil moisture will go a long way in stabilizing the yields of winter crops.

A Systems Approach for Stabilizing Yields During Monsoon Rainfall Season

One of the best ways to achieve stability in production is to put a relative proportion of area under suitable crops depending upon the relative frequency of short, medium and long duration water availability seasons. This is also referred to as "risk distribution technology". As an example, for Hissar the percentage frequency of each of the three seasons is in the proportion 40:38:22; therefore, on a watershed basis about 40 percent area can be put under such crops which can give economic yield within about 50 days, 38 percent under crops with duration

Fig.8: SYSTEMS-BASED CROPPING PATTERN



of about 70 days, and only 22 percent area be apportioned to crops taking 90 or more days to mature. The practices and identification of crops which could be intercropped or relayed in short, and medium duration crops, in case the season happens of longer duration, need to be identified. The crop husbandry technology shall have to be tailored accordingly, like the sowing of main crops on ridges and the relay crop in the furrows later in the season.

Similarly in case of Narnaul, the area under short, medium and long duration crops should be 14, 39 and 47 percent respectively and at Ambala 0, 15 and 85 percent, respectively. The considerations of the soil type and its capability class will have to be incorporated. A scheme for determining approximate cropping patterns at any given location in a transect is presented in Fig.8. By superimposing the bioclimatic map (Fig.7), the type of the crop can also be determined. For example, a 90-day crop in hot and semi-arid region will be pearl millet, it will be sorghum in hot arid semi-dry and corn in hot and less dry, as we move on a transect from Hissar to Ambala (Fig.8). The geoclimatic approach can give with physical reasoning a working hypothesis to several of the 25 questions raised in the discussion paper circulated by ICRISAT (Kampen and Krantz, 1973).

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CASE STUDIES ON FARMING SYSTEMS

IN THE SEMI-ARID TROPICS OF INDIA

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Farming system has been defined as 'the entire complex of resource preparations, allocations, decisions and activities which, within an operational farm unit or a combination of such units, result in agricultural production'.

The Farming Systems Research Program, therefore, deals with all components which in combination represent the production processes on farms. These include, soil and water management technology, cropping systems and methods of planting, power equipment packages for land development and tillage, plant protection, plant nutrient application, cultivation, harvesting and threshing (Kampen and Krantz, 1973).

It would appear from the above that 'Farming Systems' or 'Farming Systems Research' are very comprehensive in nature and deal with the entire gamut of resources, inpu nd management practices and operations in production of crops. Obvio , it is difficult to cover all these aspects in describing the case studies of Farming Systems Research. However, it is possible either to describe and discuss the contribution of individual components to crop production or to reflect the achievements of a package of practices applied. ICRISAT, while defining the Farming Systems Program, has also amplified that the program includes agricultural crops, fruit trees, forest trees, forages, grasses and animals which have potential to contribute to improved resource use and management.

It is obvious from the above that the farming system in its sweep includes the optimum land use for optimum production according to the capacity of the land.

In other words Farming Systems Research is research in planned land use for optimum production per unit of time and per unit of resource input on a sustained basis. Having thus established the bench mark and

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goals of Farming Systems Research, this paper will endeavour to discuss soil and water management technology for various land uses in semi-arid tropics.

Two of the immediate goals of the Farming Systems Research Program according to ICRISAT (Kampen and Krantz, 1973) are : (i) Improvement and maintenance of production of natural resources and (ii) Optimum utilization of natural resources while maintaining the quality of the environment.

ICRISAT has accepted Troll's (1966) classification of semi-arid tropics (i.e. regions which have 5 to 10 arid months and conversely 2 to 7 humid months) and focussed its attention on these regions where sorghum and millets occupy a competitive position in present food production systems and other areas in which sorghum and millets have not yet found an important place but where they are needed and could be expected to compete well. This paper will, therefore, confine its observations to these specific areas, as far as it is practicable.

SOILS AND SOIL EROSION

The major soil groups of the semi-arid tropics in India are the red and black soils and alluvial soils in the river valleys. As most of the area in semi-arid tropics is rain-fed, the farming is done on sloping lands on which severe erosion takes place and there is need for soil and water conservation and management measures.

Of the two characteristics of slope, namely its degree and length, the former is usually the more important from the stand-point of the severity of erosion (Table 1).

On the gentle land slopes studied at Sholapur and Kota, there was no difference in the runoff; at Deochanda, runoff was very much more at 5 percent slope than at 2 percent slope. Soil loss increased as the degree of slope increased (Ballal and Desphande, 1960; Singh, Dayal and Bhola, 1967; Mirchandani, Guha and Vasudevaiah, 1958; Vasudevaiah, Singh, Teotia and Guha, 1965).

The loss of plant nutrients increased with the increase in the degree of the slope and the increase was very steep when the degree of slope increased from 1.5 percent to 3.0 percent. The loss of plant nutrients, except organic matter and nitrogen, also increased with the increase in the length of slope (Table 2).

Table 1. Effect of Slope of Land on Runoff and Soil Erosion

Slope	Runoff (Percentage of rainfall)	Soil loss tonne/ha
Studies conducted at Sholapur (Average of 7 black soils)		
160 mm rain applied to saturated soils for 2 hours		
2%	89.9	12.8
4%	90.6	16.2
Studies conducted at Kota - Black soil - Cultivated fallow (Average of 4 years)		
0.5%	16.9	3.5
1.0%	17.3	3.7
Studies conducted at Deochanda - Red soil (Average of 3 years)		
2%	6.4	3.3
5%	28.9	23.6

Table 2. Effect of Degree and Length of Slope on Nutrient Losses (Goel, Khanna and Gupta, 1968) (Nutrients lost in runoff kg/ha)

Degree of slope	Organic matter	Total N	P_2O_5	K_2O	CaO	MgO
0.5%	86.8	5.8	10.7	42.8	53.4	41.4
1.5%	92.8	6.5	11.1	52.9	59.2	78.5
3.0%	173.9	10.8	23.5	117.8	203.2	211.8
Length of slope (metres)						
18	41.0	3.8	1.8	7.3	20.0	4.3
36	34.3	3.2	2.2	7.6	20.6	8.4
54	33.4	2.7	3.0	12.5	25.7	12.9

Table 3. Effect of Soil Group on Runoff and Soil Erosion

Soil Group	Treatment	Rainfall (mm)	Runoff (mm)	
			Runoff as % of rainfall	Soil loss (tonnes/ha)
Alluvial soil	Bidi tobacco (Clean cultivated row crop)	791	205 (25.9%)	4.8
Alluvial soil	Bajra	791	167 (21.1%)	2.3
(Verma, et al, 1968)				
Black soil-1% slope Kota (Singh, Dayal and Bhola, 1967)	Jowar (Kharif)	614	103 (16.8%)	2.4
Black soil-Sholapur (Kibe, 1958)	Jowar (Rabi)	597	112 (18.7%)	86.7
Red soil-2% slope Deochanda (D.V.C.) (Mirchandani, Guha and Vasudeviah, 1958)	Maize (Contour cultivation)	1002	64 (6.4%)	3.3

In spite of the fact that the slope, crop and rainfall are varying for different groups of Indian soils, the data in Table 3 clearly indicate the effect of soil group on runoff and soil erodibility. The red soil at Deochanda had the lowest rate of runoff; the alluvial soil at Vasad had very high rate of runoff and the black soils were intermediate, still the rate of runoff was high. The soil loss was the highest in black soil at Sholapur followed by alluvial soil and least in red soil. Ballal and Deshpande (1960) observed that under similar conditions of rainfall and slope in the laboratory, lateritic clay soil was slightly erodible while black clay soils were highly to moderately erodible.

The data on runoff and soil loss under different soil, climatic and slope conditions in Table 4 clearly indicate that if the land is left undistrubed under natural cover, the runoff and soil loss are the least; the soil loss and runoff increase steeply when the vegetation is removed and the land is cultivated.

Table 4. Effect of Land Use on Runoff and Soil Erosion

Treatment	Rainfall (mm)	Runoff (mm)	Soil loss (tonnes/ha)
Black soil-0.5% slope-Kota (Singh, Dayal and Bhola, 1967)			
Natural cover	657	33	0.3
Cultivated fallow	657	111	3.5
Jowar (Kharif)	657	79	2.9
Black soil-Sholapur (Kibe, 1958)			
Natural vegetation	342	28	1.3
Vegetation removed	342	118	44.3
Jowar (Rabi)	342	112	86.5
Red soil-2% slope-Deochanda(D.V.C.) (Mirchandani, Guha and Vasudevaiah, 1958)			
Natural fallow	1002	105	0.6
Over grazed fallow	1002	222	3.3
Maize (Contour cultivation)	1002	64	3.3

MECHANICAL MEASURES FOR EROSION CONTROL

Mechanical or engineering measures play a vital role in erosion control on agricultural, forest and grass lands. These measures include contour farming, contour bunding, bench terraces (on steep slopes), construction of grade stabilization structures, etc.

Contour farming. It has been observed that on 4 percent slope, contour farming gives much less runoff and soil loss respectively as compared with up-and-down farming of maize (Table 5). (Gupta, Ram Babu and Rawat, 1970).

Contour bunding. This practice has been found to be a very important soil and water conservation measure in arid and semi-arid areas having soils with high infiltration and permeability rates.

In the alluvial soils of Gujarat, a vertical interval (V.I.) of 1.83 m and cross section of 1.3 sq.m. was found to be suitable for land

Table 5. Frequency of Runoff (mm) and Soil Loss (Tonnes/Ha) due to Contour Farming of Maize on 4% Slope, Dehra Dun

	Runoff (mm)				Soil loss (tonnes/ha)			
	Frequency (yrs)				Frequency(yrs)			
	10	5	2	1.25	10	5	2	1.25
Up-and-down cultivation	425	320	185	110	4.50	3.00	1.40	0.65
Contour farming	290	220	90	45	2.60	1.75	0.90	0.45

with 6-12 percent slopes; for slopes less than 6 percent contour bunds with cross-section of 0.9-1.3 sq.m. spaced at 0.9-1.2 m. V.I. were found to be effective (Tejwani, Dhruvanarayana and Satyanarayana, 1960). It has been concluded at Bellary that contour bunding is not suitable in deep black soils with montmorillonite type of clay.

Graded bunding or channel terraces. Graded bunding has been used in areas having rainfall of more than 80 cm per year irrespective of soil texture. In clay soils, graded bunding is used even for areas having less than 80 cm of annual rainfall.

It has been observed at Dehra Dun that graded bunding at vertical interval = 0.3 (Slope%) ÷ 2 x 3) with a channel grade of 0.4 to 0.6 percent can be recommended for cultivation of lands up to 4 percent slope (Gupta, Ram Babu, Nayal and Singh, 1969).

Observations and experiments at Sholapur, Bellary and Kota have shown that even in semi-arid climates, contour bunding in deep black soils with montmorillonitic type of clay is not suitable. The low rates of permeability and infiltration in these soils cause prolonged impounding of water on the upstream side and the crops are consequently damaged (Sahasrabudhe, 1964).

Studies on broad based channel terraces constructed on black soils (land slope 1 percent) in semi-arid climate at Bellary showed that V.I. of 0.6 m. was better than that of 0.75 m; that channel terrace with variable grade recorded less runoff and soil loss than the channel terrace with uniform grade (Tejwani, Gupta and Mathur, 1971).

At Kota, graded bunds, 0.7 to 1.0 sq.m. in cross-section and with 0.1 to 0.5 percent channel grade were found suitable for clay loam to clay black soils (Rajbans Dayal, 1967).

Evaluation of effects of Soil and Water Conservation Measures on Agricultural Lands

The beneficial effects of soil moisture conservation by the constructions of bunds and levelling of land have been extensively demonstrated in the semi-arid alluvial plains of U.P. where 35, 63 and 98 percent increase in yield of kharif and rabi crops was obtained by bunding alone, levelling alone and bunding-cum-levelling respectively (Khan, 1962). Bunding increased yields of Setaria, cotton and jowar by 18, 11 and 17 percent in large scale field trials in Tamil Nadu (Kanitkar, Sirur and Gokhale, 1960).

Patil and Sohoni (1969) have reported that contour bunding not only increased yields of crops in dry farming areas in Maharashtra but also increased water level in wells and employment opportunities as the age of bund increased (Table 6).

Table 6. Effect of Age of the Bund on Yield of Crops, Water Level in Wells and Employment Opportunities

Age of bund (in years)	1 to 5 (control)	5 to 10	10 to 15	15
% increase in yield of jowar	-	7.0	24.0	52.7
% increase in yield of bajra	-	3.7	35.2	-
Increase in water level (cm) in wells	-	9	82	180
Average number of persons engaged full time in agriculture	3.4	4.0	4.3	4.5
% addition to area cultivated	0.5	1.1	2.0	8.7

Thus, the soil conservation measures apart from giving immediate gains also offer long range economic benefits to farmers and the nation in conservation and utilization of resources.

Increasing Production from Various Land Uses

As far as Indian conditions are concerned, it is the various Soil

Conservation Research Centres of I.C.A.R. which, since their inception in mid-fiftees, have conducted comprehensive and co-ordinated studies on productivity from various land uses. Soil Conservation Research Centres located in different parts of the country represent various types of soils: Vasad and Agra (alluvial soils), Kota (black soils where crops are grown in kharif), Bellary (black soils where crops are grown in rabi), and Hyderabad (red soils). All these centres are situated in semi-arid climatic zone.

As a case study, this paper will report the work conducted at Soil Conservation Research Centres at Vasad and Agra and highlight the very encouraging results recorded in increased production as a result of integrated and planned land use.

Erosion Control Measures Adopted

To prevent sheet and rill erosion on agricultural lands, which formed the catchment of adjoining gullies, the agricultural lands were treated with contour bunds and a peripheral bund was provided 6 m away from the gully heads. The earthen bunds were stabilized by sodding with *Dichanthium annulatum*. The gully bottoms were treated with various types of gully plugs to reduce the velocity of runoff water, re-distribute it, increase its infiltration, encourage siltation, and to improve soil moisture regime for establishing plant cover. Specification for contour bunds and gully plugs have been reported by Tejwani, Dhruvanarayana and Satyanarayana (1960).

Increasing Agricultural Production

As a result of the adoption of soil and moisture conservation measures on agricultural lands and better farming practices, the yields of rain-fed crops have consistently improved. This is illustrated by the development of good crop-rotation systems at Vasad.

A two-year rotation of green-manured bidi tobacco-Kodra and Tur mixture or sundia jowar under rain-fed conditions was found to be suitable for the lands reclaimed for cultivation. These rotations include a cash crop which gives high returns; include two legume crops one of which is used as a green manure crop for building up soil fertility and reducing soil and water losses and the other legume is a deep-rooted crop which brings up nutrients from deep layers and adds them to the soil through a heavy leaf fall (Tejwani, Srinivasan and Mistry, 1966). In another experiment at Vasad seven crop rotations were tried, 3 local and 4 considered important from soil and water conservation and production point of view.

Table 7. Yield of *Bajra* Kg/ha (Average of 6 years) in Rotation Experiment, Vasad, Gujarat. (Tejwani, Gupta and Mathur, 1971).

	Bajra Grain	Net income per rotation (Rs/ha)
Bajra - *Bajra*	566	786/-
Bajra - Cotton	731	578/-
Bajra - *Bidi* tobacco	1195	2516/-
(*Bajra* + *mung*) - (*Bajra* + *mung*)	918	1024/-
(*Bajra* + *mung*) - (Cotton + groundnut)	819	856/-
(*Bajra* + *mung*) - Cotton (green manured)	1098	1124/-
(*Bajra* + *mung*) - *Bidi* tobacco (green manured)	1701	3864/-

Varieties : Bajra - 207; *Bidi* tobacco - K.20; *Mung* - China 781;
Cotton - Co 134; Groundnut J.11.
Cover-cum-green manure crop - Sannhemp
Rotations : 1, 2 and 3 are the prevailing rotations: Slope 2.5 percent

The data in Table 7 indicate that the rotation *bajra* + *mung* - *Bidi* tobacco (green manured with sannhemp) is the most economical for the tract under rain-fed conditions.

Table 8. Grain Yield (kg/ha) and Net Income (Rs/ha) from Reclaimed Ravine land Terraces, Agra (Average of 7 years - 1958-64) (Prajapati, 1974a).

	Rain-fed crops	Irrigated crops	Net Income
Bajra + arhar			
Bajra grain	463	-	-
Arhar grain	469	-	-
Net income	-	-	425
Bajra-Wheat			
Bajra	617	-	-
Wheat	-	2084	-
Net Income	-	-	1085

In an experiment on reclaimed ravine land terraces at Agra (Table 8), the average net annual income was Rs.425/- and Rs.1,085/- from rain-fed and irrigated crops respectively. The time of recovery of invested capital was calculated and found to vary from 2 to 23 years in case of rain-fed crops and 1 to 6 years in case of irrigated crops, depending upon the type of gully reclaimed for cultivation.

At Agra, among the five rotations tried under rain-fed conditions for 7 years (1958-1964), it was observed that the rotation with nonleguminous crops only was not economical; however, when bajra was grown either in rotation with cowpea or mixed with arhar, very promising results were obtained (Table 9).

Table 9. Net Income for Various Rotations under Rain-fed Conditions - Agra (1958-1964) (Prajapati, 1974b)

Rotation	Net income (Rs/ha)
Bajra-Fallow-Bajra-Fallow	- 217.26
Bajra-Fallow-Cowpea-Fallow	426.52
Bajra+Arhar-Fallow-Bajra+Arhar-Fallow	438.48
Bajra-Fallow-Fallow-Mustard	115.49
Bajra+Arhar-Fallow-Fallow-Mustard	406.84

Increasing Production of Grasses, Fuel and Timber from Land Capability Class VI and VII

A study of the natural flora of the eroded areas showed the existence of only poor types of annual and unpalatable grasses in the place of desirable vegetation which would normally have existed in the prevailing soil-climatic environments (Tejwani, Srinivasan and Mistry, 1961). For example, in Gujarat ravines Aristida sp. and Themeda triandra were growing in place of the desirable Dichanthium - Cenchrus association. Tejwani, Srinivasan and Mistry (1961), Singh (1971) and Singh and Verma (1971) reported that as a result of closure to grazing and other biotic interference, (i) Aristida funiculata and Themada triandra were first replaced by Apluda mutica (a tall annual grass) and perennials like Eremopogon faveolatus, Heteropogon contortus, Dicanthium annulatum and Cenchrus sp., (ii) the runoff and soil loss progressively decreased from the area as the natural vegetation improved and (iii) there was not only qualitative but quantitative increase in the yield of grasses.

With closure to biotic interference, there was very considerable increase in the population of naturally occuring tree species (Table 10).

Table 10. Effect of Closure to Biotic Interference on Tree sp. in the Ravine lands at Vasad, Gujarat
(Tejwani, Gupta and Mathur, 1971; Rajbans Dayal, 1974)

Tree species	Tree population in the year			
	1960-61	1962-63	1965-66	1973-74
Acacia - nilotica	49	55	50	30
Acacia eburnea	Nil	4	20	11
Acacia senegal	23	42	81	259
Azadirachta indica	20	20	80	133
Holoptelia integrifolia	Nil	6	18	69
Prosopis spicigera	60	74	98	88
Cassia auriculata	57	44	63	44
Gymnosporea montana	3	6	6	64
Zizyphus species	101	98	321	331
Total	313	349	737	1028
Percentage increase over 1960-61		11	135	228

Table 11. Effect of Closure to Biotic Interference on Grass Species at Vasad, Gujarat (Percentage Composition of Grasses)
(Tejwani, Gupta and Mathur, 1971)

Species	Hump			Gully Slope			Gully bed		
	1960-61	1962-63	1965-66	1960-61	1962-63	1965-66	1960-61	1962-63	1965-66
Apluda mutica	33	19	77	9	14	32	7	45	82
Aristida royleana	Nil	Nil	1	32	31	15	Nil	Nil	Nil
Atylosia scaraboides	1	1	3	Nil	Nil	4	Nil	Nil	Nil
Cenchrus ciliaris	Nil	Nil	Nil	12	9	1	Nil	Nil	Nil
Dichanthium annulatum	51	50	7	25	22	4	75	29	2
Heylandia latebrosa	Nil	Nil	4	1	4	6	Nil	Nil	Nil
Heteropogon contolus	Nil	Nil	Nil	Nil	1	8	Nil	Nil	Nil
Total	85	70	92	79	81	70	82	74	84

The data in Table 11 shows that as a result of closure to grazing and other biotic interference both the quantity and quality of grass and cover increased (Tejwani, Dhruvanarayan and Satyanarayan, 1960; Singh 1971; and Singh and Verma, 1971.

Similar results have been obtained at Agra where in a period of ten years of closure, edible sp. increased from 44.6 percent to 48.5 percent and non-edible sp. decreased from 42.9 to 30.1 percent (Prajapati, 1974c).

Utilization of Land Capability Classes VI and VII, Lands for Fodder and Fuel Production

In semi-arid areas people need fodder for cattle and trees for fuel and timber. An experiment is being conducted at Vasad since 1960-61 to investigate if fodder and fuel-cum-timber tree sp. (Acacia nilotica) can be grown together without reduction in the yield of fodder.

Table 12. Forage (Green) Yield (kg/[illegible]) [illegible] Vasad, Gujarat (Rajbans Dayal, 1974)

Treatment	Year							Mean
	1960-61	1961-62	1962-63	1963-64	1964-65	1965-66	1966-67	
Pure grass block of Cenchrus ciliaris	[illegible]	4180	6135	4919	6318	5192	5224	4965
Pure grass block of D.annulatum	3948	3636	5873	4697	7277	5585	6193	5316
Fuel-cum-grass block with C.ciliaris	3375	4378	3314	6423	6754	4887	4938	4867
Fuel-cum-grass block with D.annulatum	3227	4277	5656	5493	6505	5827	5945	5276
Mean	3315	4244	5589	5728	6663	5363	5575	5106
Percentage increase in yield over 1960-61	-	28.0	68.6	72.8	101.0	61.8	68.2	

There was no significant difference in the forage yields of Cenchrus ciliaris or Dichanthium annulatum (Table 12). The overall mean forage yield increased from year to year, making the increase 101 percent in 1964-65 as compared with that in 1960-61. This increase was partly owing to the effect of closure and protection of the area and partly owing to the improvement in broadcasting of seeds and planting of grasses.

Fuel-cum-grass plots having planting of A. nilotica did not differ in forage yield from the plots of pure grass during the first 6 years, since the tree spp. had not developed crowns by that time to cast any shade.

Economics of Soil and Water Conservation

Grasses on bunds. At Vasad, 20.85 ha of area were bunded with 10214 m of bunds which gave a gross income of Rs.37 per ha and a net income of Rs.493/- per ha of area lost under bunds over a period of 8 years. (Verma et al.,1969).

Trees in land capability classes VI and VII. Afforestation trials carried out in the ravines at Vasad showed that Dendrocalamus strictus (bamboo), Tectonia grandis (teak), Dalbergia sissoo (shisham) and Eucalyptus camaldulensis were very promising (Table 13).

Table 13. Net Annual Income from Various Tree Spp., Vasad, Gujarat

Species	Rotation (Years)	Cost of production (Rs/rotation/ha)	Gross income (Rs/rotation/ha)	Net annual income (Rs/ha)
Dalbergia sissoo*	30	3380	23356	666
Dendrocalamus strictus*	30	3380	44475	1370
Eucalyptus camaldulensis*	24 (3 rotations)	12824	13478	444
Tectonia grandis**	15 years (for ballies)	1300	17500	1080

* Singh (1972) ** Rajbans Dayal, Pradhan, and Vasava (1974)

At Vasad center two-thirds of land falls under grass and forest land use and one-third area is used for agriculture and horticulture. In 1956-57, in the first year the gross annual income was Rs.2,337/- which increased gradually over the years to Rs.53,493/- in 1972-73 (Rajbans Dayal, 1974).

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WATER-HARVESTING AND MANAGEMENT FOR

FOOD AND FIBER PRODUCTION IN THE SEMI-ARID TROPICS

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Water harvesting is the process of collecting and storing water from areas treated to allow improved utilization of natural precipitation. The water storage may be in tanks and reservoirs or in the soil. Collection of water for human or livestock use is usually done with ground covers of concrete, metal, plastic, or asphalt. Water for crop production is normally collected from soil surfaces rather than ground covers and may be accomplished in a variety of ways.

Runoff farming, or water spreading, involves the diversion of runoff from a relatively small watershed to cropped fields. This is probably the earliest form of large-scale water harvesting. Farmers used this system in the Arabian Desert about 4,000 years ago by smoothing hillsides to increase runoff and building ditches to collect the water and convey it to lower lying fields. The fields were irrigated only when it rained. These simple ancient systems, subsequently destroyed by warfare, allowed the development of agricultural civilizations in regions, having an average annual rainfall of about 100 millimeters (Evanari et al., 1961). Utilization of runoff from small watersheds has been improved in a system developed by H.J. Geddes (1963) which involves storing runoff in reservoirs for later use in supplemental irrigation.

A second method that can be considered for agricultural water harvesting is the construction of level bench terraces with sloping contributing areas above the benches. The contributing areas are usually planted with hay or grain crops. These level bench terraces have not been very successful in the Great Plains Area of North America for reasons that will be discussed later.

Agricultural water harvesting can also be accomplished by building small basins or micro-catchments to concentrate rainfall for individual vines, shrubs, or trees (Evanari et al., 1971). In arid regions rainfall runoff per unit area increases as the area decreases, usually because of losses in conveyance channels. Micro-catchments represent

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an attempt to reduce conveyance losses to a minimum by providing each plant with its own collection area.

Arid Zone Research

Most of the research on water harvesting has been done in arid regions where water supply problems are usually more severe than they are in semi-arid regions. Several thousand hectares of roaded catchments have apparently been developed in Western Australia to obtain farm water supplies. These are called "roaded catchments" because the soil is graded into a series of parallel roadways or gently sloping ridges about 7.3 meters wide, with slopes of 1 in 10 or 1 in 20, that drain into the ditches separating them. These ditches convey the water to a storage reservoir. These roaded catchments reportedly produce runoff when rains exceed 7.5. millimeters, while a storm must usually exceed 19 millimeters to produce runoff from natural catchments.

Research by scientists of the Agricultural Research Service in the State of Arizona, U.S.A., has been aimed primarily at supplying water for livestock. A large number of materials for collection aprons have been evaluated, and treatments for increasing runoff from soil surfaces studied (Myers, 1973). One useful development has been a ground cover constructed of fiberglass cloth laid over the ground surface and sprayed or mopped with asphalt (Myers and Frasier, 1974). This material which has proven easy to install, is quite durable, and has produced 98 percent runoff of the 180 millimeter average annual rainfall over a seven-year period. Gravel (where available) covered sheeting of tarred paper or polythylene is lower in cost than asphalt-fiberglass and has produced 92 percent runoff. The runoff water is of excellent quality. Materials for improving water storage have also been developed. Methods for reducing seepage losses include soil treatments, plastic and elastomeric linings, and linings of field fabricated asphalt-fibreglass. No promising methods for reducing evaporation from large reservoirs have been developed, but floating covers of soft wax or foamed plastic have shown promise for use on small open tanks (Cooley and Myers, 1973). Some of these findings could be useful for developing domestic and livestock water supplies.

A number of ancient runoff farms have been reconstructed and studied in Israel. In addition to investigating the hydrologic characteristics of the contributing watersheds, numerous varieties of plants have been evaluated for ability to survive and produce useful crops under arid conditions where rainfalls are commonly separated by long intervals of drought (Evanari et at., 1971). A number of apparently successful plants have been identified, including almonds, apricots, alfalfa, and several kinds of grain. Marked differences in drought tolerance were found among varieties of the same crop. In the case of almonds, success was reportedly achieved by grafting the nut-bearing almond on a drought tolerant native rootstock.

Rainfall near Tucson, Arizona, U.S.A., is reasonaly reliable in July, August and September, although it is insufficient in amount to allow non-irrigated crop production. Rainfall multiplication through water harvesting procedures allowed the successful growth of sorghum, melons, and cucumbers. Sorghum plots, watered by runoff from untreated natural watersheds, produced from 7.8 to 44 quintals of grain per hectare in 1970 and 1971 with 190 and 246 millimeters of rainfall, respectively (Morin et al., 1973). Only 137 millimeters of rain fell during the growing season in 1972, and sorghum grain yields ranged from 0 to 11 quintals per hectare. During 1972, at a different location near Tucson, several varieties of squash, melons, and cucumbers were grown in plots that were irrigated every time it rained with the same quantities of water that would have been provided by a water harvesting catchment. The amount of water applied ranged from 690 to 780 millimeters, which was about four times the actual rainfall at the site. The squash crop was severely damaged by insects, and melon yields were low because of late germination of seeds. Cucumber yields were excellent, equalling or exceeding those achieved under conventional irrigation. Similar attempts to grow melons near Phoenix failed, partially because of inadequate rainfall, but mainly because the soil at the study site would not store enough water to support the plants between rainfalls.

Semi-Arid Tropics vs Temperate Arid Zones

There are a number of important differences among conditions in the semi-arid tropics and in the temperature arid zones that must be considered before attempting to apply arid zone research to the semi-arid tropics. Water harvesting on bare soil runoff in the arid zones has been done primarily on loess, sandy loams and loamy sands. No definitive research has been done, to my knowledge, on soils comparable to the red and black soils found at Hyderabad. The difference in soils will not only affect rainfall runoff relationships but, together with climatic differences, will also influence the kinds of crops that may be grown. This, in turn, will have a bearing on the design of agricultural water harvesting systems.

Rainfall in arid and semi-arid regions may differ not only in annual amounts but in the intensity or rate of rainfall. Contrary to the semi-arid tropics, rainfall in the temperate arid zones, with which the author is familiar, is usually of low intensity. During a ten-year period from 1961 to 1970, the annual rainfall at a test site near Phoenix, Arizona, U.S.A., averaged 183 millimeters that fell in an average of 45 showers. The average intensity of 94 percent of the storms was less than 5 millimeters per hour. Only three of the storms occuring during the ten year period exceeded 20 millimeters per hour.

Since the runoff is greatly influenced by rainfall intensities, much of the arid zone research on bare soil runoff is of questionable value to the semi-arid tropics.

One of the most important factors in the design of water harvesting systems is the method of construction. An objective in much of the research done to date has been the reduction of human labor requirements by designing systems that can be built with gasoline or oil-powered machines. Objectives in many parts of the semi-arid tropics will be the conservation of expensive oil products and the provision of work opportunities for disadvantaged segments of the local population. Accordingly, it may often be desirable to design systems for construction and management by animal and human labor. There can be significant advantages in such systems.

We must agree that there will frequently be marked differences between temperate arid regions and semi-arid tropics in terms of soils, crops, rainfall amounts and intensities, and in construction methods. The conclusion we reach is that research methods developed in arid zones should be useful to investigators in the semi-arid tropics but that many of the research findings cannot be directly transferred. Water harvesting and management for food and fiber production in the semi-arid tropics is, in most aspects, a new and challenging field of research.

Research Needs

The development of reliable principles, methods, and systems must be based on reliable information. Some of the most vitally needed information relates to characterization of climatic elements and soils. There is marked variance in the amount and intensity of rainfall from location to location and also in the occurence and duration of wet and dry periods. We must also have basic information concerning the soil, such as infiltration rates and the water holding capability of the soil profile. Obtaining these data at each site proposed for a water harvesting installation is not part of a research program. However, the development of simple, reliable devices and simple, reliable methods for obtaining the required information should be considered as an important part of the research program.

The need for studying rainfall runoff relationships is probably obvious. The effect on rainfall runoff relationships of different soils, size and shape of contributing areas, surface roughness, plant cover, and soil compaction should be determined. The effect of soil-moisture conditions may need to be considered for clay soils that crack markedly on drying. Large and extensive cracks can prevent runoff from the first rains of the season.

The control of water application and distribution can be critical.

During the early 1950's, some level bench terraces were constructed in the mid-western U.S.A. without any provision for drainage. Water ponded on the terraces during heavy rains drowned the crops. Farmers concluded that level bench terraces were bad and for some period of time did not install any more of the terraces. The bench terraces now being installed have provision for drainage and are becoming more popular. Level bench terraces with a sloped contributing area above them are still not performing satisfactorily because runoff water from the contributing area is not distributed uniformly across the level bench. Uniform water application and provision of drainage both will be mandatory in the semi-arid tropics. To avoid the possibility of runoff from extensive water harvesting installations flooding downstream areas during periods of intense rainfall, necessary provision should be made for temporary storage of water for subsequent release after the danger of flood has eased.

Intense rainfall and high winds bring with them the problem of erosion. Methods for controlling water erosion, including minimizing the length or steepness of slopes, terrace construction, planting vegetation on sloped areas, and the construction of grassed channels are well known. Methods for controlling wind erosion are also well known, but methods for implementing them are not so easy to develop. Narrow rows of stiff-stemmed grasses, in addition to trees and shrubs, have proven successful in some areas. Rough tillage is also useful in reducing wind erosion. It is interesting to note that animal-drawn wooden plows can be superior to 'modern' machinery in tilling for wind erosion. These frequently ridiculed implements do not invert the soil or bury surface residues; they work only to a shallow depth and leave the soil ridged and in a cloddy condition with residues stirred in or lying on the surface. The introduction of oil-powered equipment has sometimes led to unfortunate results, when due consideration was not given to the control of wind erosion (Hopfen, 1969). Some of our efforts to increase runoff from contributing areas may conflict with the need to control erosion, but we can hope that proper system design, combined with the management of appropriate vegetation, can cope with that problem. There will sometimes be a need to increase infiltration in the level cropped areas, and this can be done through the practice of minimum tillage which is compatible with erosion control.

Mention has been made earlier of the need to consider methods for construction and management that utilize animal and human labor, rather than oil-powered machines. The substitution of muscle power for oil-powered machinery would not only reduce expenditures on oil and create more jobs but would allow greater freedom in the design of the water-harvesting systems. In the U.S.A., the width of terraces is governed by the width of machinery; and, as previously mentioned, level-benched terraces are ordinarily too wide to allow uniform distribution of water obtained from contributing areas. Terraces and other structures built with muscle power can be narrower than those built with heavy machinery and can be more efficient in the distribution of water. There is a quotation from Hopfen that is worth keeping in mind (Hopfen, 1969). "Research and extension workers undertaking program for the introduction and improvement of hand-and animal-powered farm implements should stress the fact that it is not a sign of lack of progress to use improved simple implements under conditions where expensive power machines cannot be successful. It should be noted also that 'simple' is not synonymous with 'primitive'. Simplicity of design and operation is often the most desirable characteristic in any equipment."

When water storage is to be part of a runoff farming scheme, the first thing that comes to mind is the use of surface reservoirs. Here, we know that we must be concerned with preventing excessive losses through seepage and evaporation. Consideration should also be given to the fact that in some areas it is possible to store and recover considerable quantities of water by recharging underground aquifers with excess runoff water. This would necessitate some knowledge of the geology of the location.

The development of crop plants better adapted to efficient water use and survival under drought conditions is clearly one of the goals of ICRISAT. It has been pointed out earlier that there are opportunities for modifying plant structure to increase water-use efficiency and that increasing the photosynthetic efficiency of Mexican wheats also increased their water-use efficiency, as calculated on a yield basis (Myers, 1971). Viets (1971) has mentioned that there are opportunities for reducing the length of a plant's growing season and that the time peak water use occurs is of great importance. He has also reported that under deficient water conditions, low seeding rates led to slow moisture intake compared with high seeding rates and produced higher grain yields. Plant breeders, to date, have spent most of their efforts in developing plants that have disease or insect resistance, that produce higher yields under adequate water supply conditions, and yield a product that ships well or can be efficiently processed. There has been very little work done towards developing plants that use water more efficiently. Hopefully, this means that there are many opportunities for worthwhile accomplishments in this neglected field.

The research needs that I have mentioned are those which are more specifically associated with runoff farming or water harvesting for food and fiber production. While considering these needs, we must not forget that they relate to only one part of an overall system that also requires research on soil fertility, plant diseases, pest control, and the storage and distribution of agricultural products.

Conclusion

The preceding discussion has pointed out that there are several methods for utilizing water harvesting to produce food and fiber. These range from small basins called micro-catchments to the construction of systems involving runoff diversion, storage, and supplemental irrigation. It is evident that these latter systems are, in effect, a miniaturization of conventional river-basin irrigation schemes. It is also understood that water harvesting methods will not work everywhere. It is important that we develop principles and methods for conducting investigations, not only to design the best systems for local conditions but to first determine if water harvesting is really feasible under those local conditions. Failures brought about by attempting to utilize water harvesting concepts under unfavourable situations can damage or defeat attempts to utilize the methods under favourable conditions. It is apparent that a tremendous amount of new information is required. Much work also needs to be done to develop the required principles, methods, devices, and system designs. It is equally apparent that these tremendous needs constitute not only a great opportunity, but a great responsibility too.

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ACHIEVEMENTS IN

WATER HARVESTING TECHNOLOGY IN AUSTRALIA

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The phrase 'water harvesting' was coined in the first instance to describe a project of the University of Sydney, which involved the collection and economic storage of farm runoff for irrigation, and to differentiate the work from normal farm water conservation to provide water for livestock or household purposes.

Irrigation imposes three stringent requirements: (1) substantial quantity of water is necessary if any appreciable area is to be watered; (2) the water must be obtained at low cost; and (3) the mineral content of the water should be low enough for sustained irrigation of plants.

By contrast, animals require comparatively lesser water - it takes about 140 times as much water to grow an animal's daily feed as it does to satisfy its thirst; drinking water can be quite expensive without becoming prohibitive and the mineral content of water for livestock can be much higher than that of irrigation water.

Our phrase, 'water harvesting' has been adopted by others and given a wider connotation. In this paper, however it has been used in its original sense. The only extension is that it has been applied to the surface storage of underground water. That is not a paradoxical suggestion. The area that can be watered from a bore is determined by the daily flow at a peak demand. By storing the surplus at other times in a readily accessible form, the maximum irrigable area can be increased quite substantially even after allowance for evaporative losses.

The Sydney University project is an integrated one, though it did not begin with an integrated objective; it developed that way by its sheer inevitability. The project also did not arise as the result of a systematic attack upon the basic problem of an erratic moisture supply. It arose from an accident. It has produced a distinctive farming system, a system of producing milk much more cheaply than by conventional methods of keeping the cows on grazing throughout the entire year.

In 1936, the Veterinary School of the University of Sydney, was confronted with the problem of a steadily decreasing flow of large

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animals into its city clinic, It bought 162 hectares of land in the adjoining farming region as a base for a rural veterinary clinic and an animal husbandry centre.

Erratic Rainfall

This area is not naturally suited to dairying. The rainfall is unreliable and the soils are poor. Most of the feed for dairy cows is imported from over the mountains or bought from feed manufacturers. Sydney itself has an average rainfall of 120 cm; the farming belt lying between the city on the sea coast and the Blue Mountains, whose eastern fringe is only 25.7 km from the sea, has an average of 71 cm. The principal reason for the undeveloped state of this farming belt is the erratic nature of the rainfall. The efficiency of this rainfall is markedly reduced by three factors: (1) the tendency of the rain to arrive in a heap - it is not unusual to get a fall of 15 to 25 cm within the space of two or three days; (2) the erratic seasonal distribution of the rain; and (3) the high variability from year to year.

There is no regular pattern of rainfall in this area. Even those heavy falls can occur at any time. Conversely, the area is subject to frequent dry spells, some of which develop into serious droughts. The only constant feature of the rainfall is a tendency towards two heavy falls a year, but at any time.

Some of the rains are of high intensity. On two occassions in recent years, a rainfall intensity of nine inches an hour was recorded - one such fall lasting for 10 minutes, another for half an hour. Most of the rains exceeding 13 or 15 cm result in high rates of runoff, but not all. We had one fall of about 18 cm, spread over several days, that yielded little runoff. On another occassion, heavy runoff followed a storm of one quarter of an inch. The rainfall varies greatly from year to year. Within the past 30 years the annual rainfall in the farming belt has been as high as 168 cm and as low as 18 cm.

The 162-hectare University farm is right in the centre of the rain shadow, where the average rainfall is 66 cm. In the first two or three years of purchase all went well at the farm. The heifers came into production, pastures developed satisfactorily, good yields of fodder were obtained from the crops and large reserves of hay were stored away - all this despite the fact that the rainfall was not above average in those years, but the rains did come at the right time.

Then followed a series of seven dry years in which all the pastures died out, the native grasses took over again, poor crops were obtained and feed reserves were used up. This was a setback, but it was merely a repetition of the experience of others who had tried to farm this land over the previous 140 years. Up to that time no one else had succeeded in maintaining satisfactory improved permanent pastures.

I took over in 1940, when the long-term dry period had begun. Over the next 12 years further attempts were made to grow better pastures and raise the productivity of the land, but to little avail. Our efforts were repeatedly frustrated by a shortage of moisture at critical periods. We finally settled down to running the dairy in the same fashion as our farming neighbors did, taking whatever feed the native pastures had to offer in the occasional favorable periods. Sorghum was grown in summer and oats in winter to provide roughage, reckoning that we were doing well if we managed to avoid going to the market for our roughage needs; concentrates were bought which constituted two-thirds of the herd's requirements, and hand-fed to the herd all the year round, losing money on the dairy though we had to keep it going for teaching purposes. Our neighbors earned a poor and precarious living, but were able to survive by doing all the work themselves - we operated on hired labor - and by having herds that, being larger, were closer to an economic size.

The Breakthrough

The turning point came in 1952, when a field of 1.42 hectares, sown down to subterranean clover a few years earlier and thought to have reverted entirely to native grasses, regenerated under the influence of a favorable autumn rain. The strike was topdressed and shut up for the winter. In the spring the field carried a dense clover sward 25.4 cm high - the only grazing of any consequence on the farm. It was decided to ration it to the herd of 45 cows by letting them have as much as they could eat at a single grazing of an hour or two each day. (Cows have their fill in about an hour and a quarter and on good pasture will obtain about half their daily needs in that time). The other feed they got in the bails was measured. The field was strip-grazed and irrigated from a small stock-watering dam after each grazing. For the next 60 days that 1.42 hectares kept the herd in grazing and gave 350 dollars worth of milk to the acre - seventeen times as much as the University had paid for the land.

This unplanned trial of irrigation stimulated our interest in the possibility of repeating it on a larger scale in the next year. The first problem was to get a larger source of water, but the immediate prospects were not encouraging; in fact, we were denied most of the normal sources of irrigation water. There were no public supply channels in the district, no permanent streams or springs, no underground water. The only possibility was to collect the runoff from the farm, which was of an undulating nature. We had been doing this in a small way to get drinking water for our livestock; but this source, according to those with whom the idea was discussed, was not likely to yield enough water for irrigation nor was it likely to be economic.

Attempts to obtain information on runoff rates were fruitless. No gauging had been done locally and none of the recognized authorities was prepared to hazard a guess. The only guide we had was the large but unmeasured flow from the land during a typical deluge and the speed with which a stock-watering dam of half-a-million gallons capacity filled in such a storm.

We decided, therefore, to build two dams as a test. The first took a week to build, costing $500 and had a capacity of 22 acre-feet. A comparison with Burrinjuck Dam, the first of the large Government-built dams in New South Wales and built in 1911, showed that we had succeeded in building a storage at one-third the 1952 equivalent of the cost per acre-foot of Burrinjuck.

The low cost of this storage focussed attention upon the principles of economic storage - a simple problem in solid geometry, but one that for some strange reason did not appear to have been previously discussed in extension literature. Such knowledge must be the stock-in-trade of every civil engineer, but they, too, have been silent on the matter. One can certainly see numerous examples of the flouting of these principles in any drive around the countryside. The most flagrant example is provided by the popularity of the sunken or excavated tank - a hole in the ground without any attempt being made to use the spoil to increase the storage. Many thousands of such tanks have been excavated in Australia. There could hardly be a more expensive way to store water.

Economic storage is a matter of getting the maximum capacity with a minimum of earth movement - in the case of a dam, using the bank to contain water and push it out beyond the excavation. The obvious measure of economy is the storage-excavation ratio. Our first dam stored 27,500 cubic meters of water. The volume of earth moved was 4,585 cubic meters - an S/E ratio of 6:1. A sunken tank has an S/E ratio of 1:1. The flatter the valley floor behind the wall of the dam, the higher the S/E ratio is likely to be. Since most valleys tend to flatten out in their lower reaches, the better sites are likely to be found near the mouth of the valley although one complication at such a site is the greater chance of running into an alluvial stratum or sand lens which is poor material for building a waterproof wall.

Dam Storage

A dam requires a sufficient catchment to ensure that enough runoff water is available to fill it in most years. It is often possible to increase the catchment area with contour drains that bring in water from adjacent valleys. Such drains, if constructed on the critical gradient between siltation and erosion - about 1 in 200 are cheap to build and continue to operate without the need for much maintenance for many years.

One such drain that we built in 1944 is still functioning satisfactorily and has not required any maintenance since then. Where the economics of the situation justifies it, the ultimate goal should be to develop the entire farm as an integrated watershed. We have done that with the original farm. No water has escaped from its boundaries for the last 15 years.

Farm dams are seldom very deep and evaporative losses from them would appear to be excessive but in practice they have been less important than what was first feared. The free-water evaporation, measured over 60 years, is 109 cm a year; but this figure does not take into account the direct accession of water from rainfall on the surface of the dam. That would restore 66 cm, leaving a net loss of 43 cm. Even this figure exaggerates the actual loss because the water is not held over for a whole year before starting to use it. The water most vulnerable to evaporative loss is that in the shallow portion of the dam. It absorbs more heat than the deep water; but the shallow water, being outside the excavation, is both cheaply stored and highly recoverable. The more water there is outside the excavation, the lower the average cost of storage. Most of it is used for irrigation before evaporation can take a heavy toll of it.

Then, there is a strategy of water use. If one has several dams in the system, the first to be used would logically be that with the highest proportion of shallow water. We have a staircase of five dams in one valley, each dam being fed by a contour drain from an adjacent valley. The order of use is from the lowest to the highest. If the bottom dam is empty and a replenishing rain comes along, it gets the benefit of the entire catchment above because the higher dams, being already full, pass their overflow on. If however, water in the top dam were pumped out first, the only water trapped would be that from its own catchment. Water from the lower catchment would run to waste.

Fodder conservation represents another way to defeat evaporation by translating the water into something more durable. However, this is a poor solution. Conserved feed costs more, about four times as much per calorie as fresh grazing harvested by the animal - in part, because of the 50 percent loss of nourishment involved in the process; and also because of the cost of handling the feed.

The Mansfield process for reducing evaporation with a monomolecular film of hexadecanol did not stand up to the test of practical use and, in any event, was more costly than the average cost of conservation.

Storing Water on Flat Land

On undulating lands gully dams provide the cheapest storage. Flat country presents a double problem-that of securing a supply of water and of economic storage. A valley accumulates its runoff and provides the fall to run it into the dam. On flat lands more of the water soaks into the ground though on impervious soils and in periods of heavy rainfall the flat country sheds its water into the storm-water creeks. Initially, such creeks appear to have little value for irrigation. The supply is so ephemeral, being available for only a few days in a year and at a time when it is not needed. Furthermore, small stream-beds do not form capacious storages if dammed. There is always the risk that the first flood may sweep the structure away altogether or that it may cut the spillway down to the level of the bed and render the dam useless.

However, the storm-water creeks do form an available source of water for the flat country. We had two storm-water creeks on our boundary and decided that the best way to use this water was to divert it or pump it into an off-stream storage that would be out of the pathway of the flood waters.

The solution to the problem of storage on flat lands was found in the ringtank or, as we call it in Australia, the 'turkey nest'. This is a circular wall built up above ground level from an excavation on the inner side. This is the ultimate geometric solution. Its economy depends upon the Inverse Square Law; in other words, doubling the diameter cuts the capital cost of storage to half.

There are several factors involved in determining the optimum size of a 'turkey nest'. Increasing the diameter cuts the cost of storage. Increasing the depth increases the cost of storage, but also reduces the proportionate evaporative loss. The latter becomes more important when the opportunities for replenishments are infrequent.

A second factor affecting the economy of storage in a 'turkey nest' is the lift from the source of water, be it a creek or drain. Low-lift pumping is surprisingly cheap. One can lift an acre-foot of water 30 cm in height, with electric power at 2 cents a kwh, for power costing about 3 cents. There are times when a pump can do a cheaper job than gravity, as, for example, when the capital cost of harnessing gravity is so high that the annual charges on the investment are greater than the direct cost of pumping.

Economic storage on flat country, then, is a matter of taking advantage of a 'turkey nest' that is big enough to keep the storage cost down to a reasonable level and of the economy of low-lift pumping to fill it.

Seepage Losses

Any surface storage requires an impervious subsoil. We were unusually fortunate in that seepage losses through our subsoil, according to C.S.I.R.O. studies, were virtually nil. In many regions of Australia, seepage losses are greater than evaporative losses. In a soil scientist's book, the desirable soil is a free-draining one. The water harvester wants the opposite. Some work has been done in Australia with impervious membranes but none has so far been either cheap or durable enough. To be economic, a membrane would need to be extremely cheap as well as effective. In building 35 dams on the University Farms over the past 20 years, 101 hectares of land was submerged. A membrane of that area, had it been necessary, would have cost $12,100 for every cent per square yard.

Nature has ways of sealing the beds of streams, even those running across gravel. There may be opportunities to utilize local materials for this purpose.

Water Harvesting in Relation to Soil Conservation

It is pertinent to consider the relationship of water harvesting to conventional soil conservation practices. Water harvesting is obviously derived from the latter, but differs in that the aim is to run the water off the land rather than to absorb it as much as possible where it falls. Even if the conservationist succeeds in absorbing all the water where it falls, he does not get a great prolongation of growth in a really dry time, extending over a week or two at the most. And once the water is absorbed into the soil, he loses control over it. If it has gone too deep he cannot pull it back and put it where he wants it. By contrast, the water harvester retains control of the water he has stored. He can ration it out as he pleases, put it where he wants it, when he wants it. On most of our farms a replenishment of the storage system is enough to keep up productivity to a high level for at least a year. One farm has enough water in store to keep the dairy herd in full production for over two years without any rain.

Some of the absorbed water goes too deep to be of any use to the vegetative cover above. The soil conservationist justifies this loss on the grounds that erosion of the surface has been prevented and that the water will find its way into the ground water supply to emerge eventually somewhere else, he seldom knows where, and almost certainly not on the farm where it first fell. And to clinch the point he adds that the water, when it finally emerges, will be crystal clear, without any silt burden. Well, that may be a national point of view, but it is difficult to sell this idea to the man on whose farm the water first fell. It implies an uncommon degree of charity to the world at large.

Small and Large Schemes

I doubt, whether small individual irrigation schemes based upon water harvesting do challenge the validity of the large Government irrigation schemes, but there are some provocative comparisons to be made: (1) The individual scheme can be got operational within a year. Two or three generations often elapse in the implementation of a large scheme after it is first proposed. (2) Transmission losses between a farm dam and the area to be irrigated can be almost nil, if the water is conveyed in a pipe. In the most efficient large scheme in Australia, only 50 percent of the water released from the dam eventually reaches the farms. (3) The idea of storing the water on the farm where it falls does appear to be more attractive, superficially at least, to allowing the water to run away to a distant storage, causing erosion on the way, silting up the storage on arrival, and being lost to the area, where it fell, for ever - even if eventually trapped and stored, it is never pumped back to its source. (4) Siltation is probably more easily controlled in a small dam where the water can be led in through a single channel and passed through a silt trap. Such a measure is usually impossible on a large dam drawing water from a multiplicity of sources. (5) Small schemes make irrigation possible on undulating lands - in fact, the gently undulating country rather than the steep hill country provides better site for a dam and is itself better suited to irrigation. Public schemes are seldom used to supply anything else but flat land. Whereas hill country invariably calls for sprinkler irrigation, it is freer from some of problems of flat irrigated land, such as salinity and indifferent drainage.

An admitted weakness of the small scheme is that it does not provide as great a degree of protection against the long-term drought as the large public scheme. On the other hand, the degree of insurance in the large scheme may not be actuarially sound. One questions whether this aspect has ever been sufficiently studied.

Results Achieved

Having established that it was practicable to save the farm runoff - in that sufficient water could be saved and at a cost comparable with that of the public systems - we encountered the criticism that irrigation was unprofitable in the dairying industry. Though our own farm finances challenged this claim, we decided to extend the scope of our work to get a before-and-after comparison on the farm.

I was fortunate to enlist the services of a colleague F.C. CROFTS, then Lecturer in Agronomy, who adopted an approach which deserves a wider application. He began by making an inventory of plant resources. He did this by laying down a series of plots containing all the species that might be of value, gave them adequate water and fertilizer and measured their feed production by mowing over a two-year period. The basic thesis was that fresh grazing provided feed for cattle at one-third to one-quarter the cost of stall-feeding and that, while it might not fully exploit the productive potential of our dairy cows, the cost advantage could give us a greater profit margin per cow than higher yields more expensively obtained. This has proved to be so.

The plot results gave not only the total dry matter yield but also the seasonal spread of production - a particularly important aspect to us because we had a city milk contract which called for a steady level of production throughout the year. The target was to produce 13.6 kg of dry matter per cow per day with a minimum protein content of 15 percent on a dry matter basis.

The plot results enabled Crofts to draw up a feed program which worked exactly in practice. About this time, the University bought two farms where we followed the new system of feeding. Over the next four and a half years, we kept 400 cows on grazing alone, without buying any feed other than a little calf meal. One of the factors that played a decisive role in growing winter grazing was the relative mildness of winter. Winter grazing was obtained by seeding oats into our pastures. By using heavy seeding, four bushels to the acre along with heavy dressings of nitrogen, we would support a cow per acre throughout the winter without the need for any other feed. These crops give us three grazings over the period.

Production Results

Production can be expressed in several ways. One question is the yield attainable from an all-grazing diet. We now have four major herds. The herd averages run about 3,640 to 3,865 liters a cow with the top cows producing up to 5,228 liters. As the years go by, one gets tighter control over both feed production and its utilization. Crofts is expected to reach a herd average of up to 4090 liters. Improvements in breeding could lift the figure even higher.

We have kept individual field records. The top field has produced 4,546 liters to the acre, which compares with some of the best pasture yields anywhere. One collaborating farmer has obtained a yield from his best field of 5,428 liters to the acre.

Financial Results

On the original farm when the change-over to an all-grazing basis had been completed, it was possible to make a before-and-after comparision. Under the older conventional system of dairying, the farm showed a loss of $2,000 a year. After the change-over it showed a profit of $6000 a year. Further improvements in recent years have raised the profit from that farm to $23,000 a year. The farm runs a milking herd of 100 cows, which means that the profit margin in running at $230 a cow.

This is high by Australian standards. And it is being achieved on one of the poorest farms used for dairying in Australia.

The performance of the two new farms when taken over by the University and converted to a water harvesting system provided further confirmation of our findings. In the year before acquisition they earned a net profit of $1540, equal to a return of 1.9 percent on capital. There was no capital available for improvements nor could we operate on overdraft. Accumulated profit over the next ten years was $160,000. This was, in a sense, a compound interest proposition in that earnings were ploughed back as they became available. To achieve such a profit at compound interest, it is necessary to earn 15 percent on capital employed. The major change in policy was to switch over as rapidly as finances permitted from a stall-feeding system entailing large purchases of concentrates to one in which all the feed for the cattle was home-grown with the aid of irrigation. On one farm we did have access to a river, but because of the intermittent flow, we supplemented the supply by building three dams which we filled from the river in times of flood.

On the other farm irrigation was obtained from a chain of dams.

Epilogue

We did have an unusual combination of advantages in the project.

1. A product, city milk, capable of a high return to the acre - the highest level recorded so far from one field being about $600 to the acre;

2. The fact that the city milk price is based upon the expectation of a considerable amount of stall-feeding;

3. The high cost of the alternative method of feeding;

4. A winter climate mild enough to allow the continued growth of feed;

5. A topography that provided numerous good sites for economic water storage;

6. Subsoils that restricted seepage losses and formed impervious dam walls;

7. A kind and quantity of rainfall that yielded substantial runoff - the impervious nature of the soil was also a help in this connection; and

8. Freedom from bureaucratic influence - we were free to do whatever we wanted to do so long as we did not incur a loss on our farming operations.

Most of these advantages were fortuitous - except the last!

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SEASONAL WATER USE BY

RAIN-FED AND IRRIGATED WHEAT GROWN ON A DEEP VERTISOL[1]

M.B. Russell and R.M. Katre[2]

Efficient management of water is a very important component of the package of improved practices which must be developed by research workers and adopted by farmers if the needed growth rate of agricultu-al production in India is to be attained. The highly seasonal nature of the annual rainfall makes it imperative that the water storage capacity of the soil profile be exploited as deeply and thoroughly as possible. Under rain-fed conditions such profile-stored water augmented by the scanty and undependable winter rainfall is the sole source of water for use by rabi season crops. In irrigated areas, knowledge of the retention and release of water by the soil profile is needed for the proper scheduling of the amount and frequency of irrigations.

There are extensive areas of fine-textured Vertisols, commonly known as 'Black Cotton Soil', in central India on which rain-fed wheat is the primary crop grown in the rabi season. To obtain a more complete quantitative picture of the water regime of such soils, an extensive program of profile moisture sampling was conducted on the JNKVV Experiment Station Farm at Jabalpur, M.P. during the 1971-72 rabi season. The vertisols had a rather uniform clay content of 45-50 percent throughout the first meter of the profile. The bulk density increased from the surface to 40 cm depth (1.3 - 1.6 g/cm^3), remained almost constant (1.6 - 1.7 g/cm^3) to one meter but was slightly higher throughout the second meter (1.7 - 1.8 g/cm^3). The one-third and 15-atmosphere moisture percentage of undisturbed samples from the surface 30cm, expressed on volume basis, were 40 and 18 respectively. The eight different treatments studied were fallow, unirrigated gram, plus a 3 x 2 factorial combination of wheat and wheat + gram, each under three moisture regimes, i.e. unirrigated, one irrigation and four irrigations. A split-plot design with four replications was used with the main plots representing the three irrigation treatments and the subplots the cropping systems.

On October 31, before seed-bed preparation, the entire area was sampled at 10 cm intervals to a depth of one meter. The samples were

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1 Condensed from the PhD thesis of the junior author.
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taken as undisturbed 6.8 cm diameter cores with a tractor-mounted, hydraulically operated, 122 cm long sampling tube. Twelve cores were taken, three from each replication. Each core was cut into 10 cm long segments, immediately transferred to plastic bags to prevent loss of moisture by evaporation, and weighed. After drying at 110°C, the dry bulk density and water content on a weight basis, θ_W, of each sample was determined. The θ_W for each sample was multiplied by the average bulk density at each depth to yield the volumtric water content, θ_V.

On November 19, 1971, the entire area was sown with Kalyansona wheat at the rate of 100 kg/ha, using a tractor-mounted seed drill having 9-inch rows. Ammonium sulphate and superphosphate at 60 kg, N/ha and 100 kg P_2O_5/ha, respectively were mixed and applied as a basal dose with the seed-cum-fertilizer drill at the time of sowing wheat. Gram variety 'Adhartal 5' was sown by hand at 75 kg/ha in 9-inch wheat rows in the gram plots and in alternate wheat rows in the wheat + gram plots. The gram was treated with a suitable Rhizobium culture prior to seeding.

Immediately after sowing and the November-20 sampling, five centimeters of water was applied to the entire experimental area by means of sprinklers. Subsequent irrigations were made by surface irrigation to individual plots in accordance with the treatment schedule. Applications of 8.8, 10, 10 and 20 centimeters were made on December 14, January 13, February 7, and March 2, respectively. The volume of water applied by gravity flow to each plot was measured through a water meter. Rains of 0.5 and 10 mm fell on February 3 and February 13 respectively.

Shortly after the wheat had emerged, it was manually removed from the fallow, and gram plots and from the alternate rows previously seeded to gram in the wheat + gram plots. Although the stand of wheat was generally uniform, some gap-filling was done by intersowing to minimize within plot variability. Ammonium sulfate at 30 kg N/ha was applied to the fully-irrigated wheat and wheat + gram plots just prior to the second and third irrigations. The overall growth of the wheat on all plots was good throughout the season. The gram was slightly affected by a mild attack of wilt early in the season and by pod borers later. The plots were sprayed with 0.1 per cent Thiodane on February 26 to control the pod borers.

The unirrigated and singly irrigated plots were harvested on March 30, 1972. The fully irrigated plots matured somewhat later and were harvested on April 4, 1972. After removal of the border rows, the 10 central rows of each subplot were harvested for yield determination. In the case of the wheat + gram plots the harvested area consisted of 5 rows of wheat and 5 rows of gram. All yields were calculated on the basis of gross area sampled. On November 20, 1971, each plot was sampled at 10 cm intervals to a depth of 100 cm with a manually-operated 2 cm split-tube sampler.

The resulting θ_W of each sample was converted into volumetric moisture content using the average bulk density values obtained from the initial core samples taken on October 31, 1971. Using the same methods, similar sets of profile moisture data to a depth of 80 cm were collected on December 12, 1971, and on January 12, February 4 and February 25, 1972. These dates represented respectively the crown root initiation, tillering, flag leaf and milk stages of development of the wheat crop.

Post-harvest profile moisture samples were taken on March 30, April 4, and May 23, 1972. The tractor-mounted sampling machine was used and three 4.2 cm cores were taken to a depth of 100 cm from each plot. Each core was subdivided into 10 cm segments which were weighed, dried and reweighed in the usual manner to give the bulk density and moisture content. At the same time and in the same way samples of the 100 to 200 cm profile were, also, taken from the fallow, and the unirrigated and irrigated wheat plots. To support the soil moisture depletion data, tensiometers were installed at 30, 45 and 60 cm depths on January 9, 1972. Owing to shortage of tensiometers they were installed only in the fallow, unirrigated and singly irrigated wheat plots in three replications. When tensiometers in the unirrigated and singly irrigated wheat plots crossed their working range, they were transferred to the fully irrigated wheat plots of the same replication.

Patterns of Profile Moisture Use

Total water contents of the 80 cm profile (M_{80}) under different treatments at various times are summarized in Table I. There was a continuous decrease in M_{80} with no significant difference among treatments for the pre-sowing and stand establishment periods (0-43 days). Further progressive reductions occurred in the unirrigated gram and wheat and in the singly irrigated wheat plots right up to harvest. The slightly higher M_{80} values of the singly-irrigated wheat plots up to /3 days reflect the effect of the first irrigation given to those plots after 43 days. The higher values of the unirrigated gram plots up to 96 days indicate comparatively lower transpiration losses by gram than by unirrigated wheat during this early part of the season.

In the fallow and well-irrigated wheat plots, there was little profile depletion prior to the flag-leaf stage. In the well-irrigated plots, the lack of profile depletion indicated that the water applied in the three irrigations made during this part of the season was sufficient to meet the evapotranspiration losses. Lack of significant profile depletion in the fallow plots during that period showed that either surface evaporation was negligible or that it was not greater than the amount of water that moved into the 80 cm profile from more moist soil below.

Profile depletion occurred at increased rates from all of the plots from the flag-leaf stage to harvest at which time the M_{80} values of all

Table 1. Seasonal moisture content of a 80 cm profile (M_{80}) under different treatments

Date	Depletion time (days)	Wheat growth stage	Treatments				
					Wheat		
			Fallow (cm)	Gram (cm)	Unirri. (cm)	1 irrig. (cm)	4 irrig. (cm)
31.10.71	0	Pre-sowing	28.4	28.4	28.4	28.4	28.4
20.11.71	20	Sowing	26.8	26.8	26.8	26.8	26.8
13.12.71	43	GRI	25.7	26.1	24.3	25.2	24.3
12.1.72	73	Tiller	26.1	23.6	20.7	22.9	23.4
4.2.72	96	Flag leaf	27.2	21.5	19.5	19.4	24.4
25.2.72	117	Milk	24.2	18.9	18.4	17.7	22.1
30.3.72	151	Harvest	21.1	14.7	14.9	14.5	13.8

the cropped plots were virtually the same being about half of that at the initial October 31 sampling. Late-season losses from the unirrigated fallow plots were finite but smaller than those from the cropped plots. This indicated that under the high evaporation demand conditions of this period, surface evaporation exceeded the rate of upward water flow into the 80 cm profile, but the combined loss by transpiration and evaporation was substantially greater than evaporation alone. At wheat harvest, the fallow plots had about three-fourths of the M_{80} value which they had on October 31, 1971.

The patterns of change in moisture content in the 80 cm profile during the season may be compared in several ways. For this purpose the data are presented in four different ways in Figs. 1, 2, 3 and 4. Fig.1 clearly shows the progressive depletion of the 80 cm profile under the four contrasting treatments. Significant depletion occurred at all depths under each treatment, although the seasonal depletion under fallow was only about half of that from the cropped plots.

The general pattern of depletion throughout the profile and throughout the season was very similar under the unirrigated and singly irrigated wheat crop. The moisture content versus depth curves move in nearly parallel fashion from right to left at more or less equal rates in those two sets. This uniformity of depletion and the depletion rate throughout the profile is more clearly shown by the parallel nature and uniform slope of the curves for unirrigated and singly irrigated wheat in Fig.4.

In the fallow and fully-irrigated plots much less profile depletion occurred below the 20 cm depth during the early and middle parts of the growing season. In the case of the fallow plot this reflects the low rate of surface evaporation and/or the importance of upward water flow into the 80 cm profile during the period when the evaporative demand of

FIGURE 1. VOLUMETRIC WATER CONTENT VERSUS DEPTH AT DIFFERENT TIMES UNDER FOUR TREATMENTS.

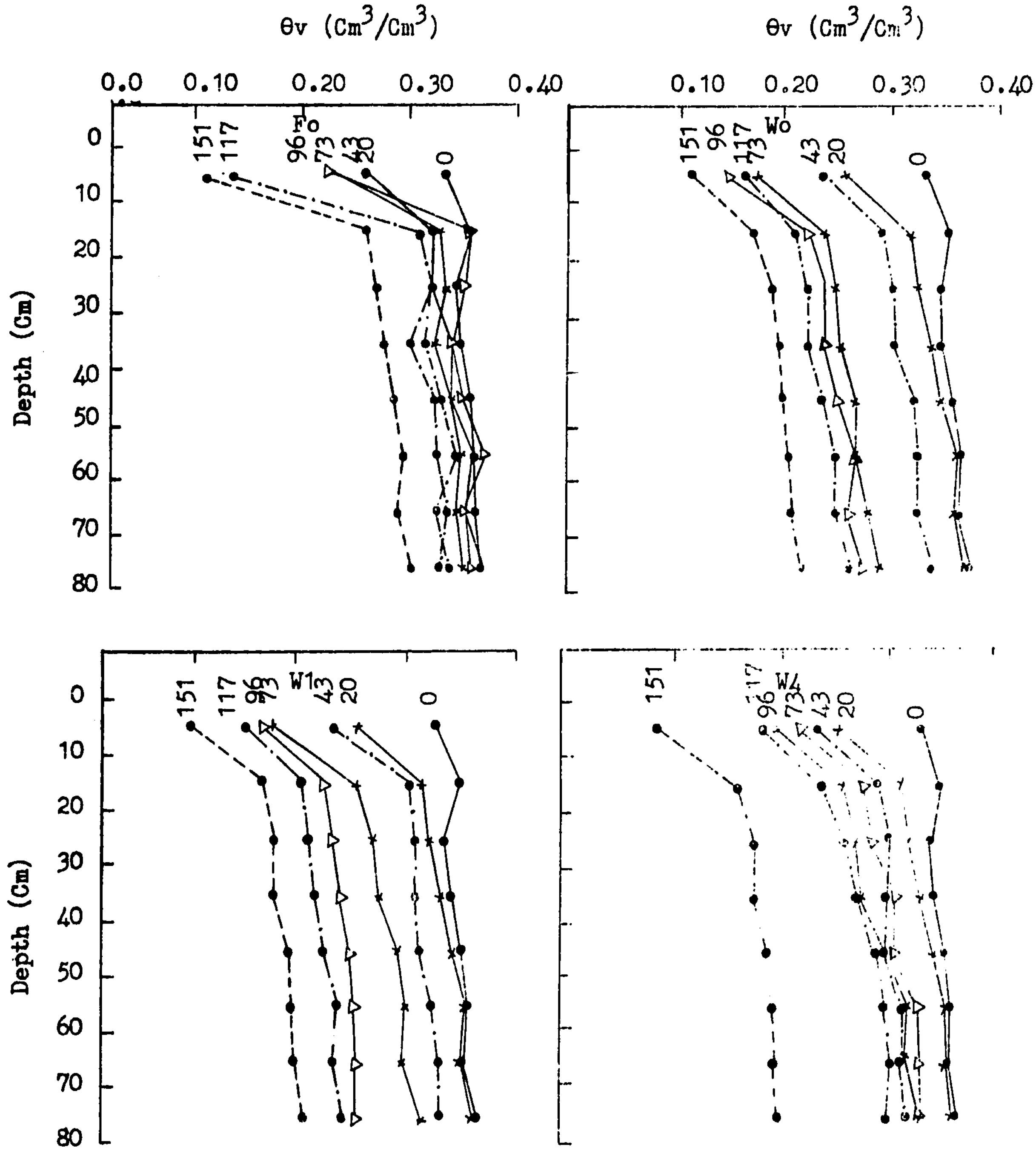


FIGURE 2. VOLUMETRIC WATER CONTENT VERSUS DEPTH UNDER FOUR TREATMENTS AT FOUR DIFFERENT TIMES.

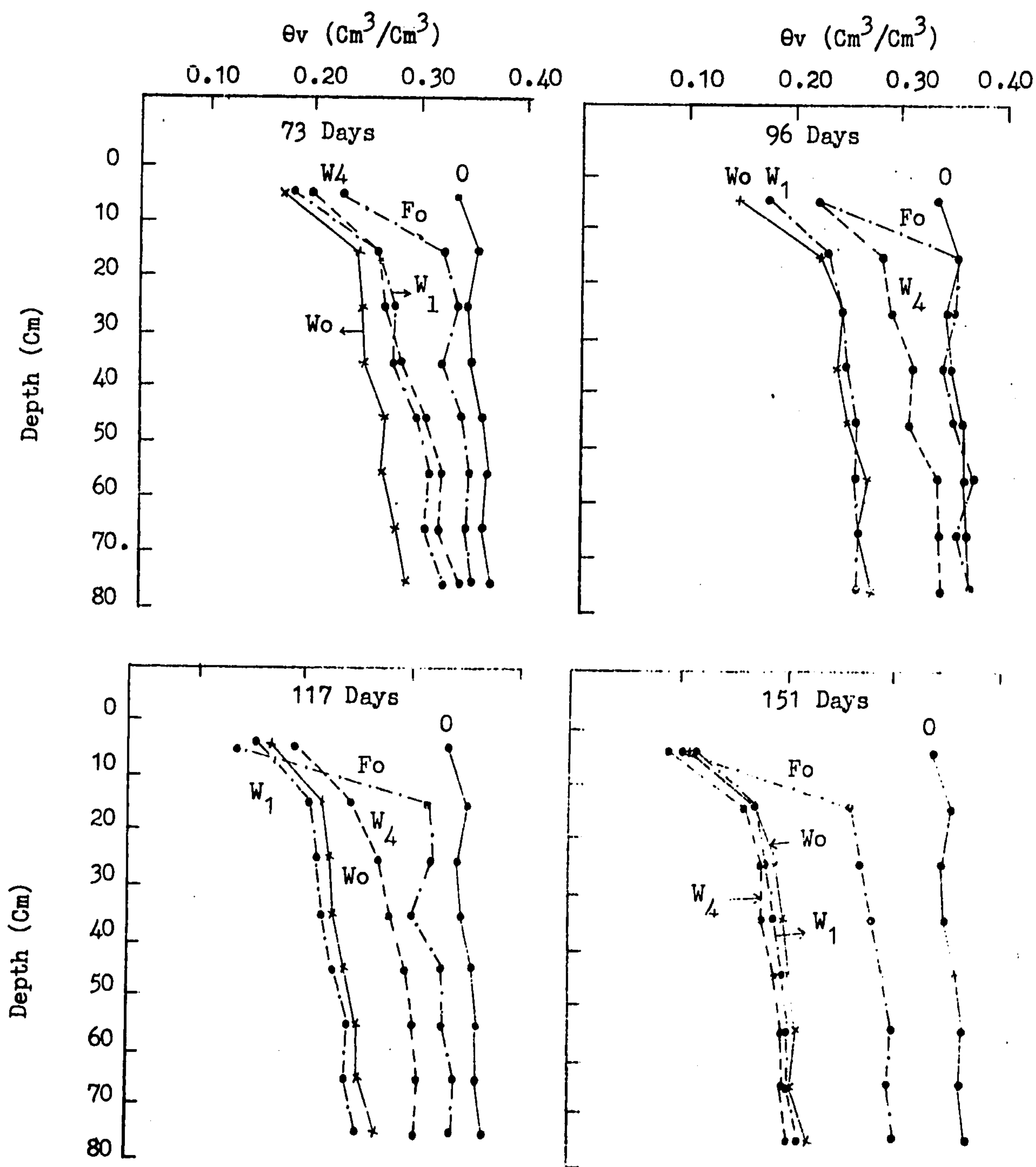


FIGURE 3. SEASONAL TRENDS OF VOLUMETRIC WATER CONTENTS AT FOUR DEPTHS UNDER FOUR TREATMENTS.

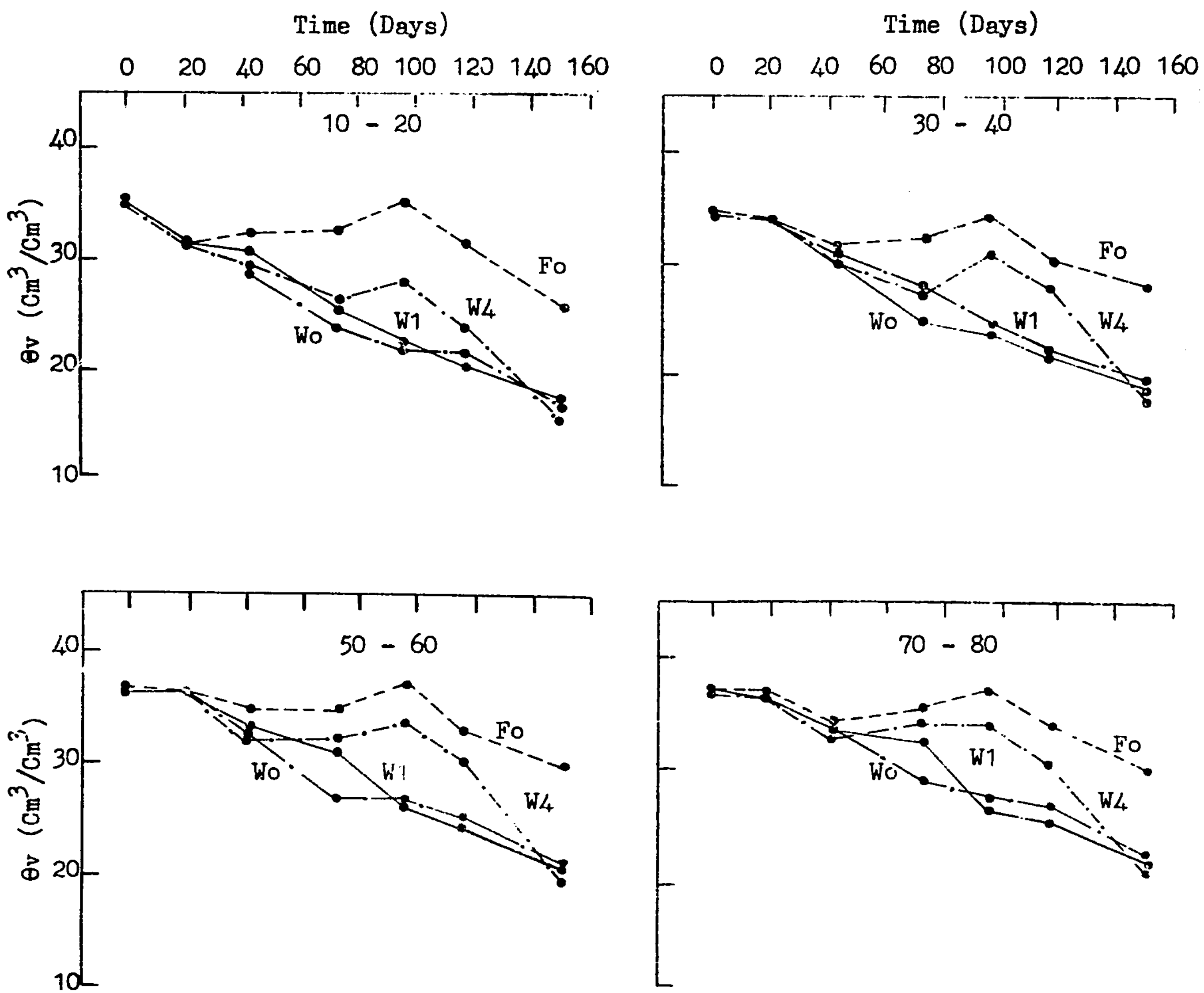
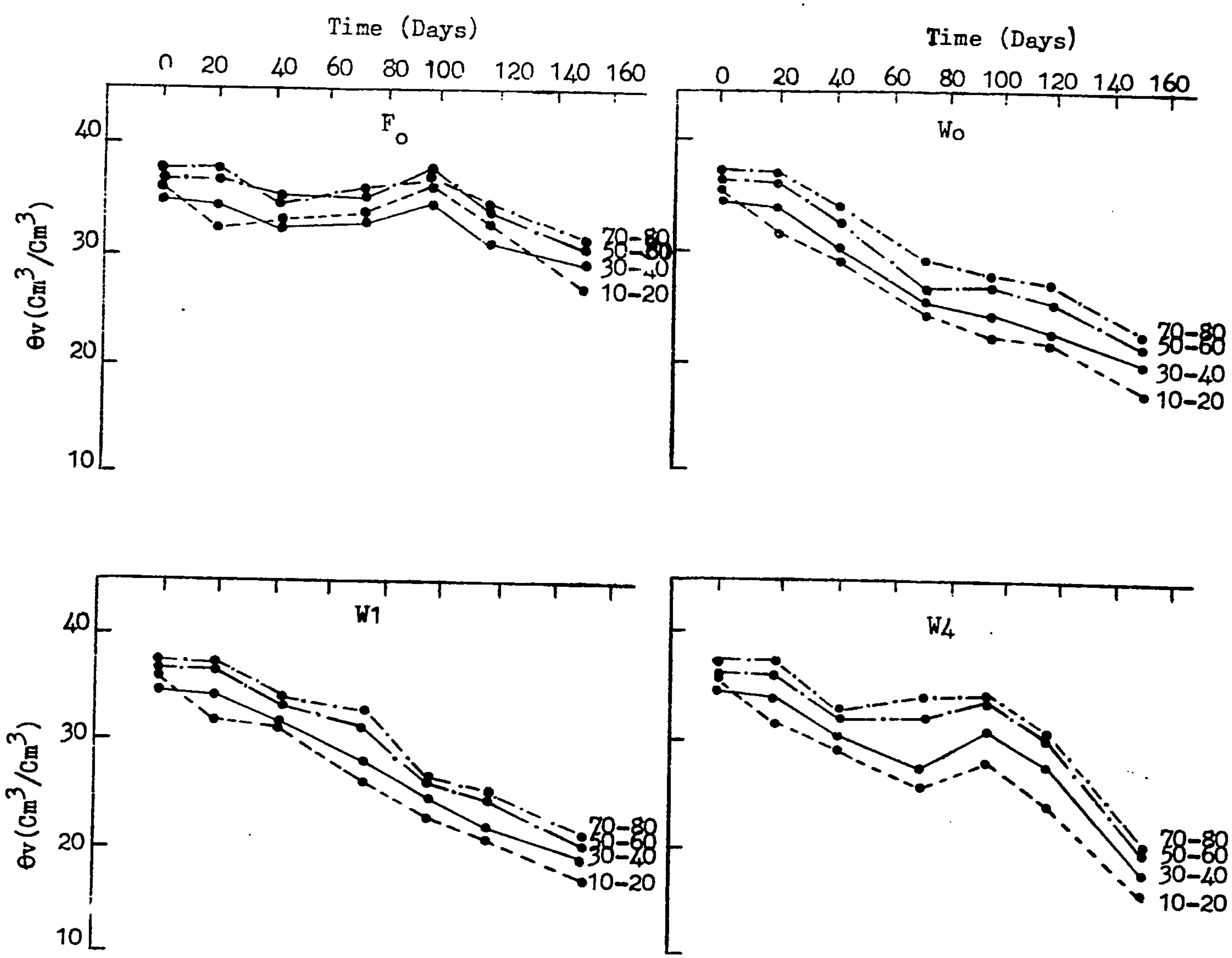


FIGURE 4. SEASONAL TRENDS OF VOLUMETRIC WATER CONTENTS AT FOUR DEPTHS UNDER FOUR TREATMENTS.



the atmosphere was low. For the fully irrigated wheat this low rate of profile depletion below 20 cm reflected both the low evaporative demand and the possible upward water movement into the 80 cm profile but also, and most importantly, the lack of depletion revealed the effects of the two irrigations that were applied to these plots during that period. The patterns of time and depth changes of moisture content of the fallow and fully irrigated plots are shown in Fig.4 by the nearly parallel nature and small slope in the 0-96 day portions of the fallow and fully-irrigated wheat sets of curves.

During the last eight weeks of the growing season, when the atmospheric evaporative demand was steadily increasing, significant depletion occurred at all depths from both the fallow and fully-irrigated wheat plots. Such depletion from the fully-irrigated wheat was 50 percent more than it was from the fallow plots (10.6 cm vs 6.1 cm) despite the fact that the wheat plots received two irrigations totalling 30 cm of water during this eight week period. In Fig.4, the late season pattern of profile depletion of the fallow and fully irrigated plots is clearly shown by the increased slope and parallel character of the sets of curves for those plots. The comparison among treatments of their profile moisture patterns at different times during the season are revealed by the curves in Fig.2. Those sets of curves reinforce the comments made in the preceding paragraphs. The between-treatment comparisons of the seasonal trends in moisture content at various depths are well depicted by the curves in Fig.4. The curves in both Fig.2 and Fig.3 show the generally uniform depletion and constant depletion rate that occurred throughout the 80 cm profile in the unirrigated and singly irrigated wheat plots. Fig.2 and 3, also reveal the general similarity of the depletion patterns in the fallow and fully irrigated wheat plots and show how the rate of depletion increased during the later part of the growing season.

Seasonal Profile Depletion

Although no samples were taken below 100 cm in the initial October 31 sampling, the lack of any consistent trend in moisture content with depth in the 50-100 cm section in the initial samples together with the continuity of moisture content, bulk density and physical appearance of samples taken from the second meter after harvest, strongly supports the assumption used in calculations of seasonal profile depletion, i.e. the initial moisture content in 100-200 cm section was 36 cm.

The total profile depletion data for 80, 100 and 200 cm depths from sowing to harvest for the various treatments summarized in Table 2 show that significant amounts of water were lost from the profile below the 80 cm depth. These data emphasize that on the deep Vertisols the seasonal water use by unirrigated gram and unirrigated and well-irrigated wheat will be seriously underestimated if based on profile depletion to a depth of only 80 cm. The ratio of seasonal profile depletion from the 80 and 200 cm profiles did not differ, being .59, .58 and .57 for the fallow, unirrigated and fully-irrigated wheat respectively. The pattern of seasonal depletion under the fallow and unirrigated wheat and well-irrigated wheat given in Fig.5 show the similarity of depletion of the cropped plots and the difference in magnitude but similarity in pattern of depletion under fallow.

Table 2. Seasonal profile depletion to three depths under different treatments

Profile depth (cm)	Treatments				
			Wheat		
	Fallow (cm)	Gram (cm)	Unirrig. (cm)	1 irrig. (cm)	4 irrigations (cm)
80	5.7	12.1	11.9	12.2	13.1
100	6.8	15.7	14.8	15.4	16.2
200	9.6	-	20.7	-	23.0

Seasonal Water Use

The water lost during any part of the season was the profile depletion measured during that period plus (a) the water added at the surface by rain or irrigation and (b) the net inflow through the lower boundary of the measured profile. In this experiment water flux across the lower boundary was not measured but in light of the discussion and data presented in the preceding section, it seems reasonable to assume that estimates of water use based on the upper 80 cm will be significantly too low at least on a total seasonal basis. If based on depletion data to a depth of 200 cm, estimates of water use will be higher and probably more correct.

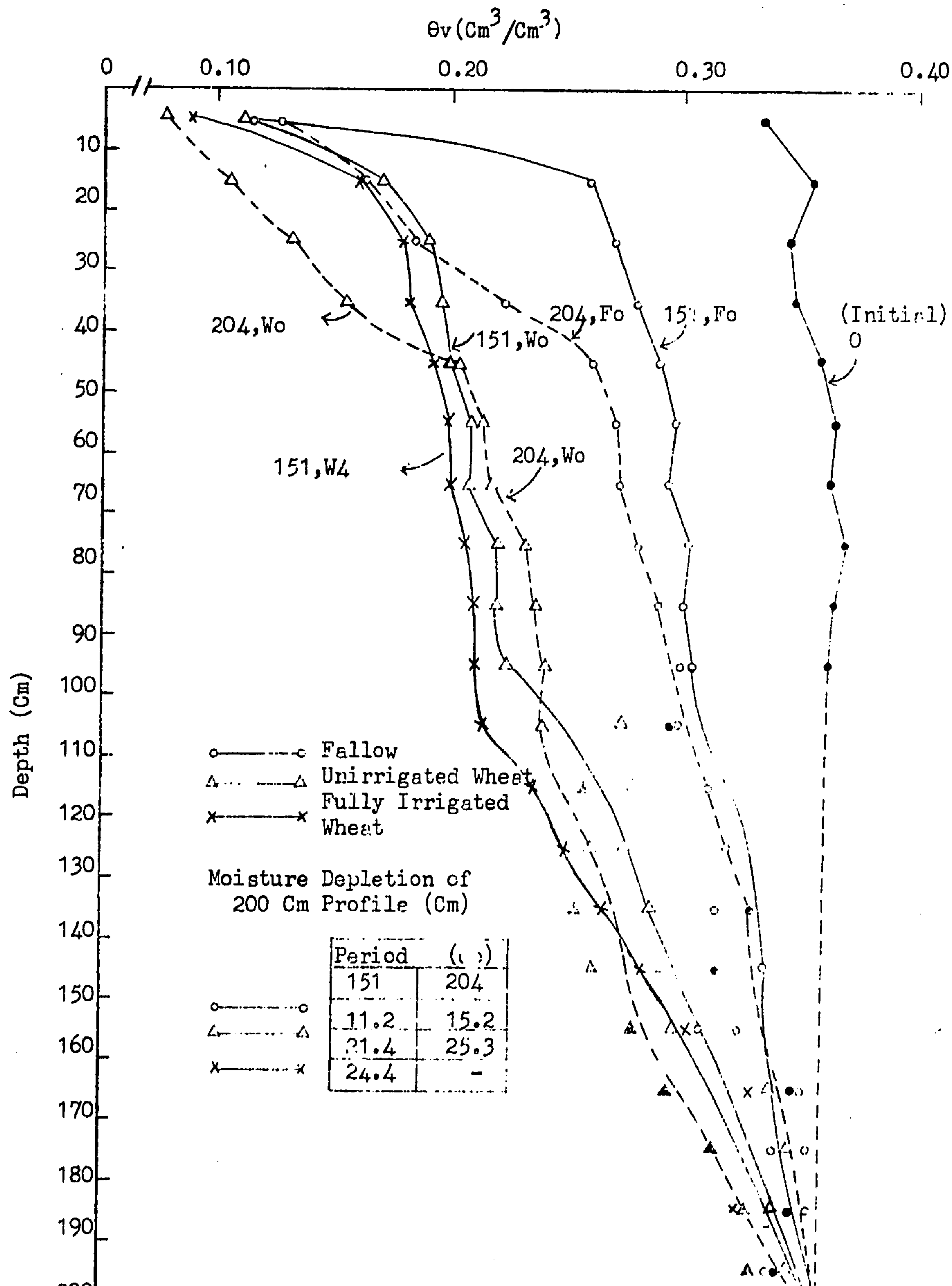
Table 3. Total seasonal water use (E_T) under various treatments

Amount of water		Fallow	Gram	Wheat		
				Unirrig.	1 irrig.	4 irrig.
Rain	cm	1.0	1.0	1.0	1.0	1.0
Irrigation	cm	5.0	5.0	5.0	13.8	53.8
ET_{80}	cm	11.8	18.2	18.0	27.0	67.9
ET_{100}	cm	12.8	21.8	20.9	30.2	71.0
ET_{200}	cm	15.6	*	26.8	*	77.8

* not measured

The water added by rain and irrigation during the growing season was measured and added to the profile depletion values to give the water-use data which is summarized in Table 3 above. These values assume that no

FIGURE 5. SEASONAL MOISTURE DISTRIBUTION IN A 200 CM VERTISOL PROFILE AS AFFECTED BY CROPPING AND IRRIGATION.



flow occurred across the lower boundary of the measured profile. The total open-pan evaporation for the 131-day growing season represented by the water use values of fallow, gram, unirrigated and singly irrigated wheat in Table 4 was 51.6 cm. For the fully irrigated wheat, which was harvested later, the value was 55 cm. If it is assumed that the 200 cm profile depletion data are best for estimating the total seasonal water use, the ratios of water use to open-pan evaporation for the fallow, unirrigated and fully irrigated wheat were .30, .52 and 1.41 respectively. The corresponding ratios based on depletion of the 100 cm profile were .25, .42, .41, .59 and 1.29 for fallow, gram, unirrigated, singly irrigated and fully irrigated wheat, respectively.

Table 4. Yield, straw-grain ratio, water use and water-use efficiency of unirrigated and irrigated wheat and gram

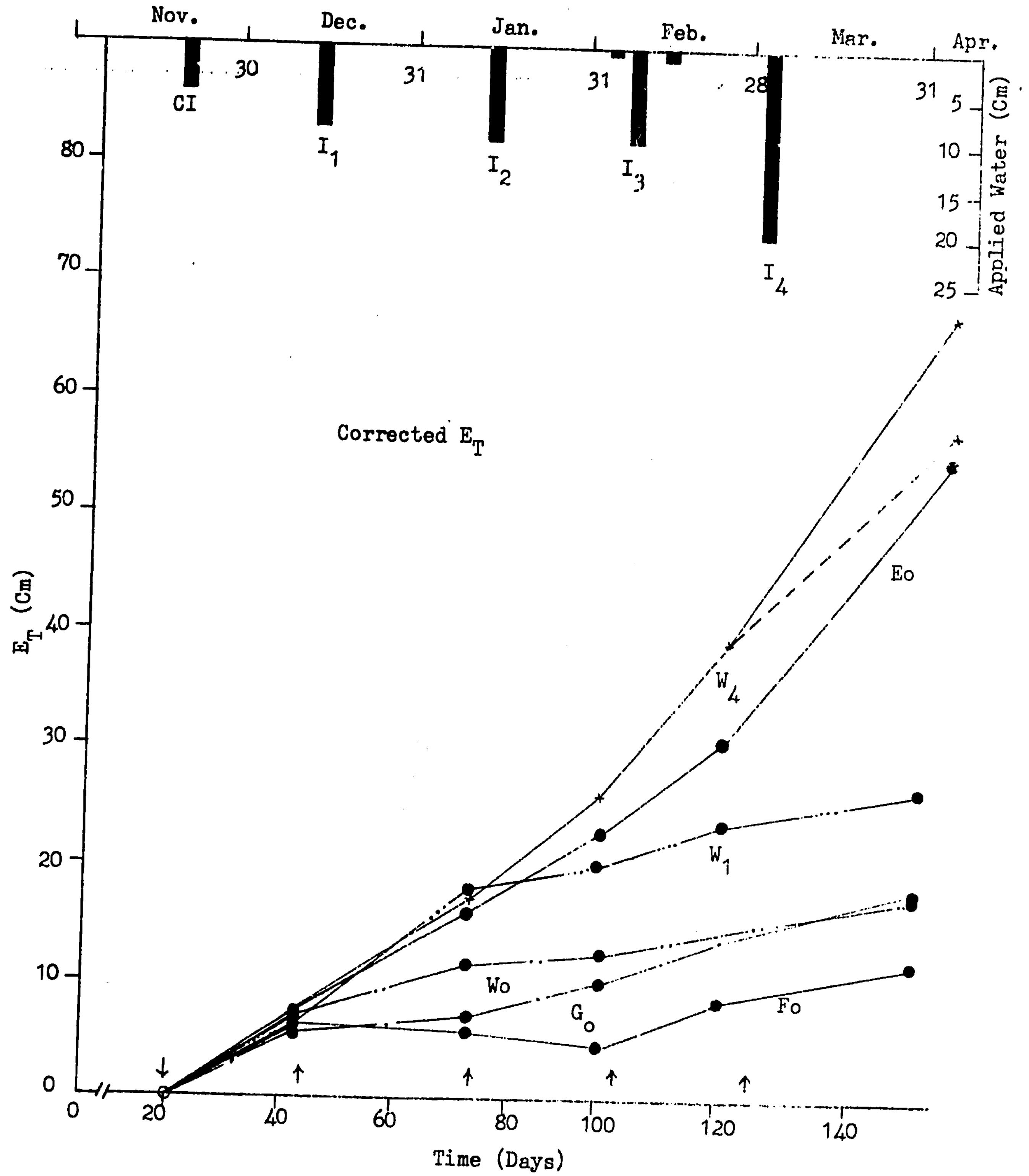
	Unirrigated			Irrigated			
				1 irrig.		4 irrig.	
	Gram	Wheat	Wheat+ gram	Wheat	Wheat+ gram	Wheat	Wheat+ gram
Grain wheat(q/ha)	-	24.5	15.8	29.7	21.5	48.8	37.4
Gram "	16.8	-	5.3	-	5.8	-	8.1
Straw Wheat "	-	39.2	23.7	38.8	28.9	58.5	43.7
Gram "	14.1	-	4.7	-	5.5	-	9.6
Straw/Grain Wheat	-	1.6	1.5	1.3	1.3	1.2	1.2
Gram	0.83	-	0.88	-	0.9	-	1.2
Water Use(ET_{100})(cm)	21.8	20.9		30.2		61.0*	
Water use effec.	0.77	1.17	0.98	0.99	0.90	0.80	0.77

* adjusted ET_{100} as explained in text

There is reason to question the high water-use values for the fully irrigated wheat. When the fourth irrigation was applied to these plots, there were large cracks in the borders and in the nearby unirrigated and singly irrigated plots. Some of these cracks appeared to be connected with the smaller ones in the fully irrigated plots. Thus, it was difficult by flood irrigation to get uniform wetting and infiltration to the plots with the 10 cm of water calculated to be required to recharge the 100 cm profile to a volumetric moisture content of 0.40. For this reason twice that amount of irrigation was applied. It was estimated, therefore, that roughly half of the water applied in the fourth irrigation moved out of the plots laterally through cracks. If this assumption is made, the adjusted water use for 80, 100 and 200 cm profiles become 57.9, 61.0 and 67.8 cm respectively and the corresponding water use versus open-pan evaporation ratios are reduced to more reasonable values of 1.05, 1.11 and 1.23.

Figure 6 shows the cumulative water use as calculated for the 80 cm

FIGURE 6. SEASONAL WATER USE AND OPENPAN EVAPORATION UNDER DIFFERENT TREATMENTS.



profile of the various treatments during the growing season in comparison with open-pan evaporation. The effect of adjusting the water use value of the fully-irrigated wheat is shown in the shift in that curve for the period following the fourth irrigation. The cumulative water-use curves show that during the first three weeks of sowing the 5 cm of 'come-up' irrigation applied to all plots led to water loss values that were between 0.8 and 1.0 of the open-pan evaporation.

During the next eight weeks, the indicated loss from the fallow plots was essentially zero because, as discussed previously, there was no profile depletion during this period. This implausible situation stems from the assumption of zero water flux across the low boundary of the 80 cm profile. During the later half of the growing season, the calculated cumulative loss from the fallow plots increased since net profile depletion occurred during that period.

The inability to account for possible upward water flow into the 80 cm profile also affects the calculated values of water use for all the other plots, although the underestimates arising therefrom are probably less than those encountered in the fallow plot data. Given that limitation, an examination of the other curves shows that water use by gram lagged that of unirrigated wheat during the first part of the season but occurred at a sufficiently higher rate later so that the total seasonal water use of the unirrigated wheat and gram crops were the same.

The water use by irrigated wheat was essentially equal to open-pan evaporation during the first seven weeks after sowing. After that period water use rate by the singly irrigated wheat declined steadily to a value one-third of that of open-pan evaporation during the last five weeks of the season. Water use by the fully irrigated wheat continued at or above open-pan evaporation throughout the entire season.

Water Use Efficiency

The grain and straw yields of wheat and gram grown alone and in combination under unirrigated and irrigated conditions are summarized in Table 4. The yield of both grain and straw of wheat and the wheat + gram mixture increased significantly as the amount of irrigation and the seasonal water use increased. The ratios of the grain yields of unirrigated, singly irrigated and fully irrigated wheat were 1:1.2:2.0 and for wheat + gram the ratios under the three moisture regimes were 1:1.3:2.2. The ratios of the yield of wheat to combined wheat and gram yield from the mixed sowing under the different moisture regimes were remarkably similar being 1.16, 1.09 and 1.07 for the unirrigated, singly and fully irrigated plots respectively. The straw to grain ratio of wheat decreased progressively with the increased water use and total yield. In contrast the straw to grain ratio of gram in the wheat + gram plots increased as the seasonal water use increased as a result of irrigation.

Although the yield of both grain and straw increased with the increase in seasonal water use, the response was not linear. Consequently, the grain produced per unit of water, which is here defined as the water use efficiency, decreased for wheat from 1.17 to .99 to .80 q/ha/per centimeter of seasonal water use for the unirrigated, singly and fully irrigated plots, respectively. The corresponding efficiencies for the combined wheat and gram were .98, .90 and .77 q/ha/cm.

DISCUSSION

A. Seasonal Profile Water Changes Under Unirrigated Crops

Wheat. The Vertisol profile which contains about 70-75 cm of water in the upper two meters after the end of monsoon loses a significant amount of water, mostly from the surface 30 cm of the profile prior to wheat sowing, and the moisture left in the seedbed often is insufficient for satisfactory germination and stand. The crop makes a good start if sowing is followed by winter rains or if a light 'come up' irrigation is applied. Once the roots reach a few centimeters below the surface, they encounter sufficient available water to carry on normal growth during the cool winter months when the evaporative demand of the atmosphere is low.

After sowing and until crown-root initiation, water extraction by roots is negligible and the profile behaves like that of uncropped land and loses water mostly by surface evaporation. This behavior is supported by the previous discussion which showed that there is no significant difference in the total profile moisture content under wheat, gram or fallow at the wheat crown-root initiation stage. Apparently evaporation induced suction gradients develop which result in the movement of water from lower layers towards the surface. Under the low evaporative demand conditions prevailing at this time, such upward flow is sufficient to meet the rate of evaporation which during this period remains nearly constant and roughly equal to open-pan evaporation. The constant evaporation rate is maintained as long as the increasing gradients in the subsurface are sufficient to compensate for the decrease in hydraulic conductivity of the water transmitting layers that results from their slowly decreasing moisture content.

After the crown-root initiation stage, when the roots become increasingly active, both water uptake by roots and evaporation from the soil surface occur simultaneously. As vegetative growth continues and root density increases, there is a progressive increase in transpiration losses. Conversely, the evaporation losses decrease due to more and more surface cover and to the continued decline of the water transmitting ability of the soil immediately below the surface. The active root zone gradually expands into the still moist subsoil and extracts more and more water from the deeper layers. At each depth, water depletion by roots results in suction gradients between that layer and the less depleted lower layers which causes water flow towards the depletion zone. Such flow will, however, decrease rapidly as the moisture content of the lower layers decreases because of the concurrent reduction in the water transmitting ability of the root-free lower soil layers. Because of the reduction in surface evaporation and the progressive reduction of moisture in the root zone, the evapotranspiration rate during the crown-root initiation to tillering period is reduced to about half of the open-pan evaporation rate.

Shortly after tillering and continuing to the milk stage of the wheat crop, the profile above 80 cm loses moisture at a very slow rate. This is due either to the penetration of roots below 80 cm or, alternatively, to the upward water flow into the root zone from root-free wetter layers below at a rate sufficient to supply most of the transpiration demand of the crop during the post-tillering stage. This uncertainty would be resolved if quantitative data on root distribution and on the presumed moisture fluxes were available. The evapotranspiration rate of unirrigated wheat in the tillering to milk stage period is only about one-fifth of the open-pan evaporation rate, if water use from below 80 cm is ignored. Since all of the post-season deep moisture samples showed significant profile depletion well below 100 cm, the actual water-use rate during this period is unquestionably greater than 0.2 of the open-pan rate as reported in the preceding section and probably is of the order of 0.5 to 0.6 of the open-pan rate.

Beginning at the milk stage, significantly wide and deep cracks begin to develop between the wheat rows. Such cracks and the comparatively high evaporative demand conditions during the remainder of the growing season combine to increase profile water loss from the upper 80 cm by evaporation. The post-harvest moisture loss from the unirrigated wheat plots indicate that as the cracks penetrade more deeply, profile depletion increases from the deeper layers with the result that at the end of the dry season, the moisture in the first meter is reduced to roughly half of the 70-75 cm that it had after the end of the preceding monsoon and the second meter has lost about one-fifth of its original water. Thus, the total dry-season depletion of a two-meter Vertisol profile amounts to about 25 cm of water or about 15 percent of the open-pan evaporation for the 8 month post-monsoon period.

<u>Gram</u>. During the three weeks after sowing, water extraction by gram is negligible and the profile behaves like those under fallow and unirrigated wheat, losing water mostly by surface evaporation. During the next month gram loses significantly more profile stored moisture

than fallow, but significantly less than unirrigated wheat because of its lower transpiration rate. The transpiration by gram is less than one-fourth of open-pan evaporation, during this period also because of its small top growth.

During the middle part of the growing season, profile depletion under gram occurs at a rate twice that of unirrigated wheat with the result that by the flag-leaf stage of wheat the residual profile moisture under the two unirrigated crops is similar. During the remaining five weeks until harvest when the atmospheric evaporation is increasing and the soil begins to crack extensively, the rates of profile depletion under gram and unirrigated wheat are similar to that of open-pan evaporation.

B. Seasonal Profile Water Changes Under Irrigated Wheat

Under fully irrigated wheat, the profile maintains a high moisture content almost all the time during the growing season. Initially, as under unirrigated wheat, gram and fallow, the irrigated wheat profile loses moisture mostly by surface evaporation at a rate approaching open-pan evaporation. Later, when root activity increases, both evaporation and transpiration continue side by side. Owing to frequent irrigations the surface remains wet most of the time and in the early part of the growing season sufficient energy reaches the soil surface through the incomplete crop canopy so that evaporation remains high and the sum of transpiration and surface evaporation approaches open-pan evaporation. Because of the high moisture level in the upper part of the profile, the ability of soil to transmit water to plant roots and towards the soil surface is maintained at a high level. By the flag-leaf stage when the canopy is fully developed, transpiration predominates although surface evaporation continues but at a reduced rate because of lack of radiant energy penetration to the soil surface. Under well irrigated conditions, the deep percolation process may be alternately downward and upward in response to the cyclic irrigation. Thus, it is difficult to predict anything about water use from the moisture profiles at lower depths. The direction of flow at the lower limit of root absorption could be inferred from tensiometer readings taken at two or more depths below that boundary. The amount of water flowing in response to the measured potential gradients could be estimated if, in addition to tensiometer readings, data were also available on the unsaturated hydraulic conductivity of the soil at various moisture potentials.

After the last irrigation and as the crop matures, profile depletion is primarily through transpiration by the fully established and actively transpiring vegetative canopy and is in response to the prevailing high evaporative demand conditions of the atmosphere. During the final stages of ripening when energy penetration to the soil surface begins to increase and when the soil begins to crack, water loss by evaporation becomes increasingly important and exceeds transpiration during the final stages of crop maturation. Post-harvest drying from irrigated wheat fields on the deep Vertisols is accompanied by the development of numerous deep wide cracks. By the beginning of the following monsoon, the first and second meters of the profile will be as depleted as those on which unirrigated wheat has been grown.

C. Seasonal Water Losses From Fallow Soil

After the end of monsoon season, the Vertisol profile is completely saturated. The surface layers contain relatively higher saturation moisture content than deeper layers due to low bulk density of the surface layers. Surface evaporation and deep drainage occur simultaneously and the profile attains a moisture content of 35-37 percent, a *de facto* field capacity in the upper two meters at the beginning of rabi season, i.e. the end of October.

During the first fortnight of November, the profile at *de facto* field capacity loses water mostly by surface evaporation following a square root law, i.e. cumulative evaporation is linearly related to the square root of time. During this period the profile loses water at a rate roughly 20 percent of open-pan evaporation largely from the upper 30 cm.

If such a fallow profile receives water either from rain or light sprinkler irrigation, like 'come up' irrigation to wheat after sowing, the evaporation and profile readjustment continue simultaneously. In the absence of further additions of water, profile drainage ceases by mid-January. The fallow profile shows no change in water content throughout February because steady state upward water flow is sufficient to meet the rate of loss by surface evaporation.

From the approximate K vs θ_v curve, which was plotted by using K at different θ_v of the previous section and using an infiltration rate of 4.8 sm/day at saturation moisture content of 0.40 cm^3/cm^3 and by assuming a linear relationship between log K and θ_v, the conductivity K at average θ_v (0.34 cm^3/cm^3) in the first meter profile of fallow plot was estimated to be 0.03 cm/day. Using this K and the average gradient of 2.5 in the 30-60 cm section of the profile, an approximate steady state flux was computed to be 0.07 cm/day. These calculations indicate that a fallow Vertisol profile in the month of February loses water by surface evaporation at a rate equal to 0.07 cm/day, i.e. the total loss of 2.0 cm of water for the whole month which is about 20 percent of the open-pan evaporation.

As the evaporative demand increases from March onwards, profile depletion augments upward water flow and evaporation loss increases. During this period more drying of the lower layers occurs due to penetration of cracks. At the end of dry season, the moisture in the first and second meters is reduced to 66 percent and 91 percent, respectively, of their initial water contents. Thus, the total dry-season depletion of a two-meter Vertisol profile amounts to about 15 cm of water or about 9 percent of the open-pan evaporation for the eight months post-monsoon period.

CONCLUSIONS

The results of the experiment led to the following conclusions:

1. Although the seasonal rate of water use by unirrigated gram is lower than that from unirrigated wheat, the total seasonal water use is the same for the two crops but only about one-third the amount of seasonal open-pan loss.

2. During the growing season substantial amounts of water are depleted from the second meter of the Vertisol profile under fallow, unirrigated wheat and fully irrigated wheat.

3. Even though the soil moisture tensions are maintained below one bar, fully irrigated wheat uses the same amount of profile water as is used by unirrigated and singly irrigated wheat. Under full irrigation evapotranspiration by wheat is equal to or slightly higher than that from open-pan.

4. Wheat yields are not proportional to seasonal water use. Higher water use efficiency is inversely related to yield and to total water use.

5. Total water use, total yield and water use efficiency under wheat and wheat + gram mixture are not different.

6. During the early cool part of the growing season, upward water movement meets the evaporation loss and no profile depletion occurs.

7. The drying of lower soil layers after wheat harvest is increased by the penetration of cracks to deeper depths.

WATER-USE EFFICIENCY

IN CROP PRODUCTION IN THE SEMI-ARID TROPICS

I. Arnon*

The basic characteristic of crop production in the subtropical semi-arid regions is that even in a given location, it is carried out under a wide spectrum of soil moisture regimes, ranging from seasons with below-average conditions, under which it may be difficult to avoid complete crop failures, to seasons with a moisture supply that may be almost or as favorable as that usually obtained in a temperature and fairly humid climate.

To start with, therefore, the choice of crops and varieties, as well as the production methods to be adopted must be aimed at efficient use of water under diametrically opposite conditions: (i) near-arid conditions of the rainfall-deficient years, during which drought resistance or tolerance and low-water use are the main requirements; and (ii) favorable environmental conditions provided during the good rainfall years.

It must further be pointed out, that even during favorable seasons, soil moisture in at least part of the root zone will usually fluctuate in a range between soil saturation and permanent wilting point. Therefore, more or less severe water stress may be experienced at any stage of development.

As there is no possibility of knowing in advance the kind of rainfall season that is expected, the crops and varieties to be grown and the management practices used must therefore be adapted to the wide range of possible conditions, from near-arid to highly favorable.

In the final analysis, the aim will have to be to choose crops, varieties, and management practices for the efficient use of water - under conditions of a limited moisture supply during the years of below-average rainfall, and of a favorable moisture regime such as is provided during good rainfall years.

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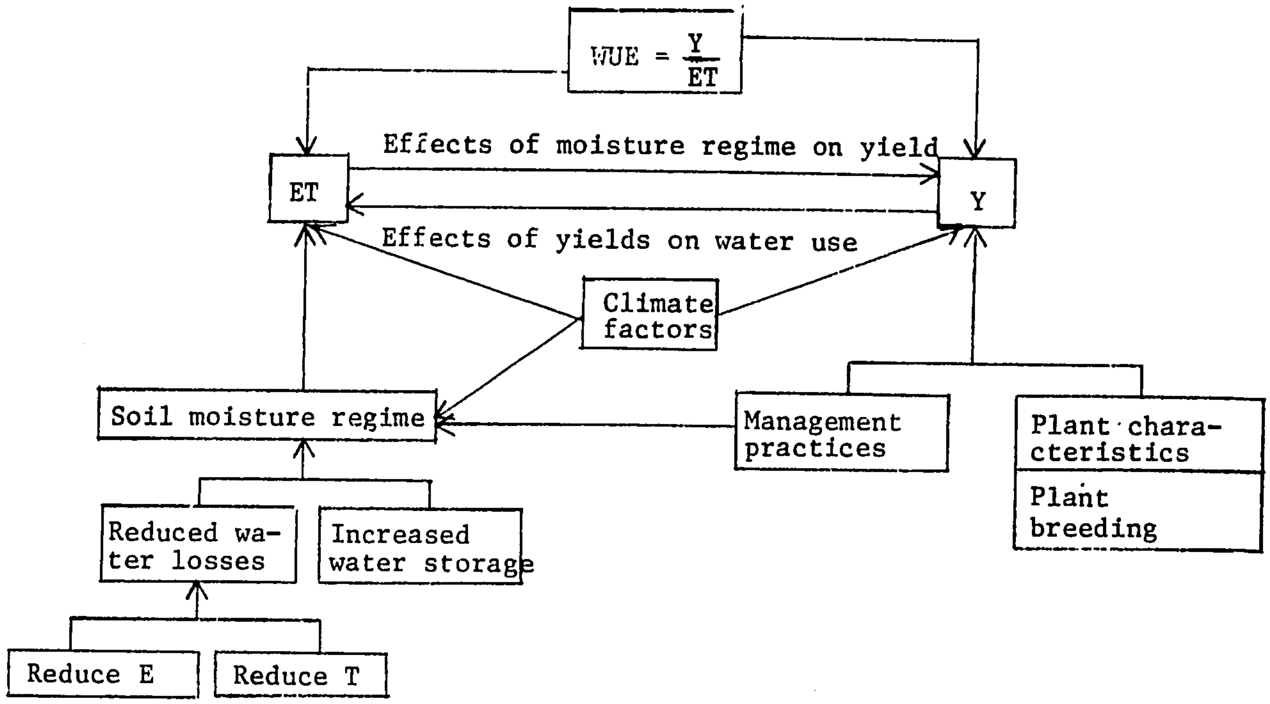
Fig.1: FACTORS INVOLVED IN WATER USE EFFICIENCY (WUE) AND THEIR INTER-RELATIONSHIPS
Y - Yield, ET - Evapotranspiration or Water use



Water-Use Efficiency

Water-use efficiency (WUE) is the yield of marketable crop produced per unit of water used in evapotranspiration. Therefore, WUE = Y ÷ ET, where Y = the yield of marketable crops and ET = evapotranspiration, or 'seasonal water-use' (Fig.1).

If yield were completely independent of ET, any factor which caused an increase in yield, or a decrease in ET, would have a favorable effect on WUE. If yield were proportional to ET, water-use efficiency would be constant. Actually, the numerator and denominator of the formula are not independent of each other. Both Y and ET can be influenced, either independently or differentially, by crop management and environment, and also the numerator Y is greatly dependent on moisture regime, in particular in dryland farming - the more the water available to the crop, the higher the yields will be generally. The greater water supply will, however, also increase the denominator ET. One of the dilemmas faced by the dryland farmer is the differential effect of management practices, environment and genetics on the two basic elements of the formula. For example, fertilizer application - essential for increasing yields - may cause a premature exhaustion of soil moisture causing reduced yields or even crop failure.

The two terms, 'Evapotranspiration' (ET) and 'Water-Use' (WU) are generally considered to be identical. This may be true quantitatively, but actually these two alternative terms highlight a dilemma presented by this formula.

The term 'Evapotranspiration' implies a loss of water, which should be reduced to the lowest possible level in order to increase WUE. The term 'Water-Use' implies the beneficial utilization of water for producing a commercial crop. From the purely mathematical point of view - increasing the denominator will decrease WUE: however from the physiological point of view it is essential, especially in dryland farming, to increase ET in order to achieve an increase in the numerator Y, our basic objective.

The practical conclusion to be drawn from the above is that every effort should be made to increase the amount of water available to the crop for production, and reduce to the minimum the losses of water due to evaporation and transpiration. Initially, these two objectives may appear to be at cross-purposes, but in practice the contradiction is more apparent than real, because fortunately, the effect on yie'ds of an increase in ET will almost always be greater than the actual increase in ET involved, so that the WUE is generally improved by an improved water supply, even though the latter signifies an increase of the denominator of the formula.

The possibility of increasing yields significantly under conditions of water deficiency with a relatively small increase in the amounts of water may be due to a number of reasons.

Notwithstanding the major influence of rainfall on yield levels, yields are generally not directly proportional to the amount of precipitation. Yield levels are determined by the amount of precipitation above the basic minimum required to enable the crop to achieve maturity. If, for instance, under given circumstances 250 mm is the necessary minimum precipitation for a grain crop, 225 mm, or a reduction of only 10 percent will result in complete crop failure. Conversely, 50 mm above the minimum requirement may double the yields; hence, the considerable importance of even minor increases in water storage in the root zone, or minor reductions in losses from ET. Certain practices, such as breaking a hard-pan, for example, which enables the crop to develop a more extensive root system, and to extract water to deeper depths and possibly to higher tensions, thereby increasing ET significantly, will result in still greater relative yield increases.

The nominator Y, depends on environmental factors, and in particular moisture supply, the kind of crop grown, and is, ofcourse, amenable to factors that increase yield, such as crop improvement for efficient water-use, and concurrently management practices, e.g. fertilizer use, planting dates, plant populations, etc.

The denominator ET depends on atmospheric conditions, the amount of stored soil water available at the time of sowing and on osmotic components of the soil water, effective rainfall during the growing season, the ability of the plant to take up water and the control it exerts over water loss (transpiration), and to a lesser degree on the actual yield obtained (Y).

Increased water storage in the root zone can be achieved by the control of runoff, improved infiltration and by water harvesting methods. Crop management practices, such as tillage and rotation are very effective in this respect and can incidentally also improve yields.

Water losses due to evaporation from the soil can be reduced by mulching and chemical treatment of the soil; water losses due to transpiration can be reduced directly by plant treatments (antitranspirants) and indirectly by management practices such as weed control, planting density and patterns.

I will attempt to highlight a few aspects only of this problem, and describe briefly the water harvesting methods used in Negev. To begin with, a few examples will be presented of how the dilemmas mentioned above are faced in agricultural research and practice.

In many dry regions, cropping systems are based on devoting one year to the storage of rainfall in the soil, so that a single crop can be grown on the cumulative rainfall of two years. Besides being highly inefficient in the storage of water, the fallow system inevitably involves the loss of one year of production out of two. In some countries (Australia, Israel), cropping systems which have a built-in auto-regulatory device ensuring a yearly, albeit fluctuating income have been devised. Such a system is based on alternating periods of two or more years of annual, self-seeding legumes - grazed by cattle or sheep - with one or more years of grain-crops. In the good rainfall seasons, the legume and the stubble of the cereal crop produce year-round grazing (provided the number of head of stock is properly adjusted to the carrying capacity), whilst good grain yields are harvested. In the poor rainfall seasons, the relatively low production of the legumes is supplemented by grazing the cereal fields which have no prospect of producing a satisfactory grain crop. What would have been a total loss in an exclusively grain-producing system, will give a fair yield of forage - even in conditions under which no grain is formed. The legumes may produce from 100 to 500 feed units per hectare even with a yearly rainfall of no more than 60-100 mm; with 200 mm, which is insufficient for grain production, the cereal may still produce 1000 to 1300 FU/ha. In a good year, the legumes will produce around 2000 FU/ha and the grain stubble will provide another 300-500 FU/ha (Arnon, 1972).

This integrated system of animal husbandry and cereal cropping also has the advantage of relatively low inputs: the annual legumes are self-seeding, so that no tillage, or only a minimum, is required. Only phosphatic fertilizers are needed, and if applied in excess of current requirements, the residues are not wasted. The legumes provide all the nitrogen that is needed by the cereal crop, but in a very good year additional nitrogen may be topdressed. The cereal can be seeded into the legume stand by a chisel-drill without additional tillage; excessive legume volunteer plants in the cereal can be controlled by herbicides. Grain volunteer plants in the legumes provide balanced grazing. Perennial weeds such as Johnson Grass and Couch Grass, are kept in check both by the grazing and by the competition of the cereal crop.

The effectiveness of the whole system depends on how animal numbers are in balance with the fluctuating forage supply.

Besides the advantage of a built-in regulating device, this cropping system is extremely effective in improving and then maintaining soil fertility. It is estimated that in Australia, the use of clover leys in the cereal areas has contributed to a 50 percent increase in yields of grain (Donald, 1960) with practically no application of fertilizer nitrogen. The fertility levels of originally poor soils have been dramatically raised to moderate and even high levels of fertility by sowing subterranean clover fertilized with super-phosphate.

BASIC BREEDING OBJECTIVES FOR RAIN-FED CROP PRODUCTION

Drought-resistance can be defined in a number of ways, particularly in terms of the ability of plants to (1) survive under drought conditions, (2) endure drought without injury, and (3) be efficient in their use of water.

Typically xerophytic plants have frequently adapted themselves to arid conditions by developing survival mechanisms, of which the most prominent is usually a reduced transpiring-surface resulting in dwarfed plants with very limited total leaf-surface. Survival is, therefore, achieved at the expense of productivity. However, in most cases, the farmer is not much concerned with the survival of the annual species and varieties he grows but with the productivity of his crops, as in case of crop failure he can always buy fresh seeds. Many of the typical xerophytic characteristics are not therefore, necessarily desirable in cultivars to be grown under conditions of limited water-supply.

In general, no satisfactory physiological, anatomical,or morphological characteristics have yet been defined which could serve as reliable criteria in selecting for drought-resistance without loss of productivity. The many tests that have been developed could, at best, serve for screening strains that are more or less capable of enduring drought, but without any consideration of their productive ability.

ABILITY TO ENDURE DROUGHT WITHOUT INJURY

A more modern school of thought believes that the only true criterion of drought-resistance for cultivated crops is the ability to endure drought without injury. In this sense, drought-resistance is defined as 'the ability of plants to adapt to the effect of drought and to grow, develop, and produce normally under drought conditions, because of a number of properties acquired in the process of evolution under the influence of environmental conditions and natural selection' (Henckel, 1964).

The 'ratio of the yield under dry conditions to the yield under optimal conditions of water-supply' is considered as a valuable criterion of this concept of drought-resistance (Levitt, 1972). However, a single example will suffice to show that this criterion of drought-resistance can be misleading in practice.

Harrington (1936), in varietal trials with wheat in semi-arid Saskatchewan, found that the variety 'Marwuis' gave more constant yields over a period of ten years and was less affected by drought than the variety 'Reliance'. According to the above criterion, 'Marquis' could be considered the less drought-susceptible variety of the two (Ashton, 1948). Yet during five of the seasons, which had a favorable moisture supply, 'Reliance' outyielded Marquis by an average of 645 kg/ha; during dry seasons, the difference was still in favor of 'Reliance', but reduced to an average of 41 kg/ha. The advantage for the whole period was clearly with 'Reliance'; indeed this variety which is, by definition, more susceptible to drought, but which has a higher yielding potential, produced for the ten-year period 3,430 kg/ha more than 'Marquis' (Harrington, 1935). Even in drought years, the yield of 'Reliance' was not lower than that of 'Marquis'.

A further point that has to be considered is the great variability in rainfall from season to season that characterizes all dry regions - indeed, the more the aridity, the greater will be this variability. A farmer will in all probability be better off if he grows varieties that have the yielding potential to give good returns in the good seasons, even if they are relatively disappointing in drought years. In general, the varieties with typical xeromorphic characters will also give poor yields in drought seasons, without being able to make up for this deficiency in seasons with favorable moisture conditions.

Ofcourse, there exist adaptations to an inadequate or fluctuating moisture supply which do not affect productivity adversely, and these, ofcourse, can and should serve as important characters, mainly for the selection of suitable parents in breeding programs.

One such possibility is genetically increasing the ratio of the economic yield component in relation to the total biological yield called 'coefficient of effectiveness' or 'harvest index'. Moisture regime determines first and foremost the total yield of dry matter produced. If grain yield accounts for only 40 percent of the biological yield as in the traditional wheat varieties, the negative economic effect of a limited moisture supply will be obviously greater than when grain production accounts for 60 percent of the biological yield - as in the new dwarf varieties. In fertilizer experiments on clay loam soils in Pantnagar, India, for three years, comparing the effects of N fertilizers on tall and semi-dwarf wheats, it was found that in the best treatments, the yields of dwarf wheats were double of those of ten tall wheats, whereas straw yields were almost equal for both types (Sharma et al., 1970).

When the biological yield is limited by external conditions, this does not always imply that the economic yield will be reduced, as surplus carbohydrate may move to the grain (Thorne, 1966). There may also be conditions in which an increase in harvest index accompanied by an overall decrease in potential biological yield may be desirable, e.g. under conditions of drought, when a crop with less vegetative development than others will be less affected by drought. Thus cereal types with very short straw and large ears may be more efficient under relatively arid conditions than types having the opposite characteristics.

Fertilizer use. In arid agriculture, the basic problem in plant nutrition is that of adjusting fertilizer applications to the moisture regime under which the plants are expected to grow. Even under conditions of limited moisture, nutrient deficiencies will reduce WUC, and therefore a moderate amount of suitable fertilizers, adjusted to the soil-moisture level, may increase WUE. If, however, the fertilizers increase water-use excessively in the early stages of growth, so that severe water-stress occurs at the critical stages, the opposite effect will result.

Basically, the problem is one of nutrient/soil moisture interactions. At one end of the spectrum, under conditions of sparce rainfall, is the need to limit fertilizer application to rates which will not promote more growth than the available soil moisture can sustain until harvest, or in other words, to prevent upsetting the very delicate and critical balance between vegetative and reproductive growth under conditions of limited moisture. At the other end of the spectrum, when rainfall is favorable, the farmer's aim is to ensure a level of nutrient supply that will enable the plant to make full and efficient use of the favorable moisture conditions which it enjoys. Unfortunately, crop response to fertilizers under varied conditions of precipitation have not been studied as intensively in the semi-arid areas as in the humid regions; many of the fertilizer experiments that have been carried out in the former have not been sufficiently reliable for predicting crop response to fertilizers. The results of the fertilizer trials are erratic, and often fail to correlate with chemical soil tests. Therefore, no clear-cut answer has yet been formulated to the question of whether and when fertilizer application is justified under conditions of low-moisture supply.

The following example gives an indication of the difficulties with which farmers and researchers are faced in deciding on fertilizer policy under these conditions. In one season, yields of wheat were increased significantly by fertilizer application in Oklahoma in seven locations out of eight; in the following much drier season, only a single yield increase with fertilizer was obtained (Eck and Stewart, 1954). In other words, whilst in humid regions fertilizer rates can be based on soil fertility levels, determined before sowing, in the semi-arid areas they depend on expected soil moisture regime, unknown at the time the decision has to be made.

Timing and balanced fertilizer application. Fertilizers, especially nitrogen, may stimulate early growth and thereby exhaust the soil-moisture supply before the period of maximum water requirement of the crop; for example, applications of N and P on sowing to rainfed groundnut in India, increased root growth, improved the root/shoot ratio, gave higher ET values and increased total dry matter production but caused a considerable decrease in yields of pods. The rapid increase in root development and leaf area apparently caused depletion of the limited soil moisture supply early in the growing period (Bhan and Misra, 1970a). However, occasionally, early stimulation of crop growth may enable a more rapid and deeper penetration of the roots into the subsoil, so that the fertilized crop is able to draw more effectively on subsoil reserves of water that have been accumulated during a previous period of fallow, or possibly the stimulation may favor a more active root system, with greater water-extraction ability (Smith, 1954). Phosphorus has been found to improve yields of wheat under conditions of relatively low rainfall, provided the drought is not too severe, by improving early growth and vigor, favoring increased root development, and advancing the maturity of the crop (Norum, 1963).

Generally speaking, a balanced nutrient supply is beneficial even under conditions of limited rainfall, as it actually enables the crop to make more efficient use of the limited soil moisture available. The applying of only a phosphoric fertilizer at the time of sowing (or to the preceding crop) and withholding the nitrogenous fertilizer, until the cereal crop shows the need for a stimulant, can be avoided.

Trends. The general tendency in semi-arid regions, even in advanced agriculture, is to be extremely cautious in fertilizer use. However, in the dry regions of developed countries, a newer trend for a more widespread use of fertilizers is evident, even where it was formerly taken for granted that fertilizer use was detrimental (Viets, 1967). This is owing, in part, to nutrient deficiencies becoming more acute as the original native fertility of the soil is gradually getting depleted through continuous cropping.

However, the main factor in promoting this trend is the more favorable moisture regime, improving crop responses to fertilizers, available as a result of the efforts for the improvement of moisture storage and reduction of moisture losses by crop rotation, improved tillage practices and chemical weed-control.

Plant population and distribution patterns. The number of plants required per unit area to achieve the highest yield depends on the nature of the crop and on its environment. This number cannot be too small, or else not all the production potential will be fully utilized; nor can it be too large, or else excessive plant competition will reduce the overall efficiency of the crop, in particular because of excessive moisture stress.

Maximum exploitation of the factors needed for growth is achieved only when the plant population excercises near-maximum pressure on all the production factors (Donald, 1963). As a result, the individual plants are under relatively severe stress because of inter-plant competition. Thus we come to the somewhat paradoxical conclusion that maximum yields are obtained from plant populations which do not allow the individual plants to achieve their maximum potential.

Plant population must be adjusted to available soil-moisture levels, either within rows or between rows. For example, increasing the distance between sorghum plants within the row to adjust to low moisture levels, generally defeats its own purpose; the young plants, with little or no intra-row competition, show excessive vegetative development - the soil moisture is rapidly depleted, and the plants are unable to form satisfactory ears or to mature their grain normally. The alternative is to space plants more closely within the row, and to increase the distance between rows to compensate for low moisture levels. In the wide-spaced rows, the soil moisture supply is not exhausted as rapidly as in narrow rows (Brown and Shrader, 1959).

It might be assumed that the wide row spacings, by exposing large areas of bare soil to radiation, would increase moisture losses owing to evaporation, thereby defeating the purpose of wider spacings. However, under dryland conditions, evaporation is influenced more by the moisture supply at the soil surface than by radiation. Therefore, once the upper soil layer has dried, further moisture losses by evaporation become negligible. Under these conditions, wide rows are not more conducive to greater water-loss by evaporation than are narrow rows.

An example of the effect of adjusting row width on yields under difficult moisture conditions is provided by an experiment in rain-fed groundnut, grown in a dry region of India. In a poor rainfall season with a total precipitation of 186.8 mm (plus the equivalent of 75.1 mm stored in the soil up to a depth of 1 m, before sowing) the best WUE was obtained from a planting distance of 60 cm x 25 cm. In the following year, with more favorable moisture conditions owing to a rainfall of 357.3 mm (plus 67.2 mm of stored water), the best WUE resulted from a spacing of 45 cm x 25 cm. In both seasons, the close spacing of 30 cm x 25 cm gave the lowest WUE (Bhan and Misra, 1970b).

Improving the water supply available to the crop. Below a certain level of water supply, crop production is not possible. Relatively small increases in moisture supply may give quite marked increases in yield.

Hence, even relatively small increments of water to the soil or reduced water losses may have disproportionally large effects on crop yields. Inevitably, ET will also be increased as a result of the improved moisture regime, but the effect on yields under moisture-deficient regimes, will always be greater so that water use efficiency will be improved.

The improved moisture regime in the soil can be achieved in two ways: (a) by increasing the amount of water stored in the root zone; and (b) by reducing losses owing to evaporation and transpiration. These two approaches can be complementary, and certain management practices, such as tillage, may have both effects concurrently.

The amount of precipitation taken in by the soil depends on runoff and infiltration. By reducing runoff and increasing infiltration, the amount of water stored in the soil can be increased, with beneficial effects on crop production, provided the total amount of effective rainfall are sufficient. However, under very arid conditions, reducing runoff and increasing infiltration rates are ineffective, as the amount of moisture that can be stored in the soil do not, in any case, suffice for crop production. In the latter case, efforts can be made in the opposite direction by increasing runoff and reducing infiltration in certain donor areas, which can then serve as a source of water-supply for the cropping areas.

Water harvesting methods. In principle, water harvesting consists in using water derived from an area that has been treated to increase runoff of precipitation to supplement soil moisture in an adjacent area, situated at a lower elevation. In many dry regions, in which contemporary precipitation alone is not sufficient to ensure a crop, harvested water plus that accumulated in the soil will suffice, if a proper ratio between donor area and recipient area is established.

There are three main methods of water harvesting: (a) creating micro-reliefs within more or less level fields; (b) conveying water from barren hillsides to adjacent relatively level land; and (c) directing flash-floods. The latter methods were developed to a fine art by the early Israelis and by the Nabateans in the Negev Desert (Evenari et al, 1971).

What motivated people to settle in the desert? During the reigns of King David and Solomon, routes were established through the Negev for trade with Arabia, Africa, India and China, mainly for luxury articles, such as Indian and Bahrain spices and perfumes and Chinese silks. To keep the overland routes open and safe from marauding bandits a network of fortresses had to be established along all the highways, which were located strategically on commanding hilltops and major cross-roads. Some of these fortresses subsequently developed into small towns. To feed these towns, garrisons and the caravans themselves, some form of local agriculture had to be established.

The period of prosperity in the Negev under the Jewish Kings lasted for about 3 or 4 centuries, and came to an end with the destruction of the Kingdom of Judah around 7th or 6th century B.C. Trade and communications were destroyed, which in time led to the abandonment of the agricultural settlements.

A new flourishing period started about the end of the third century B.C. with the Nabatean-Roman-Byzantine eras, which lasted 800-900 years. The trade routes were reestablished, fortresses and towns rebuilt. This led to renewed agricultural production, and remnants of the infrastructure are still visible to this day.

With the rising tide of Islam, the area was conquered in the 7th century by the Arabs. They did not destroy the cities, but the inhabitants slowly left their homes and moved to other places. The Negev was left to the Bedouins who became its masters for 1,300 years. Where scores of thousands had once lived in prosperity, a few hundred Bedouins barely eked out their subsistence. The ingenious farm systems were left untended and allowed to fall into a state of ruin.

Basically, three principal agricultural systems of runoff agriculture were developed in the Negev: (a) Individual terraced, narrow wadis; (b) 'Runoff' farmsteads consisting of groups of terraced fields; (c) Extensive long terraces on floodplains, adjacent to large wadis.

(a) Individual terraced wadis. Seen from the air, many tributary wadis look like rows of steps. Each step is in reality a terrace formed by building a wall of stones at right angles to the wadi. Floodwater cascades gently down from terrace to terrace, whilst silted loess soil builds up behind the walls forming a series of small, almost level fields. The terraces are thus erosion and flood control structures. These are the most primitive and simplest floodwater use systems found in the Negev. They have been used throughout the ages by all the civilizations in the Negev and the original systems are still occasionally used by Bedouins for growing barley.

(b) Farmsteads consisting of groups of terraced fields. Many thousands of farmsteads are found in small tributary wadis surrounded by barren hillsides. They differ from the former system in that most of their water is derived from the runoff from the hillsides. All these farmsteads have two basic features: (1) a cultivated terraced area in the wadi bottom; and (2) a water catchment area, divided into sub-catchments by water conduits which collect runoff from the hillsides and lead it to the field area.

The basic principle of the method is simple. The rainfall in the region is generally 3-10 mm at a time. The loess soils form a crust when wettened, which soon becomes impermeable to rain, so that runoff is possible even with light rains, whilst heavier rains cause typical flash floods which are much rarer. The system therefore is much less precarious than farming based on flash floods alone.

In research carried out at a reconstructed Nabatean farm, it was found that the total annual runoff in this system represents 15-20 percent of the total annual rainfall. If average rainfall is 100 mm, the runoff comes to 10-20 mm. As the ratio of catchment to cultivated area was found to be about 20:1, the runoff contributes 200-400 mm in addition to the 100 mm of direct rainfall, a total of 300-500 mm. It must be remembered that winter rainfall is more efficient than summer rainfall 300 mm being the equivalent of 500 mm.

A fascinating feature of the extensive ruins of the water-harvesting systems in the Negev is the wide occurrence of hundreds of thousands of stone mounds. Together with the stone mounds are always found long rows of heaped stones. The motive for the back-breaking work involved in clearing stones from the barren hillsides is not apparent at first sight.

There are four theories to account for these structures:

(i) The mounds are called in arabic 'Teleilat el Einab' (Grape mounds). The explorer Palmer (1872) accepted the Bedouin explanation that the mounds were used for growing vines, keeping the clusters of grapes off the ground. The vines were supposedly irrigated by hand with water brought up from the cisterns in the valleys. It has been calculated that the amount of water required exceeds tenfold the total capacity of the cisterns existing in the area.

(ii) The mounds are supposed to have served as 'air-wells' with dew condensing on the cold stones in quantities sufficient to drip, wet the soil underneath and provide water to the vines. It has been demonstrated that this dew formation in the mounds is not sufficient for this purpose, and that the soil underneath the mounds is not moistened significantly.

(iii) Kedar (1957), suggested that by clearing away the stone cover, erosion was accelerated and fertile silt carried down to the valley bottom where it was deposited. This is not a reasonal assumption. The total annual erosion was found to be 0.1-0.2 mm of soil. At least

200 years would elapse before building up 50-100 cm of soil. Stone mounds are also found in watersheds draining into cisterns. It is surely ridiculous to increase erosion for this purpose.

(iv) Evenari et al (1971) have shown experimentally that stone-clearing increases runoff, mainly when rains are relatively light; the increase may be 20-40 percent. With heavy rains (more than 20 mm), the runoff is greater from stone-covered slopes, but these rains are exceptional, so that the total annual runoff is greater from cleared slopes. The increased runoff from the slopes was used in three ways: (a) to flood high-lying plots receiving no other water; (b) to supplement water supply to terraces receiving water from another source; to fill cisterns.

(c) Diversion systems. The two previous systems, which were based on small watersheds, required only a few, relatively simple engineering devices. By contrast the diversion systems based on the diversion of large flash floods necessitated the building of large intricate structures. Instead of the small cultivated areas of the farm units, rarely more than 5 ha each, the fields of the diversion units covered an area of tens and sometimes hundreds of ha. A study of the diversion systems shows that we are not dealing with a single system, but with a number of superimposed stages. The most ancient system (Stage 1) was established when the water flowed naturally in a shallow depression in the original floodplain, and consisted only of stabilizing structures for the shallow depression. As alluvial silt was deposited in the terraces, and as the floods cut a progressively deeper gully in the wadi, water had to be raised out of the wadi bottom, and a diversion structure to lead the water to the terraces establishment (Stage 2). Because of the continuing silting process, the elevation of the terraces continually rose, so that new diversion structures at progressively higher elevations had to be built to control the new base levels of the wadi. When this became no longer feasible, what remained of the diversion system became a small runoff farm (Stage 3) receiving its water from two small watersheds of 35 ha, situated on the ridge adjoining the farm and no longer from the wadi itself.

The water yield of the diversion systems is low as compared to that of the two former systems. An area of 27 km^2 of the watershed supplied about 20.000 to 30.000 m^3 per year to the 10-12 ha of cultivated terraces. This amounts to less than 2 percent runoff of the annual rainfall, as compared to 10-20 percent runoff from small watersheds.

The diversion systems using large catchment areas are, in contrast with the two other systems, not only less efficient, but also lack the stability which is characteristic of the two former systems. The method proved to be over-ambitious, and led to a disturbed equilibrium in the desert resulting in erosion, silting up and finally destruction of the system.

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RECOMMENDATIONS OF COMMITTEE I:

RESOURCE ASSESSMENT AND UTILIZATION OF RESEARCH FOR FARMING SYSTEMS - LAND, WATER, CLIMATE AND MAN

J.S. Kanwar

1. Resource evaluation. To arrive at improved farming systems it is essential to initiate a continuous program on resource evaluation in the semi-arid tropics through collection of available data. The low rainfall belt of the seasonally dry tropics should receive highest priority in the establishment of "bench mark" locations.

2. Information gathering. The attainment of the objectives of the Farming Systems Program at ICRISAT can be accelerated by making a more thorough study of available research information on farming systems, by creating networks for information exchange and through cooperative research. It is essential that simple and reliable methods are developed to determine -- on the basis of climate, soil and crop data -- if a particular resource management technique is viable at a given location.

3. Agroclimatology. A major effort in agroclimatology is urgently required to complement and guide the Farming Systems Research Program. The priority tasks in agroclimatology are :

a) The assessment of climate in different regions with emphasis on biological interpretation as it affects agricultural production.

b) Quantitative water balance studies for different crops and cropping patterns to determine the magnitude of risk in semi-arid agriculture and to derive the farming systems and crops that best suit a specific resource environment.

c) Cooperation in the development of improved forecasting techniques for decreasing risk in semi-arid agriculture.

d) The determination and exploitation of regional agroclimatic potentials to supply a greater part of the nutrient requirements through cropping systems and management practices. Attention should be given to further development in the use of wind and solar power.

4. Soil and water management. For improving soil and water management

and to increase and stabilize agricultural production, the committee recommends:

a) Collection of additional information on the distribution and characteristics of the soils of the semi-arid tropics, particularly soil moisture.

b) Evaluation of the existing soil and water management techniques under varying environmental conditions and assessment of the potentials for transferability.

c) Exploration of the feasibility for better management technology on small land areas to facilitate general application.

d) Generation of low-cost runoff storage, pumping and utilization designs and the development of associated cropping systems. The crop, plant, nutrient and soil moisture interaction must be investigated in greater detail to arrive at more stable and improved farming systems in the semi-arid tropics.

e) Investigations on the role and place of small-scale water resource development for stabilizing semi-arid agriculture as compared to large irrigation proj-cts which replace dryland farming.

f) Initiation of more basic studies on infiltration, moisture storage and utilization in the soils of the semi-arid tropics.

g) Development of integrated crop-livestock systems which are profitable in rainfall-deficient years and which most efficiently use favorable environmental conditions in good rainfall years.

h) Creation of flexibility in plant population and distribution patterns to adjust to varying moisture conditions.

5. <u>Multi-locational testing.</u> A need exists for early testing of watershed-based farming systems under different environmental conditions to obtain comprehensive feedback as well as to develop the institutional requirements of improved resource management systems.

6. <u>Economic and social research.</u> Economic and social studies are needed in the evaluation and adoption of small watershed-based farming systems and associated technologies. Specific investigations should include:

a) Economic and social studies on costs, risks and benefits from alternative watershed management practices and study of factors affecting technology adoption.

b) Evaluation of alternative policies, institutions and arrangements whereby small farms can fit into larger watersheds and share in economic and social benefits, including those from runoff recycling.

Part II

Crops and Cropping Patterns

CROPPING PATTERNS FOR INCREASING AND STABILIZING AGRICULTURAL PRODUCTION IN THE SEMI-ARID TROPICS

B.A. Krantz* and Associates**

Cropping patterns are considered as a program segment which, when synthesized with many other segments, forms a Farming System.

A Farming System may be defined as follows: "The entire complex of development, management and allocation of resources as well as decisions and activities which, within an operational farm unit or a combination of such units, results in agricultural production, and the processing and marketing of the products".

The Farming Systems Program at the ICRISAT is 'resource-centered' and 'development orientated' and its major goals include the following:

1. To provide economically viable, labor-intensive technology for improving and utilizing the productive potential of natural resources while maintaining the quality of the environment.

2. To develop superior land-and water-management systems which can be implemented and maintained during the extended dry seasons thus providing additional employment to people and better utilization of available animal power.

3. To contribute to raising the economic status and the quality of life of the people in the semi-arid tropics by developing farming systems which increase agricultural output and make it more stable from year to year.

The objective of this paper is to review the evolution of the past and present cropping patterns and to evaluate the present resources and constraints as a basis for research and outreach programs aimed at improving farming systems in the Semi-Arid Tropics (SAT). The accomplishment of the above goals will involve the combined efforts of many disciplines.

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Evolution of Traditional Cropping Patterns

In temperate regions, the major physical constraint to crop growth is temperature or the length of frost-free period, while in the SAT, the major determinant of the length of growing season is the period of sufficient moisture for plant growth. The major cause of low crop yield and unstable agricultural production in the SAT has been the erratic and undependable nature of the rainfall during the wet months (monsoon period).

In the various agro-climatic regions of the world, farmers have evolved, within their resources and constraints, cropping patterns for optimisation and stabilization of agricultural production. These cropping patterns, as well as agriculture itself, have been evolved over a long period of time by trial and error method.

In some areas, factors such as malaria and other diseases in the low-land, forced early settlers into the steeper lands to avoid these problems and a system of shifting cultivation evolved. This system is still in use in many areas of Latin America and Africa but has largely disappeared in the SAT of most of Asia. Even though many of these lands are relatively steep, soil erosion was not a serious problem in the early stages for the following reasons:

1. In the 'slash and burn' system of shifting cultivation, the roots of the brush and grass remain and planting is accomplished with a minimum of soil disturbance. In some cases the only soil disturbance is in the planting operation which is accomplished by dropping the seeds in a narrow slit made by the point of a machete.

2. The shifting-cultivation areas were cropped for only 1 to 3 years and then allowed to go back to grass and brush for another 20 to 30 years.

Now, with the recent population explosion, the increased demand for food has greatly reduced the length of this rotation and even annual cultivation is practised in some fields. Thus, in some cases whole hill sides are being cropped and severe soil erosion is taking place.

In the present traditional agricultural setting, the recent expansion of cropping to more unsuitable lands is resulting in lower yields owing to soil fertility depletion, soil structure degradation and soil erosion.

Traditional Cropping Patterns in the Major Areas of the Semi-Arid Tropics

There are many factors which have influenced farmers in developing their cropping patterns in the SAT. The two major determining factors are climate and soils.

The climate of the semi-arid tropics is discussed in detail by Kampen and associates (1974). The discussion in this paper will be limited to the role of climate in determining cropping patterns. There are distinct wet and dry seasons in all areas of the semi-arid tropics and the main variation from area to area is in the amount and intensity of the rainfall during the wet season. The rainfall pattern in the SAT is erratic and short-duration droughts may occur even during the monsoon season. Thus, a crop may suffer from water-logging owing to excessive rainfall and from drought because of a scarcity of rainfall during a single cropping season. Examples of monthly rainfall variability are shown in Figure 1.

The key properties of the major soils of the semi-arid tropics are discussed by Kampen and associates (1974). This discussion will emphasize properties as they relate directly to the development of the cropping patterns. Owing to climatic factors of soil formation, most of the soils of the SAT are very low in organic matter and native fertility. This coupled with the erratic and undependable rainfall patterns makes crop production in the semi-arid tropics a relatively hazardous enterprise. In traditional agriculture with minimal inputs, the yield per hectare was low, but as long as there were ample hectares available for expansion, the farmer usually was able to meet his food needs, except in years of extreme drought when famines occurred.

To optimize production and to reduce the risk of crop failure owing to the erratic and undependable rainfall, the early farmers in the SAT evolved the following types of cropping patterns:

'Mixed cropping' - where two or more crops are grown simultaneously with no row arrangement.

'Intercropping' - where two or more crops are grown simultaneously in rows in a definite pattern.

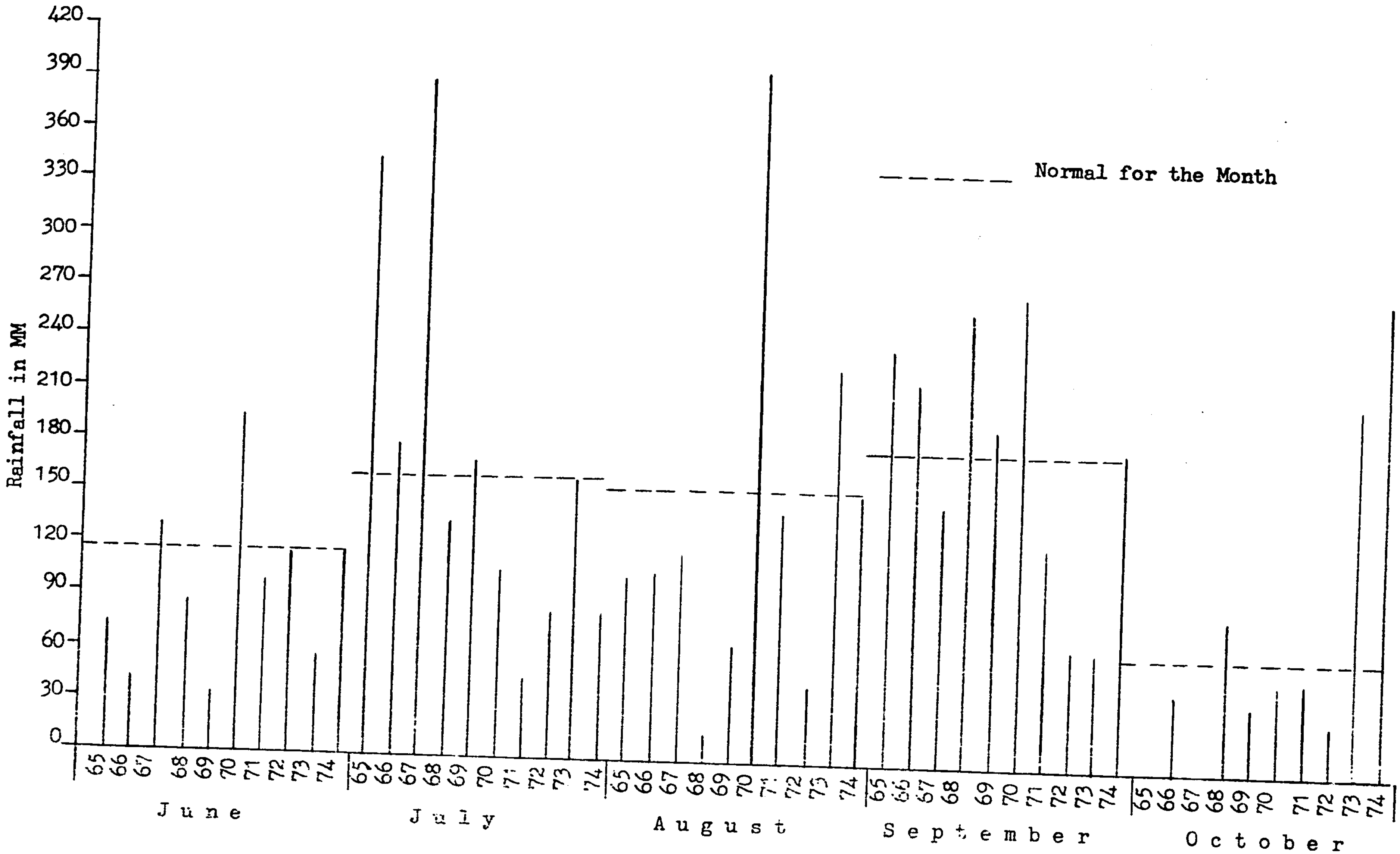
Other possible reasons for the adoption of crop mixtures were to maintain soil fertility by growing legumes with cereals, to spread labor peaks since all the crops in a mixture do not mature at the same time, and to provide the farmer with several types of food-grains.

In discussing the cropping patterns of the various areas of the SAT, no effort will be made to make an exhaustive list. A few cropping patterns in each area will be given to illustrate their relationships to climate, soil conditions and socio-economic patterns.

India

Most cropping patterns followed in the semi-arid tropics of the

Figure 1. THE VARIABILITY IN MONTHLY RAINFALL DURING THE MONSOON PERIOD FROM 1965 TO 1974.



country are based on the traditional systems of subsistence farming where every farmer tries to produce everything he needs; however, most of the larger farmers also include production for the market. The evolution of a cropping pattern is determined mainly by the physical characteristics of the land, climate, availability of labor and capital and the need of the household for food and fodder. Until recently crop production was generally based on the utilization of the inherent fertility of the soil without use of modern inputs such as fertilizers, pesticides and other ingredients of science-based technology.

Since cropping pattern data are reported on district or state basis, it is difficult to obtain accurate data relating to SAT regions of the different soil groups. A recent survey of the average cropping pattern on all soils in 84 districts representing the low-rainfall (400 to 1000 mm annually) areas is shown in Table 1. These 84 districts constitute nearly 36 percent of the net sown area in the country, covering about 47 million hectares.

Table I. Cropping pattern in the low rainfall-unirrigated areas of India[1] (average of 84 districts)

	Area under different crops in percentage of total cropped area		Proportion of All-India Acreage (In percent)
	Low rainfall unirrigated areas	All-India	
Jowar (Sorghum vulgare)	22.92	11.92	64.34
Bajra (Pennisetum typhoides)	11.61	7.56	51.39
Maize (Zea mays)	1.62	2.93	19.19
Ragi (Eleusine coracana)	2.35	1.69	46.33
Wheat (Triticum aestivum and T. durum)	7.66	8.36	30.66
Barley (Hordeum vulgare)	1.40	2.20	21.38
Chick pea (Cicer arietinum)	6.27	6.66	31.51
Pigeon pea (Cajanus cajan)	2.33	1.65	47.24
Groundnut (Arachis hypogaea)	9.17	4.15	74.06
Other oilseeds	3.31	3.30	36.52
Cotton (Gossypium arboreum, G. hertaceum, and G. hirsutum)	9.55	5.28	60.51
Other crops	21.81	44.40	-
Total	100.00	100.00	

[1]Taken from 'A New Technology for Dryland Farming,' India Agricultural Research Institute, New Delhi, India, 1970. p. 7.

The data in Table I give a general idea of the importance of various crops and indicate that sorghum, pearl millet and groundnut are the three most extensive food crops grown in the 84 districts.

The data also show the national importance of these districts in the production of groundnut, sorghum, pearl millet, pigeon-pea and chick-pea. The respective percentages of All-India acreages for these five crops are 74, 64, 51, 47 and 31. However, there are wide inter-regional variations in cropping patterns. In the case of sorghum, five districts in Maharashtra had on an average 42.9 percent of land under sorghum whereas the average for the 84 districts shown in Table I was only 22.9 percent (Kanwar, 1968). Likewise, in the case of pearl millet and groundnut, in some districts in Gujarat and Andhra Pradesh the percentage of land under the crop was two to three times the average given in table 1 for the 84 districts.

Crops are grown either as crop mixtures or as pure crops in all of the semi-arid tracts of India during either the monsoon or post-monsoon season. The crop or crop mixture used in each is discussed in the following sections.

Black Soils

Black cotton soils, also called vertisols, are formed from a variety of rocks which include traps, granite and gneisses, particularly those rich in lime feldspars. Thus they are usually rich in bases including potassium, calcium and magnesium. In the black soils, the montmorillonitic and beidelite types of clay predominate and impart the characteristic swelling and shrinking properties and a high water-holding capacity. The pH ranges from 7.0 to 8.5 and the lime content from 1 to 10 percent. Owing to their formation under semi-arid tropical conditions, the soils are low in organic matter (0.4 to 0.8 percent) and are usually deficient in nitrogen, phosphorus and sometimes zinc

Black soils are found mainly in the central region of India. The total area of black soils in India is about 60 million hectares of which about 54 million hectares are in the rain-fed (non-irrigated) area (Singh 1974). A recent survey (IARI, 1970) shows that 57.2 percent of the unirrigated SAT is cultivated. On this basis there would be about 30 million hectares of black soils under cultivation.

The cropping patterns followed in the various black-soil regions may be grouped as follows.

(a) Cropping in monsoon season only. This pattern is followed on shallow and medium textured, moderately deep black soils by utilizing the available water in the rainy season. Exact figures are not available, but it appears that less than 40 percent of the black soil falls in this group (Singh, 1974). The most common cropping mixtures and sequences are as follows:

Sorghum + pigeonpea + sesamum (intercrop)

Pearl-Millet + pigeon-pea + sesamum (intercrop)

Sorghum + pigeon-pea - fallow (2 year rotation)

Sorghum + pigeon-pea - groundnut (2 year rotation)

Sorghum + pigeon-pea - cotton (2 year rotation)

Cotton - sorghum + pigeon-pea - groundnut (3 year rotation)

The pigeon-peas which are grown in mixtures with sorghum are late maturing and are harvested by February.

(b) Cropping in post-monsoon season only. This system is commonly used in deep or moderately deep black soils by utilizing the residual moisture following monsoon season 'fallow'. Although no exact figures are available, it appears that over 50 percent of the cultivated black soil is fallowed during the monsoon and then cropped during the post-monsoon season. This would amount to a total of more than 15 million hectares. (Preliminary observation at ICRISAT indicate that if suitable soil, water and crop management systems are used, a substantial increase in food production could be realized by cropping some of the fallowed lands during the monsoon seasons. Also with short-season crops there is a possibility of relay or double cropping in the medium to high rainfall area ($>$ 750 mm) (Krantz *et al.*, 1974). However, the amount of monsoon fallow has been reducing in recent years owing to population pressures (Singh, 1974).

Common cropping mixtures and sequences followed in these areas are:

Fallow - sorghum + oilseed mixture (intercropping)

Fallow - chick-pea (continuous)

Fallow - wheat (continuous)

Fallow - wheat - fallow - gram (2 year rotation)

Fallow - wheat - fallow - linseed (2 year rotation)

(c) Cropping during both monsoon and post-monsoon seasons. In some deep black soils, a monsoon crop is grown during the rainy season followed by catch crops of pulses or oilseeds grown on residual moisture. If rains are sufficient, wheat or a post-monsoon sorghum-oilseed mixed crop is grown. Double cropping appears to be practised on less than 10 percent of the black soil area.

Common sequences followed in these areas are:

Monsoon crop	Post-monsoon crop
Sorghum	- pulse
Sorghum	- safflower
Groundnut	- safflower
Pulses	- wheat
Pearl-Millet	- wheat
Cotton	- sorghum + safflower

Red Soil

The red soils are usually developed from ancient granites or gneisses owing to the type of parent material and soil formation processes under semi-arid tropical conditions, the soils are usually low in nitrogen, phosphorus and sometimes zinc. The potassium level is usually medium to high. The pH ranges from 5.5 - 7.0. The clay fraction of red soils is rich in kaolinitic clay. Red soils range from shallow to medium in depth and have a relatively low water-holding capacity. Crops are grown only during the monsoon season. Sorghum, groundnut, setaria and ragi may be grown as pure crops or as mixtures with each other or with pigeon-pea, pearl-millet, castor, bean and cotton.

Important cropping mixtures and sequences followed in red soil regions are:

Cotton	+ setaria (intercropping)
Sorghum	+ pearl-millet + pigeon-pea (intercropping)
Finger-millet	- groundnut or horsegram (two year rotation)
Sorghum	- pulses (two year rotation)
Finger-millet	- pulses (two year rotation)
Sorghum	- groundnut - cotton - setaria (4 year rotation)
Finger-millet	- continuous

In seasons with late rains in September, crops like horsegram, sesamum and safflower are grown following early-maturing monsoon crops.

Alluvial Soil

These soils usually possess good physical condition, are easily tilled and are moderately permeable. The water-holding capacity is relatively low compared with that of the black clay soil. These soils are usually low in organic matter and are deficient in nitrogen and sometimes low in phosphorus and zinc. Potash may also become deficient after prolonged intensive cropping.

The major crops grown during the monsoon season are pearl-millet, sorghum, pigeonpea and groundnut. The major crops grown during the post-monsoon season are wheat, barley, chick-pea, mustard and rape. The cereal crops are usually grown as mixture with an oilseed or legume crop.

The common cropping pattern followed are:

Fallow - wheat (one year sequence)

Fallow - barley (one year sequence)

Pearl-millet - chick-pea(one year sequence)

Pearl-millet - barley (one year sequence)

Monsoon fallow - chickpea - monsoon fallow - sorghum + sesamum (2 years)

Sorghum + grazing - monsoon fallow - wheat (2 years)

Africa

Soil analyses and other information on African soils are somewhat limited. Richardson (1968) reported that nitrogen is almost universally deficient in the soils of tropical Africa. Phosphorus deficiency is widespread in some areas whereas potassium deficiency is more localized. Sulphur deficiency is widespread especially in the savanna zone. The apparently high fertility of tropical forest soils is illusory, for the forest trees live in a closed cycle of growth and decay; as soon as the trees are cut down and crops are grown, nutrient deficiencies begin to appear.

West Africa

The details of current farming methods employed by the West African farmer vary considerably according to climate, soils, vegetation, population densities and the tribal group to which the farmer belongs. Nevertheless, certain general statements can be made.

Most of West African agriculture is still largely based on subsistence farming. Intercropping is a common practice and many unique crop combinations are used (Norman, 1970). Most individual farmers cultivate only small, or moderate-sized areas with hand tools such as the hoe and cutlass (machete). After clearing, the general practice is to cultivate a plot until it shows signs of exhaustion, as indicated by reduced yields, or has become infested by weeds. The field is then abandoned and allowed to 'rest' and return to native grass and brush for a period of years to recover its fertility and productivity after which it is cleared and cultivated again. This is called shifting cultivation.

Two distinct types of vegetation are observed in Africa, the forest and the savanna.

(a) The forest zone. The forest zones are in the wetter areas. The most common practice in the forest zone is to plant a cereal as the first main crop, usually with some mixture of other crops, such as pulses and vegetables; then to interplant with annual, or semi-perennial root crops such as yams, and subsequently to interplant again with perennials such as bananas. Very similar procedures are followed elsewhere in the humid tropics of Africa.

(b) The savanna zone. In the savanna zones there is usually one wet season followed by a long dry season. The savanna vegetation is relatively sparse so that clearing is easy. However, the soils are often thin and gravelly and the long-established method of cultivation in many areas is to dig the land with a hoe to a depth of about four inches before planting the first crop. This procedure is repeated each season before replanting at the beginning of the rains. In the northern Ivory coast, northern Ghana, and parts of northern Nigeria the practice is to scrap up the soil into individual mounds on which the various crops are grown.

The normal subsistence food crops are yams (*Dioscorea* spp), maize, millets, sorghum and groundnuts. Cropping usually continues for a period of three to four years, during which cereals, legumes and root crops are grown, in a sequence with small amounts of interplanted vegetables. Very commonly, pigeon-pea or cassava is planted at the end of the cropping period, weeding being discontinued after their establishment, and the crop subsequently harvested during the first year or two of brush fallow regeneration.

In the wetter savanna zones of northern Nigeria and Ghana, yams are usually planted first on large, well-prepared ridges or mounds at the beginning of the rains, and a variety of other crops, such as maize, beans and various vegetables, may be sown shortly afterwards on the sides of the ridges. In the second year, maize and sorghum are planted on the remains of the yam ridges and interplanted with other minor crops. In the third year, the main crops are commonly groundnuts and millet and thereafter the land may be abandoned, or cassava may be planted in the fourth year.

East and Central Africa

In the 'chitemene' system practised on poor sandy soils in Zambia and in Northern Rhodesia (Trapnell and Clothier, 1937; Trapnell, 1943), finger-millet (Eleusine coracana) is the first crop and is broadcast without any preparatory cultivation, or with only very shallow scratching of the surface soil. A little sorghum and sesame may be mixed with the millet, and small amounts of other crops including beans, sweet potatoes and cassava, planted around the edge of the millet. Thereafter the land may be abandoned, or cropping may continue for two to four years with groundnut and beans in the second year, sorghum in the third year and cassava in the fourth year.

In parts of Malawi and southern Tanzania, the grass is not burned after clearing but is hoed up and buried in mounds towards the end of the rainy season. A crop of beans or cowpeas is raised on these mounds at the end of the rains. During the dry season the scattered trees are felled and burned. At the beginning of the following rains, the mounds are cleaned up and planted with finger-millet or maize and beans. Fairly early in the growing season, weeds are hoed out and buried in new mounds between the standing crop, and these mounds are then planted with groundnuts, beans or cowpeas. These new mounds are not destroyed when the legumes are harvested, and at the beginning of the following rains they are planted with maize or another cereal, and a quick-maturing, climbing variety of bean. Weeding is done as in the previous season, and subsidiary mounds containing buried weeds are again formed and planted with legumes. This procedure is repeated for several years so that a rotation takes place between the two spots in the field. After several years the whole of the land may be planted to cassava or pigeon-pea, after which it is allowed to revert to brush fallow.

Andrews (1974) states that farmers make very good use of local topography and soil types within their own farms. The valleys are often used for bananas or sugarcane. The best soils are planted to sorghum, maize, cotton or groundnut; the poorer soils are planted to cassava and the wet soils to cocoyam. Vegetable crops and superior varieties of sorghum or maize are planted near the homestead where they can be protected from birds and monkeys.

Northeast Brazil

The major food crops of the semi-arid tropics in northeast Brazil are maize, dry beans, cassava and bananas. According to Patrick (1972), these crops are widely cultivated throughout the states of the north-east. He further states that during the period 1950 to 1969 the total cropped area in the north-east increased from 4.5 to 10.9 million hectares, which is a 4.8 percent annual increase in cultivated acreage. However, there was no appreciable increase in average crop yield in the north-east during this 19 year period.

Most of the maize, bean and cassava are grown either as mixed crop (broadcasted) or intercrop (alternate rows). Some farmers also include such minor crops as pumpkins, castor beans and palma (a cactus for forage) The most common crop mixtures are as follows:

Maize + beans
Maize + beans + pumpkins
Maize + beans + palma (in dry areas)
Maize + beans + castor beans
Maize + beans + cassava

Most of these crop mixtures appear to be grown in the 'slash and burn' areas of the shifting cultivation regions. Many of these areas have steep slopes and with an increasing proportion of these steep lands in cultivation, soil erosion and land degradation are becoming a serious problem[1].

Increasing Food Requirements Influence Cropping Patterns

During the past centuries, population growth was relatively slow and was in balance with the current capacity of the environment. The farmers were usually able to increase food production sufficiently merely by cultivation of additional lands. The recent population explosion has resulted in the doubling of food requirements and farmers generally have not been able to meet even the minimum demand. Also the supply of suitable lands for being brought under cultivation is getting exhausted in many areas. In India, 44.6 percent of the total land area is under cultivation which is the highest in the world (Kanwar, 1968). Kanwar (1971) further points out that of the cropped area, 73.6 percent is under food-grains and another 9.6 percent under edible oilseeds. In the semi-arid tropics of India, intensity of land use is even higher than that in the rest of the country. The survey of 84 districts in the semi-arid tropics of India also showed that 57.2 percent of the total area in these districts was cultivated compared with 44.6 percent for the country as a whole (IARI, 1970).

Thus, because of increasing population and pressure on land in the semi-arid tropics, cultivation is being extended into marginal and submarginal lands. This intensive cultivation on relatively unsuitable land aggravates the problem of soil erosion. Thomas (1974) emphasized the desirability of using land according to its capability. His data showed that on some shallow red soils, greater income could be generated by growing productive forage crops than by growing sorghum, pearl-millet or sunflower.

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1 This observation by the senior author is based on a tour across the semi-arid tropical area of the State of Pernambuco in May 1974 in the company of Dr. Mohamed Faris and Mr. Lucas Ferraz of IPA (the State Institute for Research in Livestock and Agronomy).

With the low yields per hectare in the SAT, the most feasible approach to increased production is to raise the yield per unit of land, water and capital. The greatest possibility for increased production of cultivated crops is to increase yields on the best adapted land on any given farm. By increasing production on these lands, some of the steeper and more erosive soils could be taken out of intensive cultivation and put under productive perennial crops, such as forage or tree crops. (This is particularly relevant in some of the hill-areas, where shifting cultivation is practised, such as those found in North-east Brazil). By putting the steepest areas to a more suitable land use, the productivity of the land would be increased and the soil resource conserved. There is a need to 'establish more stable forms of land use to overcome the detrimental effects of over-use caused by expanding populations and thus preserve and maintain the productive capacity of the land resources' (FAO, 1974). However, it is recognized that with the population pressures, a farmer may have to use unsuitable soils in an attempt to meet his family's food needs. Thomas (1974) states that research information is needed to determine the safest and best way to utilize some of these relatively unsuitable lands for food production.

Research Aimed at Improving Cropping Patterns

The aims of the cropping patterns segment of the Farming Systems Program include the following facets:

1. To develop cropping patterns that make the most productive use of the current rainfall.

2. To provide the present and future food, feed and fiber requirements of the local people and the market potentialities of the community, country and world.

3. To generate the necessary income to facilitate the establishment of adequate educational, health, recreational and community facilities for the people in the semi-arid tropics.

4. To improve and conserve soil resources for future generations.

In much of the semi-arid tropics, water, not land, is the natural resource which is most limiting for crop production. Therefore, all cropping systems should aim at the most productive and economic utilization of the available water resources; in other words, to make the most effective use of the rain that falls on the farmer's fields.

The resource development and management aspects are discussed in detail by Kampen and associates (1974). At the ICRISAT, various aspects of crop production are being studied and attempts being made to develop alternative cropping patterns which can achieve the greatest economic production from the environment while maintaining its quality. Thus, we are trying to develop farming systems which provide a continuum of cropping from the beginning of the monsoon season and continuing as far as possible into the post-monsoon season with the given water resources. This continuum of cropping can be achieved by one or more of the following methods: intercropping, mixed cropping, relay cropping, double cropping, ratoon cropping and perennial cropping. Each of these cropping patterns are being or will be investigated at the ICRISAT and elsewhere in the semi-arid tropics. In developing alternative cropping patterns, we are attempting to work with physical, biological and socio-economic scientists, to develop economically viable farming systems that will be productive and stable from year to year. The factors which are being given major consideration are indicated in the following sections.

A. Improved Cultivars for the SAT

By exploring the vast germplasm pool for any given crop species, it is possible for breeders to develop drought-resistant and high-yielding varieties of improved quality of different maturation periods. At the ICRISAT, vigorous breeding programs are underway on four of the major food crops of the semi-arid tropics including sorghum, pearl-millet, pigeon-pea and chick-pea. Recently, it has been decided to add groundnut as a fifth crop. Close liaison between the Crop Improvement Program and Farming Systems Program at the ICRISAT is essential to 'tailor' the cultivars to the various environments. ICRISAT's Farming Systems Program is not limited to these five crops as components of its farming systems; it includes any additional crop (agricultural, horticultural or forestry), which has a potential to contribute to improved resource management and utilization. Therefore, we are starting to evaluate the most promising cultivars of many crops to select the proper species and varieties to fit them best into any segment of the potential growth season and farming systems of various environments.

B. Intercropping

Mixed cropping or intercropping, as it evolved in traditional agriculture under a low level of technology, was practised mainly to reduce risk and optimise production. Recent intercropping studies under optimum technology by Harwood (1973), Rao (1974) and Krantz et al. (1974) indicate substantial (50 percent or more) yield increases from various combinations of alternate row intercropping over those of two separate pure crop cultures. Andrews (1972) produced 70 percent more grain by growing an intercrop of sorghum, pearl-millet and cowpeas as compared with a sole crop of sorghum.

The intercropping concept has been abandoned in developed countries where harvesting is done mechanically. In the SAT, however, intercropping does not pose any problem because most crops are hand-harvested. Considerable research has been conducted on intercropping in recent times at the SAT. This work has been very beneficial in pointing out the potentialities, but to exploit more fully the concept of intercropping, further basic investigations are needed on lines including the following:

1. Evaluation of plant species and varieties as to influence of crop competition and shading upon intercrop seedlings. (Crops which show a minimum influence of shading or seedling competition lend themselves to intercropping culture. Crops which are seriously stunted by shading and seedling competition would fit better into a double-cropping pattern).

2. Investigation of plant species and geometry of plantings which favor rapid ground cover to utilize the environment and reduce the raindrop impact and subsequent soil erosion.

3. Screening of species and varieties for widely varying maturity classes to match short-and long-season crops.

4. Evaluation of species and varieties for widely varying rooting and moisture extraction patterns to use the whole soil profile more effectively.

5. Screening of varieties and species for water-use efficiency.

6. Screening of species and varieties for height, canopy density and influence of shading and moisture competition during flowering and seed-formation stage.

7. Screening of legume and non-legume crops to find combinations which would exhibit mutual production benefits, particularly at moderately low soil nitrogen levels.

8. Study of seasonal labor requirements and labor peaks of various crops to maximize labor utilization.

9. Investigations of the capital requirements, market feasibility and potential profitability of various species.

Preliminary observations indicate that pigeon-pea is ideally suited for intercropping with a fast establishing intercrop. There are several reasons for this:

1. The slowly establishing pigeon-pea seedling appears to be able to cope with considerable shading and plant competition by the intercrop in the early stages without serious reduction in the final yield of the pigeon-pea.

2. During the seedling stage, the pigeon-pea growth is very slow and therefore, weeding either by hand or mechanical methods is spread over the long period of plant establishment. A fast growing intercrop will effectively compete with weeds while the pigeon-pea is becoming established.

3. The bare soil area between the slowly establishing pigeon-pea plant is subject to raindrop impact and soil erosion problems when pigeonpea is planted as a pure crop.

For these reasons it appears that pigeon-pea should be grown with an intercrop which establishes itself quickly. Preliminary observations at APAU and the ICRISAT on variety Hy-3 suggest that an upright type plant with minimum lower branching, determinate growth and moderately late maturity offers the best possibility for high-yielding combinations of pigeon-pea and an intercrop. Also the determinate growth pattern greatly reduces the period over which plant protection is necessary in case of pod borer and/or blister-beetle attack.

C. Relay Cropping

Relay cropping refers to the interplanting of a second crop before the harvest of a maturing crop. It has been practised under irrigated agriculture and occasionally in humid climates, as a means of maximizing the use of farmers' resources of land, water and time. Early observations on relay planting at the ICRISAT indicate encouraging potentialities for effective soil and water resource utilization and increased yield.

Although relay cropping is normally not practised in the rainfed semi-arid tropics, the development of high yielding short-season varieties has opened new avenues for relay cropping in such areas, especially in the black soils, which have high water-holding capacity. Since many of the monsoon season crops mature during the period when the monsoon rainfall is waning, relay planting of the post-monsoon crops 1-3 weeks before harvest offers a method of reducing the risk of failure in establishing a second crop. House et al. (1968) emphasized the extreme importance of timeliness in relay planting operations.

In mechanized farming relay cropping would not be feasible; however, it can easily be accomplished in the semi-arid tropics by the use of animal-drawn relay crop planters. To find the most effective combinations of monsoon crops and post-monsoon relay crops, it is essential to develop the following types of basic information:

1. Screening of potential post-monsoon relay crops for sensitivity to shading.

2. Investigations of the optimum soil management and tillage operations necessary to reduce weed population and stubble competition with the relay crop seedling.

3. Date of planting studies with a wide range of crops and varieties to match relay crop plantings with monsoon crops of different maturation periods.

4. Investigation of the probabilities of having sufficient rainfall for the establishment of a post-monsoon relay crop on either red or black soil during September and October.

D. Double Cropping

Double cropping, or sequence cropping, refers to the planting of one crop immediately after the harvest of the previous crop. This can be done by complete land preparation before the planting of the second crop or by planting the second crop in the crop stubble after an inter-row cultivation to kill weeds. Double cropping or sequential cropping has been practised under intensive irrigated agriculture and in humid regions. Double cropping, like relay cropping has seldom been practised in the rainfed, seasonally dry semi-arid tropics. Since most farmers in the semi-arid tropics depend upon animal power and human labor for land preparation, it is essential to develop systems which will require a bare minimum of land preparation between the monsoon and post-monsoon seasons. Observations at the ICRISAT during the 1974 season indicate that inter-cultivation between the monsoon crop stubble kills all weed seedlings and prepares an adequate seedbed for planting the post-monsoon crops. Further investigations are planned under a wider range of crop and soil conditions. Stubble regrowth in certain crops presents an additional problem which requires further study. Double cropping and relay cropping should be used to complement each other in developing a sound farming system. By using both techniques it is possible to cover a wider range of conditions and to spread the labor requirement and reduce the labor peaks. Since rainfall patterns are quite erratic during the potential period for planting a post-monsoon crop, it is essential to maintain flexibility in the system. Depending upon the current rainfall, soil moisture status, and availability of stored water, the farmer could choose either relay planting, double cropping or post-monsoon fallowing.

Double cropping is preferred to relay cropping under the following conditions:

1. In areas with high weed population.

2. For use with post-monsoon crops such as setaria in which the seedlings are severely stunted by shading.

3. For use with post-monsoon crops which require more adequate seedbed preparation.

E. Ratoon Cropping

Ratoon cropping is another means of multiple cropping to provide a continuum of cropping for 5 - 8 months from the onset of the monsoon. Sorghum and millet cultivars exhibit varying degrees of ratoonability (regrowth after harvest). A preliminary study is being conducted this season to screen sorghum and pearl-millet cultivars for ratoonability. In the Farming Systems Program, two distincly different conditions are desired.

1. Cultivars which will regrow and produce a good second grain crop after a high-yielding monsoon grain crop. It has been found that ratoonability is generally enhanced by early harvest (Krantz _et al._, 1974). Therefore, the first crop should be harvested at physiological maturity of the grain and the stalks should also be removed immediately. Venkateswarlu (1974) has shown that in case of severe mid-monsoon season drought it may be desirable to made a 'mid-season correction' by harvesting the pearl-millet or sorghum for fodder, thus saving the crop. After the rains come a ratoon grain crop can be produced.

2. The second desired situation is to develop pearl-millet and sorghum cultivars which will possess a minimum of ratooning ability so that they could fit into a relay-or double-cropping system. Preliminary observations indicate that ratoonability can be suppressed somewhat by delaying the stalk harvest for a week, or two after the heads have been removed for grain harvest. If this practice proves to be satisfactory it can be a valuable technique in developing alternative farming systems. It has the further advantage of spreading the harvest period of the fodder, thus reducing peak labor requirement.

F. Perennial Cropping

There are many areas of the semi-arid tropics in which the soils and topography are such that the growing of cultivated crops is unprofitable and hazardous to the environment. These conditions include the following: steep soils, shallow soils, stony soils, hard-pan soils and waterlogged depressed soils. In these situations greater production and profit can usually be achieved by the use of the appropriate perennial forage and/or tree crops.

Fortunately, the ICRISAT location is representative of many of the above named soil situations which will provide opportunity for investigations of perennial cropping in the farming systems.

A preliminary evaluation of grasses has been initiated in the waterways of watersheds. The evaluations are being made on the basis of forage production, erosion control, longevity and rapidity of regrowth at onset of the monsoon. Later forage quality will also be evaluated.

Fruit trees are being established in the rocky, shallow soils of watershed RW2. Intercropping studies will be conducted in between the slowly establishing mango trees.

G. Livestock Component of Farming Systems

Although the research program at the ICRISAT is crop-orientated, we in the Farming Systems Program recognize the essentiality of livestock in the farming systems of the semi-arid tropics. Livestock provide the means of producing food from forage crops, fodder crops and residues of agronomic crops which would otherwise be wasted. They also furnish many of the needs of the small farmer, including animal power, animal products (milk, eggs and meat) and animal wastes for fuel and fertilizer.

H. Soil Fertility Management and Fertilization

The benefits of fertilization in capitalizing on the yield potentialities of high-yielding varieties and the available water resource are well known. However, the farmer of the semi-arid tropics has traditionally used little or no fertilizer for several reasons, including high risk due to erratic and undependable rainfall, capital scarcity and lack of technology for consistent profitability of fertilizer use.

Early fertilization trials at the ICRISAT have established the well-known universal deficiency of nitrogen. Phosphorus deficiency has varied, apparently due to past management and soil conditions. Preliminary observations also indicate considerable residual effect of phosphorus, particularly on red soil (Krantz *et al.*, 1974). Zinc deficiency has likewise been observed in eroded areas on both black and red soils. No potassium deficiency symptoms or responses to potassium application have been observed on any crop during the past three seasons at the ICRISAT. As a follow-up of these preliminary trials, it is planned to develop a more basic approach to soil-fertility management. This program has four major aims.

1. Management of the nutrients in the soil. Most of the work on nutrient transformations have been carried out in the temperate climates. There is a need for basic studies for more complete understanding of nutrient transformations and soil-fertility management under the seasonally

warm-wet and hot-dry conditions of the semi-arid tropics. There is a hot-dry period during the four to five months preceding the wet season. During this period there is a build-up of nitrates and sulfates due to mineralization of organic matter and nitrogen fixation by *Azotobacter* and other micro-organisms. Thus at the onset of the wet season the soil contains readily available nutrients which, if not utilized as in the case of the monsoon fallow system, may be lost due to leaching or denitrification. This loss of available nutrients can be reduced by planting a crop at the onset of the monsoon and thus utilizing the accumulated nutrients.

2. Nitrogen fixation in soils. Intercropping and relay cropping afford opportunities of planting mixtures, or grain legumes and non-legumes in a sequence. It is a generally accepted fact that the nitrogen-fixing activity of a legume is increased under low soil-nitrogen conditions. A non-legume grown in association with a legume would tend to reduce the soil nitrogen level in the root zone of the legume and thus the total nitrogen fixation of the system would be increased. Alexander (1961) reported that non-legumes benefitted from associated legumes in the following combinations: bluegrass with clover, corn with soybeans and cereals with field-peas. Recent studies indicate the possibilities of nitrogen fixation in association with non-legumes (Dart, 1974). Both of these approaches merit further studies by microbiologists and agronomists.

3. Management of crop residues and organic wastes. A by-product of more intensive cropping systems is the production of greater quantities of crop residues and organic wastes. The proper handling of crop residues and organic wastes can provide the necessary organic matter to improve soil workability and water infiltration. Over two-thirds of the potassium and zinc and about one-third of nitrogen, phosphorus and sulfur taken up by crop plants are contained in the leaves and stems of plants. If these residues are returned to the field, either directly or indirectly in the form of farmyard manure, the need for applied chemical fertilizer can be reduced.

4. Improving the efficiency of applied fertilizers. Chemical fertilizers are expensive but if properly applied in the amounts needed, they are usually a highly profitable input. Chemical fertilizers should always be considered as only a supplement to the natural fertility bank of the soil. A fertilization program should supply only the element or elements which are not available in sufficient quantity for the optimum production of the particular crop or cropping sequence desired. Crop plants vary greatly in their ability to take up soil nutrients and their response to applied fertilization. Early observations at the ICRISAT indicated that sorghum, sunflower and pearl-millet were far more responsive to phosphorus application than chick-peas and pigeon-peas (Krantz *et al.*, 1974). In fertilization of a cropping sequence, it would be logical to apply phosphorus to the most responsive plants and allow the

less responsive plants to utilize residual phosphorus. Another way of increasing phosphorus efficiency is by proper fertilizer placement at planting time.

Since nitrogen is the nutrient usually needed in largest quantities for high-yielding non-legumes, further research is needed under SAT conditions to develop a thorough understanding of the best way to achieve maximum utilization of soil nitrogen and obtain maximum efficiency of applied fertilizer nitrogen. Improved land and water management can also greatly improve fertilizer-use efficiency by reducing nutrient losses due to leaching or denitrification (Krantz and Sahrawat, 1974).

I. Tillage in Relation to Intensified Cropping Patterns

Tillage practices are somewhat site-specific and depend on soil properties, crop requirements, available equipment and power source. Since animal power is the main power source of the farmers of the semi-arid tropics, it is proposed to develop farming systems around the animal power source, under the Farming Systems Program at the ICRISAT.

The soil is the natural reservoir for the water used by plants. Thus, soil and crop-management systems should be geared to improvement of the intake and storage of water in the root zone and effective utilization of this water. Soils vary greatly in their storage capacity, but this intrinsic value cannot be altered appreciably by management. The soil surface receptiveness, however, can be greatly altered by improved tillage and crop-management systems.

The fact that excessive tillage can be a soil structure destroying process has focussed attention upon minimum or reduced tillage in various forms. With the event of chemical weed control and high fuel cost, considerable research is being conducted on 'zero tillage' (Baeumer and Bakersman, 1973).

The long hot dry period preceding the monsoon in rainfed areas provides an opportune time to apply tillage and other cultural practices for the reduction of pest populations, particularly insects and perennial weeds, as crops are normally not raised during this 'hostile' weather period. This aspect will be investigated at the ICRISAT. Experiments in progress and future research plans at the Institute will emphasize the following:

1. The development of improved animal-drawn tillage equipment.

2. Land smoothing to minimize micro-depressions.

3. Timely, minimum primary tillage including ridging immediately after the crop harvest, leaving the land surface rough and cloddy

with maximum surface receptiveness for storage of water. (Larson (1964) reported that on slopes up to 2 percent, deep furrows resulting from contour listing have a depressional storage of 7.5 cm of water on the surface).

4. Minimum tillage for weed control before planting.

5. Minimum intercultivation for effective weed control.

6. Minimum tillage for relay crop planting.

J. Weed Ecology and Management

In the semi-arid regions, crops are planted and grown under conditions that favor luxurious growth of weeds. In traditional agriculture weeds are often considered as an important source of fodder during the monsoon season. Thus, they are not removed till severe damage to the main crop has occurred. Horovitz and Kalter (1963) reported a reduction in yield of grain of 1000 kg/ha when sorghum was submitted to weed competition during the first month after emergence.

In many parts of East Africa, land is prepared by hand implements. Thus, land preparation and planting is extended over a long period of time and weeds often continue growing in the early plantings while land preparation and planting is still going on (Doggett, 1970a).

Herbicides are extensively used for controlling weeds in temperate regions, but they are not widely used in the SAT. The possible reasons may be availability of cheap labor for hand weeding, high cost of herbicides, lack of suitable spray equipment and the unavailability of herbicides suitable for treating crop mixtures consisting of dicotyledons and monocotyledons.

In developing more intensive cropping systems to better utilize the soil and water resources, it is essential to study the weed ecology under different farming systems to avoid deleterious build-ups of weed problems. Herrera and Harwood (1973) pointed out that weed problems were reduced by intercropping due to the rapid growth of the intercrop canopy and higher interception of light. With intensive intercropping, relay cropping or double cropping, annual weed problems could be reduced by inter-row cultivation and land preparation immediately after harvest, which would prevent weeds from re-seeding. This concept has encouraging potentialities and will be further investigated.

K. Pest Ecology and Management

With the use of high-yielding varieties and intensification of crop production made possible by better land and water-resource management, pest management becomes a very important segment in the development of viable farming systems. In co-operation with entomologists and pathologists, efforts are being made to study the ecology and management of pests in various cropping patterns with the aim of selecting cropping sequences or rotations in which pests can be kept at a tolerable level with a minimum of pesticides. Biological control mechanisms through selected cropping patterns and development of methods for reduction of insect and pathogen populations during the hot-dry pre-monsoon period will be investigated.

Birds and rodents assume importance as pests if their reproduction is allowed to progress unchecked. In many countries in Africa, the Quelea grain-eating bird causes severe losses in grain production of sorghum and millets. The Quelea bird is a wasteful feeder on large grains such as sorghum; the birds peck out the germ from the soft green grains and drop the rest on the ground. Doggett (1970b) reports that each Quelea may damage 50 grams of sorghum per day. Control measures aimed at limiting population densities to acceptable levels must be continued indefinitely (Thompson, 1963).

L. Crop Residual Effects

In any crop intensification program, viz. relay cropping, double cropping or sequence cropping, the residual effect of one crop upon the succeeding crop can be critical. Herrera and Harwood (1973) observed that the growth of rice was poorer following cowpea than maize. Likewise, mung bean and cowpeas exhibited serious reduction in growth following either of these legumes as compared to growth following maize. Similar effects were observed in fields following intensive croppings of sweet potato, mung bean, co and soybean in spite of additional fertilizers and the maintenance of good soil structure. At the ICRISAT no such observations have been made as yet, but this point will be investigated.

M. Socio-Economic Evaluation of Cropping Patterns

Details of the socio-economic side of the Farming Systems Program has been covered in detail by Ryan and associates (1974). Economic evaluations of cropping patterns will include the following phases:

1. Evaluation of food, feed and fiber crops in relation to nutritional requirements and local preferences.

2. Evaluation of the market potentialities of increased crop production.

3. Evaluation of the potentialities for increased and stabilized

production with present crops and technology compared to the potentialities with the introduction of new crops and improved technology in the semi-arid tropics.

N. Watershed-Based Farming Systems

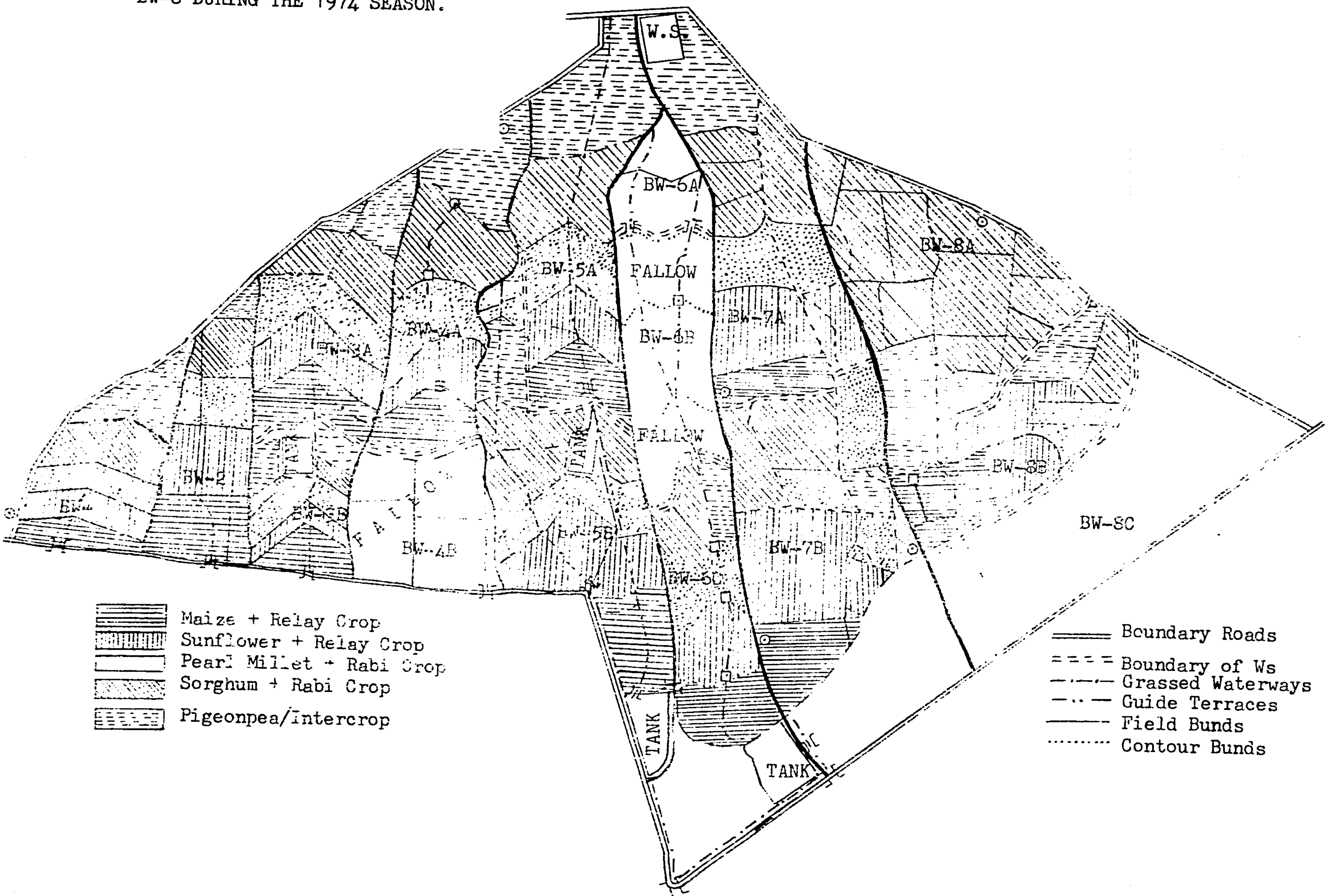
In the red and black soil watersheds, cropping patterns are being investigated under a wide range of soil-and water-management systems. As new cultivars are selected in the Crop Improvement Program and the crop evaluation trials, they will be tested in the Watershed-Based Farming Systems Program. The watersheds provide an opportunity for field-scale experiments in which many of the problems facing farmers emerge and can be identified and solutions developed. During the 1974 season, a crop complex consisting of five major crops was established during the monsoon season followed by relay cropping or double cropping in the post-monsoon season. The map with the crop layout in watersheds BW1 to BW8 is shown in Figure 2. The same crop complex was repeated in red soil watersheds.

1. Suggested cropping patterns for the watershed units for 1975-76[1]

Monsoon season crop	Post-monsoon crop
a) Sorghum 'CSH-5'	a) Heads and stalk harvested & ratooned. b) Heads harvested - relay chickpea or safflower
b) Maize 'Shakti opaque-2'	Relay chick-pea
Maize 'Deccan Hybrid'	Relay safflower
c) Pigeon-pea 'Hy 3' intercropped with sorghum 'CSH-5' Pigeon-pea 'Hy 3' intercropped with Setaria (One row of pigeon-pea and one row of intercrop on each ridge 25 cm apart)	
d) Setaria	a) Sunflower b) Sorghum

[1]Each of the four monsoon crops will occupy one quarter of each watershed unit arranged from bottom to top in the following order: Sorghum, maize, pigeon-pea-intercrop and setaria.

FIGURE 2. MAP SHOWING THE MONSOON SEASON CROPS IN THE BLACK SOIL WATERSHEDS Bw-1 TO BW-8 DURING THE 1974 SEASON.



2. The suggested planting schedule for watersheds in 1975-76 is as follows:

A. Black soil

a) Plant in 'dry' soil at 6-7 cm depth at the onset of monsoon.

1. Sorghum
2. Pigeon-pea - sorghum
3. Maize

b) After sufficient rain to provide 15 cm of moist soil, harrow or reshape ridges to kill weeds, and plant immediately.

1. Setaria
2. Setaria - pigeon-pea

B. Red Soil

After 20-25 cm of soil has been moistened by rain, harrow or reshape ridges to kill weeds, and plant immediately.

The International Program

In addition to the farming systems research conducted at Hyderabad, a major facet of our program involved co-operative research with national and state organizations and extension and outreach activities through national and state agencies.

The soil and climatic conditions at the ICRISAT provide an opportunity to study a wide range of cropping patterns in relation to all other production factors so as to generate principles which can be used as a guide in the development of appropriate cropping patterns to suit the natural resources, human resources and the socio-economic situation of any given location. It is also planned to identify a limited number of 'benchmark' locations in different parts of the SAT (Kampen and associates, 1974). Principles of cropping patterns for various regions will be investigated at these benchmark locations. It is hoped that the information developed at the ICRISAT will be used to supplement locally developed information which can then be tested in conjunction with resource management studies at the various benchmark locations.

Basic information developed in the cropping pattern studies discussed in the previous section, along with cropping pattern data from benchmark locations, will be used in computer simulation studies in an attempt to match cropping patterns to the land and water resources at any given location. By this means of initial sorting, it should be possible to greatly reduce the number of combinations necessary to be investigated to evolve optimum farming systems for a given area.

Since much of the semi-arid tropics has in recent years been plagued by food and water shortages and an exploding population, there is an urgency for the implementation of an immediate program to improve food production in these areas. To be successful an emergency food production program must be based on the best available research information and be orientated to make the best use of the presently available resources, farm equipment, power source and infra-structure for needed production inputs. What is needed is a synthesized program to provide food, raise the economic status, give a degree of self-reliance and motivate people to strive for eventual long-term improvement[1]. Gibbons (1974) suggests that recommendations should be assembled into a comprehensive package to be advanced as a whole, in a systems approach.

The emergency food production program must place emphasis on agricultural production techniques, such as improved varieties with the proper package of practices, and introduction of suitable new food crops, such as root crops, which could quickly increase the farmer's food base. At the time of starting such a food production program, a long-term plan should be initiated and carried on parallel to the short-term plan, blending with it and finally replacing it. It is believed that the limited success of some emergency food production programs may have been caused by the lack of implementation of long-term programs for the general improvement in the economic status and quality of life of the people. The preamble of the International Development Strategy for the Second United Nations Development Decade states: "The ultimate objective of development must be to bring about sustained improvement in the well-being of the individual and to bestow benefits to all" (FAO, 1974).

Often a crop production program will help generate the additional income and motivation necessary to help facilitate the establishment of better educational, health, recreational and community facilities for the people of the area. Long-term improvement, however, requires the co-ordinated effort of many disciplines in the physical, biological, and socio-economic areas both in research and outreach activities.

If the people of the semi-arid tropics are to benefit from the contributions of scientific agricultural research, greatly expanded activity in the socio economic area is essential. Investigations are needed to determine the extra resources required and the best infra-structure for obtaining production inputs and marketing outputs and for providing

[1] It is obvious that the implementation of both short-term and long-term programs must be done by the national, state and local agencies and institutions of any country. An international institute like ICRISAT can hopefully act as a catalyst and supplement the national programs through the broad-based research programs and the associated training programs.

the proper amenities for the community. Any long-term development program must also include emphasis upon family planning or the population explosion will negate all other efforts towards development and improved economic status of the people.

Summary and Conclusions

1. The cropping patterns which farmers evolved by trial and error methods over a long period of time are generally the best possible with the resources, constraints and traditional technology involved.

2. In the semi-arid tropics of the world the major determinant of length of growing season is the period of sufficient soil moisture.

3. The major cause of low yield and unstable agricultural production in semi-arid tropics has been the erratic and undependable nature of the rainfall.

4. To optimize production and reduce risk of crop failure due to undependable rainfall, farmers have over the years evolved several types of 'mixed' cropping patterns.

5. With the recent population explosion, farmers have tried in vain to meet the suddenly increased food and feed requirements by expanding cultivation and grazing onto less suitable lands. This process is resulting in increased erosion involving soil deterioration, nutrient losses and reduced crop yields.

6. Recent findings of national research programs and those of the ICRISAT suggest a great potential for increased and more stable agricultural production by an improvement of crop technology integrated with improved land and water resource development and utilization. However, any development program must include emphasis on family planning or the continuing population explosion will negate all other effects toward improvement of the well-being of the people of the SAT.

7. The ancient principle of mixed or intercropping in traditional agriculture also appears to have a great potential for increased yield per unit of water when coupled with scientific agricultural technology.

8. To fully exploit the potential of intercropping, relay cropping, double cropping and ratoon cropping, much basic plant physiological and agronomic data is needed to better understand the interaction of the many plant combinations in an intensive culture. Research to develop this basic information is suggested.

9. The development of more intensive cropping patterns must be integrated not only with the optimum development and utilization of land

and water resources but also with weed, insects and disease management practices.

10. The intensification of resource utilization and crop production into improved farming systems must be economically viable and related to the family and community needs and market potentialities.

11. Improved cropping patterns must be tested not only in experimental plots, but also as an integral part of a farming system in field-scale experimental watersheds and finally on farms under real world conditions. The accomplishment of this objective by working through national and state research and extension organizations is an integral part of the program planned by the ICRISAT.

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RESOURCE UTILIZATION APPROACH

TO CROPPING SYSTEMS IMPROVEMENT

R.R. Harwood*

The attention of crop scientists, especially at the International Institutes, is rightly directed towards the improvement of food or feed crops of importance to the geographical areas of their responsibility. With the advent of cropping of farming systems programs, however, a broad perspective is assumed. I would like to comment briefly and in very general terms on this new perspective and on the important elements of farming systems that interact with or influence crop-orientated research. I would also like to discuss the approach of an international institute to 'farming systems' research.

A Farming Systems Model

For purposes of description and study, a farm can be divided by space and time factors into different enterprises, each having its own resource requirements and productivity pattern. This system includes all activities, either on or off the farm, that use farm resources (Fig.1). Most enterprises of the system are interrelated, making it difficult to study or to even discuss an enterprise without first placing it in context. (This is precisely the reason for creation of 'farming systems' study teams). A brief summary of the various kinds of farm enterprises may be useful in studying their interaction with the major cropping systems. The special layout of the farm varies in response to many social factors as described by Ruthenberg (1971) but will be dealt with here only in passing.

Non-farm enterprises. These are enterprises conducted either on or off the farm but which do not utilize much of the agricultural land resource. These include activities, such as cottage industries, off-farm employment, contract tractor or animal work, or any activities which use the farm's human or physical resources and provide a return in the form of cash, kind or security. These activities influence other farm enterprises and thus become an important aspect of the system. Our attention to them usually need go only as far as a description of their resource use and their benefit pattern.

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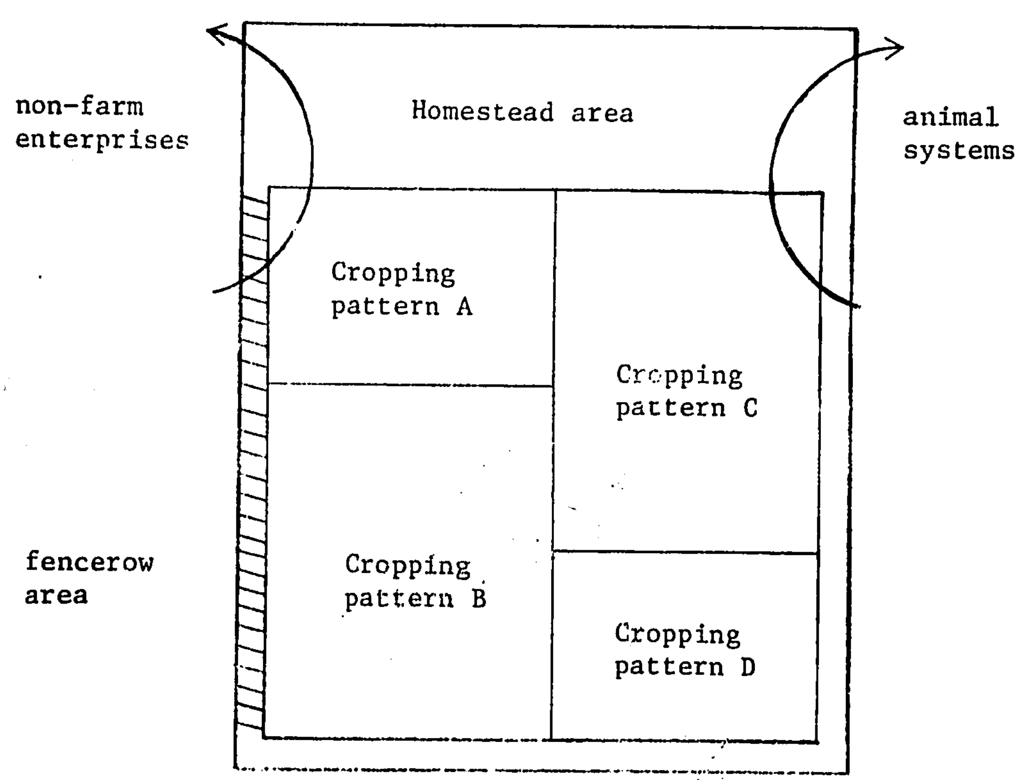
Homestead area. The homestead area is characterized by diverse mixtures of annual and perennial crops. Its function is both esthetic and economic. A well-developed homestead area provides a year-round flow of small income and a source of varied diet. Its extent and productivity depend on the style of village, the number of animals and the method for keeping them. Clustered villages, such as are common in lowland areas of South-east Asia, have far smaller homestead areas than do the scattered dwellings common to upland areas. Untended grazing animals such as goats and cows greatly reduce the variability and productivity of these areas. Since most of the plants are trees or shrubs, this area lends biological and management stability to the overall system.

Fencerows. Fencerow areas are important in most upland areas of small farm size in South-east Asian countries. They are usually planted to a species of legume (*Leucaena leucocphala* or *Sesbania grandiflora*) in wet areas and *Hibiscus* species in dry areas. The former serve as a source of human food and animal feed, with leaf protein approaching 6 percent. All are used for firewood and green manure. They are cut annually to a height of 1.5 meters, from which new shoots emerge each year

Fig.1: MODEL OF A SMALL SOUTH-EAST ASIAN UPLAND FARM



These species are ever present and an important part of small-farm agriculture. The fencerows may include other economic trees such as mango or kapok. Often they are planted to a grass species, such as Saccharum spontaeum which is useful for feed as well as fiber for thatch. This species doesn't spread to cultivated fields. Such fencerows are used in areas of seasonally high rainfall to control erosion as well as to separate fields. As in the homestead area, the diversity of plants in them and their effectiveness in controlling erosion are highly dependent on the animal systems. Uncontrolled grazing minimizes the effectiveness of these areas.

Many workers, especially in developed countries have decried the existence of hedgerows as restricting mechanization and also in providing shelter for various insect pests as well as being a source of weeds. On small farms, however, mechanization is small-scale and not likely to be impeded (Banta, 1973). The insect relationships of fencerow areas is open to question. Some workers feel that the increased diversity of insect species resulting from diversified cropping results in a more stable pest pattern and one that is more easily managed. Weeds in most well-developed fencerows are excluded by the planting of desirable grass species and by controlled grazing. The fencerows has much to offer the small farmer as long as it does not interfere with mechanization or water distribution.

Animal systems. Animals on the farm interact with all other farm enterprises. They require considerable labor for tending as well as a year-round source of feed. Cropping patterns must be adjusted to meet these needs. Some of the interactions are quite precise, as the crop-animal interaction of a Philippine system. The cropping pattern is rice followed by corn in a 1500 mm, 6 month rainfall pattern. When the corn is harvested, the chicken population is markedly increased to use the available feed. The chickens are sold just after rice planting the next year in time to provide cash for nitrogen fertilizer, the major input for growing rice. Animals also, ofcourse, supply power for farm operations. They also tend to add stability to the system, as their productivity generally does not fluctuate as widely in response to weather as does that of the crops.

Forage animals, however, can be devastating to diversity of cropping on the farm if grazing is uncontrolled. In such a situation the grazing herds are usually owned by more affluent farmers in the community; and the price for this uncontrolled grazing is generally paid by the small farmer who has no animals and whose crop options are severely limited by the animals.

Cropping patterns. The attention in institute programs is focused on cropping patterns as the key aspect of farming systems. This is also reflected in the title Cropping Systems Program for the IRRI. This does not belittle the fact that cropping patterns interact closely with other farm enterprises, but indicates that attention is being focused on their improvement in the context of other farm enterprises. We do not have time here to dwell at length on the different kinds of cropping patterns, but we might briefly mention a few relevant points.

Tree crops are common to most farming systems of South-east Asia, providing an element of stability to the system in areas of highly variable rainfall. The low-rainfall areas are characterized by mangoes, kapok and other drought-tolerant species. Long-duration annuals such as cassava and pigeon-pea serve essentially the same purpose, but are higher in productivity. Most farming systems consist of a combination of these and other crops enterprises, with field-crop sequence patterns accounting for the bulk of farm productivity. The various cropping pattern types and an estimate of their resource characteristics are shown in Table 1. Many aspects of crop management technology are closely related to the type of cropping pattern, making a systems approach essential to the successful development of new technology (Bantilan, et al., 1974; IRRI, 1974b).

Table 1. Types of Cropping Systems used in South-east Asia and their Usual Energy and Cash Characteristics

Cropping system	Energy input			Productivity	
	Human	Power	Chemical	Cash	Usable energy
1. Slash and burn (Inter-crop with native trees, complex crop mixtures)	H	0	0	VL	L
2. Tree monoculture	L	L	L	M	M
3. Tree monoculture inter-cropped with annuals	M-H	M	L	M-H	M-H
4. Intensive tree inter-planting	L	L	L	L-M	L-M
5. Homestead crops	L	0	0	L	L
6. Single crop mono-culture: Upland	M	H	L	L-M	M
Lowland	H	M	M	H	H
7. Multi-crop sequences	M	VH	H	H	VH
8. Intensive vegetable (may be intercropped)	VH	L-O	VH	VH	M-H
9. Improved complex inter-cropping (field crops)	H	O-L	L	M	M

0 - none, VL - very low, L - low, M - moderate, H - high, VH - very high.

The Resource Utilization Model

We, at the IRRI, have found that a resource utilization model is the most applicable format for the study of farming systems. Here, at the ICRISAT, you are primarily concerned with water use. In the broader context, however, the physical and socio-economic resources available to the farmer within the framework of a particular physical, biological, and social setting become dominant. He integrates these resources by using available technology through his management skills to conduct farm enterprises which in turn meet his needs (Fig.2).

The farmer's resource pattern determines his cropping system. Perhaps the best example of this is illustrated in a type of inter-cropping practiced both in South-east Asia and in Africa.

Short-season crops such as corn or sorghum are frequently inter-cropped with upland rice and cassava or pigeon-pea, creating a 9 or 10 month cropping season with several harvests and a single major tillage operation. This system is found only in intermediate farm-size holdings (1 to 3 hectares), no power, animal or tractor, being available. When the farmer has no power, a sequence pattern of crops would be impossible to achieve without having unacceptable peak labor demands. This complex intercrop pattern, then, makes optimum use of labor in a power-limiting situation (Norman, 1968). (From this example, however, it should not be assumed that all intercropping patterns are used under similar conditions for the purpose of achieving more efficient labor use; in fact, most of them suit other situations and are used for different reasons).

Most farmers, when designing their systems use a combination of enterprises having different resource requirements. Some may be of lower productivity but lend stability to the system. Others may be labor or cash-intensive and highly productive, but unstable from the biological, management or economic standpoint. The net effect is to balance the farmer's resources in meeting his needs for productivity and stability. This is illustrated by the model of Fig.3, showing a computer simulation of optimum cropping patterns with the best available technology for different-sized farms in Thailand. As farm size increases, the labor constraint dictates a change in cropping pattern to less labor-intensive crops, such as broadcast black-mung and broadcast sorghum. A limited market resource for green corn is also reflected in the model.

Evaluation of a System

The farm system is evaluated on the basis of how well it uses available resources, such as credit that could be made available. The biological stability and management stability are all-important, as is a degree of economic stability. Farmer welfare, of which cash income is

Figure 2. CONCEPTUAL OUTLINE OF THE CROPPING SYSTEMS APPROACH.

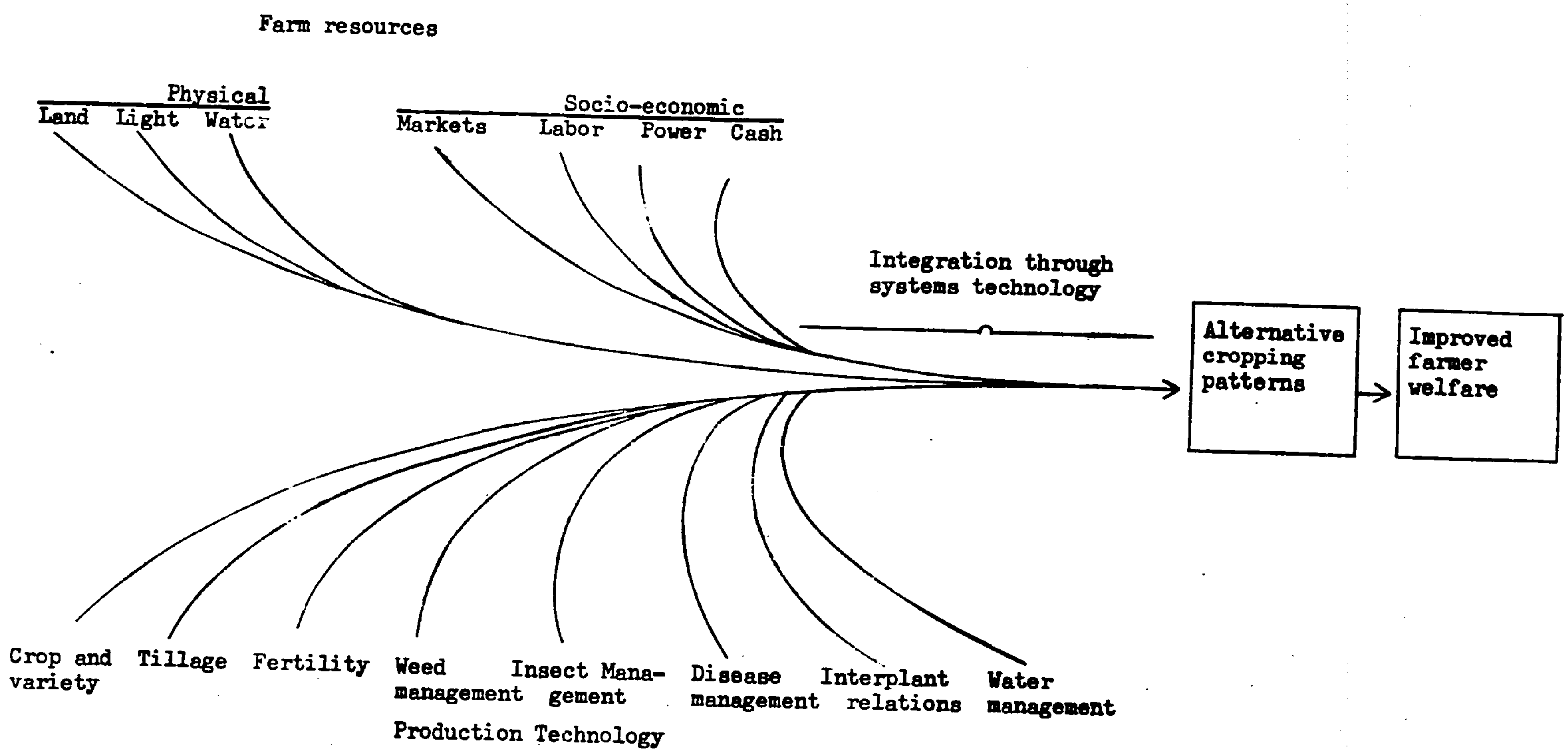
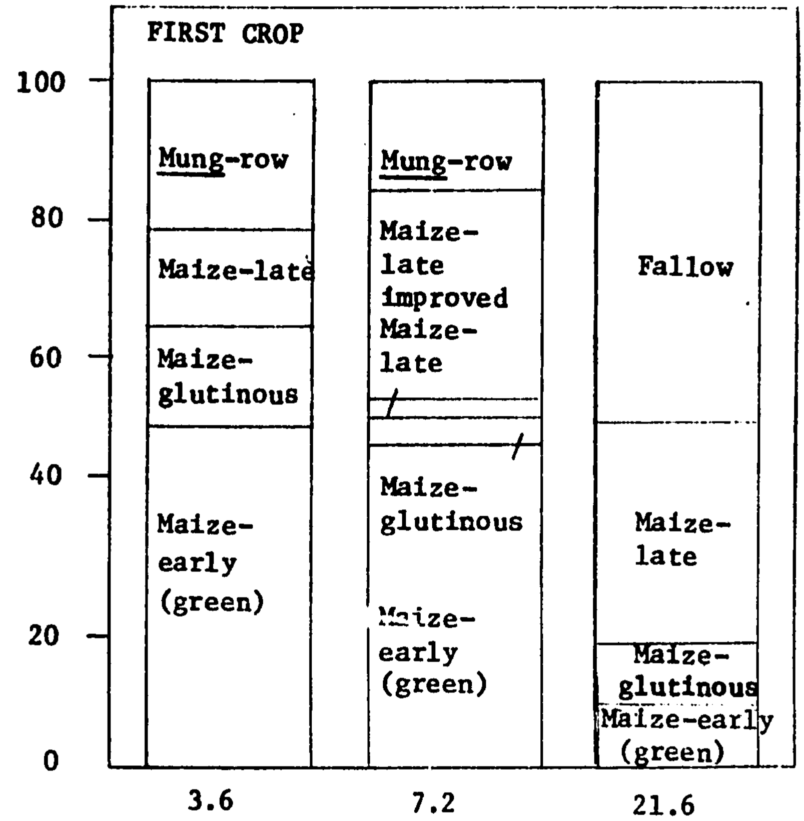


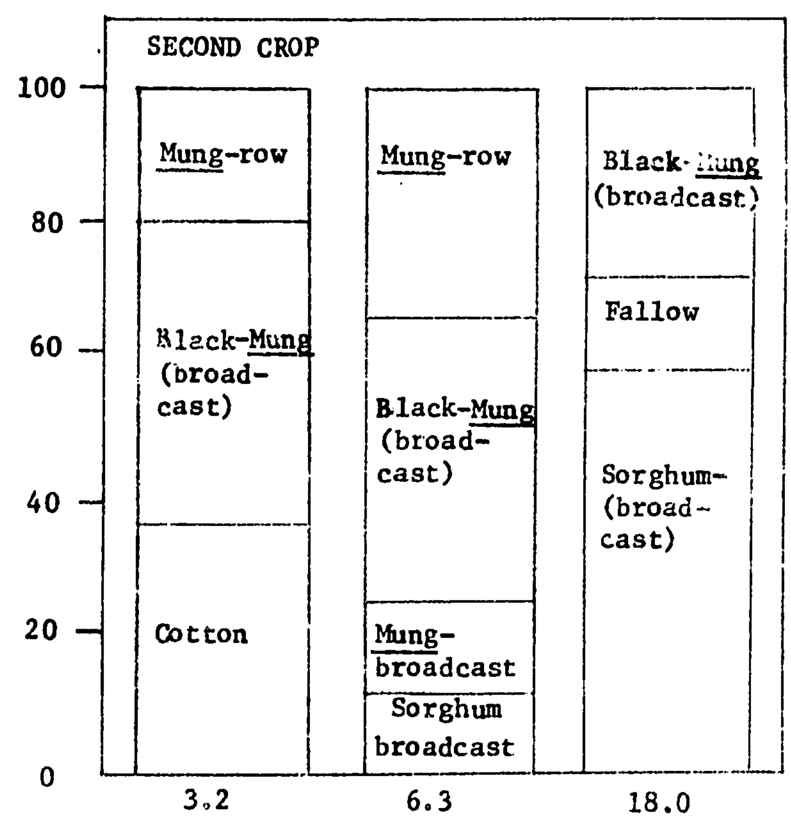
Fig.3: OPTIMUM CROPPING PATTERNS WITH IMPROVED TECHNOLOGY FOR THE CENTRAL HIGHLANDS OF THAILAND (FROM GRIMBLE, 1973)

Farm crop area (%)



Farm size (ha)

Farm crop area (%)



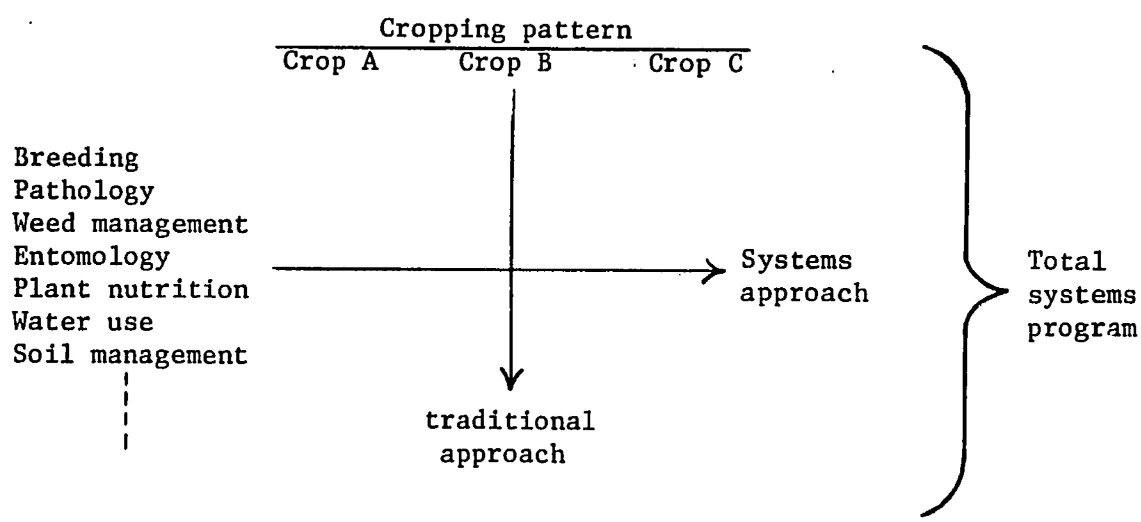
Farm size (ha)

only a part, is of uppermost importance. Farmers are not motivated, as are scientists and extension workers by national production goals.

In a low-cash system, diversity of production seems direclty related to farmer welfare. If our farm size is small and resources are limited, improvement of farmer welfare may require emphasis different from what we have given in the past.

The Research Approach to Farming Systems

The traditional method of crop improvement calls for concentration of several efforts on a single crop to improve its performance. This is the 'vertical' approach as seen in the following diagram.



The systems approach is illustrated as a "horizontal" one, going across the entire cropping pattern. Components of the system may be researched, disciplinewise, but still within the framework of the entire system.

Classification of Environment

Since farming systems are highly environment-specific, order must be brought to their study by categorizing types of systems and relating them to their environments. Such physical parameters as water availability, soil tillage characteristics, and temperature, as well as the socio-economic parameters of farm size and market availability determine farming system types. In classifying areas however, caution must be used. If climatologists and soils experts could be persuaded to plot gradients of critical parameters rather than fixed 'zones' much more use could be made of their work in locating farming systems types.

As technology changes, the boundaries of agro-climatic zones change. A summary of the amount and duration of rainfall, above and below fixed limits, plotted over a geographical area (IRRI, 1974a), permits fitting different cropping patterns to specific areas, while pre-conceived 'zone' assumes that this has already been done.

Research on Farming Systems by an International Institute

When agro-climatic conditions have been described, which determine specific types of farming systems, research can begin on complete systems within those environments. The institute is located in a representative site. Components of the systems, however, may be researched outside the area at a location where relevant conditions can be simulated. Water-use studies, for instance, may be conducted in simulated environments, for example at the ICRISAT.

Systems research, in general, is carried out under two sets of conditions :

Controlled site. One in which the research material is under the control of scientist. This may be either at the experiment station or on a farmer's field. In either case the method is suitable for studying only the physical resource characteristics of a cropping pattern or its biological interactions. These conditions are ill-suited to the study of socio-economic factors such as labor or power-use profiles.

Farmer-managed site. In this case, the research material is under the farmer's management. This presents optimum conditions for evaluation of labor and power requirements under farm constraints as well as the ability of the farmer to manage the technology.

The IRRI Approach

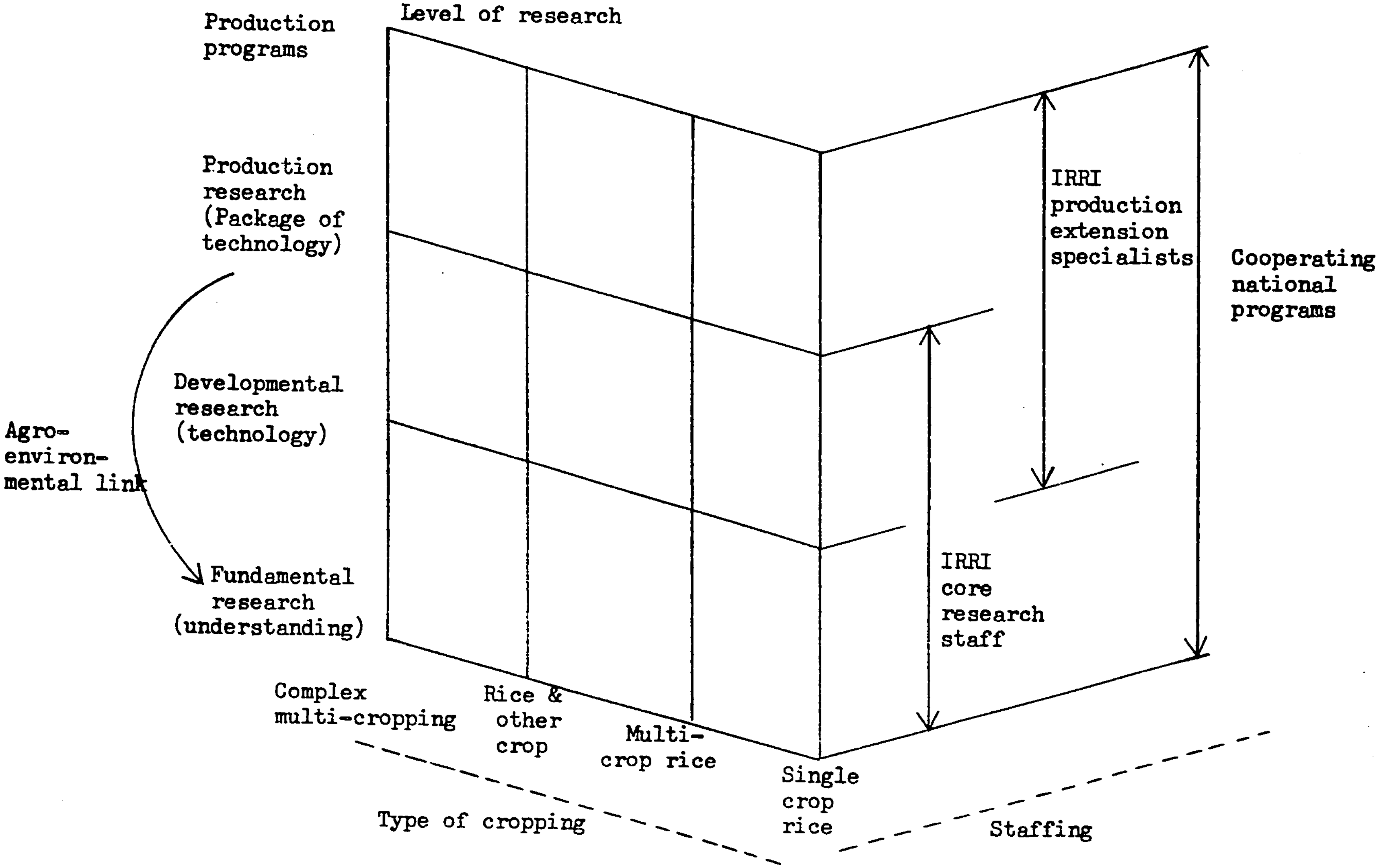
We are selecting agro-climatic zones in several South-east Asian countries for research on different cropping systems. The co-operative arrangements are made by a network co-ordinators working under the cropping systems program. Tests of systems components, such as weed control, are are conducted under both controllled and farmer-management conditions. Under farmer management, incentives are carefully offered to convince the farmer to use the desired crop pattern with the required level of management. Detailed component studies are then superimposed on farmer management. Studies of the socio-economic resource requirements of the new pattern are thus conducted under farmer management. For this purpose farmers are sometimes stratified into management capability classes. The study of the integration of these new crop patterns into the farming system is complex and requires sophisticated modelling. This will be carried out in the near future, but for the present we are simply describing resource patterns for our systems independent of farming system settings.

The conceptual model for the IRRI systems approach is shown in Fig.4. Our basic goal is to develop more efficient cropping systems to suit a range of environmental conditions. By carefully selecting our test sites we hope to not only develop patterns to fit them, but to accumulate a store of fundamental understanding of cropping systems and the physical and socio-economic environments in which they fit.

CONCLUSION

I would urge that the ICRISAT develop as early as possible a conceptual framework for the evaluation of entire systems. The ability to evaluate technology under the farmer's conditions of both controlled and farmer management is a pre-requisice for this evaluation. The desired farming-system type, with its associated animal and other enterprise components, can be selected as a background setting for the new cropping pattern. Early involvement in this kind of research will do more good than any other exercise to clarify direction and purpose for the farming systems program. Past experience at the IRRI has shown, furthermore, that certain components of technology, such as new varieties, can be quite readily transferred from an institute to the farmer. Other components of the production technology are not so easily transferred and have far less widespread adaptability. Entire systems technology will have even less mobility.

Figure 4. IRRI CROPPING SYSTEMS RESEARCH ORIENTATION AND PROGRAM LINKAGE



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THE IITA FARMING SYSTEMS PROGRAM

Bede N. Okigbo*

The International Institute of Tropical Agriculture (IITA) was established in 1967 on 1,000 hectares of land located at 3° 54' E longitude and 7° 30' N latitude, about 16 kilometers north of Ibadan, the capital of the Western State of Nigeria. It is one of a network of international research institutes where priority is given to research, training and related activities aimed at quantitatively and qualitatively increasing food production in the developing countries of the world. These countries contine to experience shortages in available food supplies resulting from much higher rates of population growth as compared to the rates of increase in food production. Specifically, IITA's activities involve multidisciplinary, problem-oriented research in food crops production which, for effectiveness and rapid progress, is restricted to the major food crops of the humid tropics. The humid tropics is defined as the broad belt girdling the earth in the lower latitutes on both sides of the equator where precipitation exceeds evaporation for more than half the year and where normally the tropical rain forest constitutes the climax vegetation.

Research and training activities at IITA are grouped into four principal programs consisting of:

1. The Cereals Improvement Program (CIP)
2. The Grain Legumes Improvement Program (GLIP)
3. The Roots and Tubers Improvement Program (TRIP) and
4. The Farming Systems Program (FSP)

The scope of activities and IITA responsibilities grouped under these programs are the result of a continuous evaluation and streamlining, and revisionary changes which the original tentative program has undergone (Donahue, 1970). Details of the background to these changes, activities and various aspects of the development of the Institute are available in the reports and publications of IITA (1967-74).

Under its four programs, IITA has global responsibilities in the improvements and development of packages of technology for three major tropical food crops, namely cowpea, yams and sweet-potatoes in addition to the development of efficient and economically viable food production systems for the humid tropics. It also has regional responsibilities

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for rice, maize, pigeonpea, soybean and cassava which are already being given top priority in the programs of IRRI, CIMMYT, ICRISAT, INSOY and CIAT, respectively. Other crops which are of potential value in the farming systems of the humid tropics and which are receiving attention in the IITA crop improvement and farming systems programs include miscellaneous legumes, e.g. Lima-bean, and winged-bean, vegetables, e.g., okra, beans, *Capsicum*, pepper, and *Celosia*; plantains, and some forage and conservation crops, e.g. *Cynodon nlemfuensis*, *Leuceana leucocephala*, *Paspalum notatum*, *Pennisetum purpureum* and *Peuraria phaseoloides*.

The crop improvement programs are concerned with increasing yields, improving quality and incorporating a range of desirable characteristics into new crop varieties that contribute to improved food production. The training and outreach programs, and other supporting services also play vital roles in the achievement of the objectives of IITA. This paper is devoted to a brief review of the objectives, organisation, scope, guidelines and priorities of the IITA Farming Systems Program.

BACKGROUND TO THE FARMING SYSTEMS PROGRAM

Physical Setting. The IITA is concerned with the broad belt of the lowland tropics at less than 600 m elevation that bestrides the equator and although of varying width mainly lies within latitutes 7° North and South of the equator except in windward slopes of tropical coasts where it extends to nearly 20° North and South of the equator. This zone comes under the 'Tropical rainy climates' of the *Af* and *Am* types according to Koppen's classification. It is a belt of maximum insolation and uniformly high temperatures with annual means averaging between 25°C and 27°C in areas near the equator and at not more than 1000m elevation. The days and nights vary very little throughout the year. Although the temperatures may not be excessively high, the high atmospheric humidity and slight air movement results in low cooling power and high sensitive heat. The temperatures are highest during periods of clearer skies and lowest rainfall during the year. The rainfall is usually heavy throughout the year varying from areas of one-peak annual rainfall in excess of 4,000mm with the *Af* climate, where the dry season is absent, to as low as between 1,000 and 2,000mm two-peak annual rainfall areas of the *Am* type with a dry season and located further north and south of the equator than those of the *Af* type. The *Af* type of climate supports a climax vegetation of tropical rain-forest or *selva* of broad-leaf evergreens whereas the *Am* type supports a mixture of evergreens and deciduous trees with a dormant period of leaf fall. Under normal conditions both *Af* and *Am* areas are covered with tropical rain-forest but human activities, such as farming, grazing, clearing and burning of forests, have resulted in the 'Derived savanna' condition found in the northern parts of the tropical rain-forest areas of West Africa. Relevant climatic data* at Ibadan, which has the Am type of climate, is presented

* IITA Annual Report, 1971

in Table 1.

Soils of the humid tropics consist mainly of ultisols and oxisols which as compared to the soils of the temperate regions, according to Donahue (1970), are characterized by (a) deeper and more intensely weathered pedons with fewer remaining weatherable minerals,(b) lower percentage silicon,(c) higher percentage iron and aluminium especially in the form of amorphous oxides, (d) higher percentage of kaolinite and smaller percentage of montmorillonite, (e) lower cation exchange capacity, (f) lower buffer capacity, (g) lower available water capacity, (h) a lateritic (plinthite) layer in some soils that hardens by crystallization of the iron on continuous exposure to cycles of wetting and drying, as would occur as a result of continuous cropping, (i) less accumulation of leaf litter as a result of more rapid decomposition and (j) smaller reserve of total available plant nutrients. Thus, in general, these soils while possessing good structural characteristics are infertile and processes of degradation are intense and active throughout the year. Fertility is maintained especially in the surface horizons under forest or vegetation cover but rapid loss in fertility and soil erosion occur with the removal of vegetation especially on slopes.

TRADITIONAL FARMING SYSTEMS AND THEIR ASSOCIATED PROBLEMS

The traditional farming systems in different parts of the humid tropics vary in the length of fallow periods, intensity of cropping, range of crop plant species grown, extent of fragmentation of holdings, etc. Although the farming systems may differ from place to place, they are all characterized by low-capital investment, high human-labor requirement, use of simple tools consisting mainly of the hoe and the matchet, use of relatively well adapted but unimproved crop varieties and breeds of livestock, absence of costly inputs such as fertilizers and pesticides, and the growing of crops in mixtures which are ecologically stable and constitute insurance against risks of various kinds.

Broadly speaking, the traditional farming systems in most of the humid tropical areas of Africa and South America are usually known as shifting cultivation in which the farmer clears, burns and crops a piece of land and after two or three years, when the yields begin to decline, allows it to revert to bush and starts a new farm at another location. During the period of fallow, which may vary from less than four to 20 years, depending on the availability of land and pressure of population, the fertility lost during the cropping period is replenished by natural recycling of nutrients returned through leaf fall and the activities of various organisms. This so-called 'shifting cultivation' very likely developed as an adaptation of the early 'slash and burn agriculture' and after many centuries of trial and error with soil and crop management practices.

Table 1. Climatic Data for the Ibadan Area

	J	F	M	A	M	J	J	A	S	O	N	D	Yearly Average
Rainfall (mm)	10	23	92	133	151	187	155	82	178	157	45	10	1226
Av. daily Temperature (°C)													
Max.	32.3	33.9	32.7	32.4	31.1	29.7	27.8	27.2	28.6	29.7	31.2	31.8	30.7
Min.	20.9	21.9	22.5	22.2	21.7	21.8	21.1	20.6	21.3	21.1	21.6	20.7	21.4
Pot. evapo-transp. (mm)	134	155	135	117	100	81	65	60	73	83	102	122	1228
Rel. humidity (%)													
09.00 GMT	81	78	81	82	84	86	89	88	88	86	83	83	84
15.00 GMT	48	73	54	61	68	73	77	77	74	69	68	52	63

Strictly speaking, the classical shifting cultivation of the humid tropics, in which the farmer more or less moves from place to place as farms are changed from year to year, has given way in most of tropical Africa to a range of transitional farming systems of varying cropping intensities and periods of fallow. Changes brought about by various factors, such as population pressure and development of more sedentary culture, resulted in the replacement of the classical shifting cultivation by long-term bush fallows and various cropping systems with higher cropping intensity and shorter periodsof fallow. These, in order of increasing cropping intensity, include (a) long-term bush fallows in areas of very low population density, (b) short-term natural bush or planted fallows of shorter duration of two to five or slightly more years, (c) rudimentary sedentary cultivation of often not more than two years' fallow and (d) permanent or continuous cropping systems or compound gardening which rely heavily on farm and household refuse and simple rotation of crops for the maintenance of soil fertility.

The shortening of periods of fallow as a result of population pressure forces the farmer to practise a more intensive and more or less continuous cropping system based on traditional crop management practices that evolved under a different set of circumstances. The shortening of periods of fallow owing to continuous cropping and inability of land to revert to planted fallow or bush regrowth is associated with the following problems: (a) loss of soil fertility and soil organic matter, (b) irreversible soil degradation and erosion and (c) persistent weed growth. Associated with these are lack of power and efficient tools for various operations and credit to purchase necessary but costly inputs. All of these lead to poor yields.* Moreover, with increased population pressure and the prevailing systems of land tenure, fragmentation of holdings results in drastic reduction of farm sizes to sometimes very uneconomic units scattered at sometimes as many as 10 locations.

THE IITA FARMING SYSTEMS PROGRAM

Objectives

The current trends in and problems of traditional agriculture enumerated earlier have led to the drawing up of a set of objectives which include:

1. To help develop optimum systems of cropping for long-term sustained yields for the humid tropics.
2. To help identify adapted crop varieties and determine their yield potentials in continuously cropped tropical soils.
3. To help find solutions to problems of soil fertility, chemistry

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* IITA Annual Report, 1973

and management resulting from continuous intensive cropping as compared with traditional methods.

4. To aid identification of pest and disease limitations under traditional and intensified cropping and develop control methods.
5. To develop mechanical techniques for upland agriculture suitable for continuous cropping systems, including tillage, spraying, weeding, harvesting and drying equipment with emphasis on small holders' problems.
6. To identify optimum combinations of crops and ways of achieving maximum economic returns from land under scientific management and traditional systems.
7. To examine practices and social organization of farmers with a view to identifying the major constraints in change.

Briefly stated, the objective of the IITA Farming Systems Program is the development of a range of efficient packages of technology for maximising production, that are economically viable, adaptable and acceptable to farmers in different parts of the humid tropics.

ORGANIZATION AND SCOPE OF RESEARCH IN FARMING SYSTEMS

Organization

The Farming Systems Research Program at the IITA is organised into sub-programs each of which represents an important discipline or area of investigations in the integrated and inter-disciplinary research activities necessitated by the systems approach which requires that the whole food production system and associated problems be investigated simultaneously. The sub-programs are grouped as follows:

A. Soils and Soil Management

1. Pedology
2. Soil Chemistry
3. Soil Fertility
4. Soil Physics
5. Soil Microbiology

B. Agricultural Meteorology

6. Agroclimatology

C. Agricultural Engineering

7. Soil and Water Management
8. Agricultural Mechanization

D. Crop Production and Management

9. Vegetable and Horticultural Crops Systems
10. Major Staples and Cropping Systems
11. Forage and Conservation Crops

E. Crop Protection

12. Nematology
13. Weed Science

F. Agricultural Economics

14. Production Economics
15. Marketing Economics

The above sub-programs while representing several disciplines of importance in farming systems cannot satisfy the objectives of the IITA program without contributions of scientists from other programs and even research institutions of excellence located elsewhere. Thus the three crop improvement programs (CIP, TRIP and GLIP) contribute inputs in terms of high yielding and improved crop varieties and their management technology that can be tested in rotations, multiple cropping and relay cropping investigations in the Farming Systems Program. Provision has also been made to obtain the services of scientists whose services are vital in the farming systems but are for convenience located in other programs where their contributions are more relevant and of greater importance than in farming systems. For example, entomologists located in the Cereal and Grain Legumes Improvement programs and plant pathologists in the Roots and Tubers and Grain Legumes Improvement Programs at the IITA cooperate in providing crop protection services and in cooperative investigations with scientists in Farming Systems.

Scope of the Farming Systems Research and Related Activities

The inter-disciplinary nature of farming systems research and the areas of specialization that contribute vital information and inputs that are needed in farming systems have been reviewed by Moomaw and Hedley (1971) and Okigbo (1973-74). The scope of activities in farming systems research should be such as to take into account the various factors which affect agricultural production. Thus farming systems research calls for research in and interaction among scientists in rural socialogy and agricultural economics, soil science (pedology, chemistry, fertility, physics and microbiology), agricultural engineering (soil and water engineering and farm power and mechanization), agronomy, horticulture, plant protection, agroclimatology, plant physiology, plant breeding and a few other related disciplines. All these scientists are involved in one or more of the following activities: (a) generation and testing of inputs, (b) manipulation of the environment or the genetics of organisms and

(c) monitoring of the environment.

BASIC ASSUMPTIONS, STRATEGY AND RESEARCH PRIORITIES

Developing countries of the humid tropics continue to experience runaway population growth, scarcity of food and other related problems. Consequently, they are more hard-pressed to develop appropriate technology and inputs that facilitate maximzation of production per unit of labour or land in a shorter time compared with the developed countries. There is therefore, need to draw up a set of assumptions or guidelines and establish priorities for farming systems research for the humid tropics so as to facilitate rapid progress.

Basic Assumptions and Guidelines

1. In many developing countries farmers constitute a major proportion of the population (sometimes upto 80%), operate on small holdings and make their own decisions. It is not likely that in the foreseeable future, rapid industrialisation which places heavy emphasis on prestigeous, costly and poorly managed industries, will soon absorb a considerable proportion of the continuously increasing population to an extent that will reduce the number of farmers and increase farm size to more than just a few hectares. Consequently, efforts must be directed to research aimed at developing intensive farming systems for the small farmer that maximize production on a unit of land.
2. The level of education of farmers in the developing countries and the financial resources available to them call for innovations that do not involve drastic changes in their lives and are technically within their abilities.
3. The present concern about the environment and the experience in the developed countries call for farming systems that involve scientific and careful management of resources in such a way that agriculture does not contribute to wastage of resources and pollution.
4. The current energy crisis and concern about the limitedness of mineral resources are having very adverse effects on the supply and cost of several agricultural inputs. Research in farming systems should aim at ways of minimizing the extent of their use, increasing the efficiency of their use, and finding alternatives that are cheaper and preferably locally available. In this regard it may not be meaningful to eliminate applications of fertilizers completely since the results of such a practice will be disastrous but unprofitable luxury supply of costly plant nutrients to crops should be avoided.
5. Whereas there is understandably much concern about producing enough food to feed the ever increasing population, research strategy should aim at a develcping a wide range of farming

systems which could diversify agricultural production, facilitate import substitution, and afford the less developed countries the opportunity of developing expertise in biological production systems in support of agro-based industries which offer the best scope for the kind of industrialisation that will enhance increased employment in agriculture and related industries. To achieve this, as much emphasis should be given to land-saving production systems as is given to labor-saving techniques.

6. Research on farming systems for the tropics should give emphasis to the evolution of permanent production systems with built-in flexibility for change by being continuously involved in the monitoring of the environment so that changes can be foreseen' and necessary measures taken promptly.
7. Research activities in farming systems should be carried out in such a way as to ensure that all scientists concerned constantly come in contact with the farmer and the realities of his world so that their investigations are related to the problems of farmers.
8. A meaningful basis for the laying down of priorities is the understanding of the farmer, his needs, problems and the social, biological and political environment in which he operates. This can best be done through inter-disciplinary study of traditional agriculture.
9. Whereas it is true that the main objective of the small farmer is to produce enough food for himself and his family, it is also relevant to recognize that he is as much interested in improving his general way of life and satisfying needs other than food as other human beings in non-agricultural jobs. Therefore, while emphasizing food production, there should be a place for food crops grown for cash and even non-food crops that could be meaningfully and profitably integrated with food crops in certain environmental situations.

Some Priorities of Relevance to Farming Systems Research

Priorities in choice of crops. The humid tropics is very rich in species of crop plants. Consequently, the number of combinations and sequences of cropping in which they can be grown in different ecological situations within the humid tropics is very large. If rapid advances are to be made in farming systems research in the humid tropics, priority should be given to a selected number of crops and all crops selected should not receive equal attention in all relevant ecological zones. In line with this reasoning, the following crops have been tentatively selected as of major importance in the IITA Farming Systems Program:

(a) Roots and Tubers	(b) Cereals
Cassava	Maize
Yams	Rice
Sweet-potato	

(c) Grain Legumes

Cowpea
Lima-bean
Soybean
Pigeon-pea
Winged-bean

(d) Horticultural Crops

Plantains
Okra
Tomato
French-beans
Celosia
Capsicum peppers

(e) Forage and Conservation Crops

Paspalum notatum
Cynodon nlemfuensis
Stylosanthes gracilis
Leucaena leucocephala
Pennisetum purpureum
Peuraria phaseoloides
Styzolobium deeringianum
Brachiaria mutica
Panicum maximum
Centrosema pubescens

Priorities in Crop Production Systems: So far in food crops research in national programs in the humid tropics, priority has been given to growing crops in monoculture or sometimes in rotations involving sequences of monoculture in each course in the rotation. Since most farmers in the humid tropics will continue for a long time to come to be partially subsistence and partially commercial farmers, priority should be given to cropping systems involving multiple, relay or intercropping. Another reason in support of this line of reasoning is that it has been recently recognized that monoculture agro-ecosystems tend to be more fragile than traditional mixed cropping systems which are ecological, more stable and minimize pest and disease damage. Studies of traditional agriculture in parts of Nigeria have shown that farmers may sometimes grow as many as 20-60 crop plant species in mixed culture in less than 0.5 hectare. These and similar studies also indicate that the following advantages of mixed cropping: (a) an efficient utilization of resources since compatible crops utilizing nutrients of various kinds and at different levels could subsist mutually with one another, (b) an insurance against crop failure due to diseases, pests and other adverse environmental conditions (Norman, 1970), (c) a continuous cover of the soil throughout the year protecting it against erosion especially when crops are harvested at different times and their growth periods overlap, (d) the availability of a range of foodstuffs at different times of the year thus ensuring a more balanced diet and minimizing storage problems, (e) a mixture of varieties constitutes a reserve of sometimes potentially useful source of germplasm of plants with beneficial characteristics and (f) efficient utilization of resources since both heliophytes and shade tolerant crops can be grown together in such densities as to sometimes smother weeds. The main disadvantages of mixed cropping which should be taken into account in investigations of potential mixture and patterns of planting include difficulties in formulating fertilizer and pesticide recommendations, the applications of other inputs, in addition to problems of mechanization.

In the groups of cropping systems that will be involved in the multiple, relay, rotational or inter-cropping systems, investigations at IITA or elsewhere in the Farming Systems Program in order of priority are as follows:

1. Cropping systems involving four or more crops and including at least two major staples, such as maize and yam, maize and cassava, cassava and yam, rice and sweet-potatoes etc.
2. Cropping systems involving several crops but with emphasis on two or more vegetable crops and/or grain legumes.
3. Cropping systems which form a part of mixed farming systems involving the rearing of small animals as sources of manure, meat and eggs and other useful products.
4. Cropping systems that involve use of forage or conservation crops with or without animal production.
5. Rotations involving two or more staples and other crops such as legumes grown in various sequences, each crop grown in monoculture.
6. Cropping systems involving inter-cropping of food crops and perennial food plants such as plantain or banana.
7. Cropping systems involving integration of food-crop production with plantation crops especially at the time of plantation establishment or renovation.
8. Cropping systems involving integration of food-crop production with quick maturing forest tree regeneration, known as 'agrisilviculture'.

Of the above groups of cropping or farming systems No. 3 and especially 7 and 8 are unlikely to be located at IITA, but may be carried out cooperatively with other institutes or organizations that give priority to animal production, plantation crops or forest tree production.

Priorities in Soil and Water Engineering: Large scale canal irrigation projects or even tube well irrigation may not be economical for farmers in the humid tropics. But supplemental irrigation as an aspect of watershed management could profitably facilitate all the year round food production. Related to this should be the priority given to management of soils of different topo-sequences aimed at optimum realisation of the potentialities of hydromorphic and valley-bottom soils.

Appropriate Technology for Smallholders

So far, in national programs in the humid tropics, emphasis has been given on research on plantation crops or large scale production of food crops by highly capitalized and privileged farmers or government corporations. There is need to develop farming systems and mechanization of the appropriate technology type for most of the farmers who farm two or three hectares and usually much less areas of land. Related to this is the problem of drifting of thousands of young men to urban centres in search of work rather than to go into farming, because of the drudgery involved in farming and of course higher incomes and better living conditions in urban areas where non-agricultural jobs are available. Development of economically viable, labor-saving practices and simple cheap but improved farm tools instead of outright tractorization should be given priority.

STRATEGY FOR INTEGRATION AND CO-OPERATION IN FARMING SYSTEMS RESEARCH

The need for an advantages of inter-disciplinary problem-oriented approach to research in farming systems is recognized by all well meaning and experienced scientists. Yet it is common knowledge that very often co-operation in research especially in developing countries, where the foundations of scientific tradition are just being laid, is difficult to come by. This problem is also often accentuated by the fact that with the current explosion of knowledge, specialization has become an economic and unavoidable necessity. Coupled with this is the fact that scientists in general and administrators of research institute in particular have had more exposure to and experience in training training and research along disciplinary lines than in the inter-disciplinary approach which is imperative in research in farming systems.

Since, however, the suitability, economic viability, and importance of any input generated by scientist in different disciplines and programs can only be determined by evaluating its performance in individual farming systems packages of technology under field conditions, there is need for provision of a mechanism for integrated research projects which combine inputs from different disciplines. Moreover, results of the performance of inputs in various combinations and sequences in field experiments supply feed-back information to scientists in disciplines or programs in which the inputs originated. For example, the performance of a maize variety in mixed or multiple-cropping combinations with cassava or cowpea will supply vital information as to whether a different plant structure is required in inter-cropping or whether the maize is more or less predisposed to insect and disease damage in such situations.

Co-ordination and Integration of Farming Systems Research

At the IITA and perhaps other research institutes, all scientists of different disciplines of relevance to a particular program are not always engaged or available on the site at the same time. The result is that scientists in the various sub-programs launch their individual projects at different times. Moreover, even if all of them are available at the same time, breakthrough may occur more quickly in some fields than in others. It is also well known that scientists perform best when they have a certain measure of freedom in pursuing research in their areas of interest.

The strategy we are adopting at the IITA is that of recognizing that there is need for flexibility in allowing scientists to carry on come research in their own disciplines based on their judgement of what they regard as important in their own projects. At the same time while allowing them to arrive at some co-operative arrangements for tackling some problem with other scientists at the personal level, efforts should be made to ensure that most of the work each scientist is doing is relevant to the established priorities of the Institute and is in no way detrimental to his participation in integrated research programs that involve other scientists at the same time. There is a co-ordinator or leader in addition to a research committee, the main responsibilities of which are to ensure that relevant units are brought together whenever necessary and that priorities are adhered to. At the IITA, for example, there are agronomists in the three crop improvement programs (CIP, TRIP and GLIP) in addition to those in the Farming Systems Program. It has been found necessary to co-ordinate the work of the agronomists by defining areas of responsibility in each program and designating a co-ordinator who ensures that all the agronomists in the different programs co-operate in studies of mutual interest and in ways that eliminate unnecessary duplication. Moreover, priorities may be highlighted through seminars, workshops or research planning meetings where various scientists discuss problems of common interest and make suggestions on the lines of research to be followed or techniques to be used. One practice which should be avoided is that of over-emphasizing the number of publications in rewarding scientists involved in co-operative projects since this will tend to lure scientists away from investigations in which they feel that working with other scientists may slow down their pace of publications in learned journals.

Problems of Shortage of Staff

The number of various disciplines that should ideally be represented in a farming systems program, as the one at IITA, may be much more than the institute can afford. This has to some extent been solved by fanning out projects to scientists in universities, other institutes or agencies. In this exercise, priority is given to institutions or laboratories of scientists that have achieved excellence in disciplines relevant to the problems at hand. Visiting scientists program and graduate-training programs also assist in the solution of the problem of staff shortage. Co-operation with scientists and other institutes is one effective way of avoiding unnecessary duplication and getting acquainted with new discoveries, equipment and techniques that originated elsewhere. For example, the IITA cannot afford to give the same emphasis on pigeon-pea as the ICRISAT, but promising varieties of pigeon-pea or techniques of growing them can be modified and adapted to conditions in the humid tropics at IITA, Ibadan.

PHASED SCHEDULE OF ACTIVITIES

Although the Farming Systems Program has been undergoing continuous evaluation and modifications, the current schedule of activities include:

1. Development of some basic assumptions and priorities in requirements of potential farming systems based on results of socio-economic study of traditional agriculture with emphasis on farmers with small holdings. Studies on traditional farming systems in different parts of the humid tropics will continue to be given priority upto about 1978.

2. Priliminary short-term field studies, the main objective of which is the testing of many treatments on crop combinations and sequences. These will yield suitable practices or combinations of treatments and inputs in complete package farming systems involving multiple cropping, relay cropping, or rotational cropping. In these preliminary studies necessary attention is given to statistical niceties in their execution. It is hoped that most of the initial experiments of this type would be completed by 1979.

3. Long-term field experiments in which selected cropping systems are tried out. These will involve few treatments of selected cropping combinations on large plots on which are superimposed pest and weed control treatments, fertilizer treatments, cultivations treatments etc. that further increase the scope in the number of input combinations and timing of testing. Some of the promising combinations may have to be tried out in larger plots for economic assessment of cost of operations in relation to returns accruing therefrom. In these long-term multiple-cropping, inter-cropping or relay-cropping experiments, entomologists, nematologists, soil scientists, and phylopathologists will monitor agroecological conditions, pesticide residues, and other changes. These investigations will be carried out on a continuing basis with modifications and additions where necessary.

4. Off-site experiments at experiment stations and on farmers' fields in a range of ecological zones. These experiments will involve crops, input combinations and practices which have performed well under field conditions. Their testing is limited to locations, relevant to specific ecological conditions and prevailing farming systems and will be carried out cooperatively through national programs or other institutes.

5. Adaptive experiments. These are used to test promising farming systems or innovations developed elsewhere, for example, rice multiple-cropping systems developed at the IRRI may be tried out at the IITA using crops relevant to tropical Africa and other humid tropical areas.

6. Modelling and simulation experiments. These will be used to study the operation of inputs in traditional farming systems and test the performance of improved inputs. They also could supply prior information on cropping systems experiments to be tested in the field. Systems analysis based on data from multiple and inter-cropping experiments may be used to generate a range of viable cropping systems that could be evaluated by computer techniques and may be adopted without further field testing.

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PRESENT CROPPING SYSTEMS: TRENDS OF CHANGE AND APPROACHES FOR IMPROVEMENT*

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The present paper is based on the earlier publications+ from the All India Co-ordinated Research Project on Dryland Agriculture which contain definitions, approaches, analysis of the problems and research findings. Since no two drylands are identical, emphasis is on principles rather than practices, except by way of illustrations.

The broad aerial distribution of rainfall in India is as follows:

Mean annual rainfall (cm)	Geographical area (%)
0-75	30
75-125	42
125-200	20
Above 200	8

Whereas the coefficient of variation of rainfall for the entire country is of the order of 10 percent extensive areas in the country suffer from variations as high as 35 to 50 percent.

The major dryland crops in India are sorghum, pearl-millet, minor millets; groundnut, rape-mustard, safflower, sesame; several kinds of grain legumes; and cotton. Nearly 75 percent of the cultivated land (100 m ha) is rain-fed and covers regions receiving a mean annual rainfall of 400 to 1125 mm in 2 to 5 months. About 42 percent of the nation's food is produced on drylands and any violent fluctuation in the production from drylands seriously affects the food position in the country.

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* Contribution from the All India Co-ordinated Research Project on Dryland Agriculture and Indo-Canadian collaborative project.

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+ Papers on 'Dryland Agriculture Research and Development' and 'All India Co-ordinated Dryland Research Project' presented at the National Seminar held in September 1972 and the International Seminar on Crop Life Saving Research held in October 1973 at New Delhi, respectively.

Traditional Cropping Systems

In regions of low rainfall (< 300 mm), short growing season ($<$ 2 months) and shallow soils, grass is the principal crop. Examples are western Rajasthan, parts of Haryana and Kutch where low rainfall and short growing season are the limiting factors. In the Deccan plateau, however, it is generally the soil depth that is limiting, particularly in the red soil areas.

With increasing rainfall and growing season, the dominant cereal changes from pearl-millet through sorghum to maize or upland rice. In majority of drylands with rainfall 400 to 750 mm the cropping intensity is unity. Inter-cropping is mainly in time, that is a combination of relatively long duration crops such as red-gram and sorghum. Relay cropping is practically unknown.

Sequence (double) cropping is usually practised in regions receiving a rainfall of 1000 mm and above and with a soil storage capacity of 150 to 200 mm of available moisture. For example, upland rice and wheat in the Indo-Gangetic plain.

Traditionally the varieties grown in drylands are of long duration, particularly in the Deccan and invariably suffer much from moisture stress. Natural selection operated in favor of survival rather than productivity so that they hardly respond to inputs and high level management. A vicious circle is thus created. Hence these traditional cropping systems are characterized by low and unstable yield.

Dryland Research - Approaches

The first breakthrough in dryland agriculture followed the introduction of high-yielding varieties. Combined with soil and water conservation practices and with improved agronomy, these varieties gave dramatic yield increases both at research farms and on farmers' fields. Their photoperiod insensitivity and short duration introduced for the first time a certain amount of flexibility into otherwise rigid cropping systems.

The high-yielding varieties are bred for population performance, that is the competition with the neighbouring plants is far less than with the traditional varieties which are bred for individual performance. This leads, in turn, to three corollaries of practical importance. First, a higher population density is necessary with high yielding varieties. Secondly, the yield plateau extends over a wide population range. Thirdly, at an optimum population, row widths are far less critical. As will be seen later, the last two considerations serve as the basis for developing intercropping systems in space, which in turn improves the flexibility.

Finally, the collection of runoff and its recycling adds a new dimension to the flexibility of cropping system. This aspect has been adequately discussed earlier in the workshop and will not be elaborated here.

Varietal Choice

The choice of crop varieties is based on estimated growing season and risk (time and duration) of moisture stress during the crop growth. Both the estimates are arrived at by analysing the climate. Some of the more precise and sophisticated methods of analysis, were presented earlier at the workshop.

A simple, proximate but useful procedure is to estimate the mean and the coefficient of variation of weekly rainfall, assuming Gaussian distribution and thus identifying the probable length of the growing season, the 'dry' periods and the sowing date (Reddy and Murthy, 1967). The underlying principle is that, although the potential evapotranspiration may be as high as 6 mm per day, many crops can stand moisture stress which permits actual evapotranspiration of about 3 mm per day for two or three weeks during the non-critical stage of development. Moisture storage capacity of the soil also provides a buffer against drought during rainless periods.

A practical approach, therefore, in choice of varieties is to first determine the crop duration appropriate to a given region and then subject entries in such a maturity group to actual field-testing to determine the most stable and top yielders. As a matter of principle, the longest duration variety within the appropriate maturity group should be selected (Quinby, Schertz and Keith, 1970).

A major consideration for choice of crop varieties in dryland agriculture is the ease of management, particularly against pests and diseases. Using field resistance as base, cultural practices could be developed. For instance, sowing of sorghum within 10 days after the first soaking shower makes it escape shoot-fly attack; raising large blocks of a maturity group of sorghum eliminates ear midge problem (Rao, 1974).

Crop Choice

The choice of crops based on the season in which they are grown (*kharif* and *rabi*) needs examination. In South India, where the temperature differences between the *kharif* (monsoon) and *rabi* (post-monsoon) seasons are not very marked, there seems to be no need to distinguish rigidly between the two seasons. This concept of *kharif* - *rabi* continuum has already yielded rich dividends, for example the conversion of rabi (September sowing) into maghi (August sowings) and advancing the sowing date of rabi sorghum from October to September (D.R.C., Bellary, Bijapur and Sholapur. Ann. Rept. 1971, 1972, 1973; and Rao, 1974).

Crops are also chosen according to soil depth. Millets do much better than sorghum on light and shallow soils. Roots of crops like castor and red-gram are able to penetrate compact sub-soils better than sorghum or millets.

It becomes abundantly clear that if a land could be cropped either in kharif or in rabi, greater yield advantage would accrue from cropping in kharif (D.R.C. Indore and Sholapur Ann.Rept. 1971, 1972, 1973). This may call for a provision of field drainage in black-soils receiving heavy rainfall.

Basically what is attempted is to introduce more efficient crops for a given situation in place of traditional ones. Typical examples are: Safflower in place of western cottons and wheat in the Deccan rabi(D.R.C,Bellary, Sholapur and Akola.Ann. Rept.1971, 1972, 1973), and replacement of wheat by barley or mustard or gram in the Indo-Gangetic clluvium from west to east (D.R.C.,Agra and Varanasi,Ann.Rept. 1971,1972,1973). Rainfed wheat should be preferred only in areas receiving 8 to 10mm of winter rains or dew fall and with mean daily temperature between 10-15^{o}C for atleast 2 months from the first week of December. Below to Vindhya range, wheat is inefficient.

The farmer attaches great importance to food crops. Rarely would he agree to buy food from the market. This should be recognized in introducing new crops.

Crop substitution should serve the national needs. In the present context in India, grain legumes and oilseeds are the chosen crops to replace inefficient cereals and cotton. Decisions should be taken on the basis of marketability and the value of the new crops. Any crop substitution implies efficient transport system to move the produce from areas of efficient production to areas of consumption.

Cropping Intensity

In regions receiving 500 to 625 mm of mean annual rainfall and with a soil moisture storage capacity of less than 100 mm, only a single kharif crop is possible.

When the rainfall is between 625 and 750 mm with a distinct period of moisture surplus, intercropping systems should be developed for improving crop production. Traditional intercropping systems are mostly in time; the crops chosen are such that they mature at different times and their peak demand for moisture, nutrient and light do not coincide. Whereas these systems have still a place in Indian dryland agriculture, more and more thinking is now devoted to intercropping in space. Here the choice of varieties within the crops becomes important. Plant breeders have already evolved varieties suitable for intercropping in a few crops (Rao, 1974).

Work is already on hand to study the competition between crops (Freyman and Shelke, 1974). Attention is also being paid to crop geometry to accommodate intercropping (Freyman and Dolman). By and large the future intercropping systems in India will be cereal-legumes, the objectives being (a) to minimize fertilizer use, (b) to fortify foods, (c) to provide legume fodder for cattle, (d) to minimize pest and disease incidence on legumes and (e) to extend useful growing season.

In regions receiving 750 to 900 mm rainfall and with soil storage capacity of 150 mm and above of available moisture, double cropping is theoretically possible. However, there are several areas in this region where moisture in the seeding zone becomes limiting if one waited for harvesting the standing crop to sow the next one. In such areas, relay cropping is recommended. Examples of this system are: relay cropping of safflower in sorghum in the Malwa plateau (Indore region) and in Marathwada region and, on a contingency basis in the Vidharbha region taking advantage of the last rains in September. Upland rice-linseed is a system developed to overcome the difficulty of preparing a good seed-bed after rice.

Beyond 900 mm and with soil storage capacity of 200 mm or more of available moisture, a sequence (double) cropping is practical. Examples of this system are mostly in the Indo-Gangetic alluvium, particularly those involving upland rice followed by bengal-gram (chick-pea) in eastern Uttar Pradesh, pearl-millet followed by barley or mustard in central Uttar Pradesh and maize or fodder sorghum followed by wheat in western Uttar Pradesh. Here the objective is to maximize the returns from the system rather than from the individual crops.

Cropping Systems for Aberrant Weather

The weather in any given season is essentially unpredictable, though it is possible to characterize the climate of a place in statistical terms. Thus, whereas crop plans are drawn up for a normal season, one must be prepared for making adjustments for an aberrant weather which, by and large, comprises the following : (a) delayed onset of monsoon; (b) long gaps in rainfall; and (c) early stoppage of rains.

Cropping systems suitable for the three kinds of aberrations have been published (Ind.Fmg. June 1974) and will be refined as more information becomes available. The principles involved are the choice of alternate crops, ratooning and thinning, use of urea spray for rapid regeneration and providing crop-life-saving irrigation to moisture-stressed crops.

The concept of 'Crop-life-saving research' which was originally developed in 1972 to meet sub-normal weather conditions has been extended in 1973 to take advantage of above normal and extended monsoon.

Cropping Systems for Minimum Fertilizer Use

These systems are particularly relevant today when there is a global scarcity of fertilizers. Although, it is unfortunate that this valuable input should become scarce at a time when fertilizer use in drylands has been appreciated by Indian farmers, one should recognize the situation and live with the problem.

It is obvious that highest fertilizer efficiency is obtained only with the high yielding varieties (AICRIP, AICSIP, AICWIP Ann. Rept. 1970, 1971, 1972). The systems for minimum fertilizer use involve: (a) improving the efficiency of fertilizer-use, split application in relation to crop needs and available moisture, placement and, in specific cases, foliar application; and (b) developing suitable cropping systems. It is a common knowledge that legumes fix nitrogen and are benefited by phosphate application, and the cereals respond to nitrogen. Hence the first area of investigation is to develop systems in which phosphates are applied to legumes, nitrogen is applied to the cereal and these crops are grown alternately.

The temperature plays an important part in the utilization of phosphates. In an upland rice-wheat sequence, the cool weather crop wheat is benefited by phosphate application more than rice (Ramamoorthy, 1974).

The second area of research is the utilization of crop residues either directly in the soil or through the animal.

The third area of study is the use of set-furrow planting which is in practice in parts of Gujarat and Rajasthan. This system makes a distinction between the area which supplies nutrients to the plants and the area which supplies moisture. In this system a furrow is opened in advance of the sowing season. Manures, fertilizers and crop residues, if any, are applied in the furrow which is fixed and is not changed from year to year or crop to crop. The inter-furrow area is cultivated to remove weeds and make it receptive to rainfall. Using this set-furrow system, the cereal-legume combination with alternate nitrogen-phosphate furrow mentioned above could be more effective.

All these three areas of study have been initiated in the Dryland Project (Spratt and Venkateswarlu, 1974).

Cropping Systems for Risk Minimization and Distribution

The traditional cropping systems are characterized by low risk and low yield. It must be recognized that the low risk will continue to be the guiding principle in developing cropping systems, in view of the poverty of the dryland farmer. The problem is then how to combine low risk with high yield.

The first approach is to develop cropping systems to meet the aberrant weather as indicated earlier in the paper. There are, however, regions in India such as Gujarat, Rajasthan and Haryana where the rainfall and the growing season are both limited. In such cases, the frequency distribution of the length of growing season is arrived at by statistical analysis of the past data, say, 60 years' rainfall distribution and then the area allotted to the crops of different maturity groups in proportions to the frequency of the growing season (Virmani, 1974). For an example, if the cumulative probabilities for a 100-day growing season are 40 percent, for a 80-day season 70 percent and a 60-day season 100 percent then ideally crops requiring 100, 80 and 60 days to mature should occupy 40, 30 and 30 percent of the area respectively. When the growing season is less than 60 days the most reliable crops are perennial fodder grasses and legumes. Intercropping systems may be developed as at Jodhpur combining perennial fodder grasses and grain legumes.

The second approach is to combine low monetary inputs with high level management. The recent trend to change over from hybrids to straight varieties wherever possible is an illustration of the shift. Emphasis should be on doing -- in time certain operations which are normal to raising crops. Selection of crops and varieties, choice of sowing date, plant population, crop geometry and weeding fall in this category.

The third approach is to supplement the natural resources with monetary inputs such as fertilizers, ground-water, etc. It is the author's belief that a farmer benefits most by cash inputs only if he has mastered the use of natural resources.

CONCLUSION

So far, cropping systems dealt with were for rain-fed conditions. Combined with appropriate runoff recycling systems, cropping systems could be considerably expanded.

Mention should be made here of the attempts to stabilize dryland agriculture by tapping ground-water resources. The disappointing thing is that when ground-water is developed, the cropping systems have no relevance to dryland agriculture. There is thus a need for developing water resources on a community basis and for community use.

Judging by earlier experience, only those cropping systems which give yield increases of the order of 50 to 100 percent, visible to the naked eye, are likely to enthuse the Indian dryland farmers.

Irrespective of the cropping system, good farming operations are basic, for example a 100 percent crop stand. It is the one improvement that is necessary before benefits can be attained from the other management techniques.

The recommended practices should be implementable at the farm level! Formulation of a package of practices is desirable. Recommendation should, however, be made keeping in view the present level of farming, the missing or faulty critical farm operations and the farmer's resources.

An estimate of yield improvement and stability resulting from the improved dryland technology is provided by the data from the Dryland Research Project and the Sorghum Improvement Project. Except in Saurashtra, western Rajasthan, Haryana and parts of Maharashtra, where the monsoon totally failed, the productivity during 1972-73, averaged over several research centers and crops, was not less than 5 quintals per hectare compared with near failure of crops in farmers' fields. During the near normal season of 1971-72, the yield increases were of the order of 100-200 percent over the local practice. Dr. N.G.P. Rao and his colleagues concluded that even during 1972-73, nearly 80 percent of the yield variation in sorghum was determined by controllable factors such as the choice of variety, sowing dates, etc.

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RESEARCH ON MIXED CROPPING WITH CEREALS IN NIGERIAN FARMING SYSTEMS - A SYSTEM FOR IMPROVEMENT

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Mixed cropping is the growing of two or more crops in the same area of land in the same season so that plants of at least one crop are associated with plants of another crop for a substantial period of time. The degree of mixing may be complete, such as when one crop is either sown with or after another crop and harvested before it(intercropping), or partial, when a crop is both sown after and harvested after another crop in the mixture (interplanting). Both are to be distinguished from sole, double or multiple cropping which are the growing of crops either alone or in succession on the same land in the same wet season.

Mixed cropping has been used for a very long time. It is practiced, in one form or another, in most countries of the world, from mixed pastures of Europe to mixed crops of Africa and Asia. Mixed arable cropping is generally associated with agricultural systems of the developing nations and particularly with subsistence farming.

Very little co-ordinated research has been done on crop mixtures, probably because of the complexity of the subject but also, perhaps, because of 'the psychological notion that because such a system is associated with subsistence farming,it is not worthy of serious research endeavour' (Norman, 1973). An inference to be drawn from this statement is that as agriculture develops, sole cropping automatically takes over because it is intrinsically more efficient and productive. Nevertheless, and despite the fact that sole cropping is generally considered indicative of 'progressive' farming, there has been little or no shift to sole cropping by subsistence farmers, even after years of extension effort. This is particularly true of Nigeria. Certainly the main stream of effort has been to extend advanced practices which have been developed from work with sole crops (and thus believed inapplicable to mixed crops?). It has also been shown that the application of advanced practices to sole crops may not be acceptable to subsistence farmers because of the work load and risk involved (Baker). However, even if these are the main reasons why mixed cropping is preferred, it is still pertinent to ask what are the constraints farmers associate with sole cropping and, fundamentally, is sole cropping in fact intrinsically more productive

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and efficient than mixed cropping?

Labor inputs

Norman, conducting a survey of three villages inthe Zaria area, found that mixed crops accounted for more than 83 percent of the 360 hectares surveyed. Mixtures of two crops accounted for 42 percent, those involving three crops 24 percent, the balance involving more than three crops. By far the commonest mixture was millet and sorghum, covering 26 percent of the total area, rising to 42 percent when other crops were included in this mixture. He proceeded to measure man-hour inputs and yield return from a wide range of mixtures and, using weighted means (dependent on area and type of mixture), arrived at average figures for these variables. Extracts from his data are given in Table 1.

Table 1. Weighted means for man-hour inputs and yield for sole and mixed crops

	Man-hours		Yield kg. ha.			
	Annual	June/July	Millet	Sorghum	Groundnut	Cowpea
Sole	362	122	-	786	587	-
2-crop	582	150	370	726	437	98
3-crop	557	151	357	536	389	138
4-crop	670	223	365	374	429	139

Farmers in the survey relied almost entirely upon family labor using hand tools, and earlier work by Norman (1970) had indicated that the area of land that can be handled in June-July (the period of the weeding 'bottleneck') governed the total area cultivated. Table 1 shows that although total man-hours for mixed crops are more than those for sole crops, the proportion of labor used in June-July was much reduced.

Further, when returns were expressed in terms of value, mixed crops gave, on average, 62 percent higher returns than sole crops. However, returns per annual manhour were 15 percent higher for sole crops and returns from mixed cropping did not compensate for the higher annual labor input. Nevertheless, Norman argued that since labor was only truly limiting during June-July, it was more valid, and realistic, to compare returns per manhour in this period. In terms of this ratio, crop mixtures gave an average return 20 percent higher than that from sole crops. Thus, although the limitations imposed by labor required in June-July may require the cultivation of a smaller area of mixed crops, returns will be greater than that of an area of sole crop using the same labor input in that period. Norman concluded that under indigenous technological conditions the profitability of crops grown in mixtures was higher than that of sole crops and also by showing that the variability of returns from mixed crops was less than that of sole crops, stated that mixed cropping was consistent with the goal of security.

It is noted from Table 1 that the yield of individual crops was depressed in mixtures when compared with sole crop yield. This was attributable to increased competition, because population of any one crop was not sufficiently lowered to compensate for the presence of other crops. Farmers in this survey did not simply mix the crops but almost superimposed them, in that plant population ha^{-1} of mixed crops averaged 67 percent higher than that of sole crops. The average population of sorghum, for example, in two-crop mixtures was 85 percent of the sole crop population. Nevertheless, if yield from the 85 percent stand of mixed sorghum is equated to the 100 percent of sole sorghum, the yield is shown to be increased by mixing (726 kg. ha^{-1} at 85 percent become 854 kg. $ha.^{-1}$ at 100 percent, compared with 786 kg. ha^{-1} from 100 percent stand of sole crop). Thus, there is much scope for investigation of degree of mixing and plant population within mixtures to lead to a better balance between inter and intra-plant competition.

Yield

Because of the farmer's reluctance to change to a sole-cropping system, partly for reasons given above, research began again at the Institute of Agricultural Research (I.A.R.), Zaria, on yield aspects of mixed cropping, primarily in an attempt to improve the system but also to settle the vexing question as to whether, if labor and other constraints are removed, sole cropping is more productive than mixed cropping. Further, and I quote from Evans (1960), it was believed that "unless sound evidence is obtained that production from pure stands is appreciably higher than that from mixed cropping, it will not be possible to introduce rotational systems of agriculture based on pure stands as long as the hoe remains the most important agricultural implement."

The list of mixed cropping trials previously conducted at the I.A.R. is a formidable one (Palmer, 1971), though yield results from these were somewhat inconclusive and the value of mixed cropping remained attributable to the greater profitability, the spread of labor use through the season, and the greater security of the system in areas where climatic risks are high. Others, however, (Evans 1960, Andrews 1972) had consistently obtained yield increases from crops grown mixed compared with crops grown alone, although it was never stated that yield from crops grown mixed should always be greater than the yield from equivalent areas and populations of crops grown solely. This is true whilst one or more of the three parameters of growth (light, water, nutrients) are limiting, for the mixing of crops, of similar habit, but with different demand periods, must inevitably lead to greater utilization of the environment resulting in greater yields. Andrews (1972) inferred this when he stated, "the main source of gain ... came from planting early maturing and slow maturing crops together, since no one crop can efficiently utilize the whole wet season." However, he also stated that, "intercropping is advantageous ...particularly to the small farmer where factors other than yield are important," suggesting that if other factors were not limiting then sole cropping would have yield advantages. It was because of the latter belief that Andrews made efforts to maximize production within a wet season through double cropping. His trials compared production from two consecutive sowing of quick-maturing cerals, millet and maize, with yield from a single sowing of a late maturing sorghum hybrid adapted to the Guinea zone. However, he found considerable difficulty in establishing the second sowings at the height of the rains, and the second sowings failed in both 1967 and 1968. In the 1968 trial, however, he also included the legume cowpea as a second crop, and with much success, gross value for the double crop being 30 percent and 70 percent higher than the value of sorghum alone when cowpea followed millet and maize respectively. Subsequent experiments in 1969 and 1970, attempted to relate more closely to farmers' mixed cropping by sowing the double crop of cereal followed by cowpea in alternate rows with the long-season sorghum. The 1969 trial, using a 1:1 ratio of crops in the mixture, gave surprisingly large benefits from the mixed crops: both sorghum/millet followed by cowpea and sorghum/maize followed by cowpea gave much greater cash returns than sole sorghum (99 percent and 70 percent respectively). In this experiment, however, there was no comparison between mixed cropping and double cropping and the 1970 experiment was expanded to include this comparison, and also to compare different ratios within the mixed crop. All crop mixtures again gave higher cash returns than sole crop, and also showed that mixed crops were significantly better than the double crop. These results are given in Table 2.

Gains from mixed cropping shown in Table 2 are represented as gross cash gains in Naira, and to obtain estimates of the gain in crop yield owing to mixing, yields must be expressed on an equivalent area basis. Thus, the yield from 1 ha of a sole crop must be compared with the yield from 2 ha of that crop grown in a mixed crop at 1:1 ratio with each plant occupying the same unit area. Taking sole crop yield for each crop as 100, relative yields from equivalent areas of the crops when grown in mixtures are given in Table 3.

Clearly, these trials not only demonstrated that crop mixtures were more profitable but also that cereals gained in yield from being mixed, i.e. the actual yield of millet and sorghum from 2 ha of mixed crop was greater than the yield of each crop from 1 ha each of sole millet and sorghum. (Yields were: from 2 ha millet and sorghum at 1:1, 4324 kg. and 4760 kg., from 1 ha sole sorghum 2893, and 1 ha sole millet 3060).

Table 2. Yield in kg. ha^{-1}, and cash value, from sole, double and mixed crops

Treatment	Grain ha.$^{-1}$	Value (N)	% gain in value
Sole sorghum	2893	31.82	-
Sole millet followed by cowpea	3060 998	36.10 14.38	+58.6
1 row sorghum 1 row millet followed by cowpea	2162 2380 229	23.78 28.08 3.30	+73.4
1 row sorghum 2 rows millet followed by cowpea	1749 2806 352	19.24 33.12 5.06	+80.4
2 rows sorghum 2 rows millet followed by cowpea	2079 2080 258	22.86 24.54 3.72	+60.6

Table 3. Relative yields from equivalent areas of the crops grown in mixtures

Crop	1:1 ratio	1:2 ratio	2:2 ratio
Sorghum	149.5	181.4	143.7
Millet	155.6	137.6*	136.0
Cowpea	45.9	52.9*	51.7

* Millet was grown only 1:1 and 2:1.

It was of particular interest that these trials were all done using fertilizers at rates higher than those normally used by farmers, thus giving some confidence to extension workers who might have doubted the value of applying advanced practices to mixed crops, and also that double-row mixed cropping opened the door to mechanization of mixed crops.

Improved Varieties and Mixed Cropping

The work described was done with the dwarf hybrid sorghum line 2123.

Recognizing that for any new sorghum variety to be acceptable to farmers, the variety must also be capable of producing an improved yield over local varieties when grown in mixed cropping systems. Andrews continued his work by comparing a range of improved varieties of different habits, although with similar maturity periods. An early millet followed by cowpea was again used as the intercrop, although an early end to the rains of 1971 resulted in failure of the cowpea crop. Results from this trial are given in Table 4.

Table 4. Grain yields on an equivalent area basis in kg. ha^{-1} for varieties

	Variety			
	FFBL	5912	453	2123
Sole sorghum	1620	2693	2724	2534
Mixed sorghum	2270	3566	3442	2946
millet	3144	3348	3416	4032
% gain by sorghum	40.1	32.4	26.4	16.3
Height of sorghum (m)	3.73	2.09	1.65	1.22

Sole millet was not grown in this experiment and it was not possible to determine total gain due to mixing. However, as before, all varieties showed gains when grown mixed, the percentage gain being proportional to the height to top of panicle of each variety. Also, relative performances of the improved varieties over the local (FFBL) decreased in mixtures, the loss of improvement being proportional to the differences in height.

In summary, these experiments by Andrews demonstrated that:

(a) considerable yield advantage can be obtained from mixed cropping with cereals,

(b) gains can be obtained under levels of input higher than that used by farmers,

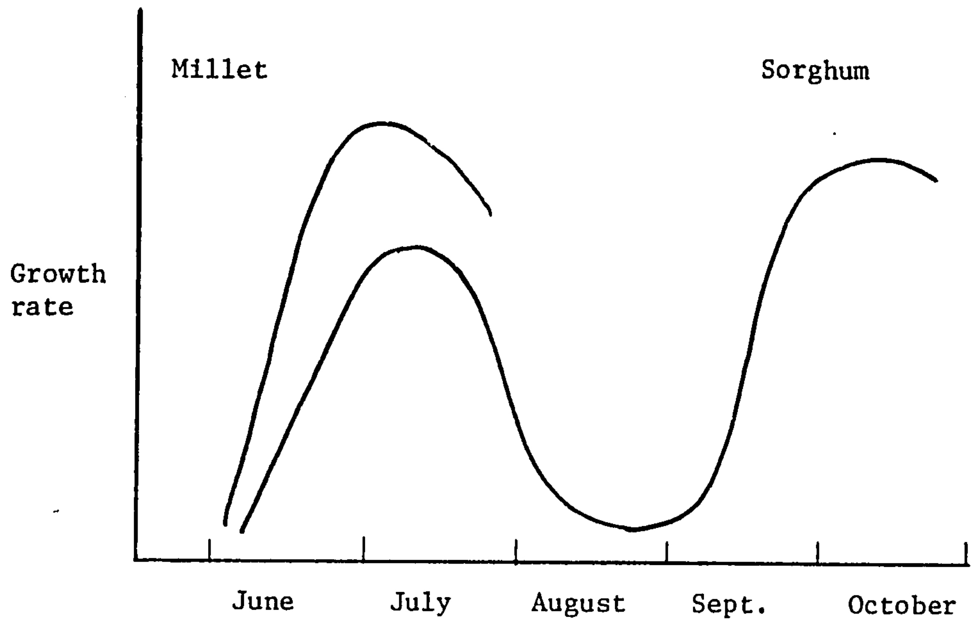
(c) that mixed cropping does not preclude mechanization,

(d) that there is scope for selection of varieties especially suited to mixtures.

Further development

The next phase in the development of mixed cropping research at the

Fig.1: 'COMPETITION GAP', THE PERIOD BETWEEN THE ACTIVE GROWTH OF TWO CROPS



I.A.R. is relating to the growth patterns of the two main crops involved, long season sorghum and short season millet. Goldsworth (1970) had already shown that the rate of dry matter production by long-season sorghum followed a cubic course, the growth being rapid until late July, then decreasing rapidly until after flower initiation in August. This is followed by a second period of active growth with heading at the end of the rains in late September, the crop maturing on residual soil moisture. Between late July and late September, the leaf-area index of sorghum remained constant at 2/3 of its final figure in experiments conducted at the Institute. Millet, on the other hand, reached maximum leaf-area index 46 days after emergence, in July (Kassam and Stockinger, 1973), and was harvested 39 days later. Thus, after flowering of millet, and during grain formation and maturation, the growth of sorghum was minimal and remained so until well after harvest of millet. It became clear that between the end of growth of millet and the restart of growth of sorghum there was a period when very little growth took place, the millet having been removed and the sorghum remaining quiescent. This is shown diagrammatically in Fig.1 and the phrase 'competition gap' was coined for the period between active growth of the two crops. It was argued that this 'gap' gave scope for crops of intermediate growth pattern to be fitted in. Once such crop is maize, not yet widely grown in the drier savannah areas of Nigeria and difficult to encourage since it is usually grown as a sole crop.

Thus work continued to examine light, water and nutrient utilization by millet and sorghum, whilst a further program was initiated testing the hypothesis that, because of the 'gap', maize could be mixed with both millet and sorghum to achieve even greater gains in production.

Before describing the first experiment in the new program, one possible source of confusion must be eliminated. Maize, in the northern savannah zones of Nigeria, will always produce a greater grain yield per unit area than either sorghum or millet (Kassam, Kowal, Dagg, Harrison, 1973). Relative yields being 100:50:40 between latitudes 10° and 12°N, and 100:65:45 between 12° and 14°N for maize, sorghum and millet respectively. Thus maximum grain production is most likely from maize grown solely. However, where more than one cereal is to be grown by a farmer, it is postulated that maximum grain production will be achieved by mixing the crops.

The first experiment in 1973 was devoted simply to measuring yield responses from all pairs of combinations of 'Ex-Borno' millet (85 days to maturity), '0 96' maize (120 days to maturity), and 'Short Kaura' sorghum (160 days to maturity), together with the three-crop mixture, and comparison with the sole crops.

All crops were sown in equal amounts, on an area basis, though each individual crop in a mixture was sown at the same spacing along the ridge as that used for the sole crop, the spacing for millet being 15 cm and for sorghum and maize 23 cm. A basal dressing of 300 kg ha^{-1} of compound fertilizer 20:10:10 was applied at sowing to all crops. The trial was originally designed to include cotton and cowpea as double crops after millet and maize but because of the late start of the rains, these crops were omitted. Thus, though the original design was that of a randomized block in four replications, because of the omitted crops replication of the remaining seven treatments varied from four (sole sorghum) to thirty-six (maize/millet and maize/millet/sorghum). The yield resuts are given in Table 5.

Table 5. Yield in kg ha^{-1} grain at 14 percent mc. for cereals grown sole and mixed

Crop	Maize	Millet	Sorghum	Both	S.e.±
Maize	4869*	5722	5690	5642	987
Millet	1531	1815	1623	1847	394
Sorghum	3075	3317	2672*	3597	463

* The yield is that of the sole crop.

Yields in Table 5 are expressed on an equivalent area basis. Yields for each crop were analyzed separately and, except for millet, where significant differences were not found. Yields of crops grown mixed were significantly better than those of sole crops. There was no significant difference between yields of millet and maize from 2-crop and the 3-crop mixtures but the yield of sorghum was highest in the 3-crop mixture.

The total grain production and gross value (Zaria market prices at harvest) of each crop are given in Table 6.

Table 6. Total grain yield in kg ha^{-1} and value of sole and mixed cereals

Mixture	Total grain	Value (₦)	% gross profit
Sole maize	4869	497.68	-
Sole millet	1815	286.77	-
Sole sorghum	2672	299.45	-
Maize/millet	3626	413.38	+ 5.4
Maize/sorghum	4382	463.10	+16.2
Sorghum/millet	2470	314.08	+ 7.2
Maize/sorghum/millet	3695	423.88	+17.3

(Maize at ₦ 10.20/100 kg bag: sorghum at ₦ 12.20/109 kg bag and millet at ₦ 17.20/109 kg bag)

Although gains owing to mixed cropping were small, the experiment did demonstrate that the maize gained from mixing with either millet or sorghum, and that the highest profit was obtained from the 3-crop mixture.

The first 1974 experiment compared yields from all combinations of 2-crop mixtures from six crops of different maturity periods. The crops were: 'Ex-Ghana' millet (75 days); 'Ex-Borno' millet (85 days); 'Bomo' local maize (90 days); 'Samaru 123' maize (110 days); 0 96' maize (120 days), and 'Short Kaura' sorghum (160 days). All crops were sown at the same time and the same basal dressing of fertilizers was given as before at sowing.

There were three replications of a plaid design, with crops arranged in rows and columns so that each block contained two replications of each 2-crop mixture whilst, before randomization, sole crops were located along the leading diagonal.

In addition to yield measurements, growth data were collected throughout the season and samples retained for analysis to give the picture of nitrogen uptake within sole and mixed crops. These data have not yet been analyzed, and 'Short Kaura' sorghum had not been harvested at the time of writing. Yields are given in Table 7.

Table 7. Yield in kg ha^{-1} grain at 14 percent mc. for sole and mixed cereals on an equivalent area basis

Crop:	Grown with: 'Ghana' millet	'Borno' millet	'Bomo' maize	'S123' maize	'0 96' maize	S.K. sorghum	S.e.±
'Ghana' millet	1764	1611	1633	1770	1868	2157	280
'Borno' millet	2238	2222	2152	1939	2167	2476	261
'Bomo' maize	3449	2762	3105	3029	3116	3728	426
'S123' maize	4330	4506	4048	3926	3956	5278	478
'0 96' maize	3353	3222	3337	3340	3246	3626	643

Yields were poor because of yet another late start to the rains and, more particularly, very much heavier than average rains in July, August and September and consequent cloud cover. Significant increases from mixed cropping were obtained only from crops grown with sorghum, though no crop showed a significant reduction in yield because of mixing. Even so, there was a trend for increases to be proportional to the disparity between days to maturity of the crops. This is more clearly seen in Table 8, where yields are expressed as percentages of sole-crop yields.

Table 8. Yields of sole and mixed crops expressed as percentages of sole crop yield

Crop:	Crop grown with: Ghana Millet	Borno Millet	Bomo Maize	S123 maize	0 96 maize	S.K. Sorghum
Ghana millet	100.0	91.3	92.6	100.3	105.9	122.3
Borno millet	100.7	100.0	96.8	87.3	97.5	111.4
Bomo maize	111.1	89.0	100.0	97.6	100.4	120.1
S123 maize	110.3	114.8	103.1	100.0	100.8	134.4
0 96 maize	103.3	99.3	102.8	102.9	100.0	111.7

A second experiment carried out in 1974 compared yields of three selected crop mixtures. The mixtures were: 'Ghana' millet, 'Bomo' maize, 'S.K.' sorghum. 'Ghana' millet, 'Samaru 123'maize, 'S.K.' sorghum; 'Ghana' millet, '0 96' maize, 'S.K.' sorghum. Three other mixtures were as above but 'Borno' millet replaced 'Ghana' millet, and the final mixture was of all the three maize varieties. All were sown in 1:1:1 ratio on an area basis, and all were fertilized with 300 kg ha^{-1} as before. All crops were sown at the same time. The design used was that of a randomized block in four replications.

Yields, on an equivalent area basis, are given in Table 9 together with percentage gains over sole-crop yields.

Table 9. Yield in kg ha^{-1} grain at 14 percent mc. of crops in mixtures and percentage gains*

	Yield	%	Yield	%	Yield	%
Mixture						
'Ghana' millet/ 'Bomo' maize/ 'S.K.' sorghum	2,479	140.5	3,784	121.9	-	-
'Ghana' millet/ 'S123' maize/ 'S.K.' sorghum	2,438	138.2	5,346	136.2	-	-
'Ghana' millet/ '0 96' maize/ 'S.K.' sorghum	2,480	140.6	3,819	117.6	-	-
'Borno' millet/ 'Bomo' maize/ 'S.K.' sorghum	2,650	119.3	3,482	112.1	-	-
'Borno' millet/ 'S123' maize/ 'S.K.' sorghum	2,670	120.2	4,918	125.3	-	-
'Borno' millet/ '0 96' maize/ 'S.K.' sorghum	3,179	143.1	3,930	121.1	-	-
'Bomo' maize/ 'S123' maize/ '0 96' maize	3,560	114.6	4,937	125.8	4,047	124.7

* Yields and percentage gains are given in order of crop for each mixture.

Selecting Cereals for Mixing

It is difficult to determine the part played by each factor producing gain from mixed cropping; factors such as the increase in light interception because of different canopy heights and structures, and more efficient water and nutrient use because of separation of periods of rapid growth. The knowledge of the parts played by these factors is a necessity for the design of crops for use in mixtures. However, in the absence of this knowledge, it may be useful to hypothesize a relationship between the gain and degree of separation of days to maturity, as measured by 'mean' plant population. Consider sole crop population as 100 and set mixed crop populations as proportions of this. For example, in the 'Ghana' millet, 'S.K.' sorghum mixture, the two crops are together until the time millet is harvested (75 days), but for the remainder of the season (85 days) sorghum is present at 50 percent of the sole crop population. Combining the two populations thus $(75 \times 100 + 85 \times 50) \div 160 = 73.4$, the 'mean' population can be obtained.

Using $\sqrt{\text{mean population}}$ in a regression analysis with the percentage yields of Tables 8 and 9 (omitting sole crops), a correlation coefficient of $r = -0.8301$, highly significant, and a regression coefficient of $b = -25.2 + 2.75X^{\frac{1}{2}}$, (X = mean population), also highly significant, and accounting for 69 percent of the total variation were obtained. The equation relating percentage yield and 'mean' population was :

$$Y \text{(percentage yield)} = 342.5 - 25.2X^{\frac{1}{2}} \text{ (mean population)}$$

It is realized that this is very much a simplification and that the same 'mean' population was applied to each crop in a mixture; nevertheless, the relationship does indicate, crudely, that the gain from mixing cereals was obtained only when 'mean' population was reduced below 90 percent of the sole-crop population. Thus, in the trials reported above, gains were obtained only in two-crop mixtures when one crop was at least 25 percent longer in duration than the other, and in three-crop mixtures when the sum of maturity periods of the two early crops was less than 1.75 the time to maturity of the third crop. This relationship, though as yet empirical, will serve as a baseline for population studies within mixed crops.

Nutrient Uptake

Very little information is available concerning nutrient uptake by crops in mixtures. Kassam and Stockinger (1973), however, have measured nitrogen uptake in a millet, sorghum mixture. They reported that millet in the mixture, utilized 80 percent of the total nitrogen, leaving only 20 percent for the sorghum. Sorghum in the mixture took up a total of 42 kg N 1/2 ha^{-1} and produced 1426 kg grain, i.e. 34 kg grain/kg N. This was much more efficient than sole sorghum which took up 140 kg N ha^{-1} and produced 2845 kg grain, a conversion of 20.3 kg/kg N.

The uptake by sole millet was not measured but mixed millet took up 140 kg 1/2 ha^{-1} to produce 1955 kg grain, i.e. 14 kg grain/kg N.

Total nitrogen removed by the mixed crop was 182 kg ha^{-1}, more than the 132 kg applied at sowing, indicating that both crops were efficient in foraging for nitrogen.

Water Use by Mixed Crops

Even less information is available concerning water use by mixed crops, and though these data are being collected at the I.A.R., they are not yet collated. However, water use data is available for a long season sorghum and a 100 day maize (Kassam et.al., 1973), and for millet (Kowal, 1974). It is to be stressed that water use by crops in a mixture may not be the same as those for crops grown solely and the extrapolation attempted in Table 10 below must be considered with caution. Nevertheless, I feel it safe to say that the removal of earlier maturing cereals from a cereals mixture must, inevitably, reduce water stress in the later crops.

Table 10. Water use by sorghum, maize and millet as sole crops and hypothetical water use of the crops in a 1:1:1 mixture

10 day periods	Ppt*	Sorghum	D**	Maize	D	Millet	D	3-crop mixture	D
May 1	46.2								
2	7.1								
3	99.6								
Jun 1	30.1	36.1	- 5.6	25.4		32.8	- 1.3	31.4	- 0.9
2	18.0	35.0	-17.0	41.2	-24.2	46.0	-28.0	40.7	-22.7
3	47.2	36.1		49.8	- 2.6	50.4	- 3.2	45.4	
Jul 1	65.-	37.1		59.7		56.1		51.0	
2	38.6	36.1		55.6	-17.0	46.8	- 8.2	46.2	- 7.6
3	68.3	37.1		55.8		48.0		47.0	
Aug 1	124.5	38.1		58.7		40.3		45.7	
2	91.2	40.1		49.8		31.9		40.6	
3	109.5	42.9		40.1		38.8		40.6	
Sept 1	11.2	45.0	-33.8	30.2	-19.0	----		23.6	-12.4
2	21.8	47.5	-25.7	----		----		15.8	
3	52.3	51.8		----		----		17.3	
Oct 1	19.0	47.8	-28.8	----		----		15.9	
2	5.1	41.9	-36.8	----		----		14.0	
3	-	32.3	-32.3	----		----		10.8	-10.8
Total	855.6	604.9		466.3		391.1		486.0	

* Ppt = precipitation
** D = deficit

Table 10 shows water used by the three crops for ten day periods until harvest. Water use is shown together with deficits from ten day rain fall totals measured in 1972 at Samaru, when the annual rainfall was 23 percent under average. The assumption is made that water use by the 3-crop mixture will be a mean of water use by the sole crops and this extrapolation is shown in the last column. Despite the dangers inherent in such an assumption, it is clear that the moisture stress experienced by sorghum from heading onwards would have been much reduced, had the sorghum been grown in a mixture. In that year, growing sorghum in a mixture might well have turned a disastrous failure into, at least, a moderate yield. Similarly, maize would have benefited from the reduction of deficit some 50 days after sowing.

Conclusions

Mixed cropping, particularly with millet and sorghum, is widely practiced throughout the semi-arid areas of Nigeria, and though much of the evidence presented here stems from early stages of experimentation, I feel the information is sufficient to state that this system of cropping is: (i) more productive than sole cropping; (ii) more profitable and more secure than sole cropping; (iii) may make more efficient use of water and thus involve less risk of failure in a bad year; (iv) may well make more efficient use of available nutrients; (v) can lend itself to mechanization, at least for sowing and during the early stages of growth; and (vi) gives great scope for improvement of varieties, mixtures and the application of advanced practices.

My own beliefs are such that the mixed cropping system gives so much scope for improvement that it would be morally wrong to attempt to force a move to sole cropping as a means of improving the farmers' well being. Other mixtures need investigation, particularly those including legumes and especially the '*gici*' system of growing groundnut with cereals which may well amount to rotational cropping within a mixture. Work has already begun at the I.A.R. on this and the other common mixture including a legume, cotton and cowpea.

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FARMING SYSTEMS IN THE MEDITERRANEAN REGION

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The Mediterranean environment is synonymous with what is usually described as the dry summer tropics. In fact, its climate varies from semi-arid temperate to almost continental. The term Mediterranean is used because most of the areas with the particular climatic pattern that is characteristic of this environment border the Mediterranean sea or basin. They are found, however, bordering the tropical zone on the western margin of all continents, stretching inland for greater or lesser distances depending on the local physiography. Generally, they are situated between 30° and 40° latitudes and are bordered by deserts towards the equator and more humid lands towards the poles, as well as by the countries fringing the Mediterranean basin; the so-called Mediterranean region includes California and Chili, the extreme southern tip of Africa and parts of South and South West Australia.

Climate

The Mediterranean climate is transitional between arid and humid with mild, wet winters and hot, dry summers. Average temperatures during winter are between 40° and 50°F with frost-free periods varying from 9 to 12 months. In summer, average monthly temperatures frequently rise above 80°F and maximum temperatures in excess of 100°F are not uncommon. A high percentage of sunshine is characteristic, even during the rainy winter, and clear skies and high radiation result in rapid heating and cooling of the land with consequent high diurnal temperature ranges.

Rainfall varies considerably, but over much of the region it is low and unreliable with great variation from year to year in both amount and distribution. This variation tends to put rather severe restrictions on the potential for, and stability of agricultural production. The greater part of the region receives less than 250 mm annual rainfall. It may go up to 750 mm and sometimes higher in coastal areas and on the mountain slopes. Dry areas frequently receive their annual precipitation in sporadic but heavy falls with consequent rapid runoff and erosion. The general pattern of temperatures and rainfall is very much influenced by topography and proximity to the sea. However, the characteristic winter rainfall pattern is common to all mediterranean areas. Most of the

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non-irrigated agriculture is found in areas with rainfall between 250 to 500 mm. Differences in elevation cause considerable climatic changes. There is, on the whole, a remarkable similarity in physical features resulting in recurring patterns of climate, soils, vegetation and land use. The combination of a high percentage of sunshine and high temperatures ensures a high rate of potential evapotranspiration even though actual evapotranspiration rates may be low unless irrigation water is available. The crop production potential of the Mediterranean region is very high with adequate irrigation.

Soils

Soils are generally calcareous throughout the region, although in coastal areas one finds soils that have no calcium carbonate in the profile and that are almost neutral in pH, such as the non-calcic brown soils of coastal Israel and Lebanon. These soils originally did contain calcium carbonate but it weathered and was leached out. On the lower slopes of hilly or moutainous areas, the most common soils are complexes of red terra rossa and black or grey-brown rendzinas. These soils have a high percentage, of clay and good water-holding capacity. Although somewhat difficult to cultivate because of their heavy texture, they are highly productive soils when of sufficient depth. An intermediate elevations, where precipitation is higher and temperatures lower, one finds brown forest soils. These are relatively fertile soils with a high organic matter content which, at higher elevations, give way to steep, rocky lithosols and exposed rock only suitable for grazing. In the valleys or river deltas, soils are deep and of alluvial or colluvial origin, either washed down from the mountain slopes or deposited by streams. Generally medium to heavy textured, they are calcareous and may be reasonably high in organic matter. They may be difficult to work but they are fertile and, with adequate provision for drainage and good irrigation management, are among the most productive of the region. In dry-land areas with rainfall between 250 and 500 mm,soils are predominantly reddish brown. They are calcareous, low in organic matter and hence deficient in nitrogen. Soil depth is variable but there are considerable areas where it is substantially less than two meters. Towards the desert areas, soils are sierozems which can be very productive if irrigated.

From this brief overview it is apparent that the physical characteristics of soils in the Mediterranean regions provide some operational difficulties. The high silt or clay content and heavy texture makes them difficult to work. They set very hard with deep cracks when dry and are liable to be sticky when wet. Crusts may be formed which prevent intake of water and may result in excessive runoff and erosion. Many of the soils are shallow and therefore cannot store much water, so important in the dry areas. Shallowness and presence of calcium carbonate or sulphate in the profile may also lead to difficulties when these soils are irrigated. Chemically, soils in the Mediterranean region are generally well supplied with nutrients except for nitrogen. Phosphorus is not as limiting but in many cases good yield responses are obtained when it is applied. Potassium appears to be adequate except in rare instances and under very intensive cropping. The calcareous nature of the soils and the frequent presence of free limestone in the profile may affect the availability of certain micronutrients.

Cropping Patterns

The predominant feature which influences agricultural activities is the winter rainfall pattern. Winter cereals such as wheat and barley are the most important crops in terms of cultivated area and production. Legumes like lentils and vetches are also widely grown. On deeper soils, where the rainfall is not too low, it is possible to grow crops like tomato and tobacco during spring and summer on residual moisture. Similarly, melons and some cucurbits are also grown even in the drier regions, and may form a standard rotation with wheat. The crops may be hand-watered at the time of planting but from then on depend on stored soil moisture. In drier areas they are often grown in dry water courses and depressions where water and soil tend to accumulate. Generally, however, since the summers tend to be hot and dry, it is impossible to grow anything during that period without irrigation, except deep rooted, drought resistant crops like vines and olives.

This pattern of winter cereals, grain and forage legumes, grapes, olives and vegetables is typical of the Mediterranean region. Where irrigation is available, summer crops, either grain or vegetables, are grown and the range of field crops and vegetables that can be grown in the winter is also extended. In addition to the crops grown under rain-fed conditions, chick-pea, linseed, broad-bean, garlic, onion, beet, turnip, cabbage, radish and carrot are grown in winter. Summer crops are rice, cotton, maize, sorghum and millets, sesame, chick-pea, cowpea, potato, tomato, okra, egg-plant, cucumber, squash, pumpkin, watermelon, melon, cowpea and green peppers. Where average temperatures are high during winter and frosts are no problem, extensive plantings of citrus and, to a lesser extent, bananas can be found. In coastal Lebanon, for instance, bananas are frequently grown in between young and establishing citrus trees.

In the areas of higher rainfall and on the mountain slopes, one finds temperate fruits and vegetables - sometimes irrigated from springs, sometimes rainfed. On lower and intermediate slopes, one finds figs, almonds, peaches, plums and apricots, whereas at the higher elevations apples are grown. The olive is widely grown under various conditions but occurs mainly on the drier slopes and rough terrain which is frequently terraced. Its yields fluctuate tremendously not only between different locations but also from year to year depending on rainfall and management. Like olives, grapes are also distributed under a wide range of conditions varying from irrigated areas to mountain slopes with low rainfall. Very often olives and grapevines are found growing together since both these crops can withstand adverse conditions and drought during summer because of their deep, extensive root systems.

Farming Systems

It is difficult to generalize on farming systems as farm structure and enterprise selection, organization and management vary tremendously throughout the region. Although broad similarities in cropping systems as described above can be delineated, agro-clamatic differences of specific locations result in wide variations in farm organization and operational management. On the other hand different levels of technical, economic and infrastructure development also result in differences in farm activities and organizations in regions or countries that may be agro-climatically very similar. In countries around the Mediterranean sea, agricultural practices may vary from those that have changed little over the last few thousand years to those based on modern technology, depending on available resources, development of infra-structure and services, social and political structure and economic and technological development. There are only few countries where farm structure and enterprise selection are highly organized and conducted at high managerial levels. In such countries the proportion of field crops in total agricultural production is usually less, although it still predominates. Production of fruits and vegetables is high resulting in a high value output per unit area. Grain crops are mainly produced in dry areas where there are no other alternatives or as a rotational crop.

Countries north of the Mediterranean Sea are generally more highly developed in their agriculture than those bordering the southern shore. Generally, throughout the region farm holdings tend to be small and in many cases fragmented. Infra-structure and agricultural services, though highly variable, are often very limited. Except in typical dry farming regions, where alternatives are few, farming systems tend to be based on mixed farming operations and single farm holdings often may combine some production under irrigation with rain-fed farming. Many farms are still at subsistence or near-subsistence level. Specialized farming activities are becoming more prevalent as markets and modern transport and storage facilities are developing. Mechanization and the use of improved seed, fertilizers and other modern techniques are also spreading gradually to the less developed parts of the region. Managerial ability, however, is still low in many instances.

Both yields and cropping intensity could be considerably improved in many parts of the region. Even under irrigated conditions, annual cropping is often practised by leaving the land idle during the summer or winter even though double or more intensive cropping is feasible. In dryland areas also, millions of hectares lie idle in fallow each year.

With adequate power and improved technology much of the land lying in fallow for 18 months or longer can be formed more intensively. Annual crop rotations now in use in areas with rainfall between 450 to 700 mm include, in addition to wheat, crops such as grain legumes, melons, tomato and forage crops. At the higher end of the moisture range they may also include potato and sugarbeet although these are more frequently found under irrigation. At the lower end of the range, the choice of crops is more limited. Depending on soil type and depth, this choice is usually limited to winter cereals and legumes, although water melon and tomato are sometimes successfully included.

Fallowing is practised in the 300-450 mm rainfall zone and the crops here are wheat, barley, lentils and sometimes watermelon. Areas that arc normally fallowed may be cropped annually at times if rainfall is favorable. Problems are inadequate seedbed preparation, stand and weed control. Fertilizer use is very low and yields fluctuate widely with the amount and distribution of annual rainfall. The fallow period in the crop-fallow system in many instances approaches more nearly a period of volunteer pasture as clean fallow is rarely practised. This is partly a question of inadequate tractive power and suitable tillage methods. In addition, the practice of grazing fallow weed is wide-spread. The grazing animals are rarely owned by the farmer. They belong to tillage-owned or nomadic flocks which graze on rangelands for most of the year and are allowed to graze crop residues and fallows in the off-season.

It is interesting to compare the farming systems of the regions around the Mediterranean basins, where agricultural practices date back for thousands of years, with those of 'new' Mediterranean regions like California and Australia, which have developed over a period of only a few hundred years. In California, this development took place against a background of a constantly expanding market in the rest of the North American Continent. It was not hampered by some of the social restrictions and land tenure problems which face the older Mediterranean countries. A scientific problem-solving approach and use of capital led to technical innovations which in turn led to a highly productive, specialized and market-oriented agriculture. Good irrigation resources on the coast and in the central valley resulted in a wide variety of farming systems. More than one-third of the State's agricultural income is now derived from fruits and vegetables. Forages, grown extensively as rotational crops, are utilized in highly intensive beef and dairy enterprizes. Enterprize organization and management are specialized and at a very high level.

In contrast, Australian agriculture developed within a framework of less favorable natural resources, such as infertile, phosphorus deficient soils, and few possibilities of irrigation. Long distances from markets, high transport rates and shortage of labor increased production costs had put Australian agricultural products at a disadvantage in competitive markets. Under these restraints, Australian agriculture evolved mainly around wheat and wool. Agricultural land was no limitation and a similar dynamic and problem-solving approach as in North America gave rise to farming systems based not necessarily on high yields per unit area but rather on a high productivity per agricultural worker and low cost of production. In dryland areas farm technology and operational management evolved towards highly mechanized, extensive systems of farming, with large farm holdings and relatively high capital investment. Because of low and uncertain rainfall, low yield per unit area and prohibitive costs of nitrogenous fertilizer, a ley-farming systems has developed based on the use of annual, self-regenerating pasture legumes in rotation with cereals. The inclusion of the pasture phase has resulted in an integration of cereal farming and livestock production. A large share of the total animal production now comes from this particular farming system.

Adapting the ley-farming system. It is obvious that much could be learned from a comparative study of agriculture in different countries with Mediterranean types of climate about the influence of socio-economic, political and technical factors on farming systems. Such studies would be useful in isolating principles and components which could be employed to increase the stabilize agricultural production and income in some of the less developed Mediterranean countries. There is considerable interest at present in the possibility of adapting the Australian ley-farming systems to dryland cereal growing areas of North Africa and the Middle East. This should be feasible because the annual legume species which is the base of the ley-system in Australia was originally introduced from the Mediterranean region. The introduction of a ley-rotation and an integrated system of crop-livestock production may do much to increase and stabilize crop and animal production, spread farmers' risk and relieve pressure on the denuded range. It also may be particularly relevant in view of the shortage and increasing price of nitrogenous fertilizers.

However, the identification of an adapted and productive legume is only the first step and this in itself does not ensure the adoption of a ley-farming system. Other technical problems need to be solved and in addition the economics of the system needs to be determined. Moreover, the decision to change to a new farming system is heavily influenced by social and economic factors as well as existing or projected infrastructures. There will be new requirements for services and probably market outlets. Changing to the new system will entail not only the purposeful seeding of a legume, but the use of fertilizers and probably fences. Pastures will have to be managed with controlled grazing of farmers' own flocks rather than nomadic or communal grazing, and fodder conservation measures will have to be adopted. The farmer will have to have adequate power to manage the ley and the managerial capacity to conduct an animal production enterprize which is compatible with his cropping program. Access to capital is likely to be required for additional inputs and investment in livestock, fences, equipment, buildings, fodder conservation, animal health maintenance, stock watering facilities as well as extra labor. Finally, because different social groups are involved the choice to change will most likely not lie with the individual but will require community consensus.

It is apparent that in manipulating farming systems to increase and stabilize production and rural incomes, many aspects need to be considered. Existing systems should be carefully analyzed and the main weaknesses and constraints identified. The effects of overcoming these constraints and changing components of the system as a whole should be evaluated and the next set of constraints then brought to light. Whether these be technical, economic or social, it is unlikely that they will be overcome without a great deal of back-up research and adaptive work. Most of this work should probably be conducted on farmer's lands rather than at the research stations. Although broad patterns of farming activities can be recognized, there are great variations in local conditions; work on farming systems is necessarily location-specific. For carrying it out at an international level, it is essential that it be very closely identified and associated with national programs.

In the Mediterranean region, like many other regions, there is a lot of descriptive and scattered quantitative information of varying quality on technical, operational and economic aspects of farming systems. Much of the available information is incomplete and statistics often unreliable. As a first requirement for a better understanding and more systematic analysis and evaluation of existing systems, a reasonably comprehensive data base needs to be built. It is possible that international institutes could give a lead in this, working closely with national organizations. At the same time, they should conduct more detailed research on production sub-systems with identified weakness.

SCIENTIFIC DATA PROCESSING IN THE DETERMINATION OF FARMING SYSTEMS+

J. Mayer*

In the 1950s, a French river, the Durance, which came down from the Alps and flowed into the Rhone south of Avignon, was diverted towards the Mediterranean through a distribution network of more than 100 kilometers. The ecology of several thousands of square kilometers in this part of Province was transformed because of this development, upsetting the working and living conditions of thousands of farmers.

The societe du Canal de Provence, which was responsible for this development, had to choose, for irrigation water, fees fixing, etc. the most suitable formula for the users, taking into account the technical, financial and psychological conditions typifying each farm and also its environment. For this purpose, it formulated the statistical processes since known as 'Provence type models', which were linear programs of a rather special kind. When applied, on the basis of specific field surveys, to a standard farm, representative of the farms in the area, the 'Provence models' make it possible to forecast what the production plan of this farm would be under given circumstances. The possible effects of different agricultural policies may thus be studied on models. This is the equivalent of the scale model of a dam or dike that engineers put through multiple tests before building the actual construction. Up to now, actualization methods made it possible to forecast the development of the technical and financial factors exactly, but the details often proved to be inaccurate owing to a subjective assessment of the farmer's presumed behaviour. The case of the Provence Canal, together with other situations over the last few years, has confirmed that the 'Provence models' gave a good account of the behaviour of the French farmers and that it was possible to simulate their probable reactions, if a given parameter in their environment was modified.

It has been realized that this type of simulation technique would be particularly useful in developing countries where farm managers from

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+ Based on the work done in the Rural Economics Department of SATEC under the supervision of J. Leblanc.

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a large number of widely scattered but relatively similar microcosmic centres are making decisions, their initiatives being controlled by the Government or its local machinery. Their behaviour is largely adapted to the decisions by which the Public Authorities model their economic environment (and sometimes even their ecological environment in the case of creating irrigated areas).

For each regional development policy decision, there is a corresponding reaction of all the farmers, and in this way, it is expected to induce them to follow a course which is considered desirable according to the objectives defined at the national level. Thus, for instance, a given country, which wishes to become more self-sufficient in food production, will decide to raise the price paid to the grower for rice, hoping that the farmers will react to this increase by turning more and more to rice growing.

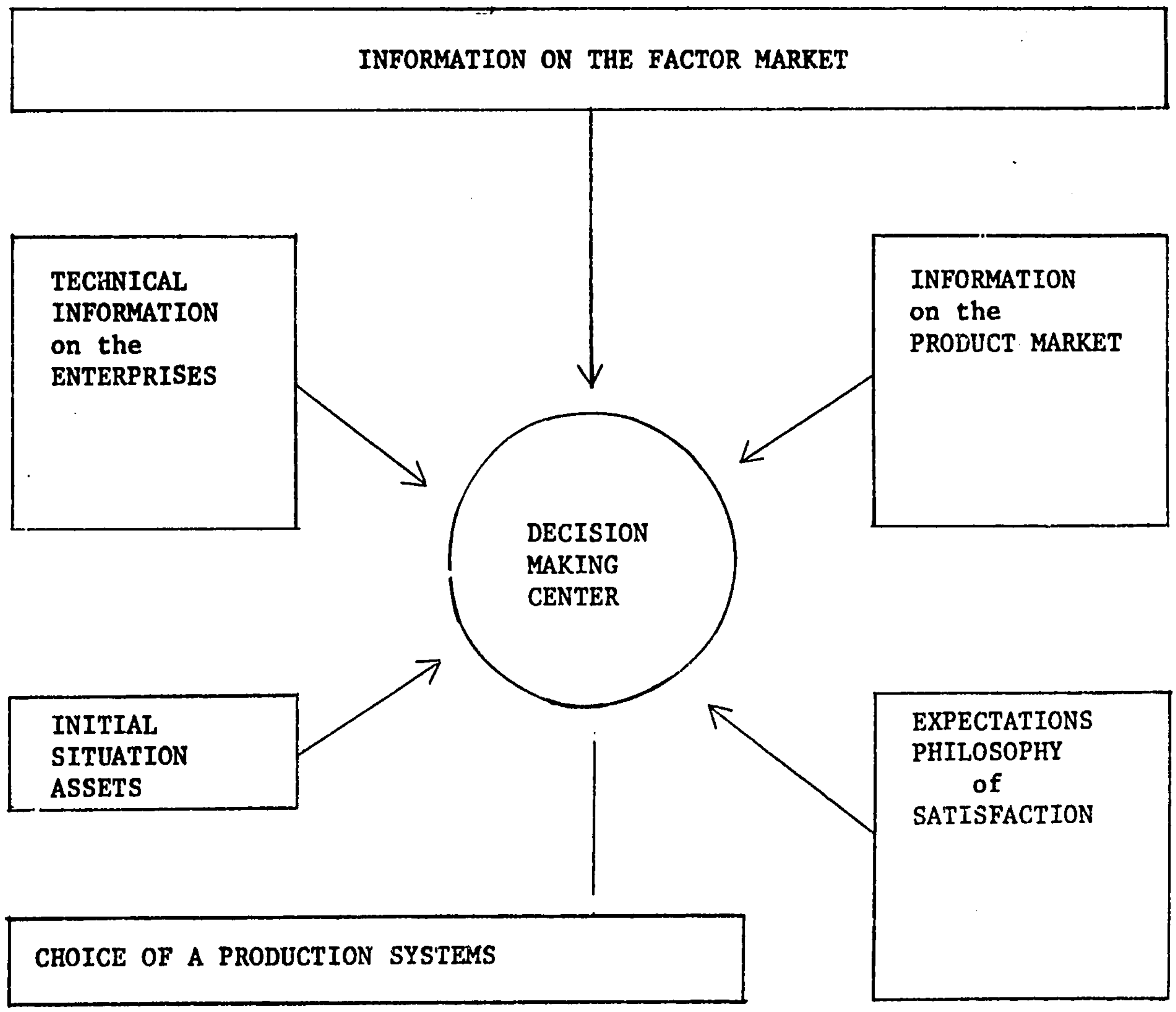
The relation between the decision of the Public Authorities and the farmers' reaction has up to now been forecast empirically, by analyzing to few constraints affecting the farm (estimated farm accounts with the new price ratio). But serious mistakes are sometimes made in this way through imperfect knowledge of the essential relations in the farmer's decision making process.

The 'Provence type models' provide information on the relationship between the decision of the public authorities and the farmer's reaction, by simulating the grower's behaviour and choices in terms of the different regional development policy hypothesis.

In agreement with the Institut National de la Recherche Agronomique and the Societe due Canal de Provence, SATEC has been able to transpose these models in different countries. This has been carried out in Madagascar, the Island of Reunion and Algeria. The first application was in Madagascar where an FAO/UNDP project was undertaken for developing the Morondava Plain (123.000 hectares - 20.000 inhabitants) on the West coast of the Island alongside the Mozambique Channel. It was the result of a proposal for substantial investment by IBRD for hydraulic development (12 million dollars). A large part of the area involved (6.000 ha out of 10.500) was to be left in the control of rural farms which formed a corresponding number of decision-making centres that were difficult to plan and check. It was necessary to foresee their reactions to the planned development, since their contribution to production was to be a determining factor.

In the rest of this article we shall describe the model formulation process used in this operation, after briefly recalling the general principles of the mathematical instrument.

Fig. 1. FACTORS IN THE DETERMINATION OF A PRODUCTION SYSTEM



1. GENERAL PRINCIPLES OF THE MATHEMATICAL INSTRUMENT

1.1. Activity-constraint analysis. The simulation method depends upon activity-constraint analysis. It involves representing, by activity, each of the possibilities open to the farmers, and expressing in equations each of the choices they are forced to make as a result of the constraints to which they are subjected.

How can the classic decision-making process be expressed diagrammatically? The farmer has a whole range of activities open to him from which he makes his choice on the basis of information on his environment and the proposed aim.

1.2 Liner Programming. This makes optimization possible within the framework of such an analysis. Applying it to the case of the farmer amounts to making the assumption that he finds satisfaction in optimizing a given function (to be chosen) within the framework of a network of constraints.

The farmer has the choice of different activities or production (1, 2, ...n). To produce the corresponding outputs (x1, x2, ...xn) he has limited resources (A, B, ... H) such as labor, equipment, land...

A unit of activity 1 (or production of a unit of output x1) does not consume the same amount of the same resource as a unit of activity 2 (or production of a unit of output x2).

'Technical coefficients' are used to express the consumption of resource A needed to produce a unit of the output x1. If q1 is the level of activity 1 (or the number of units of output x1 produced), the need for all consumption to remain lower than the resources may be written as follows:

$$a_1 q_1 + a_2 q_2 + \ldots\ldots\ldots + a_n q_n \leqslant A$$

$$b_1 q_1 + b_2 q_2 + \ldots\ldots\ldots + b_n q_n \leqslant B$$

And if R represents the revenue to be maximized and p_1 the unit prices, the solution will be sought for:

$$p_1 q_1 + p_2 q_2 + \ldots\ldots\ldots + p_n q_n = \text{max. } R$$

There is not only one possible objective function. It expresses what the farmer wants to maximize net profit, gross profit, added value, etc. Production costs, labor, etc. may also be minimized.

There may be as many constraint equations as desired. For the farmer the constraints are labor time, available capital, land, resources.

There may be as many activities as desired and in the case of Morondava there were 600 : rain fed rice, irrigated rice, with or without fertilizer, maize, cotton (Processed or unprocessed), animal husbandry, livestock fattening, etc.

It is therefore necessary to group all the technical coefficients in a table.

Activities				Resources or Availabilities
1	2	3	4	
a_1	a_2	a_3	a_4	A
b_1	b_2	b_3	b_4	B

The matrix of the constraints is thus produced.

Calculations for formulating the model are made on the basis of this matrix.

2. FORMULATION OF THE MODEL

2.1 Main Stages

2.11 Collecting information. Technical cards or crops cards were prepared for each possible activity; they give the inputs used at the different periods (labor, water, fertilizer, ...) and the outputs (yields, prices, byproducts).

It proved difficult to determine the labor times and also, in the production factors, the value attributed to the land.

2.12 Resource vector. It was necessary to determine what the farmers in the Plain had in the way of production factors : laborers (men, women), cropped areas, areas owned, livestock, etc.

They depend on each particular situation. A farm survey was carried out to define all these elements, and by giving a description of the present state of the farms, this survey made it possible afterwards to standardize the model.

2.13 Classification of the farms by regions. The Morondava Plain forms a heterogeneous environment. It, therefore, became necessary to divide it into 5 study regions which differed quite considerably in the nature of the soils, the crops grown, and the livestock and the population found on each farm.

There is a single matrix for the whole of the plain, but sub-programs specify the possible activities and availability vectors for each of the regions.

2.14 Study period and objective fuction. In the initial stage, the period chosen was a year : the solution obtained optimized the operation of the farm for the running year. In fact, the activities that produce variations in property, buying and selling of land, cattle breeding, cash or work inputs are spread over a longer period. From a mathematical point of view, the difficulties are very slight : for each year the matrix simply has to be taken and the result of the previous year included, and this is repeated up until the end of the forecast (planning horizon) beyond which the model is unusable since it necessarily becomes obsolete and inadequate for future realities. Here the planning horizon is five years.

The objective function can ly be arbitrary and the assistance of the sociologist is necessary to assess it. It is finally an awkward problem, since the farmer's objectives may well not be the same as the development organization's objective.

Here it is maximizing the value of the farm's assets at the planning horizon : this criterion therefore includes both the agricultural income of the last year and the present value of investments and accumulated property.

2.15 Actualization. The financial results of the year are used partly for consumption, and the rest for saving. Assessing these parts is particularly difficult, for it amounts to choosing the respective weighted value of the present and the future.

Preference for the present is often approximated by means of an actualization rate.

The market interest rate on capital could be used as the reference, but it is variable and multiple. The actualization rate chosen by the country could be used. But when it is given, it is on a collectivity level, whereas we need to place ourselves at the farmer's level, in the way he experiences it.

Therefore, we have recourse to a more Keynesian concept: the marginal propensity to consume, the relatively constant coefficient that expresses what part of the additional income is consumed and what part (the difference) is saved. We have taken a coefficient of 50 percent which indicates that all the income is divided equally between savings and increased consumption.

2.2 Description of the Matrix

2.21 The main activities chosen appear in columns on the matrix.

The different crops, animal husbandry. At Morondava the crops could be divided into rice, Lima bean, maize, cassava, cotton, tobacco, hot pepper, peanut and fodder crops. Three technical stages were defined : traditional, improved and mechanized or intensive. In addition, there are seven classes of soil that may be owned by the farmer or held under the share-cropping system, which represents, for example. Tsipala rice = 4 soils x 3 stages x 2 types of land tenure = 24 different activities.

Activities producing property variations. Land purchase or sale for all the possible soils, irrigated or not, and at 3 different periods of the year, or : 7 x 2 x 3 = 42 activities.

Initial and final states of the herd, sale and purchase of cattle for 5 classes of age and sex, 3 possible technological levels, 2 periods of the year, or 90 activities.

Buying and selling of rice at 3 periods of the year.

Credit facilities, loans.

External relations. Share cropping for the seven classes of soil, irrigated or not, for vary Be, Tsipala rices, Lima bean.

Work outside the farm (4 periods - men - women)

Hire of equipment, tractor, cattle for treading the soil.

Treading the soil, exploiting the forest, natural pastures.

2.22 The main constraints appear in a line on the matrix.

Land use. It is necessary to be able to express that at each moment the total areas used for the different crops for each type of soil are lower than or, at the most, equal to the availabilities of this type of soil.

Water consumption. For each period the total consumption must be lower than or equal to the water resources.

Times of operations. These form one of the main bottlenecks. To take into account the phenomenon of 'peaks', the year is divided into periods; a distinction may be made between men and women; the unit chosen is often a day's work.

Animal feeding. The lines express the different balances of consumption and resources in UF-MAD and MS*; this is done for each period of the year, since the resources cannot always be passed on from one period to another, and also because the farmers often do not store fodder.

2.23 Financial and security sub-matrix. Below is the sub-matrix showing various activities and various constraints concerning the risks and securities.

	Product activities	Income (cons-excess)	Initial balance	Final balance	Admiss. loss	Result
Liquid assets	outlay - receipts	+ 0.5	- 1	+ 1		≤ 0
Farm account or household account (CØNS)	outlay - receipts	+ 1				≤ Basic consumption
Minimum revenue (REMI)	outlay - receipts				+ 1	≤ Minimum living requirem.
Security 1	possible losses				- 0.33	≤ 0
Security 2	Possible losses				- 0.33	≤ 0

Liquid asset lines. They express that resources and consumption of liquid assets must be balanced. In these lines, the outlays (purchase of fertilizer, payment for labor, etc...) appear with a + sign, and the receipts, provided by the sale of crops in particular, with a - sign. 3 periods have been marked out for liquid assets. For the same activitity, the outlays and receipts do not necessarily occur in the same period.

Consumption and income. The minimum consumption necessary to provide for the subsistence of the farmer and his family is determined. For this purpose the surveys on family budgets and household consumption are used. In the CØ NS line, agricultural income is given as the excess of the sum of the different incomes earned for each crop over the minimum consumption. In the REMI line, the possible loss of the operation is calculated,

* UF = fodder units; MAD = digestible nitrogenous matter; MS = dry matter.

being defined as the difference between the net liquid assets and the minimum required for living (the main difference between these two notions is due to the incidence of credit). Here, it is worth, mentioning the case, which is frequently found in developing countries, where consumption of outputs by the family represents the main part of a household's budget (and, oddly enough, of the irreducible fraction).

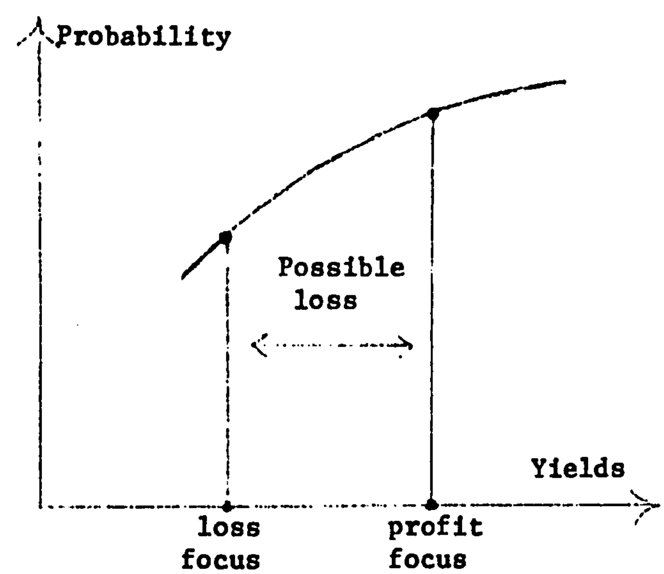
Special lines (or constraints) may be created which take into account, in physical terms, the harvests of crops consumed by the household, and include the transactions possibly carried out on these products. It is then possible to show that the balance of this line for a specific product must meet the requirements of subsistence agriculture. The relevant products may in particular be determined by taking into account the organoleptic criteria of various varieties.

Security lines. It is theoretically possible in a liner model to take into account the uncertain variables to express yields. Although the laws of crop distribution are probably normal, not all the parameters are known and it is difficult to take such laws into account.

In fact, observations by various research workers on the practical behaviour of the farmers, which have been confirmed by some theoretical studies in the U.K., make it possible to express the risk diagramatically (Fig. 2) by defining two 'focuses':

- a profit focus, corresponding to the average, normal harvest expected by the farmer;

Fig. 2. POSSIBLE LOSS BASED ON THE PROFIT AND LOSS FOCUSES



- a loss focus which is the disastrous harvest that is likely to occur every five or ten years for example.

These focuses were then evaluated for the different crops possible. It is obvious that the loss focus is all the lower when the crop is more intensive, more speculative and consumes liquid assets in the form of fertilizer, seed, etc.

The difference between the profit focus and the loss focus is the possible loss. It will then be shown that for the various types of agriculture the possible loss on each activity must be lower than 1/3 of the total possible loss defined above.

The choice of one-third cannot be justified in advance, but in practice many models built on this hypothesis have given satisfactory results.

This clearly shows that the farmer prefers 'not to put all his eggs in one basket' but to use large areas for reliable crops and small areas for speculative ones.

2.3 Computer Processing

Computer processing of such models is greatly facilitated by the agricultural matrix automatic generation program (GEMAGRI) prepared by J.M. Boussard.

In fact, instead of having to calculate and write out all the elementary coefficients of the matrix (tedious work which leads to countless errors), it makes it possible:

i) to place dated coefficients in suitable line, thereby saving the tedious work of 'pro rata temporis' apportionment of consumption or production spread over two periods;

ii) to accumulate coefficients concerning the same product but calculated separately;

iii) to define "compound" techniques (or products) that do not appear in the final matrix but act as a transition, and save having to write out, for all the crops having recourse to it, the constant aggregate of the constituents:

iv) to define groups of activities, generated automatically from the first in the group, for each season (or period) of a constraint;

v) to construct automatically the financial and safety sub-matrix, in which receipts may be calculated from the physical yield and the price paid to the farmer, this technique being more convenient for defining the parameters of prices;

vi) to define an activity by reference to another, with only the coefficients that are different needing to be mentioned;

vii) to construct automatically successive annual sub-matrics in a multi-period model, from the reference sub-matrix; and

viii) lastly, to define automatically a consumption and saving sub-matrix, showing the long term financing mechanisms.

The advantage of this program is clearly seen by following the stages of processing.

The data supplied by the agronomists are written on punch cards that may be easily understood by any agronomist.

The various types of data sheets correspond to the different sections in which the data are arranged. The main section is the one that introduces all the technical parameters of each crop.

At punching, each line on the card containing the data supplied by the agronomists, produces a standard type of computer card.

The computer receives all these cards which form the input data of the GEMAGRI program.

It may then provide, as required:

- first of all, lists of data;
- then, the collection of the matrix;
- and lastly, a picture of the production system that represents the optimum solution for the goal aimed at, as defined by the "objective function".

To illustrate the successive states in the GEMAGRI program, we may mention the following data lists : definition of the lines of 'constraints'; definition of the parameters of the 'activities'; definition of the types of resources in the right hand side, and the degree of availability of these resources, etc.

From these data, the computer generates the coefficients of the matrix in the form required for the ensuing calculations. It also provides a 'picture' of this matrix, with suitably arranged intersecting 'rows' and 'columns' : at the intersections, 'code letters' indicate the order of magnitude of the coefficients, that is to say the influence of each constraint on the activity.

The solution of the linear program is then reached. The result is a production system which the computer describes in great detail, activity by activity.

3. TESTING THE MODEL

The model constructed in this way may then be 'tested.' The activities represented are those that the farmers in the area actually practise. The coefficients in the matrix are at this stage, those that correspond to the present situation:

- yields
- prices
- use or absence of irrigation
- fertilizer dressings, etc.

The solution leads to a description by the computer of the system that the farmer tends to implement when he is placed in the socio-economic environment described.

The first solution should, therefore, describe a farming system identical to the one actually practised by the farmers in the region. If this is not so, it is advisable to re-examine either the objective function, or those coefficients or parameters that proved most difficult to asses and were evaluated empirically.

This 'test' phase thus makes it possible to assess the effect of each parameter on the result and thereby concentrate the study on the really essential objects.

The model is finally formulated by continual approach until it properly represents the actual present bahaviour of the group of farmers involved.

4. SIMULATION AS AN AID TO DECISION MAKING

After the model has been evolved, it is open to the people responsible for development policy to forecast in advance the effect of each of their decisions. These decisions will of course continue to be dictated primarily by national policy considerations which are the normal responsibility of the Public Authorities. But their local representatives will be able to give further information on the decisions thus envisaged and bring about action on some parameters.

In this way, a Government which decides to raise the 'farm-gate price' for a given crop, will be able to foresee the effect of this measure on a productivity operation involving this crop, or, on the contrary, on a diversification operation towards other crops. The same is true, for example, for decisions concerning the subsidies to be granted for fertilizers.

In another field, the decision to start an operation aimed at introducing a new crop should not be taken without first simulating the reaction of the farmer to this new activity as defined by the development agronomist, and taking into account the expected prices of factors and the price paid to the grower. If the model shows a trend to adopt the activity, extension work will be able to succeed. If it shows the opposite, it will be difficult for goodwill and teaching to ensure the development of the activity as long as the parameters defining it remain unchanged.

The whole local procedure described above is the one that everyone follows to make any development decision. The decisions are made on the basis of the data available on the present situation and the potentialities that exist. The accuracy of this information if often questionable: but the amount of information is always substantial. Taking into account the limited capacity of the human brain, these data are never all exploited systematically. This is done empirically and it is only the experience of those in charge that can provide good results. The method proposed here makes it possible to replace this empiricism, whose limits are known by shedding more light on the decisions to be made for regional development.

We feel that the mathematical and computer instruments used in the method can be mastered by any expert involved in a rural development project. When applied by competent associates, simulation is an effective aid to decision making, which gives information on the choices of the person responsible and enables the research worker to concentrate on the difficult problems of analysis and definition of the concepts, the only ones where his irreplacable understanding of the situation is indispensable.

FROM SHIFTING CULTIVATION TO SEMI-PERMANENT AND PERMANENT FARMING IN THE AFRICAN SAVANNAS

Hans Ruthenberg*

TENDENCY TOWARDS SEMI-PERMANENT FARMING

Shifting cultivation is no longer the common practice in the African savannas. The areas claimed by shifting cultivators are still very wide, but most of the farmers and the output in the African savannas are from those areas where people live in stationary villages and huts and where farmers - mostly hoe cultivators - cultivate their fields following fallow systems. Particularly important is a zone stretching from the Senegal, through Southern Mali, Southern Upper Volta, and the very densely populated areas in Northern Nigeria to the Northern Camerouns. Land use is rather similar is in the 'steppe cultivation' of East Africa.

In this type of land use the value of R is between 30 and 70. R is defined as follows: years of cultivation multiplied by 100 and divided by the sum of the number of years with cultivation plus the numb.r of fallow years. An R value of 50 can be regarded as typical, and arises when, for èxample 3, 5 or 10 fallow years follow 3, 5 or 10 years of cropping. In such a situation 50 percent of the arable land is cultivated annually. The length of fallow is mostly insufficient for fallow vegetation of forest or dense bush to regenerate. Grass or light bush are typical. The fallow vegetation is often grazed by cattle, sheep and goats and an important reason for preference of this intensity of land use is that the change in the fallow vegetation often contributes to the disappearance of the tsetse-flies. The characteristics of these farming systems are distinct from those of shifting cultivation. We classify them as 'semi-permanent' systems.

Semi-permanent farming is usually characterized by clearly defined holdings with largely permanent field divisions. Quasi-stationary housing predominates, since the changing of hut sites is a matter of moving short distances only. Families generally have de facto or registered ownership of the land, in contrast to most shifting systems, in which the holding boundaries are not usually clearly defined, housing

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is more or less of a migratory nature, and land rights are even less precisely defined. Most semi-permanent farmers cultivate a larger area than shifting cultivators in the same environment, with a fairly large cash-crop area, which may account for half of the total land cropped.

In general terms, a reduction of the fallow period causes a reduction of the yields per hectare, unless there is fertilizer application or manuring, which is normally not the case in these systems. The warmer and the rainier the climate, and the poorer the soils, the more necessary is the long-term forest or bush fallow, and the less likelihood there is of semi-permanent farming being successfully developed. It is, therefore, not a typical system in the humid zone. The main regions where it is found are the semi-arid climates and high altitudes, where there is less leaching and the soils tend to be richer. Under these conditions, extension of cropping at the expense of the fallow may lead to a rising overall production of the total area available in spite of decreasing yields per hectare cropped. The lower yield per hectare cultivated is usually more than balanced by cropping a larger area. Semi-permanent cultivation is found also on high-fertility soils, especially on alluvial and colluvial soils in river valleys and at the more fertile bases of slopes, i.e. where the motive for fallowing lies less in regenerating soil fertility than in suppressing weed growth.

CHARACTERISTICS OF SEMI-PERMANENT FARMING

Organization of Land Use

Shifting cultivators are usually very skilful in selecting their fields and in choosing appropriate crop mixtures. In semi-permanent farming land use is different and decidedly more diversified:

- Very wide spread is the catena-type of land use. Holdings often consist of a strip of land running through all the soil types of a slope. The most suitable crops are grown on each type of soil. Diversification in cropping is not so much a matter of rotations but of choosing the crop best suited to each soil type.

- Permanent gardens with fruit trees and perennial crops like bananas and papayas are found in the immediate vicinity of the hut, which is either no longer shifted or is moved only a short distance at long intervals

- Near the huts or villages what is called the 'dung-land' is mostly cultivated. It is used for crops which require more fertile soils and which guarantee a good yield. The intensity of land use frequently corresponds to garden culture.

- Adjoining this, we find semi-permanently used fields in the manner of Von Theunen circles. These fields are often used for growing the staple food and cash crops. The fallow is mostly used as pasture.

- The intensity of the crop cycle decreases proportionately to the distance from the farmstead. Between the cropping years the ground is left fallow for long periods; in other words shifting cultivation is practiced.

- In some areas the holdings include plots in valley bottoms, which are used for cropping sweet-potatoes, taro or sugarcane. On the valley bottom, rice cultivation is also widely practised. On moist plots millet or maize are cropped in the dry season, thus providing the household with an off-season supply of fresh food.

- One often finds trees scattered over the area: fruit trees (e.g. mongo in eastern Africa), fodder trees (e.g. faid-herbia albida in Senegal) or sisal hedges.

- Where cattle are kept, a calf enclosure is occasionally found near the hut or inside the kraal.

- The fallow and communal pasture are grazed by cattle, sheep and goats.

- Livestock-rearing in a stationary homestead is supplemented here and there by a certain amount of nomadic herding; some of the herds belonging to the cultivators graze on remote grazing areas watched over by herdsman.

By no means all holdings which are classified as belonging to semi-permanent systems incorporate all the activities cited above. In most cases, however, there is a catena in land use or a spatial differentiation within the holding and there is a combination of intensive agriculture and shifting cultivation, providing as it does for adjustment to differing soil conditions and labor requirements in holdings of partly-commercialized farmers with stationary housing.

Cropping Principles

The main source of semi-permanent cultivators' sustenance is arable farming, with animals playing a supplementary role only. In the savannas, crop yields vary considerably from year to year, more so than those obtained by shifting cultivators in the humid zones. Consequently, semi-permanent cultivators try above all to secure a reliable supply of food. Another aim is to obtain tasty food; millets and maize are usually preferred to manioc or sweet-potatoes. In addition, there is as a rule a dominating cash crop like cotton, groundnut or tobacco in each farming system. These are the usual objectives on which the organization of cropping is based, and they require some basically different cropping principles from those that are typical in shifting cultivation.

Pure stands and mixed cropping. Mixed cropping usually still predominates in semi-permanent systems. The cultivation of cash crops, however, has led to a considerable number of pure stands. Cotton, groundnut, rice and tobacco are usually cultivated in pure stands.

Phased planting. A widely principle is 'phased planting' of each crop, even though losses due to late planting are considerable. The cultivators point to the unreliability of the rain, particularly in the drier regions. To allow for this uncertainty, they distribute the planting of their crops over a long period, preferring to spread the risk instead of aiming at maximum yields. They also prefer to spread the demand for labor over several months by phased planting. Household requirements offer an additional explanation, planting being so timed that they can get food from the garden or field for continuous periods of several months. Thus the planting os subsistence crops in particular, such as beans, sweet potato, groundnut and maize, is spread over several months.

Crop rotation. As short-fallow systems replace long-fallow systems, one can see the pseudo-rotation' (De Schlippe) being increasingly displaced by proper crop rotations. When compared with crop mixtures and pseudo-rotations of shifting cultivators, they show several distinct tendencies:

1. Whereas the rotations of shifting cultivators tend to include a wide range of different crops, cropping is restricted to fewer crops on each type of soil, as cultivation becomes more permanent.

2. There is a tendency to use different rotations for the particular soils of different plots.

3. Fixed and regular sequences of crops like the rotations of the kind found in permanent cropping are rare, but crops demanding fertile soil are increasingly being planted at the beginning of the period of cultivation, and crops demanding less fertility are planted at the end.

Fallow systems. The organization of fallowing in semi-permanent cultivation is as a rule especially varied. According to Rotenhan (1968), the variety of forms that it takes can be classified in the following way:

1. There is a 'half-year fallow', if the land is not used during a six-month period between the harvest and the following planting. In most semi-arid climates, the six-month fallow is

the rule on all arable lands.

2. There is a 'proper fallow' if no crops at all are grown on the land during the whole year. The ground is left to be covered naturally by grass or bush. Subject to the influence of climate and soil in most African savanna areas, a 'short-grass steppe' develops. With increasing length of the fallow, this short-grass steppe changes into bush vegetation.

A distinction can be made between different forms of 'proper fallow':

1. 'Permanent fallow' exists on those arable plots which are not likely to be used for cultivation in the foreseeable future. They usually serve as grazing areas.

2. If the yields from a plot which has long been cultivated have fallen so much that further cultivation appears uneconomical, then it is given a 'long rest fallow' of 5 to 20 years. Frequently, several fields at once cease to be cropped, so that one can speak of 'fallow blocks' as opposed to 'cultivated blocks'.

3. There is a 'medium-term fallow' if a plot of arable land within a cultivated area is left uncultivated for 2 to 5 years. The aim of this form of fallow is to combine the regeneration of the soil fertility with the elimination of weeds. Medium-term fallows are particularly widespread.

4. The 'short-term fallow' of 1 or 2 years generally does not aim at restoring soil fertility, but is caused rather by other circumstances, such as the illness of a farmer or unfavorable weather, which may make the planting of the field difficult.

The high degree of diversification of semi-permanent cropping can be regarded partly as the inheritance from shifting cultivation as practised earlier, and partly as adaptation to a more intense stage of land use.

The Fertilizer Economy

The higher intensity of land use necessitates specialised manuring techniques, although it must be recognized that in most semi-permanent systems, as in shifting systems, the fertilizer economy is still undeveloped. In so for as the cultivators have recognized the problem of soil 'mining' and practise manuring, a number of fertility-restoring methods can be identified.

(a) Shifting the hut and kraal

It is in any case traditional for the home and farmstead to be shifted at fairly long intervals. "The huts become dilapidated after some years, the site foul and eroded, the kitchen gardens reach the point of exhaustion, and it is better to move to a new site than to attempt to rehabilitate the old dwellings. These rebuilding moves are generally short, sometimes a mile or more but often no more than a few hundred yards ..." (Allan, 1967). The wish to obtain an especially fertile plot which can serve as a permanent garden for some time also motivates shifting the holding and the kraal.

(b) Systematic folding

In some cases we also find a systematic folding economy (Froelich, 1963; Dumont, 1966; Pelissier, 1966). Where semi-permanent cultivation is combined with livestock, the cultivators can use the manure from the kraals. Transporting the manure to the fields, however, and digging it into the soil present considerable problems where there are no trucks, carts or draught animals. They, therefore, prefer to move the kraal and, in the case of the Wasukuma, for example, they do irregularly, thereby obtaining a series of manured plots. In some areas of Senegal, the west coast of Madagascar and Ethiopia, the kraals are moved regularly, so that fairly large plots are systematically manured. In these cases, it is the area around the farmstead which is treated in this way, with the consequence that this manuring permits it to be cropped more or less permanently.

(c) Green manuring

A widespread practice in hoe cultivation, especially in ridge cultivation, is to fallow and dig the weed vegetation systematically in the soil. Sometime the gathering of green manure from near by fields is organized as well.

(d) Mineral fertilizers

Where cotton, groundnut, tobacco and other annuals are grown as cash crops, more and more cultivators apply mineral fertilizers. Mineral fertilizer - when its application is economic - can be introduced comparatively easily in semi-permanent farming, because it can be applied efficiently on small plots without requiring trucks, carts or much labor. At the same time, it can be stored without appreciable deterioration, is easy to apply, and produces an increased crop after a relatively short period. For these reasons, it is usually easier to introduce the application of mineral fertilizers in semi-permanent farming than to introduce manuring with available cattle dung.

Even though the various stages of incipient fertilizing may be worthy of note, one must nevertheless remember that they are mostly inadequate. Semi-permanent land-use systems often represent nothing more than degraded forms of previously balanced systems with shifting cultivation.

Animal Husbandry

Whereas shifting cultivation is largely practised with few or practically no livestock, in semi-permanent systems we often find large stocks of cattle. In extended areas of the African savannas, it is the interaction of arable cropping and cattle-keeping that keeps the tsetse-fly at bay. Slash-and-burn agriculture thins out the forest or bush vegetation and destroys the breeding grounds of the tsetse-fly; intensive grazing prevents bush regeneration and therefore prevents the insect from re-establishing itself. Arable cropping and animal husbandry in unregulated ley systems are consequently closely dependent on each other.

The aims of stock-keeping are varied:

(a) Cattle are kept to cover the risk of harvest failure or sickness. When land is not privately owned, cattle are kept as a means of support in old age.

(b) In close relation to this, there are social functions. Cattle often act as a price for the bride.

(c) Farmers want a supply of meat and milk for the household; sale of this produce is not very important.

(d) A factor of increasing importance is the provision of the traction power for ox-plough cultivation.

(e) Only in a few cases do semi-permanent cultivators consider the contribution of manure as an essential purpose of stock-keeping, although it might be of considerable relevance to their farming.

Harvest residues, fallow grazing and natural grazing provide the fodder. Communal use of grazing land is customary; everybody has the right to allow any number of animals to graze on the fallows, pastures and stubbles. Fodder cropping is practically non-existent. Occassionally, balanced feeding is achieved by seasonally moving the livestock to grazing areas some distance away which have not been used earlier in the season. An important sociological feature is the fact that the ownership of livestock is much more concentrated than the cropping of land. In Sukumaland, Tanzania, for example, 25 percent of the families crop 55 percent of the cultivation area, but 25 percent own 80 percent of the animals.

Labor Economy

Important differences between shifting and semi-permanent systems may also be found in the labor economy. The increasing degree of permanency in land use, and the increasing amount of cash cropping, induces rather striking changes:

(a) Technically, a change in work pattern is found. Tree felling and clearing are the main jobs of fire-farming, shifting cultivators; the more tedious work of cultivating with the hoe and of weeding are the most time-demanding activities of the semi-permanent cultivators, particularly where these processes cannot yet be carried out with ploughs and weeders.

(b) Economically, it is almost always the case that people work for more hours each day. first because semi-permanent cultivation is more often than not more time-demanding per unit of output than shifting cultivation, and secondly because cash cropping requires additional working time.

According to Rotenhan's research, semi-permanent cultivators in Sukumaland work for an average of 6-1/2 hours a day during the growing season, which lasts for about 8 months. Haswell (1963) gives a similar figure of 6.4 hours daily for groundnut holdings in Gambia.

(c) Sociologically, a change from the rather rigid traditional division of labor between the sexes, which is still typical of many shifting systems is found towards a more flexible use of the available labor force. The demands of cash cropping seem to be the driving force behind this. An important feature is the increasing involvement of men in field work such as weeding and harvesting. This in turn indicates a new tendency in farm management. Traditionally, several persons in the household work for the food they need for themselves and their dependants on a plot which might be considered a sub-farm within the family holding. With increasing permanency and commercialization, land and labor use within a holding seem to become more centrally organized.

Typical of semi-permanent land use in the African savannas is the cultivation with hand tools of comparatively large areas of 2 to 8 hectares per family. The labor input per hectare varies between 500 and 1500 hours. A significant change in the work situation is brought about by the introduction of the ox-plough, which is technically possible wherever there are destumped areas with a fallow vegetation of grass. First and foremost, it eases the burden of work by relieving the farmer of hard toil of land cultivation. At the same time, fields of mostly regular rectangular shape are formed, the size of field increases, and the cropped area is expanded at the expense of the fallow. Ox-ploughing is rapidly increasing in various African countries.

A further feature of the land-use system in question is the seasonal nature of labor demand. In shifting systems, the task of clearing does not have the same rigid time-table as cultivation has for the semi-permanent cultivator. He must wait until the beginning of the rainy season to cultivate, whereas the shifting cultivator can carry out clearance work in the dry season. Over and above this, there are jobs which are fixed to a time-table and require a heavy labor input in weeding and often in harvesting. Such is the case, for example with groundnut. In the Sukumaland, Tanzania and Senegal 90 percent of the field work is concentrated in 6 months, and 50-60 percent in only 3 of these months. Since field work, apart from herding cattle, is almost the total work of the holding, considerable under-employment occurs during the remaining months. In this connection we must bear in mind that the number of work-hours per day does not give a satisfactory idea of the different labor demands. In seasons of peak demand on labor, performance per hour is considerably higher.

Finally, it should be pointed out that the labor economy of partly-commercialized, semi-permanent systems is usually far removed from the uniformity of traditional subsistence farming. Differences in the man: land ratio, differences in the choice of crops and the adoption of innovations, different approaches to development services and different opportunities for cash cropping - all these factors combine to bring about a wide variation in the size of enterprises and in the smallholders' performance in a given situation. In most semi-permanent systems, only a few hectares are cultivated and a few animals kept, i.e. the size of agricultural enterprise is rather small. This, however, does not mean that the average area cultivated by each family or each worker is about the same. Within each type of farming, even where land is still ample, striking differences are found as to the area cultivated per family and per member of the available labor force. The equality which characterized traditional shifting systems, in which each family only cultivated what was required to cover subsistence needs and everyone used the same practices, no longer exists. Within semi-permanent cultivation systems, are found larger and smaller units, richer and poorer families. The differentiation in cropping is all the more noticeable, the greater the extent of land shortage and the higher the degree of commercialization.

Even more pronounced are the variations in performance. On average the hours of field work per available man equivalent are low. There are, however, wide fluctuations in the input of work per hectare and returns per hour of work within the wide margin of production possibilities that their situation offers them. Farm-managerial ability, particularly in cash cropping, is one of the major factors differentiating progressive producers from others. The explanation is an obvious one : Semi-permanent cultivators differ widely, much more than shifting cultivators, as to their physical effort, their drive and their knowledge.

In most semi-permanent farming systems only about one-third to two-thirds of the available labor capacity is utilised in field work. Nevertheless, cultivators almost everywhere, regardless of the degree of under-employment, unanimously feel that labor shortage is the most important factor limiting output. When asked about this, they almost invariably argue that they would like to produce more and earn more, but they are not in a position (a) to cultivate larger areas; or (b) to change to labor-demanding crops; or (c) to cultivate, plant, weed and harvest in time; or (d) to increase the labor input per hectare of a given crop, because there is not enough free family labor available during the relevant weeks, and there are not enough funds to pay hired labor. Much, if not most, of the cultivated land is neither planted nor weeded according to a time-table which would maximize yields.

The fact that important labor shortages within family holdings and a high degree of under-employment go hand in hand, may be traced back to a number of major factors:

(a) The first factor is that labor peaks in agriculture, particularly when working with arable crops, occur seasonally.

(b) Next comes the observation that agricultural work is not the only work which has to be performed in small holdings. In 14 cotton-maize holdings in Machakos District, Kenya, Heyer (1965) established that on average throughout the year the relation of work-hours 'on the land' to 'household work' is 1:1.7, i.e. the general household work is much more time-consuming than field work.

(c) A further explanation may be found in the fact that the labor capacity of the various persons belonging to the household is not utilized equally, because of traditional concepts of the way in which work is divided between men and women. It may be, for instance, that the women cannot weed in time because the work connected with the household demands too much attention. On the other hand, the men who are unemployed at this time do not consider that tending the food crops should be part of their work.

(d) Another important factor is the low efficiency per hour of work. Sometimes it is because of unsuitable hand implements. In Sukumaland, for instance, the weeds are hoed with the same hoe that is used for ridging. The usual hoe is well-adapted to the latter activity, but not at all to the former. In addition, smallholders are accustomed to making a concentrated, sustained effort only in connection with a few procedures, such as felling, clearing and hoe-cultivation. The other jobs are traditionally done in a leisurely manner.

(e) Finally, the extent of under-employment is calculated according to norms of working hours per annum and per ME (man-equivalent). The smallholders, who refer to difficulties in the labor economy, are not familiar with such norms. Many of them do not accomplish more work because they regard a five-hour day, even at planting time, as a complete utilization of their working capacity.

Many of the problems of the labor economy in semi-permanent land use arise because these systems are a transitional phase between shifting and permanent land use. The advances in the labor economy which are characteristic of permanent arable farming, such as row cultivation, ploughing, mechanical weeding, proper farm layout, and so on, have not yet been introduced on a large scale. Usually the transition to cash cropping, resulting in increased labor demands, takes place within a fairly short period, before the farmers are accustomed to longer hours of work per day. On the other hand, the cropping areas are relatively large, and the labor requirement is seasonal. Consequently, there is much interest among semi-permanent cultivators in labor-saving innovations, even more than in yield-increasing innovations. Farmers in Sukumaland do not generally change from hoe work to ox-ploughing to gain higher returns, but to replace hard work with the hoe by easier work with the plough. Particularly striking is the general interest in tractors. Wherever finance is available, and the return per hectare high enough to justify tractor ploughing, smallholders endeavour to buy tractors or to hire tractor services.

FROM SEMI-PERMANENT TO PERMANENT FARMING

Stages in Involution

Semi-permanent cultivation in partly-commercialized holdings is distinguished from shifting systems both by more intensive land use and by the fact that technical innovations can be more easily applied. Pepple live in stationary housing with permanent gardens. New varieties and production methods can make headway, especially where a major cash crop, like cotton or groundnut, is grown. Cultivation with ploughs is possible where the fallow vegetation consists of grass. At the same time, the first step is being taken in investing labor in some perennial crops, in the construction of permanent roads and other long-term capital works.

Despite these development advantages, a number of basic drawbacks should be noted. The main problems are those of maintaining soil fertility. Manuring with animal dung and fodder cropping are exceptional, and the effectiveness of mineral fertilizers is usually marginal because of unfavorable price relations and shortcomings in husbandry, particularly in weeding. The yields per hectare are, ceteris paribus, often less than in shifting systems. At the same time, in many areas, especially where the plough has replaced the hoe, erosion damage is on the increase. Normally semi-permanent cultivation does not constitute a stable system of land use, since it generally amounts to either rapid or gradual forms of 'soil mining'.

Ley systems which might offer an avenue for a balanced system of land use are by-passed. The essentials for turning the natural grass fallow into a ley involving (i) land consolidation and reliable land tenure rights for established leys, (ii) efficient cattle for converting roughage into meat or milk, (iii) sufficient traction power for the ploughing of the leys and (iv) capital for fences, provision of water, mineral fertilizer, etc., are usually not available. The process is simply one of reducing step by step the natural grass fallow, and increasing the R-value until permanent cropping becomes predominant. There is but one area in today's Africa where large scale farming is occupying new land and this is the border area between Ethiopia and the Sudan. Elsewhere, the available land is filled with smallholders. In droughts, which occur in known probabilities, more and more people are involved.

The scope for increasing production within traditional agriculture diminishes as land reserves are exhausted and yields per hectare stagnate at a low level. Permanent farming carried out on impoverished soils may well be considered as a final stage in the land development which begins with shifting cultivation, leads to semi-permanent farming yielding somewhat higher incomes per hour of work, and ends with a low level equilibrium in permanent rain-fed farming.

The growing populations increasing subsistence demands and the extension of cash cropping, to cover increasing cash demands, are the driving forces behind changes in farming systems. Three overlapping phases may be distinguished in respect of these processes:

(a) The first step usually consists of extending a given farming system by establishing new smallholdings in expansion areas, wherever they are available.

(b) When no more expansion areas are available, or when the distance between the expansion areas and the original settlement area becomes too large, intra-farm land reclamation acquires importance, and cultivation is extended at the expense of the fallow. The transition from shifting cultivation to semi-permanent and permanent farming occurs gradually.

(c) Cropping patterns change at the same time. As land use becomes more permanent, the relative suitability of some crops diminishes, while that of others increases. Thus, a change in the

> type of crop ensues. For example, maize is preferred to millet because maize is not eaten by birds. Its yields are, however, less reliable. The cultivation of such crops as manioc and sweet-potato gains ground, since their yields and calorie returns per hectare and per hour of work are high, and they release land and labor for the cultivation of cash crops. In areas with good rainfall, the relative importance of millets gets reduced*.

As long as these three possibilities still afford a certain latitude, we can count on rates of production growth which are at least as high as those of population growth. However, as soon as the production reserves of this type are exhausted, there is a distinct danger that - using the terms of Geertz - agricultural evolution will turn into involution.

Increasing subsistence demand leads to reduction in the area under cash crops and low-yielding though high-quality foodstuffs, such as millet and maize, are replaced by high-yielding but low-quality food crops, like manioc and sweet-potato. The greater the population density and smaller the farms, the higher is the percentage of crops like manioc and sweet potato and lower the percentage of maize in the subsistence food. The final stage of this type of involution consists of very small holdings, without room for cash cropping, which grow root crops almost exclusively. The families living by this type of farming are particularly poorly nourished, diseases are more widespread than elsewhere, and the extent of under-employment is particularly great.

A similar involution can be observed in the animal economy. As long as there is sufficient grazing land available, the herds per family are of a good size and the cattle are well-fed. An increase in the area needed for arable farming necessitates a reduction of the grazing area. Simultaneously the proceeds from farming are partly being invested in cattle, to gain security and status. The results are an increase in the cattle population and a reduction in the grazing areas, both of which lead to complementory damage. The condition of the cattle deteriorates and erosion increases.

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* With yields, as they frequently are in traditional farming, of 6 quintals per hectare of millet, 12 quintals per hectare of maize, 80 quintals per hectare of sweet-potato and 100 quintals per hectare of manioc, the yields (in kcal. per hectare) of millet amounted to 2,060, of maize to 4,270, of sweet-potato to 7,750 and of manioc to 33,800. If we estimate the growing period of millet, maize and sweet-potato to be 4 months and that of manioc to be 18 months, the monthly returns of kcal. per hectare of millet amount to 515, of maize to 1,070, of sweet-potato to 1,930 and with manioc, which occupies the field for a specially long period, to 1,880.

The practice of unorganized communal grazing is at the root of the problem. Usually everybody has the right to graze all his cattle on the available grazing, including the fallows. No improvement of the grazing economy, however, is of value unless the stock numbers are limited to the carrying capacity of the grazing land, and unless the movement of stock within any given area is controlled by a rotational grazing system.

The production of fodder crops is neither customary nor competitive. This usually gives rise therefore to a situation with high numbers of poorly fed cattle. In some cases cattle are replaced by goats and sheep. Only in exceptional cases is the cattle economy integrated into some type of mixed farming. The cattle numbers per family decrease, therefore, with increasing permanency of cultivation, although livestock densities per 100 hectares may be high. The final phase of this involution is reached when the livestock economy is reduced to small herds of animals per family, mainly goats, which live on crop residues and on areas unfit for cultivation.

Towards a Low-Level Equilibrium

Two rather distinct types of permanent cropping have to be distinguished in this context. There are some areas where permanent cropping is traditional in the sense that it developed slowly during the last century. Table 1 provides information about these cases, which are usually characterized by some efforts to apply manure and to control erosion.

Where ensuring the food supply for a slowly expanding population has led to the gradual spread of permanent cropping, as for example in Ukara, Lake Victoria, often sophisticated methods of manuring have spread. The traditional methods of maintaining fertility, however, require a high labor input. The holdings are small and their yield in relation to the labor input is low. In those areas, however, where permanent cropping has developed through increased cash cropping by a local peasantry, as for example in the groundnut areas of Senegal and Northern Nigeria, the situation is mostly quite different. Incomes are higher, but soils are mined with little regard to future returns. The application of technical and biological innovations which can give stability to permanent cropping on soils of moderate fertility has only been introduced in exceptional cases. The more rapid the commercialization of production, the less the farmers worry about conserving the soil. This applies at least until the possibilities of finding new lands for cropping are exhausted.

Increasing land shortage not only reduces the marginal returns of labor, but often also those of land. The smaller the holdings, the lower is, as a rule, the average gross return and the marginal gross return per hectare, simply because of reduced scope for production of crops bringing high returns per hectare.

Table 1. Permanent Farming Systems with Soil-Conserving Practices in the African Tropics

Tribe	Country	Average Altitude feet	Average rainfall (inches)	Population density per sq. mile	b	c	d	e	f	Main crops
(1)	(2)	(3)	(4)	(5)	(6)					(7)
Malinke	Senegal Guinea	1600-3000	39	26			x			Millet, rice, maize
Baule	Ivory Coast	1600	47-55	26- 51			x			Yams, banana, taro
Kita	Mali	1600-3300	39	26			x			Millet
Dogon	Dahomey	2000	31	51-129	x	x	x			Millet, yams, banana
Bobo	Dahomey	1600	31	51-129		x				Millet, yams, banana
Gurensi	Dahomey	1600-3300	31	51-129			x			Millet, yams, banana
Nunuma	Dahomey	1600-3300	31	51-129			x			Millet, yams, banana
Mamprusi	Ghana	1600-3300	31	77-129			x			Millet, yams, banana
Losso	Togoland	1600-2600	31-79	129-258	x		x			Millet, groundnut, yams
Kabre	Togoland	2600-3300	59	568	x	x	x	x		Millet, yams, rice
Mandara	Nigeria	1600	31	129-181	x		x			Millet beans
Kamaku, Kanuri, Chamba	Nigeria	1600-3300	31	129-258			x			Millet, yams, banana
Bauchi, Berron	Nigeria	1600-3300	31	129-258	x		x			Millet
Sokoto, Kano	Nigeria	1600-3300	31- 9	310-516	x	x	x			Millet, groundnut, manioc
Batta, Mundang, Bamum, Dama, Musgu	Cameroons	2600-5000	31- 9	129-258			x			Millet, yams, banana
Bana, Adamawa	Cameroons	5000-6600	31-59	258-387	x	x	x	x		Millet, beans

....contd.

Table 1. Cont'd.

1	2	3	4	5	6	7
Kuru, Bari	Sudan	1600-3300	39-55	77-129	x	Millet
Konso	Ethiopia	5000	39-47	490	x x x x	Millet, cotton, maize
Tigre	Ethiopia	5000-6600	24-39	258-387	x x	Millet
Kipsigi, Kikuyu, Nandi, Suk, Keyu	Kenya	5000-6600	55-71	129-387	x x x	Maize, manioc
Rundi	Burundi	5000-6600	39-55	258-387	x x x	Maize, banana, sweet potatoes
Ruanda	Ruanda	5000-6600	39-55	387-516	x x x	Banana, millet, sweet potatoes
Kiga	Uganda	5000-6600	31-59	129-258	x x	Maize, banana, beans
Matengo, Makonde	Tanzania	3300-5000	39-47	77-258	x x	Maize, millet, manioc
Kinga	Tanzania	1600-5000	39-55	51-258	x	Maize, millet
Sandawe, Iraque, Fipa, Turu, Gogo	Tanzania	2600-5000	31-47	26-258	x	Millet, maize, beans
Mbugu, Shambala, Pare, Meru Teita	Tanzania	5000-6600	59-79	129-258	x x	Millet, maize, beans
Wakara	Tanzania	4000	63	542	x x x x	Millet, manioc, rice

[b] Terracing. [c] Irrigation farming. [d] Manuring. [e] Stabling.

[f] Leading crops and important mixed crops.

Source: Ludwig, 1967, pp. 92-3.

The tendency towards stagnation is revealed, for example, in 3 neighboring districts in Sukumaland, Tanzania. In the thinly populated Shinyanga area the family income rises rapidly and constantly as the labor capacity increases. In the more densely populated Kwimba area labor productivity is already considerably lower. Finally, on the island of Ukerewe, Lake Victoria, where permanent cropping is practised, there is scarcely any connection between family income and the family's labor capacity (Fig.1).

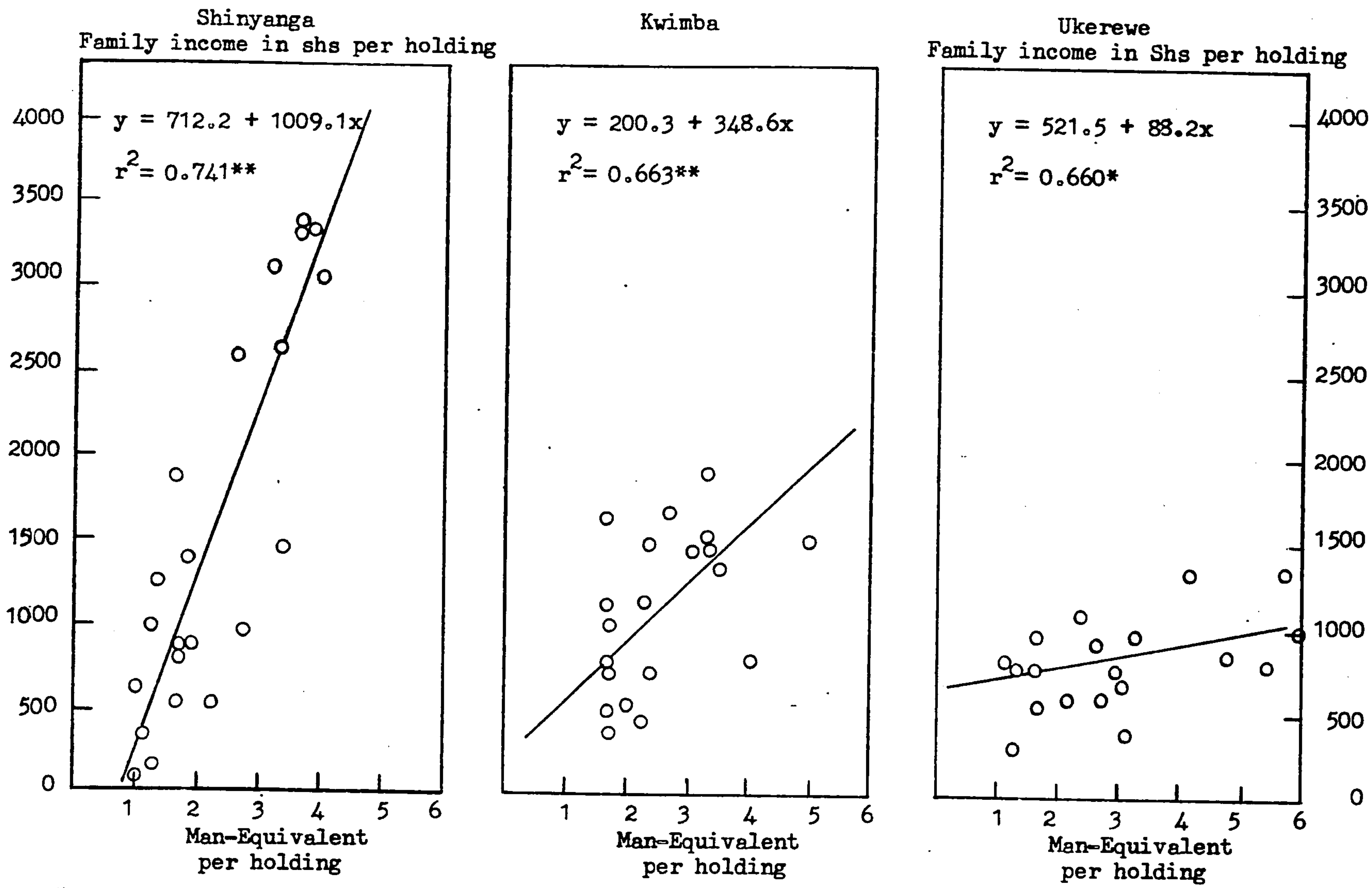
The African savannas are thus heading towards a situation wherein a great number of families live on rather small parched and eroded pieces of land. The situation is different from high-rainfall areas or irrigation farming because the marginal returns to labor are very low and under-employment is high. Yields are far below the potential because of the difficulties of introducing innovations into small subsistence holdings. Droughts occur in known probabilities and cause famines, which are worse each time because of the increasing number of people involved. The African savannas still offer wide low-density areas, but they are heading, with increasing speed, towards a situation well known in the drier parts of India and which is well described as a 'low-level equilibrium trap'. In some more densely populated areas this state has already been attained.

DIFFERENCES BETWEEN SEMI-ARID AFRICA AND INDIA

The state of affairs in the African savannas indicate that mechanisms are at work which tend to create a situation which is similar to that in semi-arid India. Because of this it may be assumed that innovations which prove to be effective under the Indian situation may be effective in Africa as well. This is basically a sound approach because the natural conditions are often similar and research and farming techniques are much more advanced in India than in most parts of Africa. Africa has a lot to learn from the Asian experience but the exchange of ideas has been rare so far. It should not, however, be overlooked, that the situation is still rather different. First, there are differences in soils and climates. Rainfall distribution patterns are not the same. In addition a number of quite important socio-economic differences, some of which are described below, have to be taken into account in order to use the Asian experience for the solution of African problems.

- Semi-arid farming in India is mainly permanent farming. In Africa, it is no longer mainly shifting cultivation but neither is it yet permanent farming. Most of it is in the intermediate stage of semi-permanent farming, a soil-mining type of farming which, however, within traditional techniques, seems to show higher returns to labor than either shifting cultivation or permanent cropping.

FIGURE 1. THE RELATIONSHIP BETWEEN LAND AVAILABILITY AND LABOUR PRODUCTIVITY IN THREE AREAS OF SUKUMALAND, TANZANIA.*



*12 families of the total of 75 have been omitted because they receive non-agricultural income.

Source. ROTENHAN, 1968,

- The situation differs widely from place to place. There are still wide areas potentially suited for cropping which are lying unused and even wider areas with low population densities. Prevalence of diseases such as trypanosomiasis, river blindness, etc., tribal claims to land and political borders have prevented a more even distribution of people over the suitable farm land. The situation is characterized by a number of densely populated areas, some of them rather large (Northern Nigeria, Senegal, Sukumaland, Tanzania) with increasing land shortage in the centre and extension areas on the border. Thus the prevalent semi-permanent type of farming is expanding like a '<u>tache d'huile</u>'. The numerous efforts to guide this expansion into medium-sized ley farms failed. Semi-permanent farming proved to be more competitive.

- Semi-permanent farming, as the prevalent mode of land use in the African savannas, is clearly a function of price relations which until recently were much less favorable in Africa than in India. Producer prices were so low in some francophone African countries in particular that the use of mineral fertilizer was very marginal and tractor farming was simply too expensive.

- Most farming communities are semi-commercialized. Cash cropping has become very important. The homogeneity in cropping which was characteristic of traditional shifting systems is rapidly disappearing. The farming community is in the process of developing more pronounced differences in farm size, output and income but there are still very few large commercial farmers because the process of commercialization took place at a time when most of the land in a given area was already taken by smallholders for hoe farming. Large farms are restricted to European or ex-Europeans in East Africa. The agricultural entrepreneur, trying to adapt research results to local circumstances, is still very rare. There are fewer competent partners for a lively exchange between research and practical farming than in India.

- There are wide variations in husbandry. Certain aspects of husbandry are very carefully carried out in some places but not in others. Hoe cultivation is effected with great care in several areas while weeding is neglected. Some groups ascribe much importance to manuring, whereas others do not bother even to bring the manure from the kraal to the field. Newly introduced cash cropping is usually better husbanded than traditional crops, but as a rule yields are far below the potential because there is lack of proper maintenance of fields and plants. Great care in cultivation often contrasts with negligence in maintenance. Farmers usually argue that this is due to labor shortages in peak seasons. However, it may also be due to a lag in cultural adaption necessary in the change from shifting cultivation to sedentary semi-permanent farming. Field and plant maintenance is not an important task in shifting cultivation. Farmers who have come up in the traditions of shifting cultivation are poorly prepared to look for field and plant maintenance. They are much more inclined to 'mine' the land and to look for new areas. For proper husbandry to spread, there apparently have to be either very strong incentives in the form of a very rewarding cash crop or of high productivity of labor owing to mechanization; or a long-term land shortage which leaves no choice but to take care of plants and fields. The poor state of most of the farming in the African savannas is mainly owing to the fact that neither conditions yet apply.

- Asia has a long tradition in the combination of upland farming and valley bottom farming, usually with some type of irrigation. In Africa this is an innovation. Increasing land shortages is, however, gradually creating an awareness of the potentials of valley-bottom farming. Here usually there are heavy black cotton soils which lend themselves to rice and cotton. The growing interest in valley-bottom rice is a continent-wide affair and year by year more advances are being made in this direction, partly induced by guided development efforts, but mainly carried by autonomous initiative. Well irrigation is almost unknown in Africa south of the Sahara and may offer great potential in some areas. Another avenue is the development of valley-bottoms for rain-fed paddy production. This, however, in order to attain sufficient returns per hour of work, will require mechanization.

- Behavioural functions of the cultivators, their objectives and preferences vary widely. The rapid change in the man/land ratio, different approaches to cash cropping and differences in the cultural background has led to a situation where the quality of the cultivators as agents in rural development fluctuates widely. However, situations where labor is willingly supplied at a low wage rate or with low productivity, because this is required for sheer survival, are still rare. 600 to 1,000 hours of work are usually sufficient to cover the subsistence food requirements and some basic cash demands. More labor is normally supplied on the condition that certain thresholds in income per hour of work are attained. There is a lot of under-employment, but this is not because labor has a marginal productivity of zero. The explanation lies much more in the fact that the return to labor is not surpassing the required threshold value. Labor demanding innovations with low or medium returns per hour of work, which may be very interesting under Indian situations, are likely to fail in the African savannas. Poverty is still too recent a phenomena to illicit low-cost labor supplies. If labor is to be mobilized, and there is much under-employed labor, then the innovations have to show sufficient returns per hour/work. This implies that mechanization when used to open up hitherto unused areas may well create more employment than efforts to obtain more labor input in densely populated areas.

- India is fully occupied by farmers and very little arable land is not yet cropped. In Africa, there is still juxtaposition of increasingly crowded areas with rather empty ones. The danger is that these low-population areas which are suited for farming may be slowly absorbed by expanding semi-permanent farming by smallholders with low returns per hectare and increasing erosion. This should be prevented. Balanced modes of land use in the semi-arid areas of Africa are tied to the tractor, which is more important for productive farming.

  - Tractors are more effective in ploughing properly and at the right time. The use of oxen is economic, but they are often meagre at the time when most of the work is required.

  - Tractors are essential for ley farming because a lot of energy is required to break the leys.

  - Tractors are much more effective in establishing and maintaining the infra-structure in erosion control.

  Motorization is expensive and still out of question in large areas because of low prices for producers. In some areas, however, where food prices are high, as for instance in Northern Nigeria, land development in tractorized units is a feasible proposition. The success of tractor farming in the Sudan/Ethiopia border areas, in Rhodesia and in several parts of East Africa clearly indicates that a judicious promotion of tractor-farming may be a better way for the opening up of still uncultivated savannas than the slow encroachment of semi-permanent farming.

IMPLICATIONS FOR RESEARCH

Semi-permanent farming, as it is prevalent in the semi-arid areas of tropical Africa, is very much in a state of flux. It may be misleading in such a situation to examine the farmers' problems and organize research in an effort to ease possible needs. The tendencies are clear. A growing encroachment of small scale semi-permanent and permanent farming on more and more land is to be expected. This may absorb a great number of people but in every dry year the problem will become apparent and famine relief will have to gain in importance. This expansion of farming by smallholders under semi-arid conditions should be reduced as much as possible. To avoid this, farming systems are required which are significantly more productive per hectare and per hour of work than the present land-use systems, and which allow soil conservation.

This implies first of all the use of high-yielding crops and varieties.

It is obvious that semi-permanent systems, in particular those with unregulated grass fallows, lend themselves much more easily to their introduction than systems with bush fallowing in higher-rainfall areas. The leaching problem is less. The fields are there, largely destumped, ready to yield more, provided new varieties and mineral fertilizers are combined with proper husbandry (timely planting and adequate weeding). The ICRISAT's task is by no means as difficult as the one faced by IITA, because changing bush-fallowing systems with high rainfall and a lot of leaching of soil is much more difficult than improving unregulated grass-fallow systems.

Research for the development of varieties with higher yields, shorter growing periods and more drought resistance, is likely to yield significant returns and has already done so, as shown by the impressive improvement in cotton, groundnut, millet and maize production. The main bottleneck is usually the labor economy. The way of thinking, stemming from over-populated rural India where the marginal utility of leisure seems to be far less than in Africa, that employment-giving innovations should be put into the foreground is a very dangerous one in the African savannas, even though there is a high degree of under-employment. The correct path towards more employment clearly is in designing technologies which are much more productive per hectare as well as per man hour.

These new technologies usually imply some degree of mechanization. Where producer prices are low, ox-ploughing is appropriate and this is reflected by the growing interest in it. Where prices are higher, as for instance in Northern Nigeria, motorization should be considered which finds much more interesting conditions in semi-arid regions than in the higher-rainfall tropics. The drier the climate, the more important is timing and greater the relative advantage of motorization. Another advantage of mechanization would be that those arable areas which are not yet under cultivation could be ploughed, possibly creating larger holdings with enough traction power to plough leys. The encroachment of small-scale semi-permanent farming, with all the draw-backs of tiny holdings on dry land with low marginal returns to labor, could be avoided. The earlier the still available lands are occupied and managed in larger holdings, the better. The arguments in favor of mechanization under African conditions should not be confounded with those for co-operative production. Co-operatives in production have proved to be a hopeless proposition, wherever voluntary participation is expected. Company farming, medium-scale individual farming and tractor-hire services are much more reasonable propositions and have proved their worth in many cases. In dry areas, the advantages of mechanization are more pronounced, simply because the production function of hand labor tends to fall much more rapidly than in higher-rainfall areas or in irrigation farming. In irrigated rice high inputs of labor can still yield appreciable marginal returns. In dryland farming this is not so. Most of the semi-arid areas are already more overpopulated, than higher-rainfall areas, if this is measured according to the marginal return of labor. Again, the drier the area, the more difficult it is to combine high productivity per hectare with a high degree of population absorption.

I still feel that researchers would be well advised to look for the most effective solution to a given problem in technical terms, for instance to find out the land-use system which, in a given location, gives the highest yield with a certain probability. Whether or not cultivators, as they are today, are in a position to apply this technology, and whether it is more or less employment creating, is something that should be asked, but I would hesitate to make this point a major one in the design of research.

The usual sequence in agricultural development is that innovations are produced, partly as a result of social needs and partly they are the outcome of scientific curiosity (research for understanding) and that the rural institutions have to be adapted to the requirements of these innovations. The more rewarding these innovations are, the greater the incentive is for politicians, administrators and farmers to act to the challenge produced by research.

SUMMARY

1. Shifting cultivation is no longer the common practice in the African savannas; it has given way to semi-permanent farming (About 50 percent of the crop land is cropped annually. The rest is under a grass or bush fallow).

2. Semi-permanent farming is usally very diversified and characterized by efforts to adapt farming to different soil types and soil fertilities.

3. Semi-permanent farming is no longer a balanced system of land-use and shows declining soil fertility and much erosion.

4. The main drawbacks for the short term increase in agricultural production in areas with low population densities are bottlenecks in the labor economy.

5. In some high-density areas, fallowing has been almost replaced by permanent farming. This is usually an indication of decreasing cash cropping and much under-employment. The tendency is towards a low-level-equilibrium.

6. Semi-permanent farming is largely an expression of the conditions of production which used to be characterized by rapidly growing needs for outputs and rather low prices for producers. In the past it

proved to be more competitive than ley farming (under small land holders' conditions of production).

7. African semi-arid farming has a lot to learn from Asia, but a number of differences have to be taken into account: (1) Price-relations are far less favorable to producers. (2) Most aspects are much more in a state of change than in Asia. (3) There is still much sparsely populated land, often close to areas with dense settlements. (4) Husbandry is probably less uniform. (5) The marginal utility of leisure is probably much higher in Africa because land shortage is a more recent phenomena. (6) Mechanization is probably much more important.

8. Innovations leading to increased yields are much more easily introduced into semi-permanent farming with grass fallows than into shifting systems with bush or tree fallows. ICRISAT's task in Africa is thus much more promising than the one of IITA.

9. The main task is to develop balanced systems of farming which are more productive per hectare and per hour of work. Mechanization will be a very important aspect in Africa.

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DRYLAND CROP PRODUCTION SYSTEMS IN SEMI-ARID BOTSWANA: THEIR LIMITATIONS AND POTENTIAL FOR IMPROVEMENT

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Although beef production from livestock ranching is the most valuable agricultural activity, the majority of the cattle are owned by a small number of people and the great majority, over 80 percent of the country's farmers and their families are principally or wholly dependent upon arable farming for their food and income. Few of these farmers grow a surplus of cash crops for the market and most of them generally produce yields of only 2.5 $q.ha.^{-1}$ on cultivated land upto 10 ha. In seasons of below average rainfall, yields are insufficient to supply the annual food needs for the family (Botswana Govt. 1972, Kweneng Resource Survey).

In an attempt to improve this situation, there has been a strengthening of the agricultural research effort, particularly for the selection and improvement of suitable food crops and, most recently, with the appointment of a Dryland Farming Research Team to study the constraints to crop production in Botswana's semi-arid environment. The team was asked to investigate the means of improving the realiability of food crop production by small farmers (Botswana Govt. 1974. Dryland Crop Production in Botswana: a review of Research 1969-74).

This paper summarises the limitations of the existing farm systems in Botswana, outlines the main findings of the Research Team during Phase I of the program (1971-74), and suggests ways of improving the techniques and systems of farming. Some suggestions have also been made for the new research and extension approaches that are appropriate in this situation.

EXISTING FARMING SYSTEM

A small number of farmers, mostly operating on the sandy soils of the south eastern corner of Botswana, have adopted mechanised systems of farming from the neighbouring region of South Africa. They grow

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some cash crops, notably groundnut and maize, and use techniques, equipment seed and fertiliser from South Africa and most of their sale crop also goes to the Republic. Large areas of land have been cleared of all vegetation and the most striking characteristic about this method of farming is the total absence of water and soil conservation and the lack of use of suitable dryland farming implements. Wind erosion is severe in the area and a considerable amount of yield potential is being lost. The same type of farming can be found in isolated areas throughout Eastern Botswana.

Another group of farmers, perhaps 7 percent of the total, are practising moderately sound farming systems using ox or donkey power and a limited range of equipment. The principal implements are the mouldbeard plough, a crude planter and a heavy inter-row cultivator.

The vast majority of Botswana farmers, severly hampered by the lack of suitable implements, are practising a system of farming that is poorly adapted to the environment and one that produces very low yields in most years. During the winter period animals are allowed to graze crop residues. The land is normally ploughed after the first heavy spring rains using teams of between ten and fourteen oxen. A mixture of seeds is broadcast on to the ploughed surface and ploughed in or covered using a bush drag harrow. Or, the seed may be broadcast on to unploughed land and then ploughed in. Fertilisers and insecticides are rarely used and kraal manure is used on small areas when available. Some weeding may be carried out using a hand hoe but this is often too late to be effective. As many farmers do not have any or enough oxen, they have to wait until their neighbour can lend them animals to make up teams for ploughing and planting. This delays planting and therefore delays harvest. Harvesting is carried out by removing the heads and threshing them on a threshing floor using a straight pole which is hand held.

Yields of main food crops (sorghum, cowpea and millet) are usually below $2.5 q.ha^{-1}$ and do not appear to fluctuate markedly with season, although the total production does due to big variations in the areas harvested in different seasons.

LIMITING FACTORS

Physical

Climate: Estimates of the land area climatically suitable for arable agriculture vary between 2 percent and 5 percent and even within these areas the chance of crop failure is high (Bawden and Stobbs, 1963; Pike, 1971).

In the main areas where crop production is of importance in the east of the country, rainfall varies between 350 mm and 500 mm and falls between November and April. Coefficients of variation of annual rainfall range from 30 percent to 60 percent. The number of years receiving less than the mean rainfall are more than those receiving above average rainfall.

An analysis of seasonal distribution of rainfall shows that over 60 percent of the total rainfall may fall in showers of over 10 mm, though these may represent only 10 percent of the rainfall occurrences.

During the growing season soils have high surface temperatures (over 60°C recorded) and evaporation rates are high (open-water evaporation exceeds 15 mm per day), most of the light showers, therefore, are ineffective in adding to soil moisture storage. The annual effective rainfall is estimated to be less than 50 percent of the total annual rainfall.

Losses by evaporation normally exceed gains from rainfall even for ten-day periods during the growing season. Annual openwater evaporation varies between 1.7 m and 1.9 m.

Soil: The soils of Eastern Botswana are ferruginous tropical which are usually coarse-grained sands or sandy loams, shallow in depth and overlying a gravelly ouklip lateritic layer which lies on granite or metamorphic rocks. Their structure is unstable following the removal of natural vegetation by overgrazing or cultivation and by the action of rainfall on the soil surface and water moving through the profile. Wind erosion is common in the finely textured soils and water-induced erosion is widespread.

Run-off occurs with the high intensity showers and may reach 70 percent during showers of over 25 mm. An average seasonal figure of 30 percent run-off has been recorded on a slope of 0.6 percent. If water can be held on a soil surface, infiltration rate increases depending on the initial soil-moisture content. Rates of 30 cm/hr^{-1} into a soil of 2 percent moisture were recorded (over a 10 minute period) and 5 cm/hr^{-1} into a soild of 12 percent moisture (over a 1 hour period) have been recorded. Under average rainfall it is unlikely that any significant deep drainage occurs.

Soil moisture is readily available in all predominantly sandy soils and available moisture ranges from 5.7 percent to 8.9 percent (between 1/10 BAR and 15 BAR). The total storage capacity for a soil depth of 100 cm has been calculated to exceed 200 mm, though this figure is rarely reached. The depth of soil above the ouklip layer has an important influence on potential storage capacity.

Most soils form hard crusts following the breakdown of soil surface structure during rain and in the subsequent drying out process. This crust can vary in strength between 400 mb and 1,000 mb and presents a severe physical barrier to emerging seedlings in addition to reducing infiltration and soil aeration.

The soils also compact with the action of water moving through the profile and bulk densities rise from $1.4 g.cm^{-1}$ after cultivation to 1.6 to $1.8 g.cm^{-3}$ over a few months. As the soil dries out, it becomes very hard and plant roots are restricted in their development and also in their ability to adapt to rapidly diminishing moisture supply. Of the main chemical elements, phosphorus is the one most commonly deficient in soils. This has been detected in many soil analyses and is reflected in consistent responses to phosphate fertiliser in field trials. Potash and most of the micro-elements are however, present in adequate quantities.

Levels of mineral nitrogen are high at the beginning of the rainy season and early planted crops show markedly better growth than late planted ones. Measurements of soil mineral nitrogen have indicated that most of it is present in the top 2 cm of soil at the start of the rains. Nitrogen is rapidly leached through the profile but high levels may return after long dry periods during the growing season. An analysis of rain water showed that 4.8 kg ha^{-1} of nitrogen was received during a season with over 500 mm rainfall. Most of this nitrogen was added during the first month of the rains.

Cation exchange capacity of most soils is low and soils are moderately acid. Organic matter is usually between 0.1 and 0.5 percent. The organic material from crop residues and kraal manure is rapidly broken down and can only have a temporary effect on soil structure.

Biotic factors: Low plant population are known to be one of the main reasons for low yields per unit area. The results from all the recent (1969-74) trials have shown the value of increasing plant populations of sorghum to 70,000 plants per hectare. In years drier than the normal, yields are not significantly different from those from lower plant population and in wetter years there is a very significant benefit from higher plant population. There is also some recent evidence (Chim Choy and Kanemasu, 1973; Ritchie and Burnett, 1971) that the total evaporative demand is reduced by increasing plant population.

Weed competition has a significant negative effect on yield, particularly in the early weeks of crop growth (Burnside and Wicks, 1969), insect pests are likely to cause big losses in wet years and bird damage is severe on late maturing crops in some seasons.

Technical Knowledge: The introduction of a European technology based on the mouldboard plough over a hundred years ago has effectively prevented the development of suitable techniques of cultivation of sandy soils in a semi-arid environment.

Although there is a growing awareness of the value of sound soil and water conservation over the whole of a watershed, most farmers are unable to appreciate the need for water and soil management techniques that improve soil structure, control weeds at all times, reduce run-off increase infiltration and reduce evaporation losses.

The lands are usually ploughed in the spring, using valuable moisture that could be used for growing a crop. Sowing techniques result in very low plant establishment owing to lack of depth control and contact between seed and moist soil. Weeds are rarely controlled during the first four weeks of crop growth when they are known to have their strongest negative effect on yield.

Crops are frequently harvested very late and the belief persists in some regions that the sorghum crop must experience a frost before it can be harvested. This practice exposes the crop to risk of further losses through birds and animals and also prevents any autumn preparation of the land for the following season.

Threshing techniques are crude and losses of grain from insect and rodent attack in store are thought to be high.

Cropping is limited to the main food crops and is dominated by sorghum. Persistent use of the same land for growing sorghum results in a build-up of the parasitic weed Striga asiatica which causes a severe reduction in yield potential.

The amount of land cultivated and planted varies with the persistence of the rains and the availability of animals and equipment. Farmers are often observed planting in late February in a season when the rains had started in November.

Power and equipment: The main sources of power are oxen or donkeys. Large teams of oxen are used in early spring ploughing as the animals are usually in poor condition at this time. Planting is frequently delayed while animals improve in condition or for teams to be made up. (Over 50 percent of farmers own no draft animals and have to borrow them for ploughing). The most widely owned and used piece of equipment is the single furrow mouldboard plough; 65 percent of the farmers own a plough and a further 24 percent are able to borrow or hire one. The mouldboard plough has a higher power requirement, is slow in covering the ground and its use results in losses of soil moisture which are excessive. Less than 2 percent of households own either a two-furrow plough, a barrow or a planter and less than 1/3 percent own a cultivator. The designs of all these imported implements are degraded and unsuitable for semi-arid conditions and sandy soils, spares are increasingly difficult to obtain and some implements have gone out of use.

Social and Geographical

Most of the rural population in Eastern Botswana is based in large villages and the farmers live at the farm only during the crop growing season; the farm may be up to 30 km from the village. Land areas frequently have no permanent water supply and so water must be carried from the nearest source or the village or the farmer will not move out to his lands until some surface water can be collected.

Many important social occasions in the village are held in the November/December period and farmers may not be at their lands before January. Draft animals may need to be brought from a cattle post(which may be 80 or more km from the village) where they have spent the winter period.

All these factors tend to delay planting and produce a series of circular relationships, which are difficult to change (Harvey, 1974), such as late planting - late harvest - late spring ploughing - late planting.

Storage, Transport and Marketing

While some on-farm grain storage does occur, many farmers need cash during the post-harvest period and sell a portion of their crop. As farms are scattered and there are very few roads, no transport system has developed in most areas, and produce is generally carried by the farmer's own wooden sledge or scotch-cart and sold to the nearest local trader.

Prices for food crops are poor at this time and the farmer may be faced with buying back the same amount of food several months later at three or four times the price he received.

Marketing arrangements for the main food crops are expected to improve with the setting up of a Marketing Board during 1974. The stabilisation of producer prices and the provision of alternative outlets for sorghum grain may provide a much needed stimulus to food crop production.

Credit

The provision of credit to small farmers is only just beginning to have some impact with the increased lending from the Development Bank and interest taken by a commercial bank. The recent increase in loans for tractors without suitable accompanying equipment is not very encouraging, particularly in view of the absence of adequate servicing facilities within the country.

Research and Extension

Until recently, research in crop production concentrated on the investigation of specific problems of production and the testing of potentially suitable crops and varieties. The extension effort has been centred on a series of single concepts or techniques and has encouraged a minority of farmers through the Pupil and Master farmer schemes.

RESEARCH PROGRAM FOR 1969-74

During the past five years, the program of research on the principal climatic, edaphic and biotic factors, limiting crop growth and yield, has provided the necessary background to experimentation for developing suitable techniques of soil and water management for the semi-arid enviornment of Botswana (Botswana Govt. 1974. Dryland Crop Production in Botswana: a review of Research 1969-74).

The minimum tillage techniques, developed in the U.S.A. (McCalla and Army, 1961; Fenster, 1960) have been shown to be appropriate and feasible with suitable adaptation to animal draft. New equipment has been designed and constructed locally in view of the unreliability and cost of imported machinery. It also provided the opportunity to stimulate the setting up of village-based workshops where a wide range of repairs and manufacture could take place. The tillage techniques are based on chisel or sub-soil implements and sweeps which have lower draft requirements than existing implements. A planter has been designed which plants through a surface layer of dry soil and has a seed packer wheel which results in good plant establishment. Weeding within and between crops rows can be carried out with L-blades attached to a steerage hoe. All these implements are attached to a two-wheeled carrier which is designed to manage a two-row precision tillage system. The carrier can also be used as a simple cart for water carrying, fire wood or crops and can be drawn by two oxen (Botswana Govt. 1974. The Versatool. Dryland Farming Research Scheme).

The research program has also involved the selection and testing of suitable crops and varieties, the study of the most appropriate plant type for the environment, plant population, variety and fertility interactions. The introduction of a simple crop rotation has been shown to have significant benefits, partly in the control of pests and diseases and in the spread of risk, but also, by introducing a complete season bare fallow, the possibility of reducing the chances of crop failure through pre-season soil moisture storage (Whiteman, 1974). The fallow also offers an excellent opportunity to break the pernicious late ploughing - late planting - late harvest cycle and enables the farmer to prepare the land when his animals are in their best condition, in the late summer or autumn.

The combination of all recent research findings has resulted in the development and testing of an appropriate farming system. To raise output significantly the system needs to be applied as a whole and not as a series of isolated steps, each operation must be carried out at the correct time and has to be completed efficiently.

The system involves soil and water conservation of lands areas, the introduction of a crop rotation including a bare fallow before sorghum, keeping the land weed-free with flat bladed sweeps, sub-soil ploughing in late summer or autumn, planting after the first suitable rain in the spring, inter-row weeding as early as possible after emergence and whenever necessary afterwards, thinning the plant population if required, applying top-dressings of nitrogen in exceptionally wet seasons, breaking up compacted surfaces to help infiltration, harvesting early and sweeping the crop stubble immediately afterwards. All operations should be carried out on the contour (Gibbon, 1974).

An examination of the implications of this system has been made and also the feasibility of a number of alternative systems. The choice and suitability of a particular system will depend on the availability of credit, whether additional labour is available for harvest and whether equipment can be shared among farmers (Harvey, 1974).

FUTURE

In developing a research program that involves the testing of the new equipment and new systems of farming, it is immediately apparent that the application of research findings from a purely technical base is very inadequate.

The experiment of the Dryland Farming Research Team and the findings of a recent report on Rural Development (Chambers and Feldman, 1972) indicate that new approaches in research and extension are needed. There is a need for the research scientist, the extension worker and the farmer to work much more closely than in the past. The research worker needs to be very familiar with the farming situation if he is to adapt his research findings in developing appropriate techniques and systems. The extension worker should also be part of the research process and the farmer, or groups of farmers, must be the starting point of any program of farming systems improvement. The research base needs to be widened considerably with more emphasis placed on social and human problems as part of the whole process of change in crop-production systems.

Arising from this early work, an intensive area agricultural development project has been devised which, if successful, may be replicated in other regions. This project involves the planning and development of all the physical and human resources within a specified lands area, and is intended to improve the living standards of the whole community.

SUMMARY

Crop growth in Botswana is primarily limited by climate (low and erratic rainfall), soil (poor nutrient status, crusting and compaction), and biotic factors (low plant population, weed competition, insect and bird damage). Crop production systems fail to make optimum use of envi-ronmental resources. Lack of soil and water conservation, absence of crop rotation, broadcast sowing, late planting, inadequate draft power at critical times and unsuitable equipment, all combine to reduce crop output. There are also other important human, social and geographical constraints that probably exert as great an influence as other limiting factors.

The combined introduction of a crop reproduction system and minimum tillage equipment, suitable for semi-arid conditions and adapted to the needs and capabilities of the subsistence farmer, can bring about sub-stantial improvementsin output and can raise the economic standard of the majority of farmers above subsistence level.

The development of improved farming systems requires new approaches in research and closer links among farmers, extension and reseach workers.

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APPLICATION TO THE SEMI-ARID TROPICS OF THE CANADIAN DRYLAND SPRING WHEAT PRODUCTION SYSTEM

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There are semi-arid areas in the temperate zones as well as in the tropics. They differ widely in soil and climatic characteristics and in many of the economic and social demands placed upon them. They do, however, have one thing in common--insufficient moisture for maximum crop production during a significant part of the production year. Because of this common dependency on soil moisture, it would be worthwhile to examine certain components of the production system developed for spring wheat in the Palliser Triangle of Western Canada for their application in the Semi-arid Tropics much of this system is based on research conducted at the Agriculture Canada Research Station at Swift Current, Saskatchewan (Campbell, 1971) and at other research locations in Canada and the U.S.A.

The Palliser Triangle

Location. The base of the Palliser Triangle is on the Canadian-United States border extending some 300 km west of the Saskatchewan-Alberta border and to some 75 km east of the Saskatchewan-Manitoba border, with the northern boundary on an east-west line passing approximately through Saskatoon (Figs. 1 and 2). It has an area of approximately 20,000,000 ha. It was first surveyed by Captain John Palliser in 1857 and was described by him as "a desert in which sustained agriculture would be a precarious industry" (Palliser, 1859).

Soil. The Triangle has brown and dark brown soils under short-grass and mixed-grass prairies, as part of the northern extension of the Great Plains. The soils range in texture from sands through loams to clays. The subsoil is a saline marine shale. In topography, the soils range from level to very much undulating. They are erodible by both wind and water, generally deficient in phosphorus and in nitrogen under continuous cropping.

Climate. The climate is characterized by cold winters, short growing season, high winds, particularly during April and May, and insufficient moisture, particularly during June and July. At Swift Current, based on a 50-year average, the growing season is 131 days commencing

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FIGURE 1. LOCATION OF PALLISER TRIANGLE.

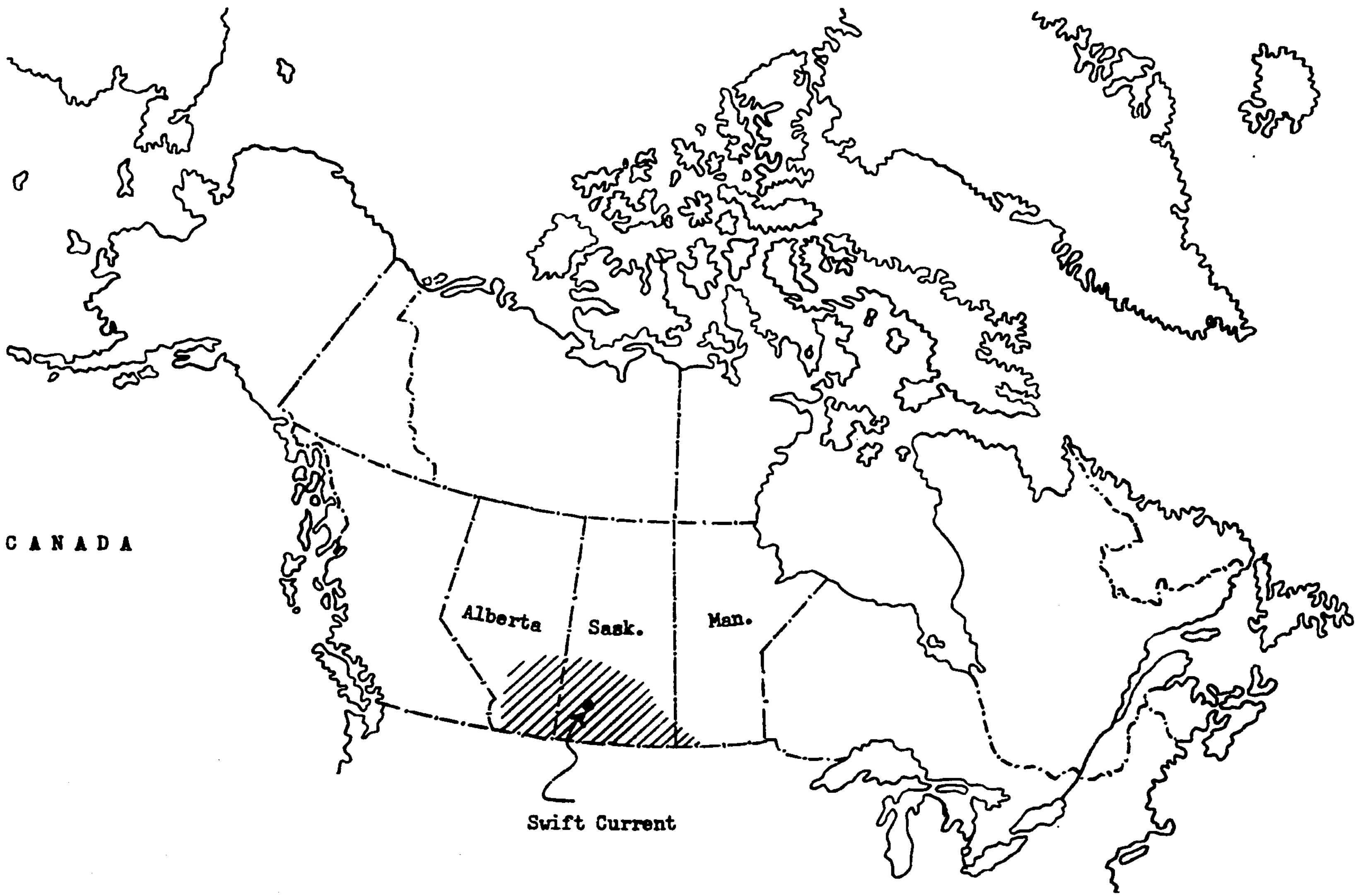
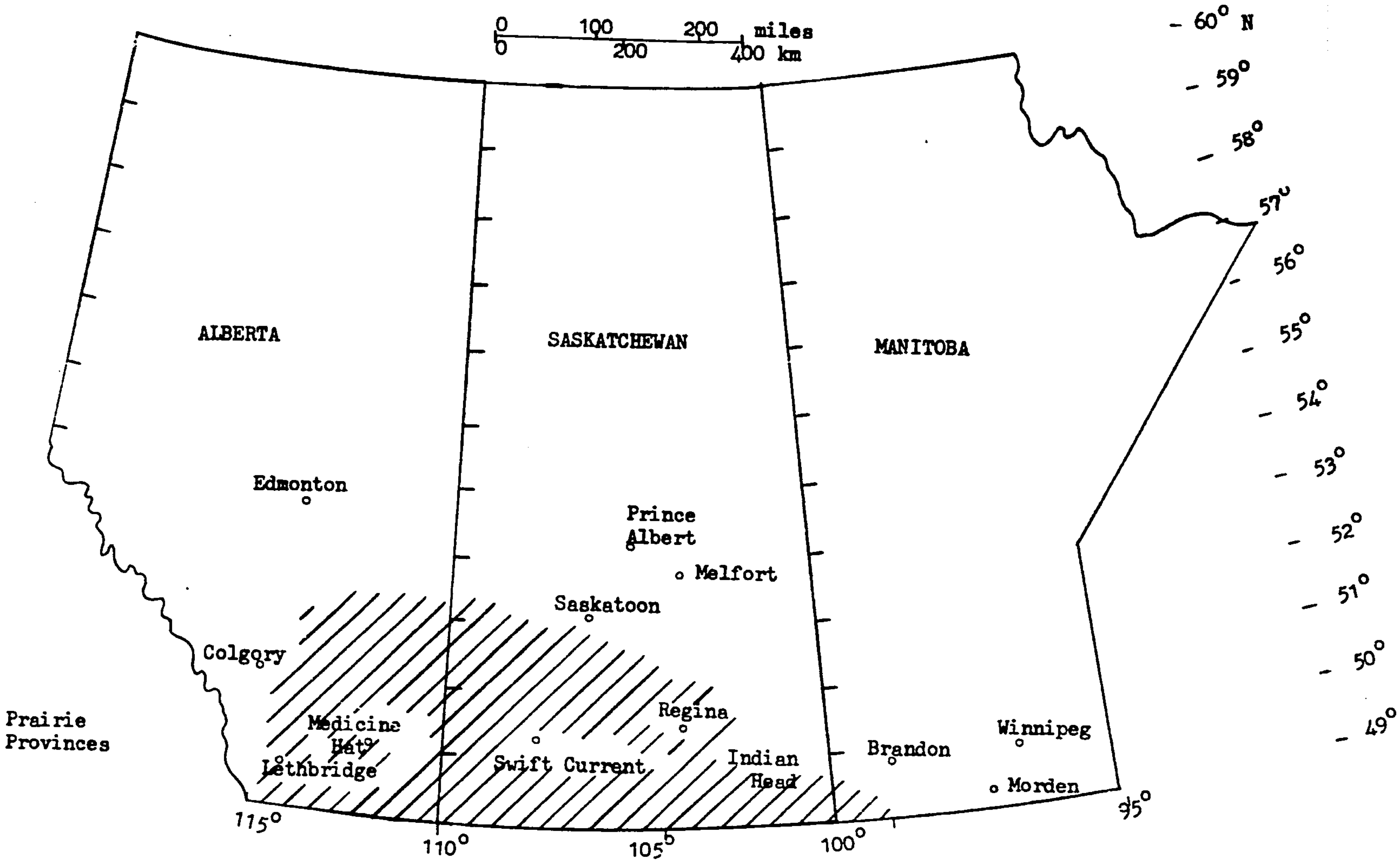


FIGURE 2. LOCATION OF PALLISER TRIANGLE.



May 15 and terminating September 24. July is the warmest month with a daily mean minimum temperature of 11.1° C, a daily mean maximum of 26.1° C and a record high temperature of 39.4° C. Average wind velocity ranges from 12.4 km/hr during January to 9.8 km/hr during July, and is 12.9 km/hr during May when the soil has the least protection from wind. During any period, there can be winds of 60 to 80 km/hr for several hours. The annual precipitation at Swift Current is only 35 cm, of which 9 cm fall as snow during the winter. Evaporation during May 1 to September 30 from the free water surface of a Class A Pan is 117 cm.

Spring Wheat Production System

Low yields and extensive soil erosion by wind during the 1930s lead to the development of a cropping system for spring wheat which is the major crop produced in the Palliser Triangle. Essentially the system has stabilized production and this is its principal advantage. It has given this stability by minimizing the influence of insufficient moisture on yield during years when soil moisture is deficient for wheat production. Obtaining still greater production stability is our major concern.

General characteristics. Maximum effectiveness of the spring-wheat production system presumes the development and availability of highly adapted cultivars, soil nutrient supplements, herbicides for control of weeds, and chemicals for the control of diseases and insects where genetic resistance is not available in the cultivars (University of Saskatchewan, Canada 1972. Guide to Farm Practice in Saskatchewan). In these respects the basis of the system is similar to that for the semi-arid tropics but the characteristics of the inputs are much different.

For maximum output, the system also requires maximum utilization of soil moisture. The initial source of moisture is snow melt during the spring prior to cropping rather than the monsoon, characteristic of the semi-arid tropics, with differences in rainfall patterns and intensity. Notwithstanding these differences, a number of the basic principles of dryland agronomy should be similar.

The cropping decision. Assuming that a farmer in the Palliser Triangle has cropped a unit of land during the previous summer, he must, the following spring, decide whether or not to again crop the land or let it lie idle as fallow in summer to build up the moisture reserve. If he is to again crop the land with expectations of receiving an average yield, he must have 10 cm of available moisture in the soil in the spring (Janzen et al., 1960). This amount plus the normal 17 cm of growing season precipitation (May 1 to July 31) will ensure a 1000-kg/ha crop of wheat using existing cultivars and production methods. On an average, each additional 2.5 cm of moisture over the basic 27 cm, whether stored in the soil at the time of seeding or received during the growing season, will increase the yield of spring wheat from 200 to 336 kg/ha up to

2000 kg/ha. Thereafter, each additional unit of moisture will promote less yield increase up to a maximum yield based on genetic yield potential, soil nutrient availability and related factors. Whereas the relationships will differ, this approach could certainly be used for making initial cropping decisions if there are areas in the semi-arid tropics where stored moisture is often deficient at seeding time.

Moisture collection. Fallow. Where the land has been cropped the previous year, there is seldom 10 cm of available moisture stored in the soil the following spring. This dictates that the land be left idle or fallowed for one season prior to cropping. When the land is fallowed, 21 months elapse from the time a crop is harvested to the planting of the succeeding crop. During the first 9 months of the fallow period (first winter), about 5.6 cm or 33 percent of the total precipitation is usually conserved. For the remaining 12 months, only 4.6 cm of 14 percent of the precipitation is stored, for a total of 10.2 cm for the 21-month fallow period (Dodds, 1957).

Because of surface runoff and evaporation, fallow is a relatively inefficient means of storing moisture. With increasing world demand for wheat, more drought-resistant varieties, reduced need for tillage because weeds can be controlled with chemicals, and increasing salinity of our soils, the general use of fallow in our spring wheat cropping system is being questioned.

In India, and presumably in other parts of the semi-arid tropics, land is also left idle or fallow either during the monsoon or in the dry season. I am led to believe that this fallow period is not required for moisture storage and is rather a misuse of the production resource. If so, the concept of fallow developed for the Palliser Triangle has no application to the semi-arid tropics.

Collection of spring run-off. When snow melts in the spring, there is a rapid release of moisture which in a minor way must be similar to that experienced in the semi-arid tropics during the monsoons. In our spring wheat production system, we have not considered holding this moisture in position until after the soil thaws in the spring but we have recently given some consideration to storage of runoff water in surface reservoirs. The prime difficulty in storing this water is the inability of the reservoirs to hold water where the soils are sandy. We have found that where the soil does not contain more than 40 percent sand, sealing of the bottom and sides of a reservoir is possible by incorporating sufficient sodium carbonate to deflocculate the soil. More recently we have had excellent results from sealing reservoirs in soil with a higher sand content by applying 5 cm of compacted straw to the bottom and sides of the reservoir and covering this with 10 to 15 cm of soil (Mirtskhulava et al., 1972). Certainly this method of reservoir sealing which was developed in Russia based on a gleization process, could be very useful in sealing reservoirs in the semi-arid tropics.

Conservation of Surface Cover. Research at the Swift Current Research Station has shown that summer-fallow should be kept weed free after May 15 for maximum yield of spring wheat the following year (Korven et al., 1962). Letting weeds grow until June 1 will remove sufficient moisture to cause a 10 percent reduction in yield and leaving weeds until July 1 before they are controlled will cause a 20 percent reduction. Adequate control of weeds during the summer-fallow season now requires three cultivations. To protect the soil from wind erosion requires a minimum of 840 kg/ha of surface trash on medium and moderately textured soils (McCalla and Army, 1961). Based on good agronomic practice, these two requirements are in conflict. The ultimate solution appears to be the elimination of summer-fallow or the maintenance of summer-fallow by the use of herbicides for weed control.

Cultivation. During cultivation, proper use of blade and disk implements in a tillage sequence is required to regulate surface trash cover on a quantitative basis (Anderson and Wenhardt, 1966; Anderson, 1961; Anderson, 1965; and Anderson 1964). The sequence is based on initial amount of surface cover and the extent to which different machines tend to destroy this cover.

The blade cultivator used for summer-fallow tillage conserves 55 percent of the original stubble and trash at the surface compared to 17 percent for the one way disk or disker and 6 percent for the plow. The disk-type implements reduce surface cover by 50 percent with each operation. With the wide-blade cultivator, the trash reduction pattern is 15, 10 and 5 percent of the original cover for the first, second and third or subsequent operations. When used for two cultivations following preliminary tillage with a disk implement, the wide-blade cultivator will return 11 percent and the rodweeder 14 percent of the original cover to the surface. Heavy duty cultivators equipped with a rodweeder attachment will conserve 12 percent more trash after two operations than can be accomplished with the cultivator alone. Obviously, these quantities are influenced by depth and speed of operation.

I assume that in the semi-arid tropics some benefit could accrue from incorporating trash into the soil surface or maintaining it on the surface either during a fallow season or during cultivation for a second crop. It will probably not be for the protection of the soil from wind erosion but possibly for greater moisture absorption and retention, the shading of the soil to reduce surface temperature and evaporation and even protection from water erosion. With total utilization of above-ground plant material, this trash may not now be available but hopefully a time will come when part of the plant material from one crop is left in or on the soil to help in the production of the following crop. The machines that will be used for cultivation and manipulation of trash will not be as massive as those used in the Palliser Triangle, but, regardless of this, the basic principles of soil manipulation are the same. The important message here is that crop residue can be manipulated by cultivation.

Herbicides. Research at Swift Current indicates that summer-fallow can be maintained weed free by using herbicides (Anderson, 1971). In five summer-fallow wheat sequences, the yield of wheat was not influenced by using herbicides. Summer-fallowing only with herbicides conserved 62 percent of the original crop residue compared with 24 percent where summer cultivation was preceded by cultivation following the removal of a crop the previous fall. In summer-fallowing with chemicals, there was less reduction in soil particle size during the 21-month summer-fallow period and the soil temperature during the summer was 2° to 4° higher. The only disadvantage appeared to be a possibility that summer-fallowing with chemicals may aggravate the nitrogen deficiency often associated with excess amounts of crop residue.

A number of standard weed control herbicides can be used during summer-fallow but most do not efficiently control volunteer wheat. However, we have very recent indications that late fall application of soil sterilants will suppress all growth during the subsequent summer-fallow season, yet dissipate sufficiently for normal crop production the following year. The chemical Atrazine presently shows the most promise.

Assuming availability of chemicals at a reasonable price, it would seem that there could be situations in the semi-arid tropics where short-term sterilization of the soil as a substitute for cultivation could be beneficial. Certainly this might apply where there was not sufficient on-farm power for cultivation or where prior to seeding, the soil was too wet for effective cultivation.

Crop establishment. Crop establishment is the most critical stage in the wheat production system for the Palliser Triangle. The soil has been idle for 21 months storing moisture, surface cover has been reduced by successive cultivations to control weeds, the soil surface may have become compacted and erodible, and the ice and snow accumulated during the preceding winter has just melted and the water has been released onto the soil surface. On land of uneven topography, the surface soil on the top of the hills will be dry, soil on the slopes will be drying and may be gullied from water erosion, and free-standing water may have accumulated in low areas. Seeding in late April or early May is required, both because of the short growing season and the advantage of placing the seed in the ground before surface moisture has evaporated. It is generally considered that from the time the land is ready to cultivate, there is only a 2-week period during which seeding of the crop can be accomplished without severe restrictions in plant establishment caused by lack of surface moisture.

For maximum yield of crops grown during the dry season in the semi-arid tropics, there is equal need for timely and effective pre-seeding tillage and for placing the seed into firm, moist soil.

Seeding. In seeding spring wheat in the Palliser Triangle, it is essential that the seed be placed in a firm moist seedbed and that it should not be covered by more than 5 cm of soil. If these requirements are met, the type of implement that is used for seeding does not influence yield. In experiments at Swift Current, yields were equal when the crop was seeded with a hope-press drill; a high clearance hoe-drill; a single, double or a triple-disk press drill; a disker followed by a packer or a cultivator-rodweeder-drill combination (Anderson, 1974). Also, as long as weeds were controlled, there was no yield advantage to cultivating the soil prior to seeding, even though it had not been cultivated during the 21-month fallow season. It would seem that the amount of extra moisture conserved by eliminating cultivation compensated for any disadvantages associated with lack of cultivation.

Seeding Equipment. This is one area in which the Research Station at Swift Current has become directly involved with agriculture in the semi-arid tropics. Under the sponsorghip of the All-India Dryland Program, Indian design engineers have been working with design engineers at Swift Current to develop more suitable seeding and pre-seeding cultivation equipment. During 1973, a small tractor-drawn seeder was developed (Dyck and Kataria, 1974). It is basically a ridger-seeder combining the ridging-furrowing and seeding operations for both kharif and rabi crops. It places seed on the ridge or at the bottom of the furrow. It also places fertilizer 2.5 cm below the seed for rabi seeding. It is now undergoing extensive testing at Hissar.

This year the engineers have just completed the design and construction of a bullock-drawn seeder for the plateau region of Bihar State (Tiwary, 1974) and a bullock-drawn cultivator-seeder for Maharashtra State (Shende, 1974). Both are light weight and simply constructed. They have been tested at Swift Current and are now on their way to India for further testing by their designers.

Harvesting. Harvesting consists of cutting the wheat with a swather and placing it in a windrow on the remaining stubble. When it dries to at least 14.5 percent moisture, it is picked up and threshed with a combine and placed in storage. Windrowing can be commenced when the Kernel of the standing grain reaches a 35 percent moisture content (Dodds, 1957; Dodds, 1967). Swathing as early as possible is recommended as the standing wheat is vulnerable to shattering by wind and the kernel dries more rapidly in the windrow. Research at Swift Current shows that early swathing often increases yield by as much as 100 kg/ha and does not reduce grain quality (Dodds and Warder, 1966). Realising this, the farmers now windrow their grain much earlier than previously and effectively shorten the production season.

Through involvement in the All-India Dryland Program, Swift Current is now establishing the moisture-harvesting relationship for sunflower. If moisture-harvesting relationships have not already been established for the major crops, these studies would be a useful component of the farming systems research program for the semi-arid tropics.

Influence of Climate on the System

Certain moisture-related aspects of the wheat production system for the Palliser Triangle have been described earlier. Essentially, this production system is based on response to average climate. It is relatively inflexible and to increase the efficiency of the system, flexibility must be introduced. In an attempt to do this, we are now trying to develop models that will explain the various responses with a view to injecting the influence of long-term trends and short term variability in climate into the production system. Such models could form a basis for the farming systems being developed for the semi-arid tropics. I will give two examples.

Climatic trends. We have used 50 years of weather data to develop a mathematical relationship between the yield of spring wheat and weather and to investigate the influence of changing weather conditions on wheat yield (Robertson, 1974). During the earlier part of the 50 years, the climate was characterized by unsettled conditions involving hot, dry summers of a few to several years duration broken by spells of cool, wet summers. These conditions resulted in periods of drought accompanied by very low wheat yields intermingled with periods when the yields were very high. During the past 15 summers, the weather has been characterized by normal to below normal rainfall and normal to below normal temperatures. During these years the wheat yields were average to above average and much less variable than during earlier years.

The relationships indicate that in spite of a low-summer rainfall, yields during the last decade have been near normal as a result of cool summers. This indicates that because of the lower evaporation associated with cooler summmer, dependence on moisture for wheat production has been reduced. Should this trend continue, as we expect it will, it increases the feasibility of moving away from the summer-fallow-wheat rotation that we have been using. It means that we should adjust downward the 10 cm of available moisture that the farmer must have before initiating cropping. It may also explain the problems that we now appear to be having with increasing salinity in drylands when using the wheat-summer-fallow production system.

Influence of weather on wheat yield. A mathematical model was developed which accounts for 73 percent of the yield variability due to weather variations (Robertson, 1974). The model treats summer-fallow-season and growing-season precipitation as additive functions. These functions are modified progressively throughout the growing season on a monthly basis by correction factors which are quadratic functions of monthly averages of the daily maximum and minimum temperatures and of global radiation derived from measurements of bright sunshine.

It is felt that the mathematical equations can provide a practical and convenient model for making progressive estimates of wheat yield in crop-condition surveillance programs and also for determining the intensity of management throughout the growing season. For example, if yield expectations are very low, it might not be sound economic practice to apply expensive chemicals for control of weeds or insects. On the other hand, should yield expectations be very high, it might be economicall sound practice to intensify management.

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CROPPING SYSTEMS IN THE SEMI-ARID TROPICS OF INDIA*

S.L. Chowdhury**

In the techno-economically advanced countries, profitability is a major determinant of cropping systems within the constraints of climate and soil in a region. In the semi-arid regions of India, where most farmers are small-holders, the cropping systems have emerged, within the same constraints, as a result of the basic human needs for food and fibre and fodder for draught animals and milch cattle. Ignoring the wide inter-regional variations at this stage, the general cropping pattern in the low-rainfall, unirrigated, semi-arid areas of India is summarized in Table 1 below:

Table 1. Percent Area Under Various Crops in the Semi-Arid Regions

Crop	Percent area under the crop in the semi-arid regions	Proportion of area under the crop in India (percent)
Sorghum	22.92	64.34
Pearl-millet	11.61	51.39
Maize	1.62	19.19
Finger-millet	2.35	46.33
Wheat	7.66	30.66
Barley	1.40	21.38
Chick-pea	6.27	31.51
Pigeon-pea	2.33	47.24
Groundnut	9.17	74.06
Other oilseeds	3.31	36.52
Cotton	9.55	60.51
Other crops	21.81	-
Total cropped area	100.00	

* Contribution from the All India Co-ordinated Research Project for Dryland Agriculture - an Indo-Canadian collaborative Project.

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The bulk of the country's area under sorghum, pearl-millet, finger-millet, pigeon-pea, oilseeds and cotton is, thus, in the low-rainfall, unirrigated semi-arid regions of India. Whereas oilseeds and cotton are the important cash crops, 42 percent of the nation's food is produced on these lands. Any shortfall in production on these lands, therefore, is immediately reflected in the total yearly food supply for the people.

Understandably, land productivity in these areas is low and unstable. It is low because the traditional long-duration crops in use are those adapted to harsh conditions of growth and a low level of soil fertility. It is low because cultivation has been extended to marginal and sub-marginal lands. The fraction of cropped area relative to total area in these regions is 57.2 percent as against the all-India figure of 44.6 percent. It is unstable because the common production technology is not geared to needed adjustments and manipulation so often necessitated by aberrations in weather.

The low-rainfall (400 mm to 1000 mm), semi-arid regions constitute nearly 36 percent (about 47 million hectares) of the net sown area in the country. As many as 84 districts fall in this category spread over the states of Punjab, Haryana, Rajasthan, Gujarat, Maharashtra, Uttar Pradesh, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu.

CROPPING SYSTEMS

Detailed accounts of the cropping systems in different semi-arid regions of India are clearly beyond the scope of this paper. Only two aspects of the systems in common use in some selected regions are briefly indicated: i) the soil, seasonal rainfall and crops grown with area and productivity (Table 2); and ii) development potential created by research in these regions.

Table 2. Cropping Systems

State	Region	Soil type	Seasonal rainfall (mm) Kharif	Seasonal rainfall (mm) Rabi	Cropping systems and productivity (percentage figures denote area under the crop in the season and figures in brackets the average yield in q/ha)
(1)	(2)	(3)	(4)	(5)	(6)
Punjab	Ludhiana	Alluvial	638	82	Kharif*: Maize 80% (20.0), moth 10% (2.0), fodders 10% (200) Rabi** : Wheat 70% (8), chick-pea 15% (8), rape and mustard 5% (5), lentil 4% (2).

* May-June to Oct-Nov.
** Oct-Nov. to March-April

....Contd.

Table 2 contd.

1	2	3	4	5	6
Haryana	Hissar	Sier-ozem	413	42	Kharif : Pearl-millet 78% (3.5), guar 18% (3.0), green-gram 2% (2.0) Rabi : Chick-pea 80% (3.0), oil-seeds 20% (4.0)
Rajas-than	Jodhpur	Sier-ozem	360	12	Kharif : Pearl-millet 51.3% (1.6) Grain legumes 18.6% (0.9), Sorghum 9.6% (3.1) Rabi : Chick-pea 35.4% (6.7), Barley 12.7% (11.2)
Uttar Pradesh	Varanasi	Allu-vial	998	54	Kharif : Maize 8.5% (1.0), upland-rice 35.2% (7.2), pearl-millet 4.5% (3.8), Grain legumes 7.1% (7.0) Rabi : Wheat 18.1% (10.9), Barley 3.1% (9.6), chick-pea 9.5% (7.6), oilseeds 8% (2.9)
	Agra	Allu-vial	726	25	Kharif : Pearl-millet 42.5% (7.0), Pigeon-pea 45.0% (16.9) Rabi : Barley 11.0% (13.7), Chick-pea 11.3% (8.6), Mustard 3.3% (7.7)
Gujarat	Rajkot	Black	589	6	Kharif : Groundnut 33.7% (6.6), Pearl-millet 16.1% (6.8), Cotton 13.6% (1.9 lint), Sorghum 10% (2.3) Rabi : Rabi crops in drylands are not possible in the region.
	Anand	Sier-ozem	810	5	Kharif : Cotton 20.3% (1.8), Pearl-millet 17.3% (8.8), Sorghum 11.7% (3.7), Castor 3.2%(7.9) Rabi : Rabi crops on drylands are not possible in the region
Maha-rashtra	Akola	Black	697	47	Kharif : Cotton 38.2% (0.6 lint), sorghum 32.3% (5.2), ground-nut 2.7% (5.1), grain legumes 9.4% (3.0)

.... contd.

Table 2 contd.

1	2	3	4	5	6
Maharashtra	Akola	Black	697	47	Rabi : Wheat 8.8% (2.6), linseed 1.2% (2.5), Safflower 0.5% (3.5)
	Sholapur	Black	573	18	Kharif : Pearl-millet 8.3% (17), groundnut 6.5% (4.9) pigeon-pea 4.4% (2.3) Rabi : Sorghum 62.3% (2.5), wheat 1.9% (2.6), Chick-pea 1.7% (2.7)
Andhra Pradesh	Hyderabad	Red	689	23	Kharif : Castor 55% (7.0), sorghum 35% (3.0) Rabi : Rabi crops on drylands are not possible in the region.
	Anantapur	Red	429	26	Kharif : Sorghum 16% (3.4), pearl-millet 6.2% (2.9), grain-legumes 9.8% (1.2), groundnut 27.4% (5.6), cotton 3.9% (0.5) Rabi : Rabi crops on drylands are not possible in the region.
Karnataka	Bangalore	Red	582	59	Kharif : Finger-millet 40% (10.0), Grain legumes 10% (4.5) Rabi : Rabi crops on drylands are not possible in the region.
	Bellary	Black	384	26	Kharif (light soils) : Sorghum 21% (4.5), groundnut 11.6% (5.5), cotton 11.8% (2.5), pearl-millet 4.5% (5.0) Rabi (heavy soils) : Sorghum 8.4% (2.5), cotton 6.7% (1.1), chick-pea 1.1% (1.7), wheat 1.5% (1.5)
Tamilnadu	Kovilpatti	Black	-	455	Kharif : -- Rabi : Cotton 19% (2.0), pearl-millet 20% (7.0), horse-gram 4% (1.5)

.... contd.

Table 2 contd.

1	2	3	4	5	6
Madhya Pradesh	Rewa	Black	997	52	Kharif : Upland rice 44.9% (5.2), minor millets 25.1% (2.6), sorghum 8.5% (9.6), maize 4.4% (9.8), pigeon-pea 6.1% (7.2), sesamum 6.9% (1.7) Rabi : Wheat 51.7% (6.9), chick-pea 21.4% (6.8), linseed 14.6% (2.3), barley 9.6% (8.0). barley 9.6% (8.0)

In the above summary the percentage figures may not add up to 100. Minor crops have not been included. Some area is fallowed or is not sown for various reasons.

From the summary above two points emerge:

1) The crops and cropping systems vary widely from region to region. This is understandable as these have evolved over centuries of experience of operating in a given soil-climate environment.

2) The per hectare yields of all crops are extremely low. Evaluated in strict economic terms, no crop enterprise could be considered profitable except, perhaps, once in a blue moon under exceptionally favorable conditions of weather. This is a reality reflected in the universal poverty and squalour prevalent in these areas.

The causes of low yields, briefly, are:

1) The crops and varieties (non-descript) in use are of long-duration types. Most often these have to pass through a period of acute moisture stress towards their late growth and development, the yields suffer drastically as a consequence. Their yield potential also is low.

2) No skill or planning (management) go into the production practices. The decisions are usually habitual and the systems have no flexibility for exercising choices so often necessitated by aberrant weather.

3) The crops and their varieties in use show poor response to yield-boosting inputs, such as fertilizers. At Hyderabad, the yield of local sorghum increased from 4.3 to 11.1 q/ha when 40 kg N/ha was

applied. Whereas the yield of CSH-5 sorghum increased from 17.8 to 29.1 q/ha with the same amount of nitrogen.

4) Effective weed control, particularly in the kharif (rainy) season, is difficult with hand weeding techniques. This lowers crop yields seriously as evidenced by recent researches.

5) Plant protection measures are conspicuous by their absence. Insects reduce crop yields drastically, particularly in grain legumes.

6) The seeding methods employed and, in many regions, the development of soil crusts after seeding give inadequate and uneven crop stands that affect yields.

7) To be self-sufficient in their domestic needs, the farmers usually cultivate many crops regardless of their adaptability to the conditions of growth in the region. Productivity of some adapted efficient crop in the region is not exploited because some area in the holding is to be sown to less efficient crops for reasons of self-sufficiency.

8) In some regions, such as Deccan rabi area, farmers adhere to conventional time of planting and lose much of the conserved soil moisture on which alone these crops are raised. Advancing the date of sowing for these crops increases their yield considerably.

Development Potential

Research efforts to improve crop production in the semi-arid regions of India have been in progress for four to five decades. Worthwhile success, however, came only with the advent of short-duration input-responsive varieties of crops which established their pronounced superiority over the old varieties when evaluated on the drylands both in favorable and in adverse weather conditions. Enthused with these successes, the All-India Co-ordinated Research Project for Dryland Agriculture (ICAR) was launched in 1970 with the collaboration and active participation of the Government of Canada. Adequate research data from different regions have been collected during the last three years which could now be used to materially enchance and stabilize crop yields on the drylands in India.

ACTUAL AND POTENTIAL PRODUCTIVITY OF LAND

In the table 3 below the yields/ha of crops realized under sound management practices on the Project Research Farms and farmer's fields in the same region are presented.

Table 3. Average Yields of Efficient Crops at Research Centers and on Farmers' Fields

Region (1)	Season (2)	Year (3)	Crop (4)	Yield (q/ha) Research fields (5)	Farmers' fields (6)
Ludhiana	Kharif	1972-73	Maize	31.4	20.0
		1973-74	Maize	36.1	
	Rabi	1972-73	Wheat	28.3	8.0
		1973-74	Wheat	33.7	
Hissar	Kharif	1972-73	Pearl-millet	9.2	3.5
		1973-74	Pearl-millet	8.4	
	Rabi	1972-73	Eruka sativa	8.1	3.9
		1973-74	Eruka sativa	10.8	
Jodhpur	Kharif	1972-73	Pearl-millet	9.2	1.7
		1973-74	Pearl-millet	32.7	
Rajkot	Kharif	1972-73	Pearl-millet	9.0	6.8
		1973-74	Pearl-millet	10.5	
Hyderabad	Kharif	1972-73	Sorghum	17.8	3.0
		1973-74	Sorghum	45.2	
		1972-73	Pearl-millet	11.8	New crop
		1973-74	Pearl-millet	22.0	
Anantapur	Kharif	1972-73	Pearl-millet	7.3	3.0
		1973-74	Pearl-millet	6.5	
		1972-73	Sorghum	11.8	3.4
		1973-74	Sorghum	16.2	
Bangalore	Kharif	1972-73	Finger-millet	57.2	10.0
		1973-74	Finger-millet	36.4	
Anand	Kharif	1972-73	Castor	24.1	7.9
		1973-74	Castor	24.4	
Udaipur	Kharif	1972-73	Sorghum	21.0	5.5
		1973-74	Sorghum	11.1	
Agra	Kharif	1972-73	Pearl-millet	19.9	7.0
		1973-74	Pearl-millet	19.3	
	Rabi	1973-74	Barley	24.6	13.7
Akola	Kharif	1972-73	Sorghum	20.8	5.2
		1973-74	Sorghum	27.6	

....contd.

Table 3 contd.

1	2	3	4	5	6
Indore	Kharif	1972-73	Sorghum	39.5	9.8
		1973-74	Sorghum	24.8	
	Rabi	1972-73	Safflower	32.7	New crop
		1973-74	Safflower	26.1	
		1972-73	Sunflower	10.2	New crop
		1973-74	Sunflower	16.7	
Varanasi	Kharif	1972-73	Upland rice	23.2	7.3
		1973-74	Upland rice	23.1	
		1972-73	Maize	35.9	1.0
		1973-74	Maize	11.8	
	Rabi	1972-73	Wheat	37.7	10.9
		1973-74	Wheat	35.3	
		1972-73	Barley	30.7	9.6
		1973-74	Barley	33.3	
		1972-73	Chick-pea	38.3	7.6
		1973-74	Chick-pea	29.6	
Rewa	Kharif	1972-73	Upland rice	52.5	5.2
		1973-74	Upland rice	28.9	
	Rabi	1972-73	Wheat	18.8	6.9
		1973-74	Wheat	14.2	
Bhubaneswar	Kharif	1972-73	Upland rice	32.4	10.6
		1973-74	Upland rice	45.9	
Ranchi	Kharif	1972-73	Upland rice	38.3	8.0
		1973-74	Upland rice	24.6	
Kovilpatti	Rabi	1972-73	Sorghum	24.0	New crop
		1973-74	Sorghum	28.6	
		1972-73	Seedcotton	7.8	2.0
		1973-74	Seedcotton	7.9	
Sholapur	Rabi	1973-74	Sorghum	12.8	2.6
		1973-74	Safflower	17.2	New crop
Bijapur	Rabi	1973-74	Sorghum	22.6	6.3
		1973-74	Safflower	21.1	New crop
Bellary	Rabi	1973-74	Sorghum	26.7	2.3
		1973-74	Safflower	12.9	New crop

The major handicaps with the farmers are the non-availability of good quality seeds and fertilizers. They have also to be educated in the technology suited for the most efficient crop production in the region.

INCREASING CROPPING INTENSITY

With the availability of short-duration crop varieties, two crops can be successfully raised in a year, in some regions, in place of the common practice of growing only one crop a year - either kharif or rabi. Both production and income go up with the increasing cropping intensity. Data presented in Table 4 are results from some regions.

Table 4. Production and Incomes with Different Cropping Intensities

Region	Crop sequence (yield in q/ha within parenthesis)		Income
	Kharif	Rabi	(Rs/ha)
Dehra Dun	Fallow	Chick-pea (16.8)	1304
	Maize (46.1)	Chick-pea (15.4)	2766
Ludhiana	Fallow	Wheat (27.6)	3036
	Maize (31.9)	Wheat (20.9)	4660
Indore	Fallow	Wheat (21.8)	3762
	Soybean (29.0)	Wheat (19.4)	7971
Sholapur	Fallow	Chick-pea (14.9)	3503
	Sorghum (37.2)	Chick-pea (8.4)	7311
Varanasi	Fallow	Chick-pea (34.8)	4876
	Sesamum (5.0)	Chick-pea (33.8)	5940
Bijapur (light soils)	Fallow	Safflower (12.4)	2724
	Green-gram (7.6)	Safflower (12.9)	4100
Akola	Fallow	Safflower (10.0)	2512
	Green-gram (6.1)	Safflower (13.5)	4595

1 U.S. $ = Rs. 7.5

The practice of fallowing is, thus, unnecessary and counter-productive.

HANDSOME DIVIDENDS FROM LOW RATES OF FERTILIZER APPLICATIONS

New varieties of dryland crops in most regions have shown economic responses to nitrogenous fertilizers even to as high rates of use as 50 to 100 kg N/ha. At low rates, the responses are higher and more remunerative. In these days of fertilizer shortages and high prices, the farmers may use only low rates for substantial gains from their small operational holdings. In the Table 5 given below, data are presented showing attractive gains in yield from the use of small quantities of nitrogen as against yields obtained without use of this fertilizer.

Table 5. Response of Crops to Application of N at Low Levels Only

Region (1)	Crop (2)	Year (3)	Yield in q/ha Without N (4)	Yield in q/ha with N (5)	Level of N (kg/ha) (6)
A. Kharif season					
Dehra Dun	Maize	1972	28.6	39.6 (22.0)*	50
	Maize	1973	22.0	28.7 (13.4)	50
	Upland rice	1973	30.9	36.6 (14.3)	40
Ranchi	Upland rice	1972	2.8	13.0 (25.5)	40
Varanasi	Upland rice	1972	10.2	13.3 (7.8)	40
		1973	9.1	18.2 (22.8)	40
Bangalore	Finger millet	1972	18.1	22.6 (15.0)	30
Anand	Pearl millet	1972	7.8	17.2 (23.5)	40
Rewa	Upland rice	1972	21.6	36.5 (37.3)	40
		1973	11.3	15.9 (11.5)	40
Samba	Maize	1972	15.3	24.3 (22.5)	40
Sholapur	Pearl millet	1973	24.4	27.6 (12.8)	25
Hyderabad	Sorghum	1973	17.8	29.1 (28.3)	40
B. Rabi season					
Ludhiana	Wheat	1972-73	22.5	37.0 (36.3)	40

....contd.

Table 5 contd.

1	2	3	4	5	6
Samba	Wheat	1972-73 1973-74	19.4 32.0	33.8 (57.6) 37.3 (21.0)	25 25
Varanasi	Barley	1972-73	13.8	21.7 (39.5)	20
Agra	Barley	1972-73	13.7	18.4 (23.5)	20
Sholapur	Safflower	1973-74	7.9	12.8 (19.6)	25
Ranchi	Wheat	1972-73	9.3	16.8 (18.8)	40

* Figures in brackets denote response in terms of kg grain/kg N. At current prices 4-5 kg of any of the above will buy 1 kg N.

In some regions, such as Varanasi, Jhansi, Bijapur, Sholapur, Agra, Samba, Bangalore, Anand and Rewa, crops have also responded economically to application of P_2O_5 @ 20-25 kg/ha.

The gains from the use of nitrogenous fertilizer improve further if it is applied to kharif crops, in one or two split doses and to rabi crops by deep placement (drilling).

STABILIZING PRODUCTION

Stabilizing crop production in the semi-arid regions is even more difficult than increasing the crop-yield levels. Here it is only 'Good Management' and 'Good Luck' that click. All production depends on the time, intensity, length and distribution of the wayward monsoon rains. Even as some estimates are available, the parameters are very variable both in space and time.

While we plant for a normal season, therefore, we have to be prepared for the aberrant weather. The Project Research Centres have been gathering needed data on this aspect and there is enough dependable information now in hand which can be profitably used to meet the changing weather in many regions. The weather aberrancies are usually of three types:

a) early onset of rains;

b) delayed onset of rains; and

c) rainless gaps of varying lengths in between rains.

Practices have been developed to meet the changing situations. These can be best illustrated by those developed for the Hyderabad regions.

i) Crops identified for early or late sowings

a) Crops for early/normal plantings (mid-June to mid-July) - sorghum (CSH-5 or 370), pearl-millet (HB-3) castor (Aruna or 63-1-21) and pigeon-pea (S-8 or T-21).

b) Crops for delayed plantings (mid-July to mid-August) - sunflower (EC-68415) and pearl-millet (HB-3).

c) Crops for very late plantings (mid-August to early September) - setaria (HK-289), cowpea (C-152 or EC-4216) and field beans (Co-6 or Co-8).

ii) Overcoming adverse effects of droughts

The droughts may extend over periods of 3-4 weeks to 5-6 weeks. Several practices have been developed to mitigate the damaging effects of these dry spells. These are:

a) Thinning of stands, particularly the more sensitive component in crop mixture, such as sorghum in a sorghum pigeon-pea mixture.

b) If adequate rains are received after a near-killing drought and there is a sufficiently long season left, ratooning of sorghum and pearl-millet helps greatly. The ratoon crops yield about as much as the plant crop. Urea spraying helps quicker regeneration of crops that cannot be ratooned, such as legumes and castor. If the crops have suffered beyond recovery, it is better to plant new crops suitable for late sowings, such as cowpea, setaria, horse-gram*.

ACKNOWLEDGEMENT

The author is grateful to his scientist colleagues at different Research Centers of the Project, whose data have been used in this paper.

* For other regions, see Crop Production Strategy in Rain-fed Areas under different weather conditions, or the Indian Farming, June 1974.

RECOMMENDATIONS OF COMMITTEE II:

CROPS AND CROPPING PATTERNS

J.S. Kanwar

Some general characteristics of the semi-arid tropics which need systematic study are:

1. Integration of cropping and animal husbandry. The virtual separation of arable cropping in the higher rainfall areas and animal husbandry in the drier areas results in inefficiencies in resource use. Integration of animal husbandry into the arable cropping pattern would necessitate inclusion of forage legumes in the rotation. Integration would provide manure, additional income and improve nutritional standards. This integration should be progressive in order to familiarize the farmers with appropriate animal management procedures fertilizer use and tillage methods for improved moisture retention and effective erosion control.

2. Nomadic agriculture. Arable cropping traditionally based on a system of shifting cultivation with brush and grass regeneration during the fallow period poses special problems for encouraging capital improvements and improved farming systems.

3. Population pressure effect on land use. Increased population pressure causes a general trend of reduction in the fallow period, which is different only in degree in the different parts of the semi-arid tropics. The practice has been least affected in Africa, has completely disappeared in parts of Latin America and is practically non-existent in South Asia. As a result of the reduced brush and grass fallow maintenance of soil fertility and prevention of erosion are primary concerns.

4. Efficient water management. Little or no effort is made to supplement the rainfall that falls directly on the farmer's field in the semi-arid tropics. As a result, only one monsoon or post-monsoon crop is generally grown each year; only on exceptionally deep soils are two successive crops occasionally grown. Considerable amounts of water could be added to the land, if appropriate techniques are developed. This would increase yield levels, improve production stability and enable double cropping. Hence the need for research on efficient water management.

5. Farm power. Animals provide most of the draught power in the semi-arid tropics. While some areas have sufficient number of animals, they are often poorly fed and utilized. Draft animals are often in poorest condition when power requirements are greatest. Equipment is of poor design and not fully suited to the semi-arid areas.

6. Mixed cropping. Previous research indicates that mixed cropping provides the most efficient use of the available resources. Further research is needed to determine the best crop associations for different situations and the best management practices.

7. Cropping patterns and agronomic research. The research program outlined in "Farming Systems Research" by ICRISAT is appropriate and substantially meets the needs of the situation. However, special attention should be paid to these aspects of the research program:

   a) Socio-economic implications of the technology. Socio-economic implications of the application of the results of research need to be measured to help orient further research and determine priorities.

   b) Production techniques. Special emphasis needs to be given to production techniques that would benefit the small farmers.

   c) Selective mechanization. Selective mechanization should concentrate on improving the efficiency of the existing human and draught power. There is ample scope for improved implements and equipment for draught animals. It may be necessary to initiate study of mechanization in forms appropriate to the specific conditions of the semi-arid regions at a later stage. This may be particularly important for resettlement projects within the framework of regional development programs.

   d) Extension of agronomic studies to different environments. Information from environmental and physiological studies must be used to extend agronomic studies at other sites besides that of ICRISAT. The growth of crops can be analyzed physiologically and the consequences of experimental treatments generalized to some extent. The many cropping systems that are biologically possible can be modelled but must then be screened for physical and economic practicability.

Part III

Socio-Economic Research in Farming Systems

SOCIO-ECONOMIC ASPECTS OF AGRICULTURAL DEVELOPMENT IN THE SEMI-ARID TROPICS

J.G. Ryan* and Associates**

The significant semi-arid tropical (SAT) zones of the world are spread over four continents occupying all or part of the land mass of 48 countries. The total area of SAT is estimated at about 19.6 million km^2 and the population at 512 million[1]. On an average about 34 percent of the total land area in these 48 countries is semi-arid tropics.

Although diverse agricultural practices are followed in all these countries, they are linked by one common characteristic - they all have a period of between two and seven months when rainfall exceeds potential evapotranspiration. This fact gives an impetus to our Farming Systems Program, a major part of which is built around a small watershed concept in which it is hoped to achieve increased and stabilized agricultural production by making optimum use of the monsoon rainfall, plus the human and non-human capital resources existing in the SAT. By farming systems we mean all aspects of farming operations in the semi-arid tropics. The program includes the use and management of resources both on and off farms, cropping patterns, response to environmental and other risks, household production - consumption activities, the use of modern technologies etc. The farming systems in the SAT countries, which come under ICRISAT's mandate, differ markedly, not only between countries but also within countries. In the present paper an attempt has been made to indicate the relevant socio-economic characteristics of the various countries of the

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1 The delineation of SAT areas has been based largely on the definitions by Troll (1966), using dry and thorne savanna regions. For more details, see the papers by Krantz and Associates (1974), and Kampen and Associates (1974) presented at this Workshop. These figures must be regarded as preliminary and subject to revision as more country data is gathered. As far as possible, areas and populations within large Government irrigation schemes have been excluded.

SAT with a view to identifying significant differences among them. This information may be useful in developing farming systems technologies to suit each region.

As shown in Table 1, the largest single semi-arid tropics area in the LDC's is in India, which occupies 9 percent of the total[1]. It sustains a population of approximately 260 million people, or 51 percent of the total population of the SAT. The second largest area of SAT lies in the Sudan, with 8 percent of the total land and only 3 percent of the population. Mexico comes next with 6 percent of the SAT land and 5 percent of the population, followed by Brazil (5 and 4 percent), Nigeria (4 and 8 percent), Tanzania (4 and 2 percent), Zambia, Angola and Mali (each 4 and 1 percent), Niger (3 and 1 percent), Chad (3 and 0.5 percent), Botswana (3 and 0.2 percent) and Thailand (2 and 4 percent). The remaining countries are of less significance using these two criteria.

The countries in the semi-arid tropics produce about one half of the world's sorghum production, 40 percent of the millet, 90 percent of the chick-pea, 95 percent of the pigeon-pea, and 60 percent of the groundnut. India is the largest producer of sorghum, with 36 percent of the SAT's total production, followed by Nigeria (19 percent), Argentina (16 percent), Sudan (9 percent) and Ethiopia (5 percent). India is the largest producer of millets with 54 percent of the SAT countries production, followed again by Nigeria (18 percent), Mali (4 percent) and Niger (3 percent).

India is by far the largest producer of chick-pea in the SAT (and the world), with 90 percent of the total SAT production. The only other SAT country with a significant production is Pakistan with 9 percent. India dominates the pigeon-pea scene even more, with 98 percent of the SAT countries production. It also produces 50 percent of the SAT groundnut, followed by Nigeria (12 percent) Brazil (8 percent) and Senegal (5 percent).

ICRISAT's FIVE CROPS IN WORLD MARKETS

The ICRISAT is concentrating in its breeding program on five dryland crops which on the basis of their food composition can be classified into three different groups.
(1) Millet and Sorghum
(2) Chick-pea and Pigeon-pea
(3) Groundnut

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[1] Australia has the largest area of SAT in the world, with 10 percent of the total. However, it contains less than 0.2 percent of the world's SAT population and the country is not classed as less developed.

Table 1a. Selected Socio-Economic Data on Semi-Arid Tropical Countries[a]

	Portion of Country Semi-Arid (%)	Semi-Arid Area ('000 km^2)	Semi-Arid Population (million)	Semi-Arid Popn/Land Ratio (people/ha)	Population Growth Rates[b] (%)	Area of 5 'ICRISAT' crops as % of Total Arable Land[d] (%)	Per Caput Gross Domestic Product[f] ($ US.)	Agric. as Percentage of Total G.D.P.[b] (%)	Domestic Production as % of Total Available Food Supplies[b]		Net Food Supplies Per Caput Per Day[b]	
									Other Cereals (%)	Pulses, Nuts, Seeds (%)	Calories (k.cals.)	Protein (gms.)
1	2	3	4	5	6	7	8	9	10	11	12	13
Asia												
Burma	25	170	7	0.41	n.a.	5.78	92	34	117	111	2010	44
India	54	1700[i]	261[i]	1.54	2.2	32.86	99	45	100	100	1990	49
Pakistan	5	40	3	0.75	n.a.	11.60	136	38	100	100	2410	55
Thailand	60	308	25	0.82	2.7	1.85	176	29	62	112	2210	51
Sub-Total or Average	36	2218	296	1.33	2.45	13.02	106	37	95	106	2013	49
Africa South of the Sahara												
Angola	60	748	3	0.04	n.a.	14.59	201	n.a.	132	135	1910	40
Botswana	100	569	1	0.02	2.8	36.87	n.a.	43	n.a.	n.a.	n.a.	n.a.
Camaroon	25	119	1	0.08	n.a.	10.10	162	50	92	118	2230	59
Cent.Af.Rep.	50	311	1	0.03	2.2	3.17	131	31	100	109	2170	48
Chad	40	514	3	0.06	2.3	14.93	69	48[m]	100	101	2240	78
Dahomey	80	92	2	0.22	2.5	12.20	24	36	100	156	2170	52
Ethiopia	50	611	12	0.20	1.8	13.17	72	52	100	113	1980	66
Gambia	100	10	1	1.00	2.1	101.5	123	59[m]	100	183	2320	62
Ghana	50	119	4	0.34	3.0	65.58	260	n.a.	97	101	2070	43
Guinea	70	172	3	0.17	2.2	2.73	106	n.a.	100	141	2060	45
Kenya	90	524	10	0.19	3.1	25.08	135	31	110	99	2200	68
Madagascar	50	294	4	0.14	n.a.	1.62	107	30	99	100	2240	51
Malawi	75	88	3	0.34	n.a.	21.21	58	48	88	123	2400	63
Mali	60	721	5	0.07	2.1	12.08	77	48[m]	100	116	2130	68
Mauritania	25	258	1	0.04	2.2	100.26	211	42[m]	85	100	1990	73
Mozambique	50	376[i]	4[i]	0.11	n.a.	19.38	228	n.a.	96	191	2130	40
Namibia	30	247	1	0.04	2.0	7.69	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Niger	40	507	4	0.08	2.7	15.92	91	51	105	215	2170	78
Nigeria	75	693[j]	42[j]	0.61	2.5	55.53	97	49	99	137	2290	50
Portug.Guinea	100	36	1	0.28	0.9	34.01	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Rhodesia	100	389	5	0.13	3.3[l]	34.30	225	16	103	96	2550	73
Senegal	100	196	4	0.20	2.4	35.09	209	33[m]	100	155	2300	64
Somalia	50	319	2	0.06	2.3	32.95	70	n.a.	97	100	1770	57
Sudan	60	1491[i]	15[i]	2.10	2.8	44.06	137	32	106	152	2090	59
Tanzania	60	752	10	0.13	2.6	2.55	77	34	101	139	1700	43

Table 1a. (contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13
Togo	80	45	2	0.44	2.5	16.38	138	43	100	102	2210	51
Upper Volta	100	274	5	0.18	2.1	36.48	46	44	100	109	2060	70
Zaire	10	234	2	0.09	4.2	4.31	n.a.	8	75	99	2040	33
Zambia	100	753	4	0.05	2.9	8.20	399	6	101	98	2250	69
Sub-Total or Average	64.83	11489	157	0.13	2.5	26.96	123	38	99	127	2155	60
Southern and Central America												
Argentina	15	416	3	0.07	1.5	10.16	950	11	204	110	3160	105
Bolivia	20	220	1	0.05	2.6	n.a.	197	19	100	119	1760	46
Brazil	12	1036(840)[k]	20(14)[k]	0.19(0.16)[k]	2.8	2.22	422(150)[d]	13	104	112	2820	67
Guyana	40	86	1	0.12	2.3	0	307	21	n.a.	n.a.	2080	46
Elsalvador	30	7	1	1.43	3.7	27.55	296	27	101	94	1850	45
Mexico	60	1183	29	0.25	3.2	5.32	649	11	110	102	2620	66
Nicaragua	30	43	1	0.23	n.a.	7.97	402	24	104	118	2330	63
Paraguay	60	244	1	0.04	n.a.	3.15	250	33	100	108	2540	65
Venezuela	10	91	1	0.11	n.a.	0.56	1012	8	77	95	2430	60
Sub-Total or Average	30.78	3326	58	0.17	2.7	7.12	469	19	113	107	2670	67
Near East and North West Africa												
Arab Re.Yemen	20	39	1	0.26	2.7	106.64	61	n.a.	100	107	1910	57
Iran	5	82	1	0.12	3.0	0.78	385	19	100	103	2030	55
Oman	20	42	–	0.12	3.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Peoples Rep. Yemen	10	29	–	0.17	3.0	15.48	113	n.a.	79	132	2020	67
Saudi Arabia	5	419	–	0.01	2.7	8.63	814	6	77	64	2080	56
Sub-Total or Average	12	611	2	0.03	2.9	32.88	303	13	89	102	1997	58
Oceania												
Australia	25	1921	1	0.01	1.9	1.33	3008	9	147	38	3160	92
Total or Average	33.72	19565	512	0.26	2.5	22.26	159	29	102	117	2132	54

a Semi-Arid Areas and Populations were estimated by using Troll's map for climatic regions of the world by estimating the regions V_3 and V_4 (dry savanna and thorne savanna) in each country and examining population densities in these areas as contained in Hamond Incorporated World Atlas (1972). n.a. denotes data not available.

b United Nations 1973. Statistical Yearbook 1972.

c FAO Production Yearbook (Various Issues).

d Estimated GDP per caput for Northeastern Brazil as contained in The Modernization of Brazilian Agriculture, p.4. Schuh, (1973)

e FAO, Rome. Trade Yearbook 1972.

f FAO, Rome 1970. Provisional Indicative World Plan for Agricultural Development, pp 17-19.

Table 1b.

	Rate of Growth Real GDP Per Caput[b] (%)	1970 Radio Receivers Per 1000 People[b] (no.)	Average Size of Agricultural Holding[c] (ha)	Annual Average Rate of Growth of Agricultural Production 1961–71[e] (%)	Arable Land Per Person Economically Active in Agriculture[c] (ha/head)	Fertilizer (N + P + K) Consumption Per Hectare Arable Land[g] (1972–73) (kg/ha)	Cattle and Buffaloes Per Hectare of Arable Land[h] (head/ha)	Area of Arable Land Per Tractor[h] (ha/tractor)	Coefficient of Variation of Yields[h]: Sorghum (%)	Coefficient of Variation of Yields[h]: Millet (%)
1	2	3	4	5	6	7	8	9	10	11
Asia										
Burma	0.6	15	n.a.	1.5	2.4	3.09	0.47	3310	-	23.89
India	0.9	21	2.52	2.1	1.1	16.78	1.44	2470	8.32	14.11
Pakistan	2.9	14	2.60	3.3	1.48	20.57	1.71	1832	10.07	4.33
Thailand	4.9	78	3.47	3.6	0.7	16.41	1.09	1874	9.44	-
Sub-Total or Average	2.3	26	2.72	2.6	1.15	15.89	1.36	2411	9.28	14.11
Africa South of the Sahara										
Angola	n.a.	17	n.a.	3.5	0.85	24.78	3.11	n.a.	-	4.35
Botswana	n.a.	13	4.75	2.5	1.84	13.90	3.47	314	37.05	55.90
Camaroon	n.a.	37	n.a.	4.3	2.92	2.13	0.29	140042	-	24.89
Cent.Af.Rep.	n.a.	30	2.29	1.4	7.89	0.91	0.08	73000	-	20.52
Chad	n.a.	16	n.a.	0.3	5.86	0.40	0.66	53846	-	11.82
Dahomey	n.a.	32	n.a.	0.4	2.24	3.43	0.45	19325	11.02	13.10
Ethiopia	2.9	6	n.a.	2.9	1.4	1.00	2.00	9464	4.38	2.94
Gambia	n.a.	137	n.a.	2.3	1.26	3.0	1.35	3175	-	14.48
Ghana	-0.5	78	n.a.	2.4	0.42	3.52	1.19	284	11.21	13.66
Guinea	n.a.	23	n.a.	1.5	1.0	1.87	1.24	n.a.	11.15	-
Kenya	3.7	48	221	3.2	0.42	38.51	6.33	220	-	0.17
Madagascar	n.a.	80	1.04	2.8	0.9	4.73	3.26	1264	10.24	-
Malawi	1.6	20	n.a.	4.4	1.5	6.86	0.21	3000	8.84	-
Mali	n.a.	12	4.35	1.7	4.47	0.86	0.43	21091	-	16.26
Mauritania	n.a.	47	n.a.	2.3	0.83	n.a.	8.91	n.a.	-	21.80
Mozambique	n.a.	12	n.a.	2.4	1.5	5.74	0.89	457	0	0
Namibia	n.a.	n.a.	11,400	n.a.	5.0	n.a.	4.07	305	0.59	6.67
Niger	n.a.	36	n.a.	2.6	13.49	0.02	0.27	833,333	13.07	3.67
Nigeria	1.7	23	n.a.	0.4	1.49	0.71	0.52	21795	14.85	16.75
Portug.Guinea	n.a.	0	3.02	n.a.	1.6	n.a.	1.14	12250	-	-
Rhodesia	2.8	28	36.27	0.8	1.6	69.62	2.23	105	10.95	10.57
Senegal	n.a.	69	3.63	0.4	4.23	3.00	0.43	10304	-	12.84
Somalia	n.a.	18	n.a.	2.3	1.1	3.76	2.98	1018	-	22.87
Sudan	3.3	12	n.a.	5.0	1.75	7.51	2.07	1578	13.98	14.59
Tanzania	2.5	11	960	5.5	3.03	1.24	0.88	2490	19.78	26.23

Table 1b. (contd.)

1	2	3	4	5	6	7	8	9	10	11
Togo	n.a.	22	2.62	4.7	3.53	1.04	0.10	34081	-	16.23
Upper Volta	n.a.	16	n.a.	2.3	2.0	0.21	0.45	126,548	9.45	18.78
Zaire	1.0	3	n.a.	4.1	1.2	0.60	0.13	6780	-	14.51
Zambia	6.9	18	1173	3.8	4.2	5.85	0.34	1655	6.60	7.68
Sub-Total or Average	2.6	46	74	2.6	2.05	3.12	0.89	2467	11.45	14.85
South and Central America										
Argentina	2.6	370	270	1.5	17.7	3.65	2.26	129	14.84	12.41
Bolivia	3.3	288	n.a.	4.0	3.4	1.68	0.74	2576	-	-
Brazil	2.3	60	79	3.3	2.37	52.38	3.31	283	-	-
Guyana	-1.5	105	n.a.	1.1	10.8	14.46	0.31	219	-	-
Elsalvador	2.1	85	6.96	2.5	0.8	187.79	2.71	222	9.80	-
Mexico	3.6	276	124	3.4	3.37	31.91	1.15	237	11.23	-
Nicaragua	3.2	55	37	5.5	2.0	40.84	3.73	115	12.3	-
Paraguay	1.4	71	109	3.4	2.06	6.3	7.21	359	19.56	-
Venezuela	1.8	164	82	5.8	5.38	15.78	1.87	228	34.52	-
Sub-Total or Average	2.1	191	104	3.4	3.65	29.74	2.30	205.91	17.04	12.41
Near East and North West Africa										
Arab.Rep.Yemen	n.a.	n.a.	n.a.	0.1	1.0	n.a.	1.17	n.a.	4.76	-
Iran	6.0	93	8.29	3.1	4.48	10.75	0.37	646	0	1.45
Oman	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	-	-
Peoples Rep.Yemen	n.a.	52	n.a.	1.6	1.2	n.a.	0.37	229	-	33.01
Saudi Arabia	6.7	11	n.a.	2.2	0.6	3.27	0.43	1020	2.03	0.28
Sub-Total or Average	6.4	62	8.29	1.7	2.9	10.41	0.42	640	2.26	11.58
Oceania										
Australia	3.4	211	1842	n.a.	103.3	25.44	0.62	131	19.42	14.27
Total or Average	2.7	45	46	2.7	1.78	15.22	1.29	537	11.71	14.39

g Food and Agriculture Organization, Rome. The State of Food and Agriculture, 1973.

h Calculated from data in FAO Production Yearbook (Various Issues).

i Excludes the areas irrigated from major Government Irrigation schemes.

j The 1973 Census in Nigeria puts the population of Northern Nigeria at 51 million, the area at 730,000 km. and the population/land ratio at 0.7. Source: Kassam et.al. (1974).

k Figures in brackets are estimates of Paiva et al. (1973).

l Southern Rhodesia only.

m Curtin (1974).

Sorghum and Millet

The world production of sorghum and millets increased from about 74 million tons in 1961-65 to 93 million tons in 1970-72 (Table 2). World trade as a proportion of world production increased from about 5.2 percent in 1961-65 to over 10 percent in 1966-67 and then continued at about 7.3 percent in 1970-72. In the world markets, sorghum and millet are traded primarily as an animal feed, imported mainly by Japan and Western Europe. The major exporters of sorghum and millets are the USA and recently also Argentina. The peak levels in sorghum world trade were to some extent brought about by India's import of about 4 million tons from 1965-66 to 1967-68 as a consequence of drought. Except for that period India has been importing sorghum only occasionally and in negligible quantities. Despite these variations in the volume of world trade, prices of sorghum remained relatively stable at around US $60 per ton c.i.f. European Ports up to 1971, with a coefficient of variation of 9 percent (Fig.1).

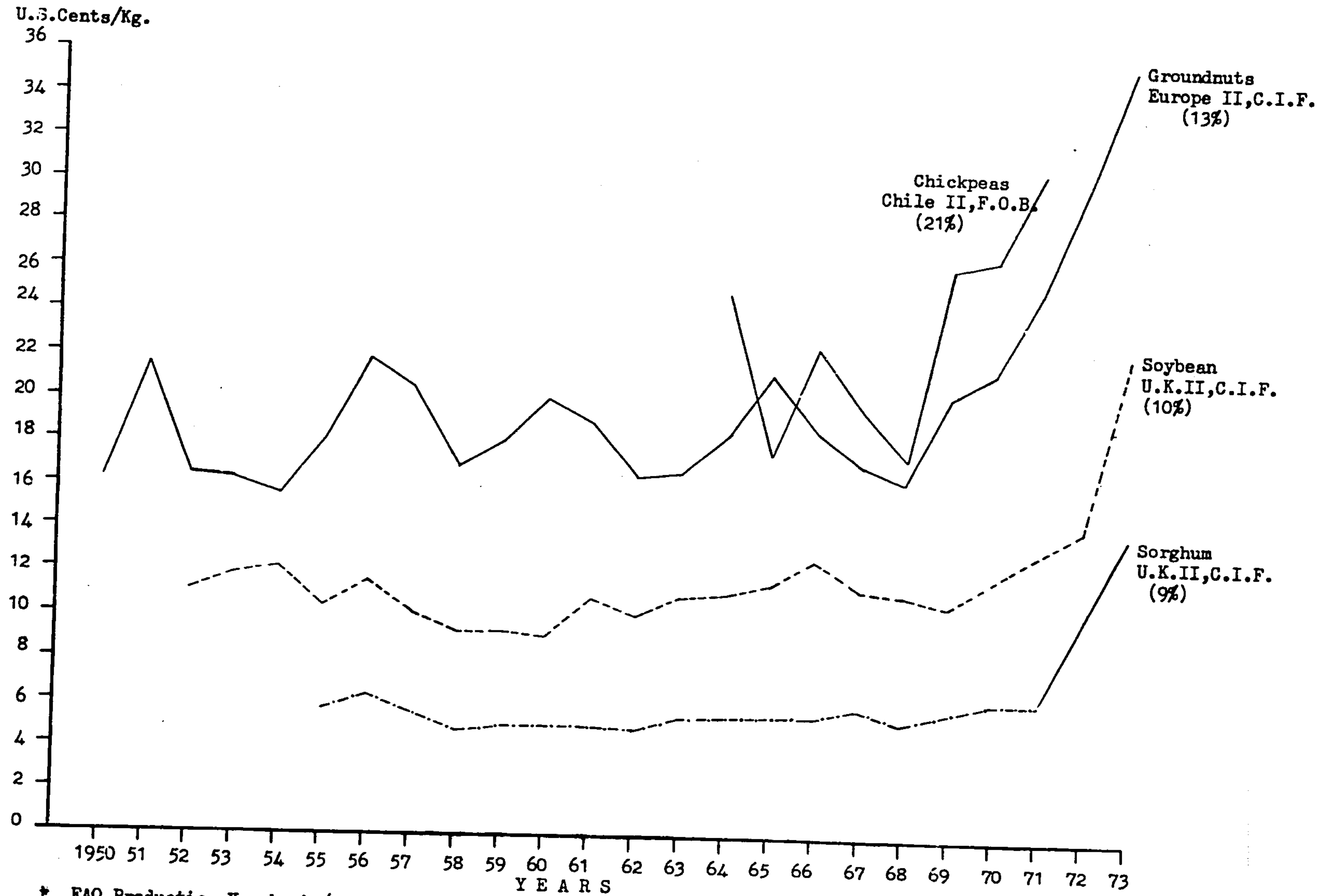
The reason for this relative price stability lies in the high price of compounded feeds. Sorghum as a feed grain can be readily substituted by other coarse grains such as maize or barley if relative prices are in favor of these; producers also have been found to be relatively responsive in acreage adjustments according to price changes. Price variation within SAT countries for sorghum were available only for Ethiopia and India and for millet only for India (Figs. 2 and 3). The coefficients of variation for sorghum prices were 24 percent in India and 35 percent in Ethiopia, and for millets 26 percent in India. Of course sorghum and millet are primarily subsistence crops which are consumed in close proximity to areas where they are produced. They hence do not enter into the domestic commercial markets to a substantial extent. They do however have a major place in the agriculture of semi-arid tropics and in the food budgets of the people of these areas.

Chick-pea and Pigeon-pea

The world trade in chick-pea is relatively small and almost negligible in pigeon-pea. The total world trade in beans, pea and lentils amounts to only about 2 million tons out of a total world production of 44 million tons of these pulses (Table 3). Of these 44 million tons of beans, pea, lentils, and chick-pea constitute about 15 percent and pigeon-pea a little more than 4 percent.

The only price series available is relating to export of chick-pea from Chile and shows a coefficient of variation of 20 percent. Prices within India and Ethiopia for chickpea show variation coefficients of 34 and 36 percent, respectively (Figs.2 and 3).

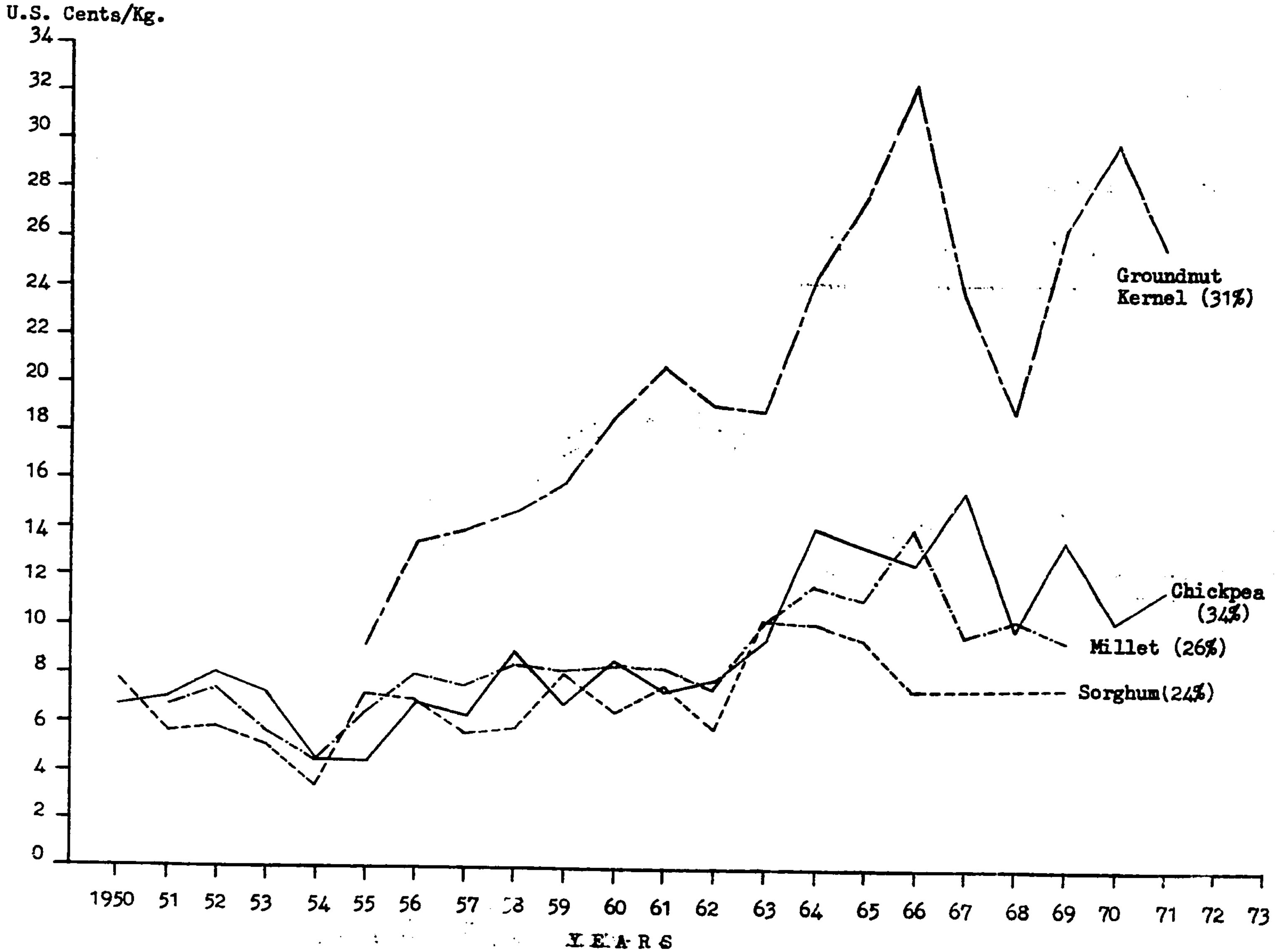
FIGURE 1. IMPORT AND EXPORT PRICES OF SELECTED PRODUCTS*
(COEFFICIENTS OF VARIATION UPTO 1971 IN BRACKETS)



* *FAO Production Yearbook* (Various Issues).

(ICRISAT/EC-9/11-74)

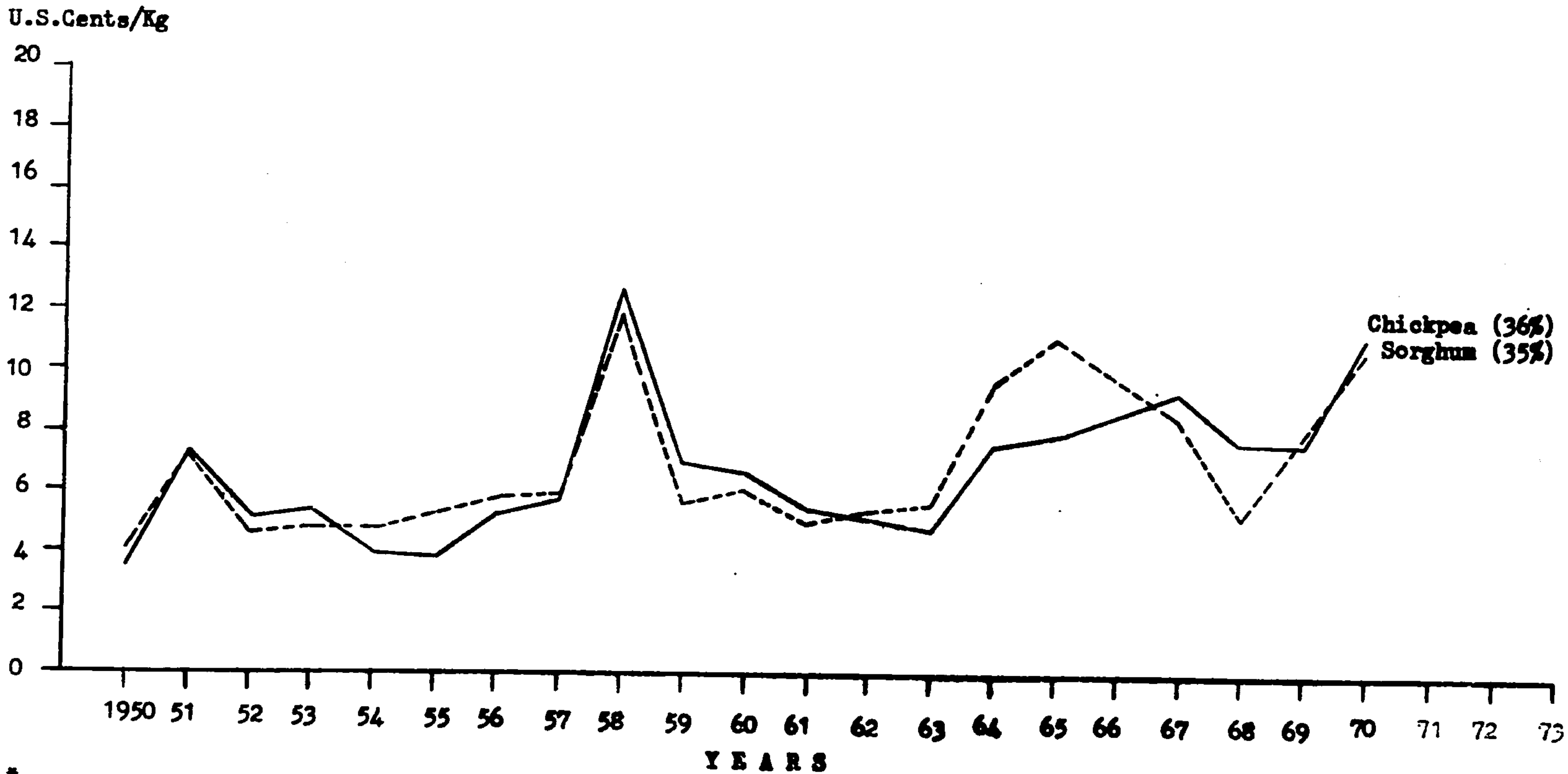
FIGURE 2. WHOLESALE PRICES OF SELECTED PRODUCTS IN INDIA*
(COEFFICIENTS OF VARIATION IN BRACKETS)



* FAO Production Yearbook (Various Issues).

(ICRISAT/EC-10/11-74)

FIGURE 3. WHOLESALE PRICES OF CHICK-PEA AND SORGHUM IN ETHIOPIA*
(COEFFICIENTS OF VARIATION IN BRACKETS)



* FAO Production Yearbook (Various Issues).

(ICRISAT/EC-11/11-74)

Table 2. Area and Production of Millets and Sorghum and World Trade of Millets, Sorghum and Other Grains[a]

Year	Area		Yield		Production			World Exports	
	Millet (m/ha)	Sorghum (m/ha)	Millet (kg/ha)	Sorghum (kg/ha)	Millet (m tonnes)	Sorghum (m tonnes)	Total	Quantity (m tonnes)	As Propn. of Prodn. (%)
1961	66.6	37.0	543	882	36.1	32.6	68.7	2.4	3.5
62	66.7	37.6	567	953	37.8	35.8	73.6	3.9	5.3
63	66.6	38.6	568	948	37.8	36.6	74.4	4.0	5.3
64	66.5	38.5	609	917	40.5	35.4	75.9	3.9	5.1
65	67.6	38.7	572	972	38.7	37.7	76.4	5.4	7.1
66	67.7	38.7	584	1067	39.5	41.3	80.8	19.2	11.4
67	69.7	40.9	613	1090	42.7	44.6	87.3	7.7	8.8
68	68.3	40.0	581	1060	39.7	42.4	82.1	5.3	6.4
69	69.3	41.7	644	1082	44.6	45.2	89.8	4.7	5.2
70	68.6	41.7	694	1070	47.6	44.6	92.2	6.6	7.6
71	68.0	42.7	667	1194	45.3	51.0	96.3	6.8	7.1
72	65.1	39.9	660	1170	43.0	46.7	89.7	6.6	7.4

[a] FAO Trade Yearbook 1972. Vol. 26; and FAO Production Yearbook (Various issues)

Table 3. Area and Production of Chick-pea and Pigeon-pea and World Trade of Beans, Pea, Lentils and Other Legumes[a]

Year	Area (m/ha)		Yield (kg/ha)		Production (m tonnes)				World Trade of Beans, Peas, Lentils and other Legumes	
	Chick-pea	Pigeon-pea	Chick-pea	Pigeon-pea	Chick-pea	Pigeon-pea	Total	Beans, peas, lentils and other legumes	Quantity (m tonnes)	As Propn. of Prodn. (%)
1970	10.1	2.9	699	674	7.051	1.972	9.02	44.7	1.8	4.0
1971	10.2	2.9	644	691	6.594	2.024	8.62	43.6	1.8	4.1
1972	10.5	2.6	637	665	6.718	1.720	8.44	43.6	2.0	4.6

[a] FAO, Rome. The State of Food and Agriculture, 1973; and FAO Production Yearbook (Various Issues).

Groundnut

The world production of groundnut is about 18 million tonnes. The world trade in groundnut as such has decreased from about 1.6 million tonnes in 1968 to 0.9 million tonnes in 1972. At the same time the combined world trade in groundnut cake and groundnut oil has remained at a level of about 1.9 million tonnes. This quantity is equivalent to approximately 2.7 million tonnes of groundnut in the shell. Thus the world trade in groundnut and groundnut products decreased from 4.6 million tonnes or 37 percent of world production in 1968 to 3.6 million tonnes or 21 percent of world production in 1972 (Table 4).

Major importers of groundnut are developed countries, especially those in Europe. Exports originate almost equally from Africa, North Central America and Asia, while Europe re-exports. World market prices of groundnut show a fairly regular four to five year cycle with a coefficient of variation of 24 percent (Fig.1). Groundnut prices in India have a variation coefficient of 31 percent (Fig.2).

The above preliminary observations suggest some tentative conclusions:

(i) Index prices and real prices of groundnut and pulses in comparison to cereals show that in the world markets as well as in the various domestic markets for which relevant price series are available, groundnut and pulse prices have tended to increase faster than prices for cereals (Figs. 4, 5 and 6). This is partly explained by the higher demand for oil and protein than for starch, and perhaps partly by the fact that in Kenya, India and some other countries, the introduction of high-yielding varieties of wheat, rice, maize, jowar and especially bajra, has brought about production increases in these crops, whereas similar improved varieties of groundnut and pulses were not available. This may imply that pulse crops are gradually becoming more competitive in terms of price and are likely to maintain an increasing proportion in the cropping pattern.

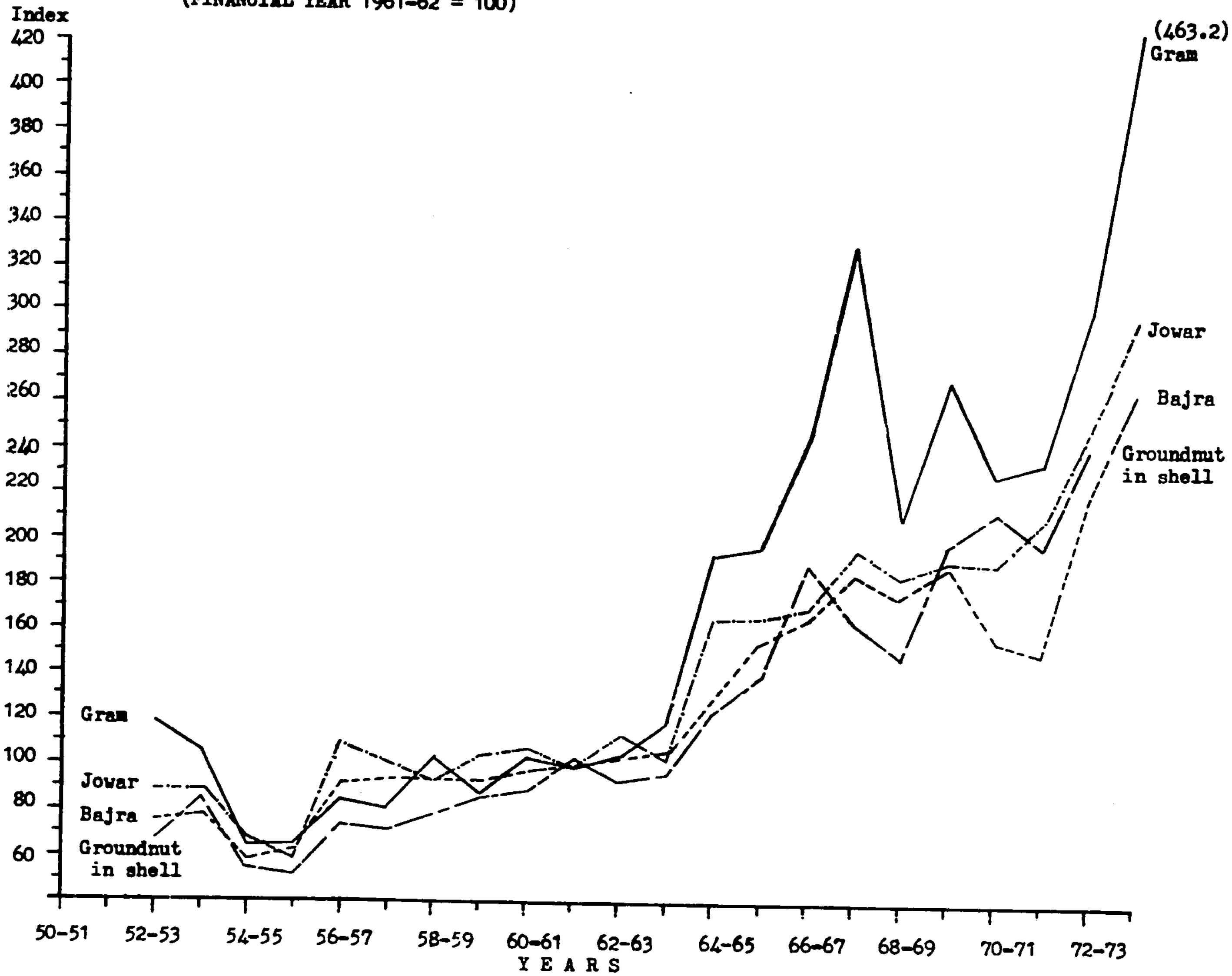
(ii) The world market price series show coefficients of variation of about 13 percent for groundnut, 10 percent for soybean and 9 percent for sorghum, whereas in individual markets, price variations yield coefficients of variation of between 24 percent for millets in India to 36 percent for chick-pea in Ethiopia. Naturally, prices in world markets vary less than in individual countries, because in the former, the effects of good and bad harvests and of other effects on production are pooled on a larger scale than in domestic markets. Hence negative correlations of production and prices among regions and countries serve to reduce the overall variance of these statistics. Consequently, the price risk as such decreases as farmers begin to enter the world market. However, in the case of

Table 4. Area, Production and World Trade in Groundnut[a]

Year	Area (m/ha)	Yield (100 kg/ha)	Production (m tonnes)	World Trade: Groundnut in shell (m tonnes)	World Trade: Groundnut cake (m tonnes)	World Trade: Groundnut oil (m tonnes)	Total in: Equivalent of groundnut in shell (m tonnes)	Total in: Propn. of production (%)
1967	18.6	9.2	17.2	1.5	1.5	.4	4.2	24.4
1968	17.6	8.5	15.0	1.6	1.6	.5	4.6	36.6
1969	-	-	-	1.3	1.3	.4	3.7	-
1970	19.9	9.2	18.2	1.0	1.5	.4	3.7	20.3
1971	20.0	9.1	18.2	.9	1.3	.3	3.2	17.6
1972	19.7	8.6	16.9	.9	1.4	.5	3.6	21.3

a FAO Trade Yearbook, 1972; and FAO Production Yearbook (Various Issues).

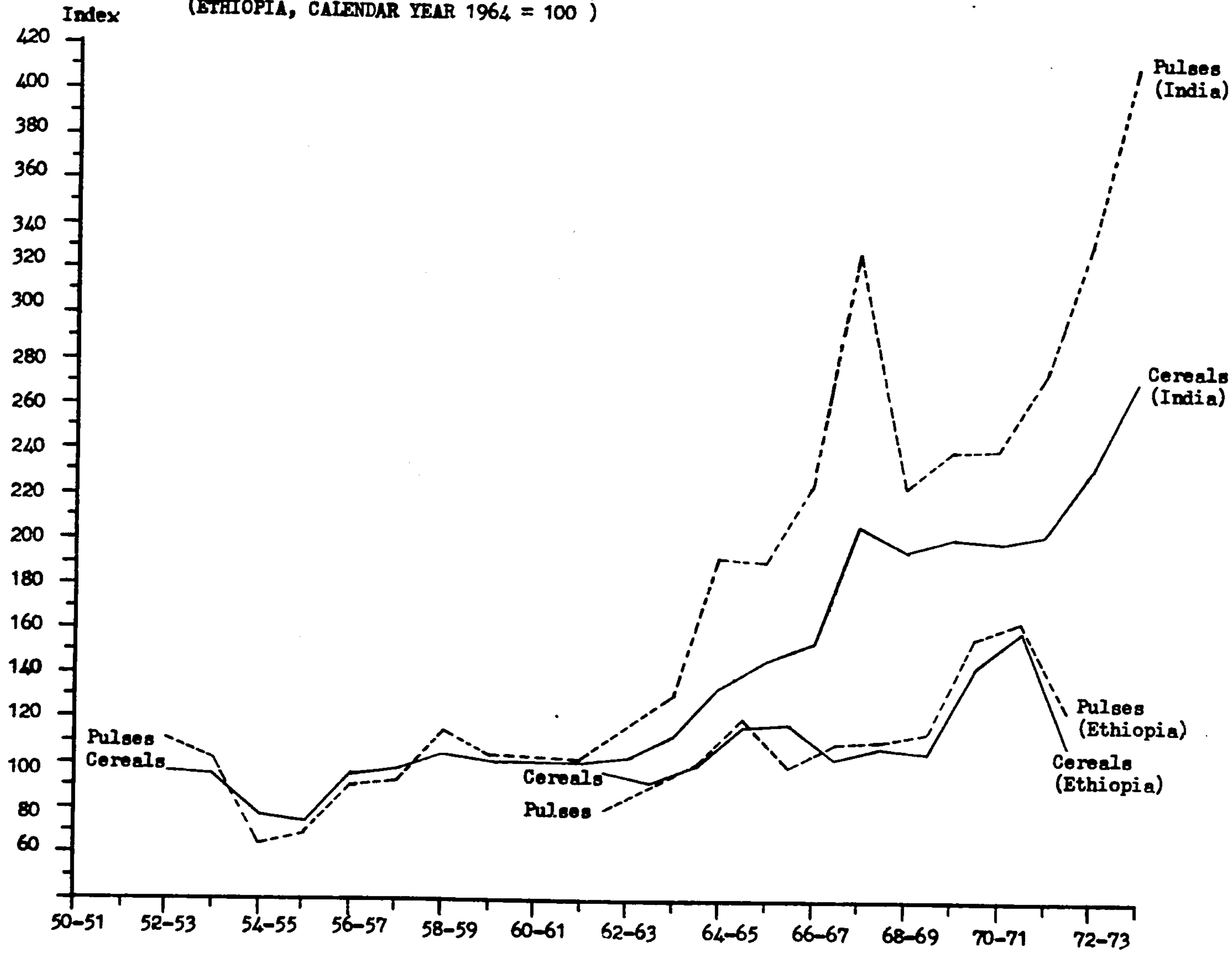
FIGURE 4. INDEX NUMBERS OF WHOLESALE PRICES OF SELECTED PRODUCTS IN INDIA*
(FINANCIAL YEAR 1961-62 = 100)



* Government of India, Bulletin on Food Statistics; Issues 20 and 23, 1970 and 1973.

(ICRISAT/EC-12/11-74)

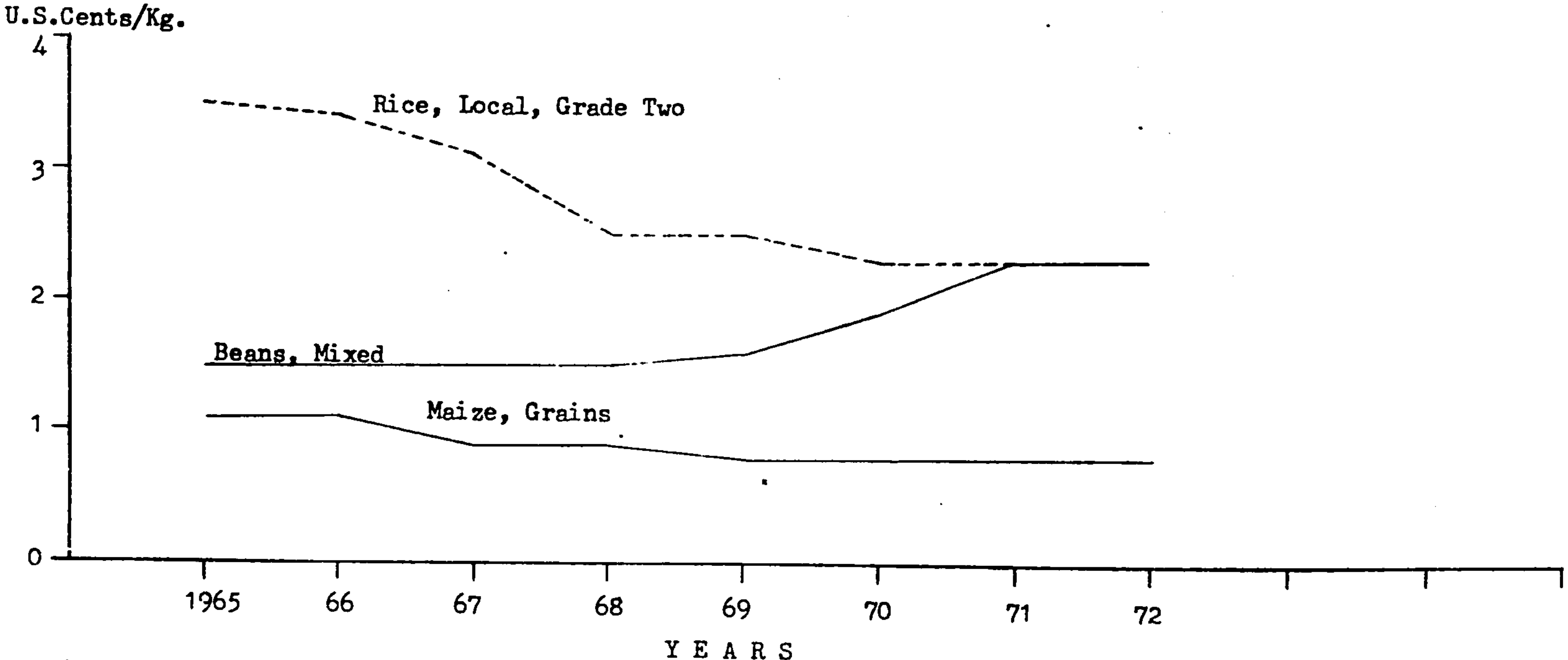
FIGURE 5. WHOLESALE PRICE INDICES FOR CEREALS AND PULSES FOR INDIA AND ETHIOPIA*
(INDIA, FINANCIAL YEAR 1961-62 = 100)
(ETHIOPIA, CALENDAR YEAR 1964 = 100)



* Government of India, Bulletin on Food Statistics. Issues 20 and 23, 1970 and 1973; and Imperial Ethiopian Government. Statistical Abstract 1972.

(ICRISAT/EC-13/11-74)

FIGURE 6. AVERAGE RETAIL PRICES OF SELECTED PRODUCTS IN KENYA.*



Note: Rice Local & Beans Mixed had Equal Prices in 1971 & 1972.

* Republic of Kenya. Statistical Abstract 1973.

(ICRISAT/EC-14/11-74)

India and several other SAT countries, domestic price levels are generally above world market levels, and to enter the world market successfully costs of production have to be relatively low.

(iii) Price variations in the various products over time generally are positively correlated, indicating that in the short-run different crops are affected inthe same way by factors increasing or decreasing prices. Therefore crop diversification may not decrease the market risk of an individual producer substantially.

We will proceed to discuss some of the significant socio-economic characteristics of three of the five major regions of the SAT, namely Asia, Africa South of the Sahara and South and Central America. We will not discuss in detail Oceania or the Near East and North West Africa.

SEMI-ARID TROPICAL ASIA

Four countries comprise this SAT region, namely Burma, India, Pakistan and Thailand. They have a combined SAT population of some 300 million people, most of whom reside in SAT India[1]. India has more than half of her land in the SAT region while Thailand has about 60 percent. The density of population per hectare in SAT India is 1.53, which is about four times that in SAT Burma and about twice that in SAT Pakistan and Thailand. The average density for the Asian SAT region is 1.33 inhabitants per hectare, which appears to be roughly ten times higher than that for SAT Africa South of the Sahara, and seven times higher than that for SAT South and Central America. According to the FAO Provisional Indicative World Plan for Agricultural Development (1970), the area of arable land per caput of agricultural population is 1.10 and 0.45 for all of Africa South of Sahara, and Asia and the Far East, respectively. About half of the latter region's total land area is classed as suitable for crop production whereas for the former, the estimate is only 20 percent. The countries of the Far East are much ahead along the road to utilizing their potentially available arable land than the African countries South of the Sahara. The former have 84 percent of potential arable land under cultivation and the latter only 50 percent.

The implications of these data for farming systems research may be that technology developed for SAT Asia should be relatively land-saving and labor-using while for SAT Africa and to a greater extent SAT South

[1] All relevant statistical details related to the textual discussion are given in Tables 1 and 5 to 7.

and Central America, the technology may be more in the direction of being labor-saving rather than land-saving. However, with population growth rates of around 2.2 percent per year for Asia and 2.6 percent for Africa South of the Sahara, the pressures of population on land in all areas is expected to increase. Producers of technology must keep this fact in mind while planning research.

Of the four Asian SAT countries, Burma and India are the least affluent. The Gross Domestic Product (GDP) per caput in Thailand is almost twice that in these two countries[1]. Thailand's actual rate of growth in GDP is also far greater than those of the other three countries.

More than 39 percent of operational holdings in SAT India are less than 0.4 hectares in size, and 54 percent are less than one hectare. There are only 3 percent of holdings larger than 10 hectares (Table 5). However, whereas more than half the holdings are less than one hectare, only 5.5 percent of the land is under farms of this size range. This illustrates the skewed distribution of landholdings in India. The implications for our research are that if 'small-farmer technology' is developed, then at least for India, and probably elsewhere, the productivity gains will be spread over about 43 percent of the farmland[2]. This would be of a positive value in improving the lot of the small farmers which is a very real and contemporary concern of many countries, but might be at the expense of considerable gains in aggregate resource productivity[3].

The data in Table 5 refer to farm size distribution in both the irrigated and rain-fed regions together. It is difficult to obtain data on farm size distribution for rain-fed areas separately. However, Table 6 contains the All-India distribution of irrigated farms and irrigated land. It can be seen that almost half of Indian farms of all sizes except those less than 0.19 hectares have irrigated land of one type or another. Almost two-thirds of irrigated farms are less than two hectares and these farms occupy about 30 percent of the irrigated land. These small farms have more than 60 percent of their land under irrigation. This proportion is inversely related to farm size. Although these data do not refer only to SAT India, it is probably that similar statistics would be revealed for SAT areas also.

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1 These refer to national statistics and not to SAT zones only. Unfortunately, data limitations often force us to use such national statistics. We have much more detailed information about India and North-eastern Brazil than any other country at the present time.

2 Assuming small farms are classified as being less than 5 hectares.

3 It is not altogether clear that one can in fact 'direct' research to benefit a particular group in this manner but, to the extent one may be able to, then the said implications arise.

Table 5. Cumulative Percentage of Holdings and Area Operated by Size Class of Household Operational Holdings in India [a]

Size class of operational holdings (Hectares)	Andhra Pradesh		Gujarat		Madhya Pradesh		Tamil Nadu		Maharashtra		Karnataka	
	House holds	Area operated	House holds	Area operated	House holds	Area operated	House holds	Area operated	House holds	Area operated	House holds	Area operated
1	2	3	4	5	6	7	8	9	10	11	12	13
Upto 0.19	46.15	0.35	33.46	0.00	24.88	0.07	51.98	0.63	35.61	0.10	31.79	0.04
0.20 - 0.39	50.07	0.94	36.42	0.23	28.09	0.36	58.17	3.03	38.21	0.32	34.17	0.26
0.40 - 0.99	65.96	6.76	47.08	2.31	39.20	2.90	75.06	17.72	48.6	2.55	43.98	2.61
1.00 - 1.99	77.10	16.07	58.67	7.32	54.99	10.02	88.00	40.80	60.99	8.16	57.21	8.78
2.00 - 2.99	84.57	26.45	67.11	14.17	67.47	19.72	94.15	59.74	69.04	14.33	70.22	20.08
3.00 - 3.99	88.26	33.90	74.85	22.42	75.32	28.48	96.44	70.02	75.09	21.04	78.49	30.02
4.00 - 4.99	91.09	41.20	80.80	30.77	81.32	36.96	98.08	79.14	80.14	28.29	84.29	39.11
5.00 - 5.99	92.78	46.57	84.33	37.17	85.57	44.66	98.64	83.21	83.42	34.18	87.21	44.93
6.00 - 7.99	95.22	56.12	89.42	48.8	91.46	58.02	99.28	88.90	88.34	44.98	91.05	54.16
8.00 - 9.99	96.89	64.50	92.44	58.3	94.47	67.04	99.66	93.29	92.07	55.88	93.82	62.58
10.00 - 11.99	97.61	68.91	94.86	67.2	96.36	73.75	99.73	94.31	94.14	63.22	95.73	70.32
12.00 - 19.99	99.05	82.59	98.81	87.6	99.01	87.06	99.91	97.59	98.28	83.45	98.53	85.00
20.00 & above	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Contd...

Table 5. contd.

Size class of operational holdings (Hectares)	Punjab		Rajasthan		Uttar Pradesh		All India		SAT States	
	House holds	Area operated	House holds	Area operated	House holds	Area operated	House holds	Area operated	House holds	Area operated
1	14	15	16	17	18	19	20	21	22	23
Upto 0.19	45.75	0.11	14.00	0.01	27.24	0.43	35.95	0.32	34.62	0.19
0.20 - 0.39	49.32	0.56	15.56	0.13	35.40	2.12	41.96	1.27	39.44	0.86
0.40 - 0.99	56.61	2.48	26.89	1.66	55.88	11.27	57.59	6.86	54.12	5.54
1.00 - 1.99	65.07	7.56	43.47	6.28	77.47	32.21	73.76	19.19	69.33	15.88
2.00 - 2.99	73.85	16.87	56.12	12.42	87.73	50.29	82.78	30.92	78.82	26.81
3.00 - 3.99	79.94	25.90	65.08	18.53	92.23	61.43	87.59	39.89	84.27	35.63
4.00 - 4.99	85.11	35.92	71.74	24.34	95.16	70.81	91.03	48.14	88.31	42.58
5.00 - 5.99	88.68	44.00	76.58	29.48	96.67	77.07	93.01	54.09	90.74	47.91
6.00 - 7.99	93.57	59.09	83.24	39.27	98.30	85.44	95.54	63.67	94.00	58.50
8.00 - 9.99	96.01	68.95	87.73	47.60	98.96	89.90	97.04	71.06	95.96	66.68
10.00 - 11.99	97.49	76.42	90.44	53.81	99.39	93.77	97.91	76.36	97.14	72.75
12.00 - 19.99	99.45	91.64	96.43	71.72	99.88	98.70	99.35	88.41	99.13	86.78
20.00 & above	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.01	100.00	100.00

a The Cabinet Secretariat, Government of India. The National Sample Survey, No. 144, pp.152-168

Table 6. Distribution of Irrigated Farms and Irrigated Land in India[a]

Size Group (ha)	All India No. of operational farms ('000)	All India area operated ('000 ha)	All India average size (ha)	Farms with irrigation in each group (%)	No. of farms with irrigation ('000)	Percentage distribution of farms with irrigation (%)	Average irrigated land per farm with irrigation (ha)	Percentage of irrigated land in each group (%)	Proportion of irrigated land (8/4)
0.00 - 0.19	4838	458.00	0.10	35.89	1557	6.85	0.10	0.60	1.00
0.20 - 0.39	4255	1230.40	0.29	44.72	1903	8.37	0.22	1.55	0.75
0.40 - 0.99	10772	7200.00	0.67	46.85	5047	22.20	0.49	9.43	0.74
1.00 - 1.99	11180	16036.40	1.43	49.05	5484	24.13	0.84	17.43	0.59
				(44.12)[b]		(61.55)[c]		(29.01)[c]	
2.00 - 2.99	6158	14806.00	2.40	48.02	2957	13.01	1.30	14.48	0.54
3.00 - 3.99	3478	11808.00	3.39	47.27	1644	7.23	1.70	10.53	0.50
4.00 - 5.99	3881	18353.60	4.73	46.04	1787	7.86	2.19	14.78	0.46
6.00 - 7.99	1843	12436.40	6.75	45.58	840	3.69	2.54	8.04	0.38
8.00 - 9.99	1111	9556.40	8.60	45.72	508	2.24	3.18	6.08	0.37
				(46.52)[b]		(34.02)[c]		(53.91)[c]	
10.00 - 11.99	663	7082.40	10.68	46.00	305	1.34	3.61	4.15	0.34
12.00 - 19.99	1121	16376.80	14.60	42.99	482	2.12	4.28	7.77	0.29
Above 20.00	523	15565.20	29.76	39.00	204	0.89	6.66	5.12	0.22
				(42.66)[b]		(4.35)[c]		(17.04)[c]	
Total	49824	130910.80	2.62	45.61	22725	100.00	1.17		0.45

a Sen B. 1974. The Green Revolution in India - A perspective, p.36 (Information derived from the National Sample Surveys conducted by the Government of India).

b Average for the group

c Total for the group

If this is so, then the implications for farming systems research are that may be half of the farms in SAT India already have some access to irrigation facilities. This no doubt increases the level and stability of production on these farms. Research can no doubt productively focus on these types of farms particularly, as most of them are small in size. Ways of profitably integrating their irrigated and dryland farming systems could go a long way towards increasing and stabilizing aggregate agricultural production in SAT India. Of course this research would go hand in hand with the perhaps more urgent need to develop systems for the other half or more farms which are entirely rain-fed.

Another factor which will have to be taken into account in developing farming systems technologies is the considerable spatial diversification of holdings, as illustrated in Table 7 for India. Even in the smallest size group of farms (less than 0.19 hectares) there is generally more than one parcel of land per operational holding. On farms of between two and three hectares there is an average of more than five parcels of land of an average size of 0.51 hectares each. On average, for all of SAT India there are 4.81 parcels of land per holding of an average size of 0.82 hectares. Group action to harness the benefits of the larger watershed development along the lines of that being researched at the ICRISAT and elsewhere in India would probably have to involve land consolidation and redistribution, in addition to other measures.

Agriculture is more important in the national economy of India than of the other countries, comprising 45 percent of GDP. Except for Thailand, the SAT Asian countries are self-sufficient in coarse grains and pulses. Assuming the average per caput requirements for calories and protein at 2373 k. cals and 42.7 grams per day respectively, as calculated by Ryan et. al. (1974) for India, it appears that all of SAT Asia is adequately supplied with proteins but the Burmese and the Indians have about a 15 percent deficiency of calories. An integral part of farming systems research everywhere should therefore be the measurement of output of protein and calories of the various cropping patterns and systems examined, in addition to yields and net monetary values. This will enable more informed policy choices to be made by decision makers in SAT countries regarding price and production programs.

The five crops in ICRISAT's Crop Improvement Program occupy one-third of India's total arable land[1]. The average size of agricultural holdings in India in 1960 was 2.52 hectares whereas that for the Asian region was 2.72 (Table 1). The average size of operational holdings in 1961-62 was 1.82 hectares in India, whereas for SAT India it was 2.11 (Table 8). This is much smaller than for any other of the SAT regions,

[1] This is the gross cropped area of the five crops rather than the net area, together with all arable land, both SAT and other.

Table 7. Estimated Number of Parcels Per Operational Holding and Average Area of Parcels for Each Size Class of Operational Holding - All India and 'SAT' States[a]

Size Class of operational holding (ha)	All India		Andhra Pradesh		Gujarat		Uttar Pradesh		Karnataka (Mysore)	
	No. of parcels	Aver. area (ha)	No. of parcels	Aver. area (ha)	No. of parcels	Aver. area (ha)	No. of parcels	Aver. area (ha)	No. of parcels	Aver. area (ha)
Upto 0.19	1.82	0.05	1.63	0.06	1.72	0.09	2.21	0.05	1.35	0.04
0.20 - 0.39	3.07	0.10	2.43	0.11	1.81	0.16	3.36	0.07	1.85	0.14
0.40 - 0.99	4.45	0.15	2.95	0.22	2.40	0.28	6.15	0.10	2.31	0.30
1.00 - 1.99	6.05	0.23	4.32	0.33	3.49	0.40	8.33	0.17	3.18	0.45
2.00 - 2.99	6.79	0.35	5.03	0.46	4.17	0.59	9.27	0.25	3.85	0.64
3.00 - 3.99	7.63	0.44	5.10	0.65	4.39	0.72	11.57	0.28	4.62	0.72
4.00 - 4.99	7.56	0.56	5.06	0.83	4.16	0.90	11.05	0.38	4.37	1.02
5.00 - 5.99	8.02	0.66	6.18	0.86	5.09	1.08	13.47	0.38	4.32	1.26
6.00 - 7.99	7.92	0.84	6.64	0.97	5.37	1.23	14.02	0.46	4.54	1.52
8.00 - 9.99	8.78	0.96	9.38	0.92	6.24	1.26	18.96	0.40	5.12	1.72
10.00 -11.99	8.00	1.32	7.85	1.35	6.57	1.64	13.96	0.66	5.38	2.06
12.00 -19.99	8.07	1.78	8.35	1.71	6.67	2.20	22.52	0.65	5.19	2.79
20.00 & above	9.44	3.11	10.95	2.65	9.62	2.97	21.76	1.17	7.33	3.80
All Sizes	5.66	0.46	4.32	0.66	4.30	1.03	7.78	0.23	3.79	1.07

Size Class of operational holding (ha)	Madhya Pradesh		Tamil Nadu (Madras)		Maharashtra		Rajasthan		Punjab		SAT States (Average)	
	No. of parcels	Aver. area (ha)	No. of parcels	Aver. area (ha)	No. of parcels	Aver. area (ha)	No. of parcels	Aver. area (ha)	No. of parcels	Aver. area (ha)	No. of parcels	Aver. area (ha)
Upto 0.19	1.26	0.07	1.69	0.06	1.73	0.05	0.92	0.07	2.19	0.03	1.63	0.06
0.20 - 0.39	2.10	0.13	3.07	0.10	2.52	0.12	1.94	0.51	4.73	0.06	2.70	0.16
0.40 - 0.99	3.13	0.22	3.77	0.18	0.80	0.24	2.96	0.24	3.75	0.17	3.14	0.22
1.00 - 1.99	4.31	0.34	5.40	0.26	3.50	0.41	3.66	0.39	4.32	0.32	4.50	0.34
2.00 - 2.99	4.95	0.49	6.58	0.36	3.51	0.69	3.89	0.60	4.65	0.52	5.10	0.51
3.00 - 3.99	5.99	0.57	9.05	0.44	3.83	0.89	4.29	0.80	5.28	0.63	6.01	0.63
4.00 - 4.99	6.02	0.72	9.20	0.47	3.95	1.12	5.49	0.73	4.86	0.88	6.02	0.78
5.00 - 5.99	6.36	0.84	11.00	0.50	4.12	1.31	5.18	1.01	5.13	1.00	6.76	0.91
6.00 - 7.99	7.11	0.96	11.61	0.58	4.66	1.47	5.25	1.22	5.43	1.18	7.18	1.07
8.00 - 9.99	8.14	1.06	10.52	0.81	5.10	1.70	5.30	1.53	5.71	1.42	8.27	1.20
10.00 -11.99	8.37	1.28	13.60	0.78	4.67	2.24	5.85	1.83	6.82	1.53	8.12	1.48
12.00 -19.99	9.77	1.45	17.83	0.80	4.88	3.02	5.20	2.75	6.40	1.93	9.65	1.92
20.00 & above	13.72	2.22	20.80	1.22	7.51	3.85	4.64	7.07	7.27	2.84	11.52	3.09
All Sizes	5.30	0.74	4.96	0.30	3.78	1.22	4.27	1.29	4.76	0.80	4.81	0.82

a Cabinet Secretariat, Government of India 1962. The National Sample Survey, No.144, pp 170-171.

b As Haryana was not formed in 1961-62, the figures refer to the composite Punjab (i.e. present Haryana and Punjab).

Table 8. Selected Socio-Economic Data on Semi-Arid Tropical India

State	SAT area[a] ('000 km^2)	SAT population[a] (millions)	SAT population/land ratio[a] (people/ha)	Cropping Intensity in Rain-fed areas[a]	Percentage occurrences of kharif droughts of class[b]: Moderate & worse (%)	Severe & worse (%)	Coefficient of variation of yields[c]: Sorghum	Millet	Months where[d] PET > P (Range)	Average Annual Rainfall Range[e] (mm)	Fertilizer (N+P+K) Consumption per ha of arable land[b] (kg/ha)	Average Farm Size[g] (ha)	Arable Land per tractor[h] (ha/unit)	Cattle and buffaloes per ha arable land[a] (head/ha)
Andhra Pradesh (Interior)	221	32	1.45	108	25.2	10.0	11.59*	14.55	3 - 4	600-1100	16.4	1.70	5770	1.88
Gujarat	194	26	1.34	106	24.4	6.9	26.78	41.72***	2 - 4	700-1200	14.8	2.96	3706	1.19
Haryana	35	8	2.29	130	23.8	12.0	29.85[l]	43.69*[l]	2 - 3	700-1000	24.6	2.18[l]	787	1.45
Karnataka (Interior)	149	22	1.48	105	22.8	9.9	24.67****	30.28	2 - 5	500-1600	14.1	2.72	5509	1.43
Madhya Pradesh	259	24	0.93	112	20.0	10.5	24.74**	27.02	3 - 5	1000-1450	5.5	3.05	10137	1.51
Maharashtra (Interior)	274	44	1.61	105	24.5	12.5	22.18***	19.76	2 - 4	700-1400	8.7	3.09	6995	1.11
Rajasthan (East)	249	18	0.72	107	31.3	16.8	22.96	37.99****	2 - 3	550-1100	2.2	4.95	6408	1.39
Tamil Nadu	108	31	2.87	109	21.0	7.7	6.89	12.46	2 - 3	600-1300	37.5	0.95	2642	2.84
Uttar Pradesh	211	56	2.65	140	21.4	11.8	20.15	18.90**	3 - 4	760-1300	24.6	1.21	2080	2.37
Total or average for SAT India	1700	261	1.54[i]	112[j]	23.8[k]	10.9[k]	9.42[n]	22.16[n]	2.3 - 3.9	600-1600	13.1	2.11 (1.82)[m]	4107[i]	1.63[i]

a Estimates by Economics Department of ICRISAT using data from Troll's World Mapsof Climatology (1966), the Hamond Citation World Atlas (1972), Directorate of Economics and Statistics, Ministry of Agriculture, Government of India. Estimates of Area and Production of Principal Crops in India, 1954-55 to 1964-65, 1970 and Fertilizer Association of India, Fertilizer Statistics, 1973. Excludes area covered by Government Canal Irrigation Schemes.

b George et al. (1973). Data from SAT subdivisions of the states averaged. Most of the data in the publication relate to historical records from 1904 to 1971.

c Data relate to the years 1955-56 to 1972-73 except for Madhya Pradesh which extends from 1950-51. The SAT total coefficient of variation calculated using the former years only.
Sources: Fertilizer Association of India. Fertilizer Statistics, 1973. Directorate of Economics and Statistics, Ministry of Agriculture, Government of India. Estimates of Area and Production of Principal Crops in India 1954-55 to 1964-65, 1970 and Indian Agriculture in Brief, 1974. Directorate of Agriculture, Madhya Pradesh, India. Agricultural Statistics, Madhya Pradesh 1973, and Jha et al (1969). The four major producing states for each crop are marked with asterisks, with a larger number of asterisks indicating a larger production.

d Rao et al. (1971). There may be other areas in these states with longer wet seasons. Analysis was restricted by the availability of PET data.

j Average weighted by net rain-fed area sown.

k Simple average.

l Undivided Punjab

m Figure in brackets is for All-India.

n Derived by pooling area, production and yield data for [illegible] SAT states and computing the SAT region coefficient of variation.

although the data for Africa are scanty. However, data on the arable land per person economically active in agriculture (Table 1) show that the all-India figure is 1.1 hectares per head, whereas for the Asian SAT region it is 1.15. This compares with figures of 2.05 hectares per person active in agriculture for SAT countries in Africa South of the Sahara, and 3.65 for those in South and Central America.

The total fertilizer consumption (N, P, and K) per hectare of arable land is almost 17 kilos in India. The figure is much lower for SAT India at about 13 kilos (Table 8)[1]. Asian fertilizer use per hectare appears to be about five times that in Africa, but about half that in South and Central America. Cropping intensity in India in 1967-68 was estimated to be 117. We have estimated the cropping intensity in the SAT States of India at 112, with a range of 105 to 140 (Table 8). There would appear to be scope for improvement in cropping intensity in the SAT, utilizing techniques such as relay cropping, double cropping, inter-cropping, ratooning, etc. For the countries of Africa South of the Sahara, the Food and Agricultural Organization (1970) estimates the cropping intensity at 42.

There is a probability of severe or extreme drought in the <u>kharif</u> in SAT India approximately once in nine years (Table 8). The probability is least in Gujarat (6.9 percent) and greatest in East Rajasthan (16.8 percent)[2]. Once in four years there is a kharif drought of moderate or worse severity in SAT India. Again East Rajasthan is the most affected (31.3 percent) and Madhya Pradesh is the least drought prone (20.0 percent) using this definition.

Table 9 shows that the average percentage occurrence of kharif droughts of moderate or worse severity in the various SAT subdivisions of India do not vary a great deal amongst the six wet months. It appears July is the least drought prone and October the most. The source of these data was George et al. (1973) and they are graphed in Figs. 7 and 8. The most drought prone SAT area in India according to Table 8 is East Rajasthan. However, the variability in millet yields is slightly less

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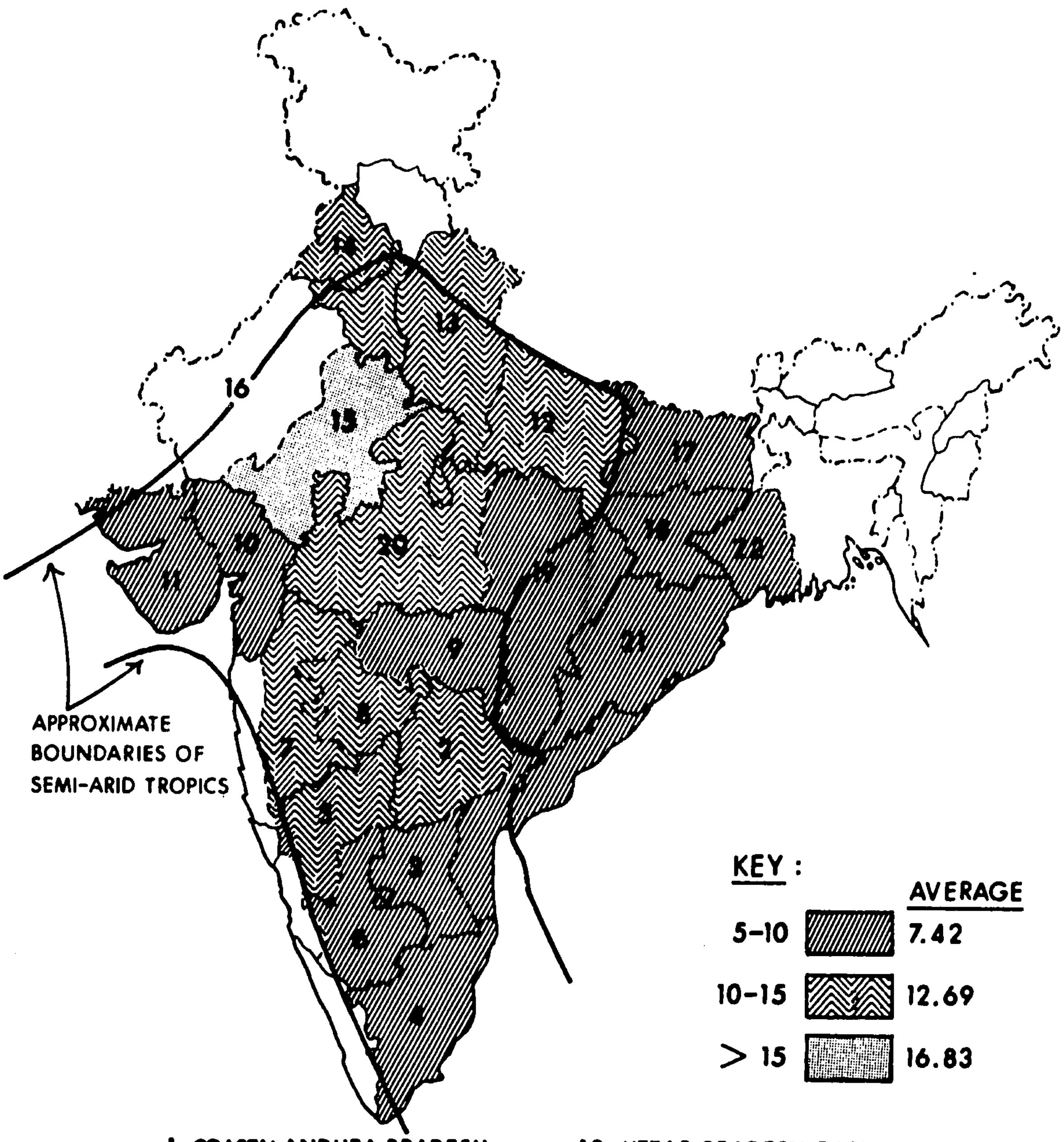
[1] This represents the nine Indian states with all or part of their land in SAT climate. It was not possible to separate non-SAT data.

[2] The technique employed by George et al. (1973) involves computation of a Palmer Index on the basis of current and antecedent rainfall, runoff, evapotranspiration and soil moisture. The index is said to be most relevant to semi-arid and dry sub-humid regions and takes into account the normal crop needs at different periods of the growth cycle. Hence even in relatively dry months such as November, droughts may not be frequent as crop moisture needs may not be substantial at that time.

FIGURE 7: PERCENTAGE OCCURENCES OF DROUGHTS OF CLASS SEVERE AND WORSE IN THE KHARIF SEASON

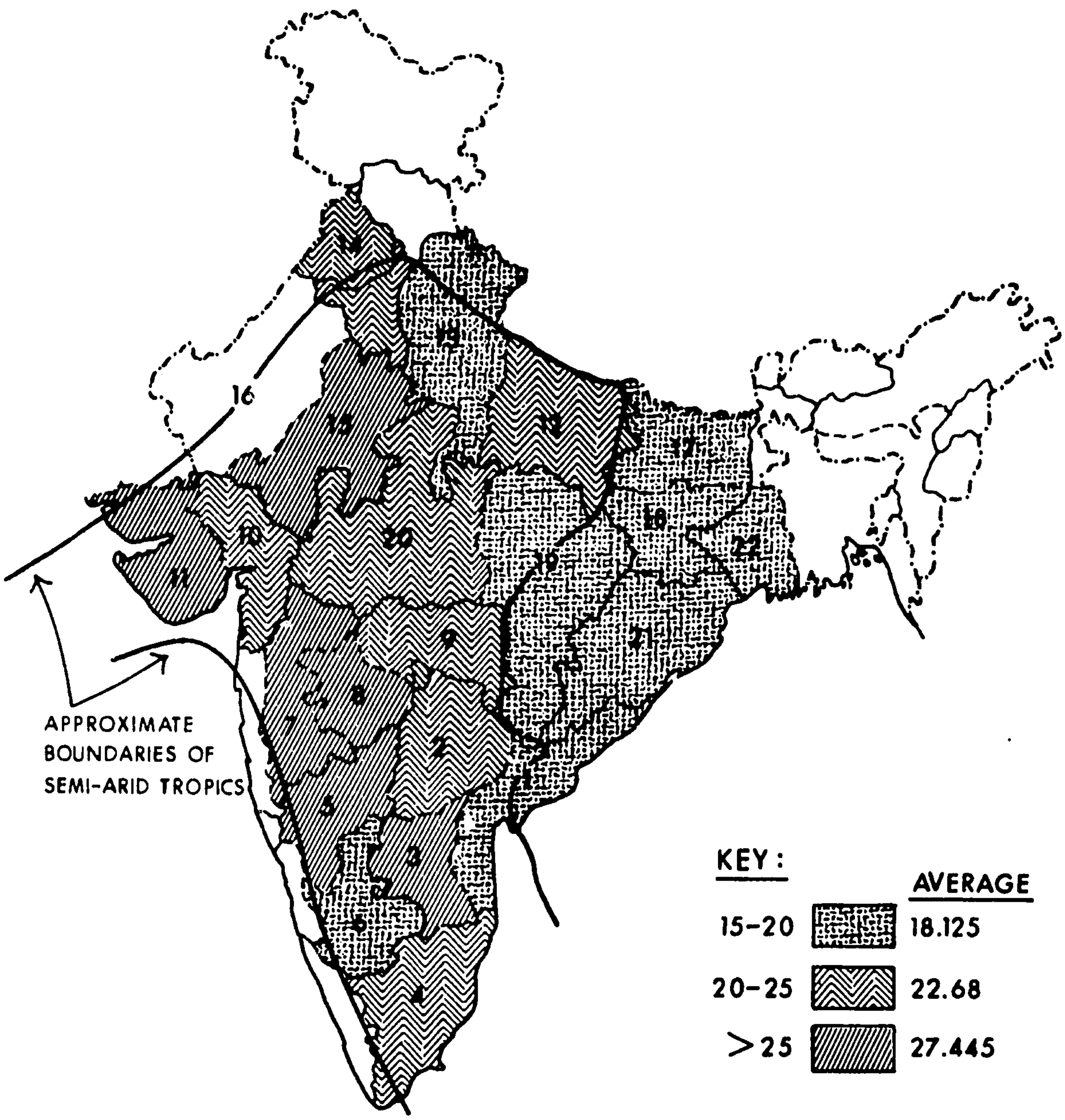


1. COASTALANDHRA PRADESH
2. TELANGANA
3. RAYALASEEMA
4. TAMIL NADU
5. INTERIOR MYSORE NORTH
6. INTERIOR MYSORE SOUTH
7. MADHYA MAHARASHTRA
8. MARATHWADA
9. VIDARBHA
10. GUJARAT
11. SAURASHTRA & KUTCH
12. UTTAR PRADESH EAST
13. UTTAR PRADESH WEST
14. PUNJAB & HARYANA
15. RAJASTHAN EAST
16. RAJASTHAN WEST
17. BIHAR PLAINS
18. BIHAR PLATEAU
19. MADHYA PRADESH EAST
20. MADHYA PRADESH WEST
21. ORISSA
22. GANGETIC WEST BENGAL

SOURCE: GEORGE et al. 17 AND TROLL [35]

ICRISAT/EC-6/11-74

FIGURE 8: PERCENTAGE OCCURENCES OF DROUGHTS OF CLASS MODERATE AND WORSE IN THE KHARIF SEASON



1. COASTAL ANDHRA PRADESH
2. TELANGANA
3. RAYALASEEMA
4. TAMIL NADU
5. INTERIOR MYSORE NORTH
6. INTERIOR MYSORE SOUTH
7. MADHYA MAHARASHTRA
8. MARATHWADA
9. VIDARBHA
10. GUJARAT
11. SAURASHTRA & KUTCH
12. UTTAR PRADESH EAST
13. UTTAR PRADESH EAST
14. PUNJAB & HARYANA
15. RAJASTHAN EAST
16. RAJASTHAN WEST
17. BIHAR PLAINS
18. BIHAR PLATEAU
19. MADHYA PRADESH EAST
20. MADHYA PRADESH WEST
21. ORISSA
22. GANGETIC WEST BENGAL

SOURCE: GEORGE et at. [17] AND TROLL [35]

ICRISAT/EC-8/11-74

Table 9. Percentage Occurrences of Droughts - Moderate and Worse in the Kharif Season[a].

Code[b] No.	Semi-Arid Tropical Subdivisions	June	July	Aug.	Sept.	Octr.	Novr.
2.	Telangana	22	17	19	22	30	30
3.	Rayalseema	24	28	30	27	27	27
4.	Tamil Nadu	20	22	23	23	21	17
5.	Interior Mysore South	20	15	19	15	23	20
6.	Interior Mysore North	25	23	29	26	30	29
7.	Madhya Maharashtra	20	27	25	23	31	30
8.	Marathwada	25	23	25	23	30	25
9.	Vidarbha	20	20	24	21	25	24
10.	Gujarat	25	15	13	20	27	25
11.	Saurashtra-Kutch	22	25	25	30	35	31
12.	Uttar Pradesh East	20	27	20	25	25	27
13.	Uttar Pradesh West	18	17	18	18	22	20
14.	Punjab-Haryana	22	17	25	25	27	27
15.	Rajasthan East	33	25	25	30	38	37
19.	Madhya Pradesh East	17	13	13	17	21	18
20.	Madhya Pradesh West	23	22	20	21	25	30
	Simple Average	22.3	21.0	22.1	22.9	22.3	22.1

a Source: George et al. (1973).

b Refers to codes used in Figs.7-8.

than in the much less drought-prone state of Gujarat. In the other major millet producing area of Uttar Pradesh, the coefficient of variation of millet yields is half of that in East Rajasthan. In all of SAT India variability in millet yields is more than twice that of sorghum. This places a greater challenge on millet breeders to develop more stable yielding varieties/hybrids for the major millet growing areas including disease and drought resistance. It also implies that the problem of stabilization of production in major millet-growing areas of the world is likely to be a more significant problem for farming systems research than in sorghum growing areas. However, we really need to study variability of total farm production in different areas to gain a complete picture of risk in farming before making any firm inferences. The all-SAT India coefficients of variability in sorghum and millet yields are more than one half the average for each State taken separately. This reflects the fact that many areas of the country have yield movements which are inversely related. Generally speaking, sorghum and millet yields in SAT Asia are more stable than those in other major SAT regions (Table 1).

SAT Asia has some 52 percent more cattle per hectare of arable land than countries of SAT Africa South of the Sahara. However, on an average they both have roughly the same number of hectares per tractor at about 2,400. These figures, especially for tractors, do not present an accurate picture for the SAT regions of these countries, as mechanization for the most part has been restricted to the more developed irrigated or high-rainfall areas. For example, the aggregate figures for India and Brazil are 2470 and 283 hectares per tractor, while for the nine SAT states and North-eastern Brazil the corresponding figures are 4107 and 13,700 respectively[1]. Cattle numbers in India and Brazil as a whole average 1.44 and 3.31 head per hectare whereas for their SAT regions the figures are 1.63 and 0.51 respectively. This explains the predominance of animal power in SAT Asia and of human power in SAT Africa and Brazil[2].

SEMI-ARID TROPICAL AFRICA SOUTH OF THE SAHARA

This zone consists of 29 countries with a semi-arid tropical land area of some 11.5 million km^2, which represents about 60 percent of the total SAT land area in the world. On an average two-thirds of the area of the countries which comprise the region are classified as SAT and they contain an estimated 157 million people. The SAT regions are shown in Fig. 9.

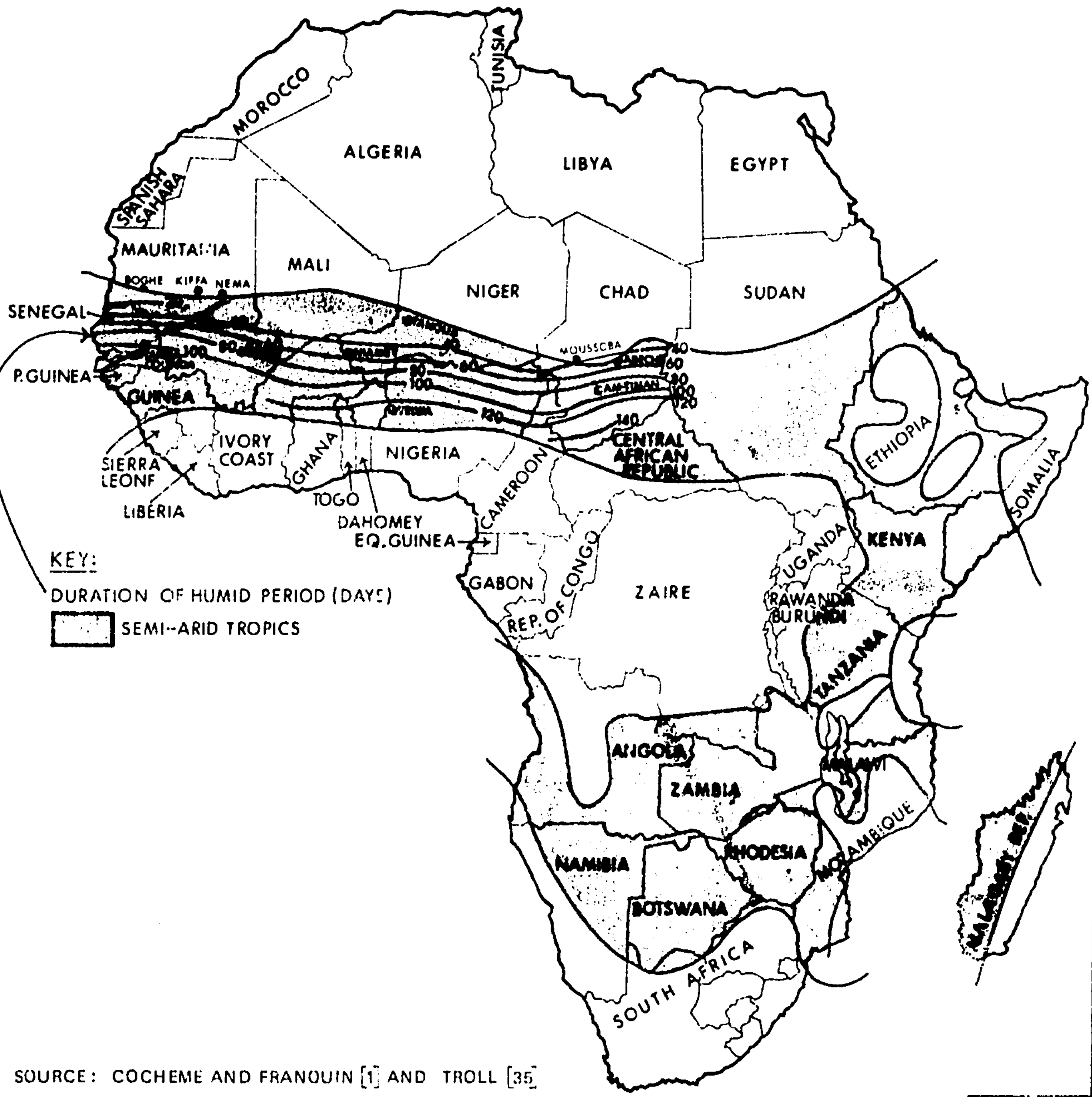
The population density of this semi-arid tropical region at 0.13 inhabitants per hectare is one-tenth that of SAT Asia. The most populous SAT regions in Africa lie in Nigeria (42 million), Sudan (15 million), Ethiopia (12 million), Kenya and Tanzania (10 million each). Gambia has the most densely populated semi-arid tropical region with about 1.00 inhabitant per hectare, followed by Nigeria and Togo with 0.44, Ghana and Malawi with 0.34 and Portugese Guinea with 0.28. Even though these African countries have much lower SAT population densities than Asia, average population growth rates seem somewhat higher in the former.

The African SAT countries South of the Sahara have a per caput GDP of $123, which is 16 percent higher than SAT Asia but much lower than

[1] Table 7 and Patrick (1972). SAT Brazil data relate to 1960 whereas those for SAT India are for 1971.

[2] In 1960 Patrick (1972) reported that about 96 percent of farms in North-eastern Brazil used human power only while 3 percent used animal power.

FIGURE 9: SEMI-ARID TROPICAL REGIONS OF AFRICA SOUTH OF THE SAHARA AND DURATION OF THE HUMID PERIOD



SOURCE: COCHEME AND FRANQUIN [1] AND TROLL [35]

South and Central America. The most affluent of the SAT African countries is Zambia with a per caput GDP of $379, followed by Ghana ($260), Mozambique ($228), Rhodesia ($225) and Mauritania ($211). The least affluent are Upper Volta ($46) and Malawi ($58). Proper data is not available on the rate of growth of real GDP per caput for Africa, but the average for 10 countries for which data are available is 2.6 percent per annum. This is higher than those for Asia and South and Central America. Agriculture represents some 38 percent of the total GDP of the SAT countries of Africa, which is the same as in Asia but much higher than those in the other areas.

Generally the African SAT countries are self-sufficient in coarse grains and have a 27 percent excess of pulses, nuts and seeds. The average diet of SAT Africa is about 9 percent deficient in calories but with a surplus of 40 percent in protein. Zaire, Tanzania, Mozambique and Angola appear to have the most deficient diets.

Data on the average size of agricultural holdings are very scanty for Africa. What we have been able to obtain indicates an average size of some 74 hectares, with 2.05 hectares of arable land per person economically active in agriculture. Very little fertilizer is normally used in Africa except in Rhodesia, Kenya and Angola where 70 kg, 38.5 kg and 24.8 kg respectively of fertilizer is applied per hectare of arable land. The five crops in the ICRISAT Crop Improvement Program are more important in the agriculture of the SAT African countries than that of Asia, as measured by the 27 percent of arable land they represent in the former. The five crops appear most significant in the agriculture of Gambia, Mauritania, Ghana, Nigeria, Sudan and Upper Volta. As previously mentioned, the cropping intensity in Africa is at present very low at 42.

In the Sudanian and Sahelian zones of African countries west of Chad, Cocheme and Franquin (1967) estimated the coefficient of variation of rainfall to be inversely related to average annual rainfall. Hence, as one moves towards north in this SAT area, the rainfall decreases, as does the length of the humid season (Fig.9), but rainfall variability rises. For example, in SAT Mali the coefficient of variation varies between 16-27 percent, SAT Chad 23-28 percent, SAT Niger 20-42 percent, SAT Nigeria 15-22 percent, SAT Senegal 20-30 percent and SAT Upper Volta 13-19 percent. Based on the coefficient of variation of sorhgum yields during the past 12 years of more than 11 percent and that of millets of more than 14 percent for these countries of the SAT Africa, it would appear on average that SAT Africa has more variability in crop yields than SAT Asia. However, when we compare the individual country coefficients of variation of yields in Africa with the individual State figures for India, the latter have more than double the variability of the former. The inference from this would be that risk (as measured by yield variability) appears greater in the various SAT states of India than in the countries of SAT Africa. Aiming at yield stability in farming systems and crop improvement research programs hence would appear to be more important for Asia than for Africa. However, we really require a more comprehensive measure of variability of farm production in these areas than the coefficient of variability of sorghum and millet which are only two components of the systems, before we make definite conclusions.

SEMI-ARID TROPICAL CENTRAL AND SOUTH AMERICA

This is the third major SAT zone in the world, occupying 3.33 million km^2 or 17 percent of the total SAT land. It sustains a population of some 58 million which implies a density of 0.17 inhabitants per hectare. Population growth in this region is slightly higher than that in other regions, at 2.7 percent annum, and the per caput GDP is much higher at $469. However, when we look at North-eastern Brazil, we observe a per caput GDP of $150, whereas the figure for the whole of Brazil is $422. Most of the North-east Brazil has SAT climate and its living standards are lower than those in the rest of the country. Unfortunately, we do not have much information on the SAT areas of the other eight countries in the region but it is likely they are similarly disadvantaged vis-a-vis the rest of their respective countries.

The five crops in ICRISAT's crop improvement program do not occupy a major place in the cropping patterns of these countries, representing only some 7 percent of arable land. They are relatively more important in El Salvador and Argentina than in the other countries. All countries produce more than their requirements of coarse grains and pulses, nuts and seeds. All except Bolivia and El Salvador have adequate average diets with respect to both calories and protein.

The average farm size is more than 100 hectares in SAT Central and South America. There are 3.65 hectares of arable land per person actively employed in agriculture, which is much larger than those in Asia or Africa. They apply almost 30 kg of fertilizer per hectare of arable land and their agricultural production has been growing at an average rate of 3.4 percent per year.

The countries are well endowed with cattle, with an average cattle/land ratio of 2.3 head per hectare of arable land. In North-eastern Brazil, according to Patrick (1972), there are 13.73 million head of cattle. With an estimated arable area of 27 million hectares, this would mean that there are about 0.51 cattle per hectare of arable land for the major SAT area of this region. Again this illustrates the large differences that exist between national statistics and those for the SAT areas.

The region appears relatively well equipped with tractors, with some 206 hectares per tractor. Here again, calculations for North-eastern

Brazil indicate much fewer tractors in operation for this area: in 1960 there were almost 14,000 hectares of arable land per tractor unit.

The coefficient of variation of sorghum yields is relatively high at 17 percent for the whole region. With the exception of Oceania, it is the highest of all five SAT regions in the world, although the variability within individual countries is much less than that within the nine SAT states of India.

As we have more information about SAT Brazil than the other major SAT regions in Central and South America due to the excellent work of Patrick (1972), Schuh (1973) and Paiva et al. (1973), we will spend some time now describing various aspects of its agriculture[1].

Fifty eight percent of the 28 million population of North-eastern Brazil is rural and has a population growth rate of 1.8 percent per year, compared with 2.3 percent for the whole population of the North-east(NE). The agriculture of the region produces 40 percent of the national income of the NE and agricultural exports represent approximately 9 percent. The primary NE crops are corn, dry beans, manioc, banana, cotton, rice, sugarcane, cocoa, tobacco and sisal. Cotton occupies 28 percent of the cultivated area, millets 19 percent, beans 14 percent, manioc 9 percent and sugarcane 6 percent. The animal sector represents 25 percent of gross agricultural output and consists mainly of beef, milk, eggs, pork and mutton. The importance of the livestock production industry differentiates NE Brazil from many of the other SAT countries we are concerned with.

With the exception of sweet potato, yield increases have not explained any of the production increases for NE crops. From 1948-50 to 1967-69 increases in the area of land cultivated were the primary source of growth. However, during the 1960s yield increases became a little more significant. Crop prices in the NE have been fairly stable whereas animal prices have risen during this period. There has tended to be a shift towards greater production of food crops (such as rice, dry beans, corn), fruit and vegetables away from industrial and other crops.

The average farm size was 45 hectares in 1960, and the trend is towards smaller farms. In Brazil as a whole, the average size is 74 hectares. The distribution of farms by size is shown in Table 10. Since 1940 there has been an increase of 120 percent in the number of farms of less than 10 hectares. This was 75 percent of all new establishments.

[1] Most of the data refer to the North-eastern statistical region of Brazil. Patrick (1972) estimated only 51 percent of the north east to be semi-arid. The reader hence should keep this in mind while studying the information presented.

Table 10. Number of Farms of Various Sizes and Area They Occupy in the Semi-Arid Tropical States of North Eastern Brazil[a]

States	< 10 ha		10 - 100 ha		100 - 1000 ha		1000 - 10000 ha		>10,000 ha	
	Number %	Area %	Number %	Area %	Number %	Area %	Number %	Area %	Number %	Area %
Piani (100)[b]	43.8	1.1	37.1	13.1	17.5	45.7	1.6	30.1	0.1	9.9
Ceara (100)	28.3	1.5	53.8	22.4	16.9	48.1	1.0	23.4	-	4.6
R.G. do Norde (75)	41.8	2.3	44.3	20.3	13.0	46.3	0.9	24.9	-	6.2
Paraiba (45)	61.5	6.3	32.0	26.6	6.0	43.5	0.4	20.9	-	2.7
Perramburo (60)	76.6	9.9	19.5	25.3	3.7	43.8	0.2	16.3	-	4.7
Alagoas (10)	69.3	7.9	25.6	24.3	4.7	41.3	0.4	22.5	-	4.0
Bahia (40)	49.3	4.2	42.2	29.4	8.0	42.0	0.4	19.9	-	4.5

a Source: Patrick (1972).

b Figures in brackets refer to the percentage of the state which is SAT.

In 1960, 90 percent of farms were individually owned. Indeed expansion of land and livestock have been the primary forms of capital growth in the NE since 1940. About 14 percent of the farm land is under crop, 20 percent is fallow, 34 percent is pasture and 24 percent is forested. It is estimated that up to 25 percent of the farm-land could be cropped. One percent of cropped area is irrigated and most of this in Bahia state. As has been stated previously, almost all farms use only human power. There is very little use of animal power, although the potential is there with the size of the cattle population.

In 1969, average fertilizer consumption per hectare was 5.0 kg. Almost 50 percent of it was in the form of potassium. Only 5 percent of farmers are using fertilizers. This indicates the need for research for identifying the reasons for such a minimal use of fertilizer, including examination of crop-fertilizer response functions, the riskiness of applying fertilizer, and the availability of fertilizer.

The average annual rainfall ranges from less than 500 mm up to 1000 mm in the SAT NE, and the wet season is from January to May. In the last 258 years there have been 33 droughts of which ten were region-wide and severe. Thus there is a 13 percent probability of drought of any severity and a four percent chance of severe droughts. This makes NE Brazil much less drought-prone than India (Tables 8 and 9). There are about 850 public and private reservoirs constructed in the NE. Hence there may be a potential for the development of improved water-harvesting systems in this area.

In summary, production increases in the NE have largely occurred through resource growth rather than through resource productivity improvements in the agricultural sector. Patrick (1972) believes that NE population will greatly increase in the future and that this prospect must influence the type of technology developed for the area. However, at present the NE has a relatively high land/man ratio compared with those for other SAT countries. This would suggest rather more emphasis on labor - rather land-saving technology, at least in the medium term. There would appear to be lack of packages of viable technologies for SAT Brazil at present and this has been the primary reason for the lack of 'modernization'.

The remaining two SAT regions - namely the Near East and North West Africa, and Oceania are relatively minor in terms of population, although the latter comprises a large land area. We will not discuss details of the agriculture of these regions but leave it to readers to examine the data on them contained in Table 1.

SOCIO-ECONOMIC STUDIES IN SEMI-ARID TROPICS

To gain a better insight into problems of agricultural development at a micro-level, we are initiating studies in three regions of SAT India commencing in December, 1974, with a view to understanding existing farming systems. We want in these studies to examine why farmers farm the way they do and to identify the constraints which dictate what they can do. In this way we feel we will be better able to define high payoff research and extension activities where adoption rates will also be high. It may also enable us to evaluate the potential of the watershed-based farming systems technology in these areas. 'Benchmark' studies may help us in developing pilot watershed projects in the study areas at a later date when it is felt there is an economically viable technology developed. A comparison can be made of the before - and - after situation to determine the feasibility of major efforts to introduce this new technological concept. Later we intend to conduct similar studies in other SAT countries as our knowledge and experience of the appropriate methods and procedures in studies of this kind increases[1]. Narpat Jodha has a major responsibility for this project and it will be conducted in close collaboration with B.A. Krantz and J. Kampen, and the All India Co-ordinated Research Project on Dryland Agriculture.

Another study which is underway by H.S. Sandhu, involves examination of the economic history and current utilization of tank irrigation in SAT India. This system is confined largely to Andhra Pradesh, Tamil Nadu, Uttar Pradesh and Karnataka. We are interested to know why paddy is the predominant crop grown and what the potential is to replace it with other crops which consume much less water per unit of production. We believe such a study may give us important insights into the likely behavior of farmers' in all SAT areas when a viable water-harvesting technology is devised.

We are also studying historical intra and inter-seasonal rainfall distributions, and experimental data relating runoff to such things as daily rainfall, rainfall intensity, vegetative cover, antecedent rainfall, soil type, land slope and type of cultivation. The aim is to determine for various agro-climatic regions in the SAT, what the frequency distribution of runoff might be so that we can ascertain the likelihoods of filling tanks both in and in between seasons. We also need to determine what the probabilities are of being able to profitably apply this harvested runoff at different times in crop growth periods. This involves the determination of crop-water response functions for various durations of moisture stress and with frequency and amount of irrigation considered. These two aspects will be integrated to determine expected payoffs from the water-harvesting technology. Any information on the determinants of runoff and on crop-water response functions in the SAT areas, would be useful.

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1 A more detailed discussion of this and other current research projects in the Economics Department of ICRISAT can be found in papers by Ryan and von Oppen (1972) and Ryan (1974).

Another project relates to the evaluation of alternative strategies which SAT farmers adopt (or might adopt) to alleviate risk in their farm, off-farm, and market operations. The aim would be to compare strategies such as grain storage, water harvesting, mixed cropping, off-farm work, etc. from the point of view of insurance against risk. Hans Binswanger, an Associate of the Agricultural Development Council, on assignment with us at the ICRISAT, is planning the research in this area. As yet it is still in the formative stages.

A study in pulse marketing is being planned by Matthias von Oppen. This aims at determining the economic value of seed size in pigeon-pea, chick-pea and groundnut. It appears there is a market premium for large seeds in these pulses, other things being equal, owing to the fact that there is less pericarp per unit weight. Hence, there seems to be a larger out-turn when processing bold seeds, i.e. when producing dal from pulses and kernels from groundnuts. It is planned to monitor various major pulse markets in India and take samples of each consignment of produce marketed for analysis of the various economically relevant characteristics by the biochemists, breeders and physiologists. We will also record the unit price, grade, variety, and also the yield obtained by the farmer, if possible. In this way we hope to be able to assist the plant breeders in making decisions about whether to breed for yield with little regard for seed size, or to lay more emphasis on seed size (and the presumably larger percentage of edible end-product) in the breeding program in the quest for improved food supplies per unit of farm resources, if this choice arises.

This study will be followed up soon by a similar study determining economically desirable characteristics of sorghum and millet grains. It is a well known fact that the consumers' aversion to unaccustomed color, taste and other qualities of new high yielding varieties often restricts their introduction; consequently it is imperative to study and define desirable qualities, so that they could be included in the breeding program.

SUMMARY AND CONCLUSIONS

It is difficult in a paper such as this to draw too many valid inferences as the data have been of necessity of an aggregative nature, and in many instances have referred to both the SAT and non-SAT regions of the 48 countries concerned. It is only for India and Brazil that we have been able to compile more detailed information about their SAT regions. We are continuously gathering data from individual countries with a view to obtaining a better picture of the agriculture of the SAT tracts. Nevertheless it is hoped that in this paper we have been able to highlight the relevant aspects of the agriculture of the major

SAT regions and that this will help to focus our attention on the problems facing farmers in these areas.

Some of the implications which might flow from the data compilations and analyses in the foregoing paper are as follows:

(i) Farm sizes and land/labor ratios in SAT Asia are much smaller than in SAT Africa South of the Sahara and SAT Brazil, whereas animal power/land ratios are much higher. This implies that in the development of improved farming systems for SAT Asia they might be rather more labor and animal-intensive than in the other two regions. In the strategy for the agricultural development of SAT Africa and North-eastern Brazil, therefore, more emphasis may have to be put on the development of implements and power sources than is necessary in SAT Asia.

(ii) Domestic and world prices of pulses and groundnut have increased recently relative to those of cereals. Pulses are becoming more competitive in farming systems because of this and also because of their contribution to organic nitrogen in the soil with fertilizer prices high. However, pulse yields have not kept up with some cereal yields.

(iii) Price variability, as measured by coefficients of variation of SAT crops, is less in the world market than in domestic. In India and some other SAT countries domestic prices are higher than world prices. To enter world markets these countries have to reduce costs of production.

(iv) Prices of the main SAT crops are positively correlated, hence crop diversification cannot be expected to decrease substantially the market risk of producers as opposed to the production risk.

(v) May be half of SAT Indian farms have some irrigation - more so on small farms. Research can productively be focussed on these types of farms also to develop profitable ways of integrating irrigated and rain-fed farming. This could be important in increasing and stabilizing aggregate SAT production. Of course the more urgent concern would be the development of systems for the other half or more of farms in India (and the vast majority in other SAT areas) which are entirely dependent on rainfall. Data on the irrigation status of farms in other SAT countries is required.

(vi) There is a large amount of fragmentation of farms in India. This is probably also true of other countries. Hence, group actions for agricultural development on a watershed basis will likely have to involve land consolidation and redistribution.

Again data on the fragmentation of holdings in countries other than India are required to confirm this.

(vii) Farming Systems research should measure nutrient outputs as well as yields and monetary values. This will ensure that farmers and policymakers obtain the required information upon which to base decisions.

(viii) There appears to be scope for increases in cropping intensities in all SAT countries, especially those in Africa.

(ix) Individual within-State variability of sorghum and millet yields are much higher in India than in Africa South of the Sahara, and Brazil. Hence, the need for stability in farming systems and in individual crop varieties is more pressing for Asia than Africa and Brazil. Millet growing areas also have more variability in yields than sorghum areas, indicating an even more significant stability problem for these regions.

(x) Livestock production represents 25 percent of North-eastern Brazil's agricultural production. This appears to differentiate it from other areas of SAT.

(xi) The reasons for the lack of fertilizer use in SAT Africa South of the Sahara and in SAT Brazil require investigation. It appears to be due, at least in the latter, to a lack of responsive crops and varieties.

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IMPACT OF NEW TECHNOLOGY ON SMALL-FARM AGRICULTURE

C.A. Francis*

The goal of the many international research and training centers in the developing tropics is to increase the quantity and quality of food, thereby improving human nutrition and income. Since the majority of the food is produced by a large number of 'small farmers', there is an increasing awareness by the centers that research and development efforts should focus more sharply on this group. The problems which limit production and income on the small farm are complex, and many have roots far beyond the boundaries of the individual farm. It is this complex situation which faces national agencies in charge of research and extension, and into which technological innovations must be introduced.

Research and training at the international centers have focussed on technology -- improved varieties, proper use of insecticides and fungicides, fertilizer recommendations, better cultural practices, and other innovations which have proven successful in raising yields of certain crops in certain areas. Primary emphasis has been given to genetic improvement. There has been concern by scientists and funding agencies when the results of these research activities have not been immediately adopted by farmers in a target zone. This is due in part to the wide range of problems -- many of them non-technological -- which limit the adoption and impact of our best designed innovations. The integration of appropriate crop and animal technology, the recognition of the importance of multiple cropping, and the need to reduce risk as a result of adoption of new practices or varieties are among the realities on the farm which test the relevance of technology, we are producing to the complex problems of the small farmer. These considerations have not been an integral part of most crop improvement or production systems projects, and may help to explain the limited adoption of some of our hard-earned results.

For international centers and national agencies involved in promotion of increased production to reach their objectives of development and improved human welfare, it is essential that we consider the farmer's problems in the context of his complex economic, nutritional and cultural situations. The individual crop/animal species improvement or production systems program at the centers can better assure adoption of new technology

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through an orientation from the outset to integrate each crop into the predominant multiple cropping systems in the target areas and into the crop/animal combinations which provide subsistence for the farm family. An examination of the current organization and orientation of research and resource allocation to the international centers in relation to the complex problems facing the farmer has led to the organization of our several farming-systems programs.

How does a center focus on the serious problems which presently limit production on the farm? How are resource allocation decisions made within a center and people put to work in the critical areas to cause greatest impact on the farm and help us most efficiently and rapidly meet stated objectives? What type of inter-disciplinary team can be organized to conduct research and train others, working together in the field with national agencies, to overcome the technological and other constraints which hold down production, productivity and income of the small farmer and the nutritional level of his family?

Experience in the international centers is limited, as most teams are in the early stages of organization, orientation, and field operation. The CIAT Small-Farm Systems Program is attempting to integrate biological, engineering and social science expertise to study the complexity of small farmers' problems and offer relevant alternatives within the current context on the farm which will best help the farmer increase production. Tentative guidelines which are directing our program's efforts to meet this challenge are summarized below, with the hope that a part of this experience will be useful to those in other centers. We also look to our colleagues in other centers for suggestions to improve this program. It is encouraging to find that each team and each center has taken a somewhat unique approach, dependent on the climatic and cultural situation which characterizes each region, and this range of experiences among the centers will eventually provide valuable insights into the optimum organization and allocation of resources for this type of research and development activity.

Research Methodology

A logical and systematic approach to recognize problems and provide relevant alternatives or solutions includes the following steps: (1) An analysis of present traditional systems, (2) the synthesis of prototypical systems, (3) the design of improved technology, (4) the validation of this new technology on the farm, (5) implementation of change in specific zones, and (6) evaluation of the impact of the new technology on farm income and human nutrition.

1. Analysis of present traditional systems. Typical systems of tropical agriculture in Latin America are being studied through analysis of current production, marketing and consumption on the farm. We are

describing how the farm family reaches decisions and uses available resources of time, land, energy, crops, animals, information and available services to produce food and income in the context of their current natural, economic and socio-cultural environment.

2. Synthesis of prototypical farming systems. Information and experience from the analysis phase in a specific zone are used to further study physical examples and create analytical models of prototypical farming systems, and these farms are used to predict and then test the impact of new technology.

3. Design of improved technology. Analysis and synthesis of farming systems leads to the specification of which among the available or potential technological alternatives are best suited for introduction into the small-farm system. This step identifies areas in which research has yet to provide answers to farmer's problems. In the context of the complex environment in which the small farmer operates, an understanding of the constraints which influence his production decisions leads to the selection of crop/animal species, cultural practices and levels of inputs to be studied on experiment stations and tested on the farm.

4. Validation of new technology on the farm. This process is validated by demonstrating that small farm families in a selected zone can reach their objectives through adoption of new technology selected by the process. It is necessary to demonstrate that the same procedure can be applied by national agencies to identify and quantity problems, and to generate relevant solutions elp farmers achieve their goals.

5. Implementation of the process in development. Implementation or application of the process is an appropriate role of national agencies and CIAT collaborates with these groups in specific zones to (a) develop technology, (b) design alternative systems, (c) test systems on the farm, and (d) train personnel in use of the process. Our involvement in implementation allows testing the applicability of this process within the context and the constraints of a national program, and of a specific small farm environment.

6. Evaluation of impact on the farm. The development of methodology, and identification of key indicators for evaluating the impact of new technology on farm production and income and on family nutrition and welfare is essential. This methodology is needed by national programs, international centers and lending institutions as a guide to the allocation of limited research and development resources to the activities which have greatest impact.

This process provides guidelines for identifying limiting factors on the farm and selecting research procedures and solutions which can most rapidly and efficiently solve these problems. It provides a procedure for predicting the probable adoption of research results and the impact of that adoption on food availability and income. The process suggests alternative ways for the farmer to reach his objectives. This dynamic process is useful in planning and analysis of multiple cropping/animal systems, timing of investment and changes on the farm, and sequencing the development and introduction of other new technologies.

The CIAT Small-Farm Systems Program operates in collaboration with national agricultural development agencies and the CIAT commodity teams to provide information and methodology for identifying problems and predicting the impact of technology or other solutions. The ultimate clients of our programs are the small-farm families of Latin America which benefit from the implementation of research results by national agencies.

UNDERSTANDING THE SMALL-FARM SYSTEM

To select the appropriate available technology which will be adopted by small farmers, and to stimulate the development of relevant solutions to additional problems, it is essential to understand the complex socio-economic, ecological, and nutritional situation in which the family operates. The first step in the process outlined above is analysis of present systems, and this must include an evaluation of present and potential agricultural production, economic and nutritional status of the family, and cultural variables which influence the decision-making process and adoption of change. The problems which farmers perceive as most limiting, and the ways in which they describe these problems in relation to agricultural production, are important in our selection of research priorities and design of relevant innovations and their introduction. The design of an alternative technology or an improvement on the farm is most useful if generated within the context of the farmer's current system, and this will facilitate eventual adoption. Development of technology which is not realistic for farm adoption within the constraints which characterize the farmer's operation, or which does not answer immediate problems that limit production, is a luxury which we cannot afford in light of the immediacy and severity of problems which currently hold back agricultural production and rural development.

Many of the most serious problems which influence productivity, farm production and income are non-technological. There are government policies and limitations in infra-structure which may cancel the potential effects of new technology, and our centers' research and training activities have spent relatively little time on these problems. Although there are many problems beyond the reach of our organizations, there are at least two reasons why we must understand and quantify these constraints and relate these to the development and introduction of new technology. First, the importance of non-technological problems and the probability of overcoming them may dictate our selection of zones, crops and research strategies to provide change within the farm environment. If the short supply of a production input such as fertilizer is not likely to change, research should concentrate on alternatives such as maximum response to limited quantities, selection of varieties for low fertility conditions, recommendation of appropriate rotations with legumes, or a shift to other species which are more adaptable to low fertility. A second reason is to search out the route for overcoming these constraints, even though the solutions may be beyond the responsibility of our research and training organizations. To specify and analyze a problem and provide relevant information to the appropriate government institution or ministry is the first step toward change.

Inter-Disciplinary Team Organization

The inter-disciplinary team is a current solution to the complex challenges which face industry and governments, and which has proven effective in such difficult challenging tasks as putting a man in orbit and on the moon. The inter-disciplinary work is valuable, and in many situations essential, but is not a panacea which will magically and automatically solve all problems in development.

Ideally, the integrated and inter-disciplinary research team is a pre-requisite of a program with specific research and development objectives, and a result of some preliminary understanding of the most serious limiting problems. From an assessment of what limits production and farm income, the researchable parts of the problem are identified and specialists recruited to work in their respective areas on the same problem. Although there is much leeway on how to solve problems, and even a continuous review of which problems are most relevant, the recruiting of new personnel should be dictated by the need to solve specific known problems of small farmers.

To operate effectively and solve complex problems on the farm, the team must reach beyond the traditional limits of concern about technological solutions, and must be more than a collection of highly competent scientists, each working in his own area. After assessing the problems currently limiting production on the small farms in Latin America, we have chosen a team which reflects the complexity of our situation. The core team currently includes an agricultural economist, anthropologist, agronomist, rural sociologist and a systems engineer. Direct support from commodity programs in agronomy, plant protection, agricultural engineering and training complement the full-time team. Additional expertise is needed in animal production, human nutrition, communications, and soil science. However diverse these specialities may sound, the focus of all individuals is on identification and resolution of the serious production-limiting problems which are found on the farm.

Design of Appropriate Technology

Although highest efficienty and most profitable results on the farm in temperate zones have occurred in single crop culture and independent animal enterprises; a much different set of objectives and constraints often characterize the small farm in Latin America. The uncertainty of climate and the operation of small farmers so near the edge of subsistence and poverty make risk one of the single most important factors in the decision-making process. The small farmer often reduces this risk by planting a series of crops at the same time, or on successive dates, in the same field. This system which we have too-often rejected as 'traditional' 'primitive; or inefficient', assures the farmer of a continous food supply when insects, diseases or drought seriously affect one crop. The systems also helps to diversify his family's diet. Before recommending a drastic change in this system, we should fully understand how and why the farmer has chosen his present system and be sure that modifications will guarantee an increase in production or quality, or reduce risk. Even better is a concentration on research which considers changes of variety, planting date, fertilizer or pesticide recommendations within the system which is known to the farmer. New systems or changes in crop/animal species must be relevant to the ecology and culture of a zone, and acceptable to the farmer.

The small farm in Latin America almost always includes some animals as a part of the system. Although there are 'subsistence' farms with primarily animal operations, ie. some beef cattle renches in the Colombian llanos, most small farms are crop orientated, with income and family nutrition supplemented by small animals (poultry, rabbits, guinea pigs, fish) or other larger species (swine, sheep, goats, or cattle). An important aspect of most animal and crop activities on the small farm is the interaction among these species and the complexity of the biological system which provides a direct food resource for the family, feed for animals, and some animal products for home consumption. The designing of new technology, or the adapting of existing technology, to meet these complex production, economic, and nutritional needs of the small farm family, is a challenge to our capacities as research and development specialists. In this task, our own traditional, discipline-oriented training may have only limited utility.

What are the basic components of these farming systems, and how can they be studied? With the risk of over-generalizing a complex situation, several points can be specified. Multiple cropping in some form is an integral part of many small-farm operations, and a research focus on understanding the complex interactions among crop species is badly needed. This includes light and nutrient competition, population and planting date combinations, species mixes of two or more crops, and the decision-making process which leads to a particular cropping system in the field. Small animals make a significant contribution to the protein needs of a farm family; our international centers should give more attention to animal protein production with these species, or help specific national programs to locate and mobilize funds for this research task. The feed supply for animals on the small farm is generally a bye-product of other crop production for direct human consumption. In our improvement efforts on individual crops or the design of production technology, both the multiple-cropping and animal participation in these systems must be considered. These multiple crop/animal schemes help to reduce risk and to spread income over the year. Concentration of research on the farm under the same conditions as those existing on farmers' fields can facilitate the transfer of technology, once these alternative systems have been designed and tested.

Integration of Commodity Programs

The development of inter-disciplinary, commodity-orientated research teams in the several international centers has already produced tangible and valuable results in some crops. The interaction among specialists who are capable of considering complex production problems from several points of view can also lead to a better understanding of the small farm production situation. Critical to the success of the farming systems programs, and to the international centers in reaching their objectives, is an integration of systems research with the current activities of the commodity programs. The systems team in each center, through continuous visits to farmers and assessment of their problems, can present new challenges to the specific crop and animal teams. The results of these teams' activities, in terms of varieties, improved practices, insect and disease prevention or resistance, and application of new technology can logically be put into practice through the activities of a systems team, whether its objectives focus on multiple cropping (IRRI), slash and burn agriculture (IITA), maximizing use of scarce moisture (ICRISAT), or introduction of technology into a complex socio-economic small-farm system (CIAT). And the integration must extend beyond the teams of each center and each country's national programs to the international network of research centers.

Complete Process of Development

From their inception, national programs of the foundations in the developing tropics, and more recently the international centers have concentrated on research and training. Activities in extension, rural development, communications and other applied aspects have been relegated to specialists in other agencies. Although an efficient use of specialized personnel, and even a logical and convenient system from an organizational standpoint, the administrative separation of research from extension has too often led to a breakdown in communications, and as a result neither group meets its objectives. There is a similar potential danger in the concentration on research in the international centers.

If we cannot assure that results will reach the farmer, nor continually assess the priorities which various alternative activities should have within a program, we may be unsuccessful in our attempts to increase food production, stimulate economic development, and improve human welfare.

Some level of activity in monitoring current production problems, and assessing their priorities for research, is clearly indicated for our production-oriented commodity research programs. And a concern for the entire chain of events from problem identification, to research results in the center and their applications on the farm can help assure the practical use of this information and germplasm, as well as lead the centers meet their stated objectives. The training components in each center can help to meet this need for communication through national agencies to the farmer. The systems programs in several centers can also catalyze this process of integration, and may provide the most efficient route to understanding how available technology can be brought to bear on the most critical problems limiting production.

CONCLUSIONS

Goals of the international centers are to increase production and productivity, and to stimulate economic development in the tropics. To integrate appropriate crop and animal production technology, and to make these alternatives relevant to the complex problems which face the small farmers is a challenge to the centers and to their newly organized systems or multiple-cropping teams. The research methodology in use in CIAT includes (1) analysis of traditional systems, (2) synthesis of prototype systems, (3) design of relevant improved technology, (4) validation of technology on the farm, (5) implementation and multiplication in specific zones, and (6) evaluation of impact on farm production, income, and family welfare.

It is essential to understand the small-farm system, and how the farmer perceives his most limiting problems. Generation and testing of technology within the context of the small-farm situation is one approach to assuring relevance and use of the solutions to these problems. The importance of non-technological constraints, many of which have roots far beyond the boundaries of the farm, must be realized, and solutions sought which are operational within the complex economic, cultural and political environment of the small farmer. An inter-disciplinary team is crucial to this research, and the specialists currently working in CIAT include an economist, anthropologist, agronomist, sociologist, and a systems engineer. Additional support is needed in animal production, plant protection, engineering, training, human nutrition and communications.

The appropriate technology to offer to small farmers includes alternatives which are realistic within his present system, and often improvements in a multiple-cropping system or a crop/animal species mixture which maximizes food production and return from available resources. Integration of commodity programs of other centers is critical to a successful design and testing of appropriate technology, and provides valuable feedback to the specific teams. Finally, the involvement of international centers in understanding and participating in the entire process of development from problem identification to implementation and evaluation of impact on the farm is critical to our assurance that technological solutions generated in our programs can reach the farm and solve real problems which limit production. The systems programs in our several centers can stimulate this orientation, and supply the linkages needed with national programs to provide a realistic application of research results on the farm.

SYSTEMS OF CROPPING IN THE DRY TROPICAL ZONE OF WEST AFRICA - WITH SPECIAL REFERENCE TO SENEGAL[+]

C. Charreau*

In this paper we shall review the following items: Systems of cropping, rotations, multiple cropping, experimental data concerning the combinations of mineral fertilization and soil tillage, and economic considerations. We shall also discuss the problems of soil management in the main ecological regions in the dry tropical zone of West Africa and suggest measures for the future agricultural development of this zone.

1. SYSTEMS OF CROPPING

It is convenient to distinguish four broad categories of systems of cropping, differing in their degree of intensity: (a) Present peasant systems or so-called 'traditional' system, (b) improved traditional systems, (c) semi-intensive systems, and (d) intensive systems of cropping. Their main characteristics will be described, referring mainly to Senegalese examples before discussing their comparative effects on soils, crops and economic returns.

1.1 Present Peasant Systems of Cropping

The present peasant farming systems or so-called 'traditional' systems have undergone numerous and great changes. These changes have resulted from increasing population pressure and from the development of

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cash crops; they concern mainly the duration of the fallow period and the ratio of cultivated to fallow land.

The main characteristics of these systems may be summarized as follows:

Progressive clearing of land; removal of stumps, if any.

'Half' shifting cultivation: The villages are permanent, only the fields change. The cropping cycles are broken by fallows, the duration of which is decreasing more and more.

Livestock may be present, but there is no true mixed farming. Owing to the lack of animal power, it is not possible to have deep tillage and to incorporate harvested residues or grass fallow into the soil.

Owing to inadequate equipment, there is poor control of weeds.

Mineral fertilization is absent or inadequate.

The number of plants which can be cropped is limited, species and varieties having high requirements for water; and mineral elements cannot be utilized.

Rotations are more or less without definite plan.

Association of plants on the same field (multiple cropping) is frequent.

Selected varieties are little used.

Control of diseases and parasites is inadequate.

As noted above, despite low yields, such systems can no longer maintain soil fertility, in contrast to former traditional systems based on short cropping cycles and long resting periods.

1.2 Improved Traditional Systems

As a first step, agronomists tried to improve the peasant systems of cropping without upsetting the basic system and using only techniques adapted to the very low financial resources of farmers. Efforts were made successively on the following:

Use of high-yielding and disease-resistant varieties.

Disinfection of seeds, which is an inexpensive and beneficial operation; in some cases (mainly for cotton), control of diseases and pests during the vegetative cycle.

Improvement of cultural techniques: plant population, planting in rows making hand or mechanical control of weeds easier, adequate timing of cultural operations, use of horse draft and light equipment for planting, application of fertilizers, and mechanical weeding.

Use of low amounts of mineral fertilizers in the most profitable crops to minimize the burden on the farmers' finances.

Adoption of defined cultural successions and intercultivation in the rotations of short-lasting grass fallows.

1.3 Semi-intensive Systems

Compared with the preceding systems, semi-intensive systems are characterized by the development of mechanized cultivation by drought-oxen. This implies total removal of stumps and permanent settlement of fields. Regular plowing brings about an improvement of soil macro-structure, promotes better plant rooting and helps in the control of weeds, thus resulting in increased yields. In these systems the land under grass fallow or green manure is plowed every four or five years. Only superficial tillage is practised in the other years. Crop rotations are interrupted every four or five years by a grass fallow which does not last more than one or two years. Grass fallow is often replaced by a green manure crop, generally pearl-millet or sorghum, planted at high density as a forage crop and the regrowth plowed under after grazing. As in the preceding systems, improved cultural techniques, varieties, and weed and disease-control practices are followed. Mineral fertilization is heavier and additions of mineral elements are calculated to maintain soil fertility.

1.4 Intensive Systems

In these systems, there is continuous cultivation without interruption of the rotation by resting periods of fallow or green manure. Plowing land under fallow or green manure is replaced by plowing under straw of short season cereals. Plowing and incorporation of vegetative matter in the soils are made as often as possible. Due to the objective of plowing under straw, the use of new, short season varieties of cereals is more common than in the preceding systems. In some cases animal power is replaced by motor power.

Table 1 summarizes the main technical characteristics of the systems of cropping described above.

2. ROTATIONS

Rotations vary according to the various systems of cropping.

Table 1. Major Characteristics of the Various Systems of Cropping Investigated in Senegal

Systems of cropping	Type of cultivation	Type of management Systems	Removal of Stumps	Soil tillage	Rotation	Fallow	Crop residues	Weeding	Mineral Fertilization
1. Present systems (F_0T_0)	Hand	Shifting cultivation	Very incomplete	Superficial	No fixed plans	Variable duration burned	Removed from field or burned	Hand — inadequate	Nil
2. Improved traditional systems (F_1T_1)	Horse or mule draught	Partially shifting cultivation	Partial	Superficial	4-6 years rotation including fallow	1-3 years duration burned	Burned	Hand and mechanical	Slight
3. Semi-intensive systems (F_2T_2)	Oxen draught	Permanent cropping	Total	Plowing under fallow	4-5 years rotation including fallow	1-2 years of grass fallow or green manure plowed under	Burned	Mechanical and hand; adequate	Heavy
4. Intensive systems	Oxen draught or tractor	Permanent cropping	Total	Plowing under crop residues	Continuous cropping	No fallow	Mostly plowed under	Mechanical, hand, and chemical; adequate	Heavy

2.1 Rotations in the Present Peasant Systems and in Improved Traditional Systems

In the present peasant systems, it does not seem that precise rules exist for crop sequences. The latter depend mainly on the food crop to cash crop ratio, which is largely influenced by the population and ecological conditions. The number of combinations is indeed limited, as few species and varieties can be cropped under conditions of low fertility.

In the improved traditional systems, the number of cultivated plants is also limited due to inadequate improvement of soil properties. In Senegal, for example, only two cereals, pearl-millet and sorghum, and two legumes, groundnut and cowpea, are commonly cropped in these systems. Other crops, such as cassava, may be grown outside the rotation. The most commonly recommended rotation is: Grass fallow - groundnut - cereal - groundnut. The duration of grass fallow is theoretically a function of the ecology. It is one or two years in the wet southern zone and three to four years in the dry northern zone. In fact, the duration of fallow is largely determined by the population pressure. In some regions where the population is more than 70 to 80 inhabitants per square kilometer, fallows have practically disappeared. In these systems where plowing is not practised, fallows are burned before cultivation.

Attempts have been made to analyze the agronomic effects of these short-period grass fallows (Charreau, 1972-73).

Compared to the annual cropping, the beneficial effects of fallows on soil properties can be listed as follows:

Better protection of soil against wind and water erosion, mainly during the dry season and at the beginning of the wet season;

A slight action of roots on soil structure; this action is less localized than that of annual crops (mainly cereals) and concerns the whole surface of the field;

A noticeable influence on the phosphorus-potassium balance, due to the decreased removal by vegetation;

A specific effect on the potassium nutrition of the crop due to the increase in potassium availability.

As for the humus balance, the effect of these short-period grass fallows does not seem to differ significantly from those of annual crops.

The disadvantages of grass fallows in relation to annual crops are the following: Increase in weeds making weed control more difficult for the following crops; waste of water stored in soil at the beginning of the dry season, which may result in very depressive effects on the succeeding crop if rains at the beginning of the following wet season are inadequate; and economic deficit, which can be partly offset if the grass fallow is used as a temporary meadow for cattle grazing.

Effects of length, nature and various treatments of grass fallows on crop yields were studied in many long-term experiments, especially by IRHO[1] in Senegal (IRHO-Senegal, 1960-1968; IRHO-Senegal, 1962-68). From these data, it seems that the effects of burned short-term grass fallows on crops yields would be of some importance in the poorest and driest regions (northern and central Senegal) and of little importance in the regions where soils and climates are more favorable to agriculture, as in southern Senegal (Charreau, 1972-73).

2.2 Rotations in the Semi-intensive Systems of Cropping

In the semi-intensive systems of cropping, the duration of grass fallow is reduced to one year. It can, however, be two years, in the driest regions. As the grass fallow is incorporated in the soil by plowing at the end of the rains, effects on soil properties are much more beneficial than in the case of burned grass fallow. Soil macro-structure is largely improved for two or three years, resulting in beneficial effects on rooting of the succeeding crop. Water stored in the soil profile by the end of the rainy season is conserved throughout the dry season. Control of weeds is easier. Effects on the humus balance are likely to be more marked, although there is little evidence of this. Grass fallow can be replaced by a green manure or an annual forage crop. Pearl-millet and sorghum, planted at high density, are most commonly used for this purpose. By the end of August, the forage is mowed and the regrowth is plowed under by the end of September or in October. It is thus possible to combine the benefits of soil improvement and of forage production. Such green manures or annual forage crops have about the same benefits on soils as grass fallow but they usually have a higher production in dry matter and are more easily mowed and plowed under than natural grass fallow. On the other hand, their extension to farmers is more difficult (Charreau and Nicou, 1971).

After plowing under the fallow or green manure, the cropping sequence which has been recommended for a long time in Senegal is the same as in the improved traditional systems of cultivation, that is: one year of fallow or green manure plowed under - groundnut - cereal - groundnut or cowpea. The cereal usually is a long-season pearl-millet or sorghum.

2.3 Rotations in the intensive systems of cropping

In these systems, recently studied, the resting period is eliminated and plowing under grass fallow or green manure is replaced by plowing

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[1] Institute de Recherches pour les Huiles et Oleagineux or Research Institute for Oil and Oil Crops.

under straw of short-season cereals. The beneficial effects on soil properties have proven to be about the same (Charreau and Nicou, 1971). This was made possible by the recent development of new short-stem and short-cycle varieties of cereals: pearl-millet, sorghum, maize, and rain-fed rice.

As soil fertility is largely improved by soil tillage, incorporation of organic matter and sufficient addition of mineral fertilizers, more species and varieties of plants can be cropped. This cropping sequences are also more varied.

Some general rules can be drawn from rotation trials conducted in Senegal (IRAT-Senegal, 1972):

(i) Groundnuts grow well after any crop but benefit little from plowing and incorporating vegetative matter into the soil. Groundnut is a good crop to precede any cereal, especially rain-fed rice.

(ii) Cotton gives the best yields after maize, groundnut, and pearl-millet. It is better to avoid growing it after sorghum. Two successive years of cotton within three years of cultivation is not recommended. Cotton is the best crop to precede maize.

(iii) Crops suited for growing before maize are: Cotton, green manure or grass fallow plowed under, groundnut. Maize is the best crop to precede cotton.

(iv) Rain-fed rice is not a good crop to precede any crop. On upland soils, two successive rain-fed rice crops must be avoided. Groundnut is the best crop to precede rain-fed rice.

(v) Sorghum grows well after any crop, especially after cotton and groundnut. On sandy to coarse loamy soils, sorghum is a poor crop to precede many crops and in particular cotton and sorghum itself. It is better to avoid growing two successive sorghum crops and even two sorghum crops within three years.

On these bases, several models of rotations were proposed for the different ecologic zones of Senegal. The major characteristics of these zones are summarized in Table 2.

In the northern and central zones, the rainfall is low and irregular and the introduction of new crops is difficult without irrigation. The major crops grown are groundnut (several varieties), pearl-millet, and to a lesser extent, sorghum and cowpea.

Due to the short and variable rainy season, plowing after early groundnut and early pearl-millet are possible in some years but not every year. It is, therefore, necessary to use pearl-millet as a green manure

Table 2. Major Characteristics of the Main Ecological Zones in Senegal

Zone	Mean annual rainfall mm	Number of humid months (R ≥ 50 mm)	Main parent materials	Main Soils
Northern	250 - 500	2-3	Eolian deposits[1]	Brown and reddish brown sub-arid (Orthids)[1]
Central	500 - 750	3-4	Eolian deposits	Slightly leached ferruginous soils (Orthids and Ustropepts)
Sine-Saloum	750 - 900	4-5	(Eolian deposits) + Clayey sandstones from continental terminal[2]	Leached ferruginous soils (Haplustalfs, Paleustalfs, Phinthustalfs) + slightly desaturated impoverished ferrallitic soils (Alfic Eutrustox)[2]
Eastern	750 - 1000	4-5	Clayey sandstones from continental terminal[3]	" " "
Southern	1000 - 1500	5-6	"	" " "

1 Also in this zone are alluvial deposits of the Senegal River with hydromorphic and halomorphic soils occupy a large area.
2 Also in this zone are alluvial soils of the Sine, Saloum and Gambia Rivers, with hydromorphic and halomorphic soils occupy a large area.
3 Also in this Zone, toward the southeast, are primary outcrops with various rocks and soils.

or have a grass fallow plowed under at the beginning of the rotation. The classic four year rotation: Fallow or pearl-millet as green manure - groundnut - cereal - groundnut is always of value.

As a cereal does better than groundnut after the fallow or green manure is plowed under and as the effects of this plowing last more than three years a five-year rotation may also be recommended: Fallow or green manure - pearl-millet - groundnut - pearl-millet - groundnut. Other rotations making broader use of groundnut as a cash crop may also be considered and are under study.

In the Sine-Saloum and the eastern regions, three crops recently introduced are in progressive development. They are: cotton, maize and rain-fed rice. In these regions the rainy season is long enough to enable one to replace the plowing under of fallow or green manure with the incorporating of the straw of short-season cereals into the soil. This technique has the same benefits for the soil as plowing under the green manure or grass fallow with an additional benefit resulting from easier control of weeds for the following crops.

On these bases many combinations are possible for a four-year rotation.

For the first year, there is a choice between a fallow or a green manure plowed under or a short-season cereal (maize, rain-fed rice, early pearl-millet), the straw of which incorporated into the soil by plowing,

For the second year: Cotton or groundnut,

For the third year: Long-season cereal (sorghum, late pearl-millet, rain-fed rice),

For the fourth year: Groundnut.

The balance between food crops and cash crops is adequate. From this model many combinations are possible providing substantial flexibility in the choice of rotation. The most common rotations in these regions are: (a) Fallow plowed under groundnut - sorghum - groundnut, (b) Fallow plowed under cotton - sorghum - groundnut, and (c) Early pearl-millet or maize - cotton - sorghum or rain-fed rice-groundnut.

In the southern region it is impossible to grow cotton due to the high rainfall resulting in a high incidence of diseases. Groundnut is, therefore, the only cash crop. On the other hand, the ecological conditions are favorable for all cereals, which can produce high yields. From an agronomic standpoint, it would be feasible to establish rotations where cereals predominate, but from an economic standpoint there is a marketing problem in the sale of cereals for livestock production, a problem which is not yet solved in Senegal.

Two kinds of rotations are presently practised:

(1) A four-year rotation: Fallow plowed under-maize-rainfed rice-groundnut; or

(2) A three-year rotation: Maize (with straw incorporated into soil)-rain-fed rice or late pearl-millet - groundnut.

Studies on rotations are still going on in Senegal and other countries of dry West Africa. Special attention should now be paid to two topics which might become of increasing interest due to present changes in economic conditions. They are: (i) The use of legumes as an annual forage crop and/or green manure for replacing grass fallow, or cereals used as forage or green manure, and (ii) the introduction in the rotation of annual or perennial crops with deep rooting, such as Cajanus cajan (Pigeon-pea).

Legumes as green manure or/and forage were studied many years ago in French-speaking countries but for various reasons, both technical and economic, they were judged to be of secondary interest and their study was somewhat neglected. As nitrogen fertilizers are now very expensive in these regions, and as substantial progress has been achieved in recent years in soil and crop science, including inoculation of legumes, this question should be examined again with a new perspective.

In the same manner, deep-rooted plants would be useful for recovering the mineral elements lost by leaching from surface soil layers. This would save appreciable amounts of fertilizers. Lucerne (alfalfa) plays this role in temperate and Mediterranean countries. Pigeon-pea (Cajanus cajan) or other plants could play a similar role in tropical countries. More thorough studies should be undertaken on this.

3. MULTIPLE CROPPING

Multiple cropping is the general rule in traditional systems of cropping. The most common associations of plants in the same field are: Groundnut and cereals (pearl-millet or sorghum) and pearl-millet and cowpea (in the northern zone). Multiple cropping has many advantages in the exploitation of moisture and mineral reserves of the soil by the differential rooting of the crops, more effective use of light, the modification of microclimate, and the soil cover. Some experiments on multiple cropping have been carried out in Senegal (Nicou, 1964-65; Charreau and Nicou, 1971; Schilling, 1965) and in Niger (Nabos, 1963-65); they generally showed a slight agronomic superiority of multiple cropping over monoculture.

In mechanized systems, however, single cropping is generally preferred to multiple cropping because soil tillage, planting, mechanical weeding, and fertilization are done more easily in this system.

Some recent experiments in an equatorial or humid tropical zone with or without irrigation (Bradfield, 1970) have showed that mechanization and multiple cropping are not incompatible. The use of the soil is very intensive and the productivity per surface unit reaches record levels. The cultural system is very sophisticated and cannot be practised by farmers unless an effective extension service is developed. For this reason, such systems cannot be extended very widely but can be used as reference models.

In the dry tropical zone, possibilities of land use without irrigation are less and experiments on intensive multiple cropping are few. Some carried out in northern Nigeria, however, gave promising results. More such studies need to be carried out.

4. EXPERIMENTS ON SYSTEMS OF CROPPING IN SENEGAL

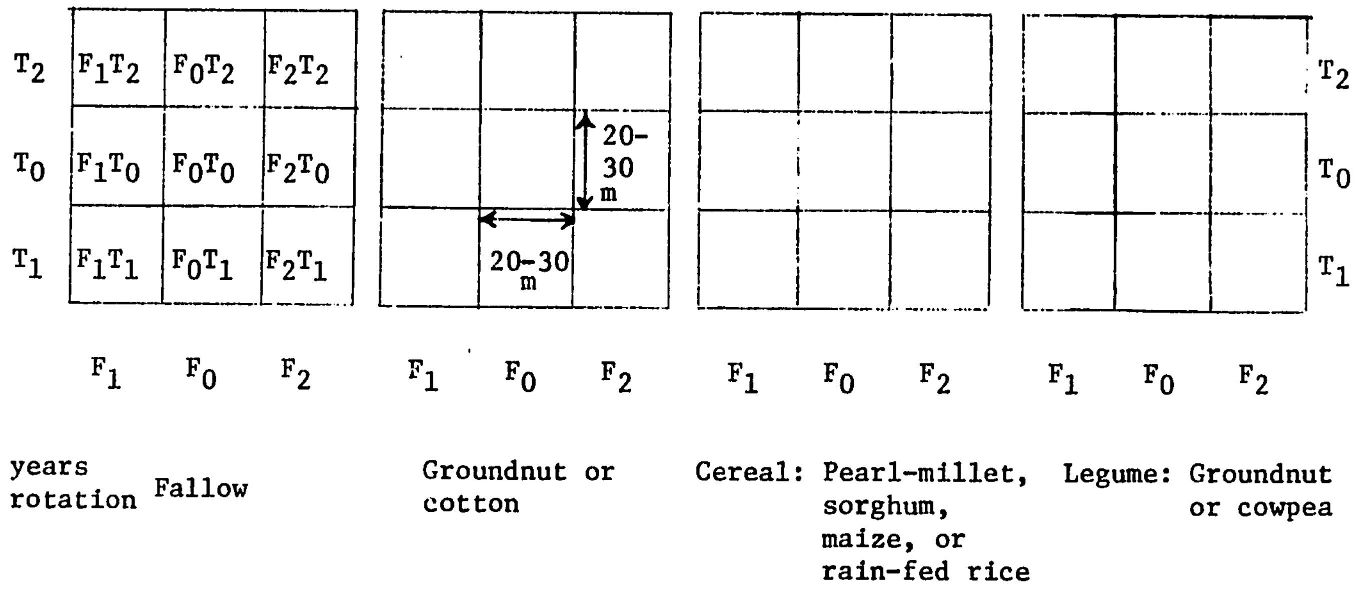
4.1 Generalizations

Separate and combined effects of soil tillage, the incorporation of vegetative matter in the soil, and mineral fertilization have been studied in long-term factorial experiments in Senegal since 1963. These experiments were carried out at about 15 sites, distributed in the various ecological regions of the country (IRAT-Senegal, 1972).

At all sites crops were in a four-year rotation but the rotation varied from one site to another. All crops of each rotation were represented every year. There was no replication. So at each site the experiment comprised four blocks - each block having one crop of the rotation for the year considered. The area of the blocks ranged from 4000 to 9000 m^2. As shown in Table 3 each block contained nine plots. The area of these plots ranged from 400 to 900 m^2, which was much larger than the area of the usual experimental plots (30 to 50 m^2) and approached the area of farmers' fields. The nine plots represented the nine treatments in the factorial combination of two factors, each of them at three levels. The factors were: Mineral fertilization and soil tillage. The levels of mineral fertilization were: F_o, and F_1, and F_2. The amounts of mineral fertilizers corresponding to these different levels are shown in Table 3. Level F_1 corresponds to the fertilization levels which are presently recommended. Level F_2 corresponds to fertilization recommended in semi-intensive systems.

Levels of soil tillage are: T_o, T_1, and T_2. Corresponding treatments

Table 3. Factorial Experimental Designs for the Study of the Combined Effects of Soil Tillage and Mineral Fertilizers in Senegal



Soil tillage: T

T_0: Superficial hand tillage - burning of fallow and harvested residues

T_1: Superficial tillage with horse draft - burning of fallow and harvested residues

T_2: Plowing under of the fallow with oxen draft - burning of harvested residues

Mineral Fertilization: F

F_0: No mineral fertilization

F_1: Light annual complete fertilization
Groundnut and cowpea: 150 kg/ha of 6-20-10
Cereals: 150 kg/ha of 14-7-7
Cotton : 50 kg/ha of ammonium sulphate + 50 kg/ha of dicalcic phosphate

F_2: Heavy fertilization, distributed over the rotation
Fallow : 500-700 kg/ha of rock phosphate (190-266 kg of P_2O_5/ha)
Legumes: 91 kg/ha of KCl (55 kg of K_2O/ha) + 30-50kg/ha of ammonium sulphate
Cotton : 133 kg/ha of ammonium sulphate + 62 kg/ha of KCl + 17 kg/ha of dicalcic phosphate
Cereals: 150 kg/ha of ammonium sulphate + 60 kg/ha of urea.

are indicated in Table 3. T_1 corresponds to superficial tillage with horse draft which is recommended for the improvement of traditional systems; T_2 corresponds to soil tillage used in the semi-intensive systems, that is, only one plowing during the four-year rotation. This plowing incorporates the vegetative matter of grass fallow into the soil.

Among the nine factorial combinations studied, only three will be considered here. They are: F_o T_o, F_1 T_1, and F_2 T_2; these combinations correspond to three systems of cropping.

F_oT_o is the so-called 'traditional' system, that is, the present system without mineral fertilization, without adequate soil tillage, and without incorporation of vegetative matter into the soil. Only hand cultivation is practiced. In these experiments, the F_oT_o treatment actually is an improvement of the traditional system because crops are in a regular rotation, varieties are improved, plant population is increased, and timing of cultural operations, weeding, and control of diseases are adequate.

F_1T_1 corresponds to the 'improved traditional systems', that is the system which is presently recommended for extensive use.

F_2T_2 corresponds to the 'semi-intensive' systems which are used by advanced farmers in limited areas. The four-year rotations are shaped as follows:

First year - Grass fallow everywhere

Second year - groundnut, cotton or maize

Third year - cereal (pearl-millet, sorghum, maize, rain-fed rice)

Fourth year - groundnut or cowpea

4.2 Agronomic Results

Comparative agronomic results for various crops and regions are shown in Table 4.

As can be seen from these data for all plants and all regions, crop yields were higher in the improved traditional systems (F_1T_1) than in the peasants' systems (F_oT_o), and they were higher in the semi-intensive systems (F_2T_2) than in the improved traditional systems (F_1T_1)[1]. Differences between F_1T_1 and F_oT_o were generally higher than that between F_2T_2 and F_1T_1. Substantial increases in yields, however, could

[1] An exception is groundnut in the central zone.

Table 4. Comparative Agronomic Results from Three Systems of Cropping in Senegal, for Various Crops and Regions*

Crops	Regions	Number of experimental sites	Years of comparison	Number of annual results	Yields kg/ha			Yield indices		
					F_0T_0	F_1T_1	F_2T_2	F_0T_0	F_1T_1	F_2T_2
Pearl-millet	Northern	2	66-70	9	578	689	948	84	100	133
	Center	3	65-70	13	366	688	999	53	100	145
	Southern	3	63-70	13	1,105	1,763	2,429	63	100	138
	Weighted mean	8	63-70	35	695	1,088	1,517	64	100	139
Sorghum	Sine-Saloum	5	65-70	28	893	1,597	2,100	56	100	131
	Eastern	4	65-68	9	1,086	1,723	2,729	63	100	158
	Southern	1	67-68	2	1,617	1,905	2,190	85	100	115
	Weighted mean	10	65-68	39	975	1,642	2,166	59	100	132
Maize	Eastern	1	66-68	3	792	1,338	2,425	50	100	182
	Southern	1	67-70	4	168	1,284	2,684	13	100	209
	Weighted mean	2	66-70	7	436	1,308	2,573	33	100	197
Rain-fed rice	Southern	3	68-71	9	443	1,711	2,630	26	100	154
Cotton	Eastern	2	65-68	6	1,109	1,531	2,061	67	100	135
Ground-nut	Northern	2	65-70	10	861	920	1,044	94	100	114
	Center	3	65-70	30	998	1,238	1,154	81	100	93
	Sine-Saloum	5	65-70	52	1,454	1,732	1,997	84	100	115
	Eastern	4	65-68	26	1,426	2,232	2,339	64	100	105
	Southern	3	63-70	19	1,644	1,905	2,072	86	100	109
	Weighted mean	17	63-70	137	1,311	1,669	1,821	79	100	109
Cowpea	Northern	2	65-70	9	653	727	875	90	100	120

* Source: IRAT - Senegal, 1972

Mineral fertilization
- F_0: No fertilization
- F_1: Light fertilization
- F_2: Heavy fertilization

Soil tillage
- T_0: Hand superficial tillage
- T_1: Superficial tillage with horse draft
- T_2: Deep tillage (plowing) with oxen draft

Systems of Cropping
- F_0T_0: Traditional shifting cultivation
- F_1T_1: Improved shifting cultivation
- F_2T_2: Semi-intensive cultivation

be obtained going from F_1T_1 to F_2T_2. The magnitude of these increases depended on (a) the ecological zone and (b) the nature of the crop. In general, increases were higher in the southern and eastern zone than in the northern and central zone. They were also generally higher with cereals and cotton than with groundnut.

4.3 Economic Data

Economic calculations were made in these experiments to compare the net benefits from the various systems of cropping. These benefits have been calculated per unit area and per man.

Income per unit area. As the rotation was the same for the three systems, the net benefits per unit area could be computed from the equation:

$$E = \underset{\sim}{M} \times S - Cf \qquad (1)$$

where E = net benefits for the area in the rotation

$\underset{\sim}{M}$ = difference between gross returns and variable costs of the rotation

S = area of the rotation in ha

Cf = fixed charges for the area of the rotation.

As $\underset{\sim}{M}$ and Cf are constant for a given site, E is a linear function of S.

Calculations were made in 1972 in Francs C.F.A., which is the currency used in Senegal (IRAT-Senegal, 1972). They were then transformed into U.S. \$ on the basis of 1 U.S. \$ = 250 Francs C.F.A.

It should be mentioned that due to recent increases in the cost of fertilizers after the energy crisis, the same calculations made in 1974 would result in quite different figures. Net benefits would be lower in F_1T_1 and F_2T_2 systems.

Calculations of $\underset{\sim}{M}$ included on one hand the value of the crops and on the other, the cost of seeds, pesticides, and fertilizers used in the various systems. The cost of fertilizers was by far the most important of the inputs.

Calculations of Cf included the annual charges of amortizing the purchase of draft animals and mechnical equipment and the annual expenses for feeding draft animals.

The area which can be cropped by one draught animal and the corresponding mechanical equipment are limited and variable in the different zones. It depends mainly on weed control which requires an increasing number of work hours going from north to south. Areas which can be cropped by one drought animal in the different regions are as follows:

	Northern and central regions	Sine-Saloum region	Eastern region
F_1T_1 (1 horse)	8 ha	6 ha	4 ha
F_2T_2 (1 pair of oxen)	16 ha	10 ha	8 ha

Above these area limits the farmer must buy a second draught animal with the corresponding mechanical equipment. This results in a doubling of the annual fixed charges and a break in the linear curves representing the net income versus the cropped area.

Comparisons of net incomes versus cropped areas in three systems of cropping are shown in Figs.1 and 2 for four regions in Senegal. They concern five rotations with various crops.

As can be seen, the net incomes are very variable depending on the regions. They are low in the northern and central regions where climates and soils are not favorable to agriculture; they increase in the Sine-Saloum and, above all, in the eastern region where both climates and soils are better.

Economic responses to the three systems of cropping are also quite variable depending on the regions and the rotations. Considering Fig.1, it is seen that improved systems are not profitable in the northern zone; in the central zone with higher rainfall, the economic result of improved systems approach those of traditional systems on sandy soils; in the same zone, but on more clayey soils (Interdune) where sorghum can be cropped instead of pearl-millet, profits are higher on F_2T_2 than on F_oT_o and F_1T_1, resulting from large increases in yields of sorghum through plowing and heavy fertilization.

In Fig.2, the three systems of cropping show little differences in profits in the Sine-Saloum region in contrast to the eastern zone where profits from F_1T_1 are clearly higher than from F_oT_o and profits from F_2T_2 are clearly higher than from F_1T_1. It will be noted that differences in profits between F_2T_2 and F_1T_1 increase in this zone when cotton is substituted for groundnut as the second crop of the rotation.

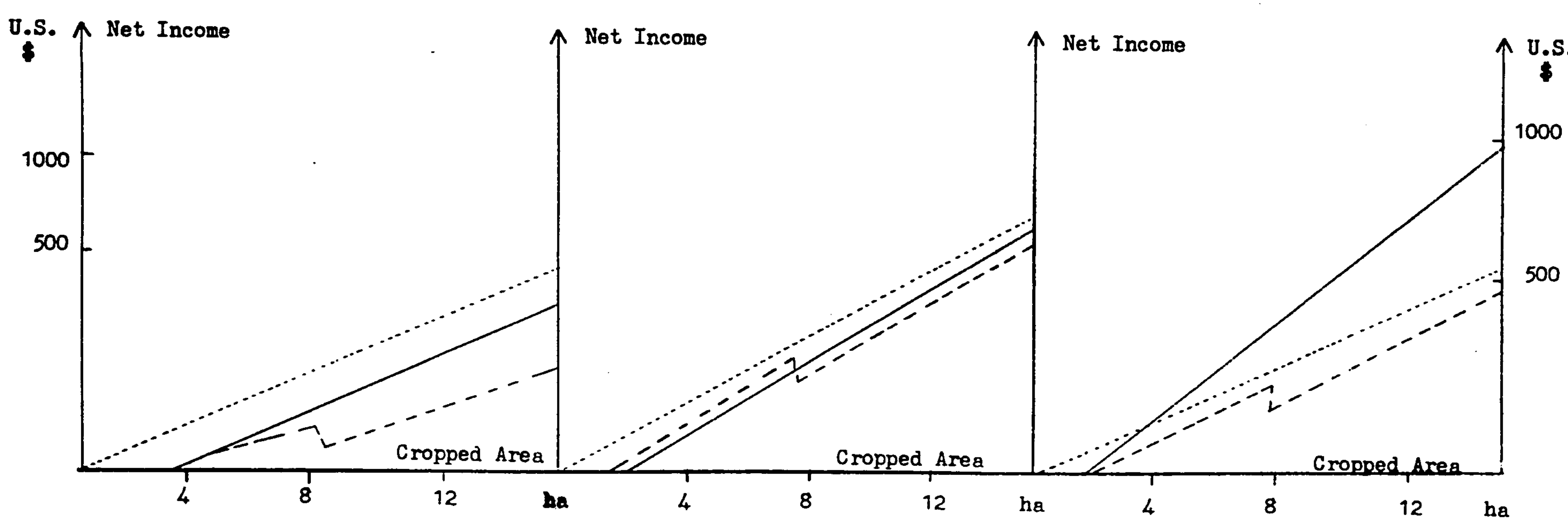
Income per worker. In the present systems of cropping (F_oT_o) with hand cultivation, one man can crop 0.8 to 1.2 ha depending on the region

FIGURE 1. NET INCOME VERSUS CROPPED AREA IN TWO REGIONS OF SENEGAL COMPARED IN THREE SYSTEMS OF CROPPING AND THREE ROTATIONS.

- - - - - - - - - F_0T_0 Traditional shifting cultivation

— — — — — — F_1T_1 Improved shifting cultivation; 1 horse can crop 8 ha.

———————— F_2T_2 Semi-intensive cultivation; 1 pair of oxen can crop 16 ha.



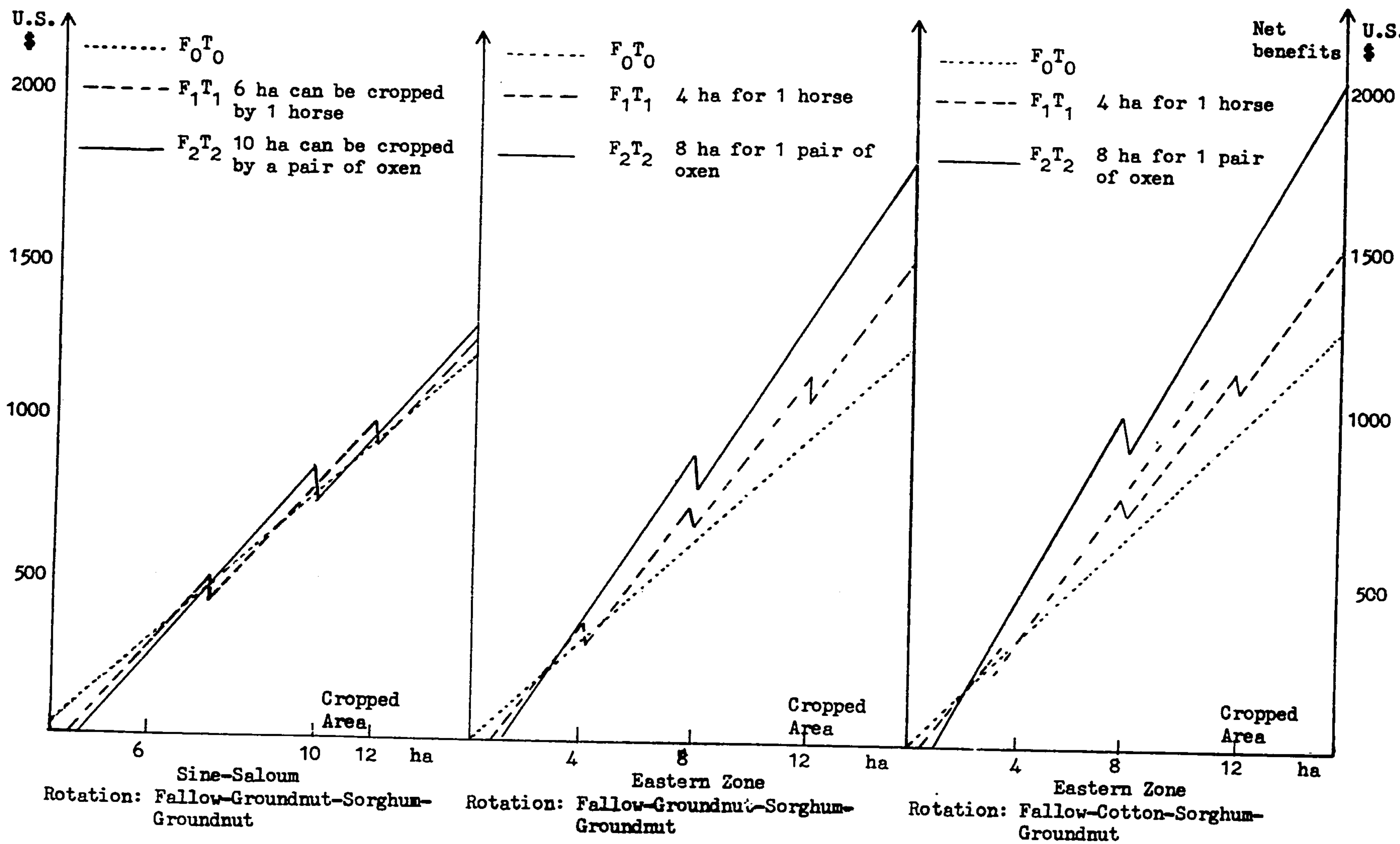
Northern Zone
Rotation: Fallow-groundnut-pearl millet-cowpea

Central Zone-Dunar Soils
Rotation: Fallow-groundnut-pearl millet-groundnut

Central Zone-Interdune Soils
Rotation: Fallow-groundnut-sorghum-cowpea

Source: IRAT -. Senegal, 1972.

FIGURE 2. NET INCOME VERSUS CROPPED AREA IN TWO REGIONS OF SENEGAL COMPARED IN THREE SYSTEMS OF CROPPING AND TWO ROTATIONS.



and the rotation. In the improved systems of shifting cultivation (F_1T_1) and in the semi-intensive systems of cropping with mechanized cultivation (F_2T_2), one worker can crop 2 to 3 ha. Broadly stated, on an average one man can crop 1 ha in the present systems and 2 ha in the other systems of cropping. This means that where the benefits per unit area are the same in the three systems as in the Sine-Saloum region (Fig.2a) the income per worker will be double for the improved systems of cropping (F_1T_1 and F_2T_2). On this basis, in contrast to the benefits per unit area, the benefits per worker are always higher in the improved systems than in the present systems, even in the northern regions, the most unfavorable for agriculture. Under the most favorable conditions, the differences between the systems will be accentuated. For example, in the eastern zone (Fig.2c), the ratio of income per unit area in the semi-intensive to the present systems is 1.62 to 1.00 whereas the ratio of incomes per worker is double, 3.24 to 1.00. In this case, the net income per worker reaches $250 in the semi-intensive system as compared with $78 in the present systems.

Moreover, given the same benefit per unit area or even the same benefit per caput, the improved systems contribute more than the present systems to increased food production, to increased gross national product, and to maintenance or improvement of the soil fertility. This is especially true for the semi-intensive systems of shifting cultivation (F_2T_2).

4.4 Preliminary Results from Intensive Systems of Cropping

Despite progress in the use of improved and semi-intensive systems for increasing the net incomes per ha and per worker, these increases remain at a rather low level. Recent attempts were made to increase the net income by more intensive cultivation. In these intensive systems the fallows or green manure is eliminated and continuous cultivation is practised. Plowing under crop residues is done as often as possible during the rotation. In this regard, the use of short-season cereals is more common than in the other systems. Experiments on these systems began only recently in Senegal. Some of the first results of these systems are shown in Table 5, where the net income per ha and per worker is compared with that of the three first systems previously studied (IRAT-Senegal, 1972). As can be seen, increases in net income per ha and per worker are substantial, especially in the Sine-Saloum and in the central zone. The net income per ha is 1.3 to 2.6 times higher and the net income per worker 3.6 to 5.6 times higher than that of the present systems of cropping, depending on the region.

If a comparison is made with the agricultural income in temperate countries, it appears that in these intensive systems the net income per ha is not very different from that of many temperate countries. On the contrary, the net income per worker remains at a much lower level. The

Table 5. Mean Net Income per ha per Worker in Various Systems of Cropping in Different Regions of Senegal

Systems of Cropping	Years of study	Number of sites studied per region	Net incomes per ha, U.S. $				Net income per worker[1], in U.S.$			
			Northern zone	Central zone	Sine-Saloum	Eastern zone	Northern zone	Central zone	Sine-Saloum	Eastern zone
1. Present Systems (F_0T_0)	1965-70	2-5	36	46	75	77	36	46	75	77
2. Improved Systems (F_1T_1)	1965-70	2-5	19	40	74	93	38	80	148	186
3. Semi-intensive systems (F_2T_2)	1965-70	2-5	30	43	91	114	60	86	182	228
4. Intensive Systems	1970-71[2]	1	--	119	131	133	--	258	310	279

1 The net income per worker was estimated for the three first systems and was measured for the fourth system

2 Except for the eastern zone where only the year 1971 was considered

Source: IRAT-Senegal, 1972

differences in human productivity can be largely explained by the special difficulties of weed control in the dry tropical area. This problem might be resolved by a wider use of chemical herbicides and of tractors.

5. CONCLUSIONS

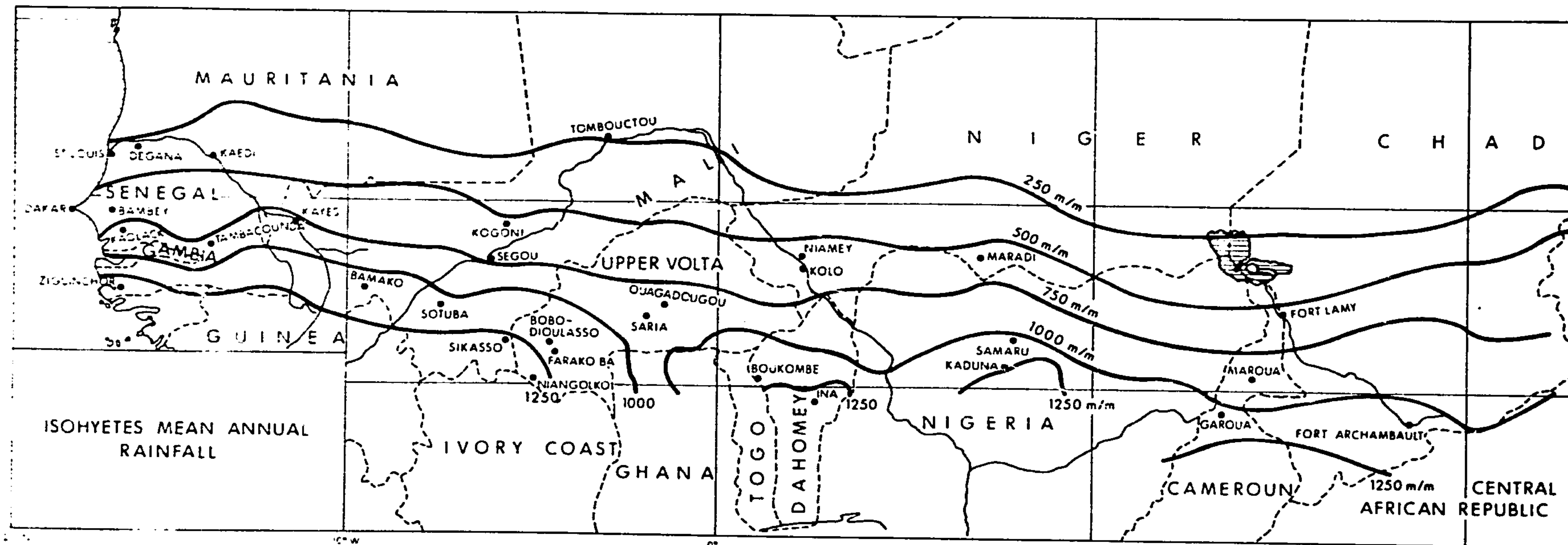
In conclusion, I would like to emphasize the large margin between the potential and the actual productivity in the dry tropical area of West Africa. This margin is largely explained by the general inadequacy between the needs of crops for water and the supply of water by rainfall throughout the year.

This factor, however, does not have the same degree of limitation for crops everywhere in the area studied. In this regard, it will be convenient, although somewhat arbitrary, to distinguish three main regions in the area studied according to the yearly rainfall (Fig.3).

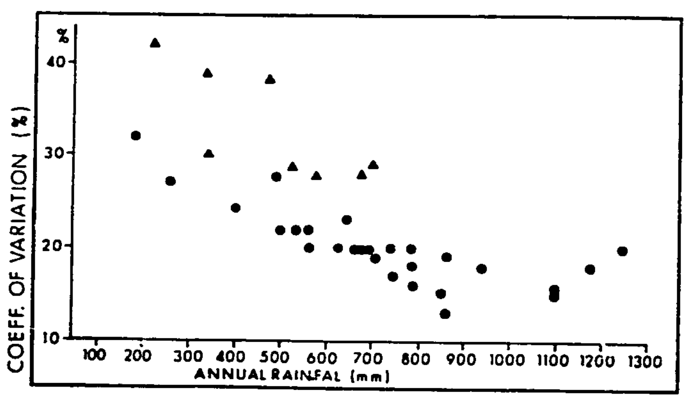
The first region extends from the Sahara Desert in the north to the 250 mm isohyet to the south. This corresponds to the southern part of Mauritania and the middle parts of Mali, Niger and Chad. Senegal and Upper Volta are not included. This region has not been studied here, because there is practically no farming. It is the "transhumant" zone where herds of cattle move from one place to another during the short rainy season in search of pasture. By the end of the rainy season, the herds move southward into the agricultural zone where they feed on the crop residues in farmers' fields. By the end of the dry season cattle gather in the wettest areas, mainly the plains of the Niger and Senegal Rivers.

During recent years world attention has been drawn to this area due to the drastic effects of successive annual droughts on men and cattle. Most of the references to the so-called "Sahelian" zone in the newspapers apply, in fact, to this transhumant zone. Effects of successive droughts were greatly accentuated by the large destruction of the natural vegetation in this area resulting from overcrowding of cattle. The cattle died rather of hunger than thirst. In the last fifteen years, the cattle population has been increasing mainly due to the improvement in health and decrease in mortality because of better veterinary services. The first rule of management for this zone is to accept the fact that without irrigation it has very low potential and therefore cattle and human population have to be severely limited to avoid harmful effects on vegetation and soils. If the cattle population is limited, some progress can be made in the management of livestock. Moreover, it must be pointed out that the management of this arid zone cannot be considered separately from the other two zones which constitute the dry tropical

Fig. 3. MEAN ANNUAL RAINFALL IN THE SEMI-ARID AREA SOUTH OF THE SAHARA



MEAN ANNUAL RAINFALL VS. COEFFICIENT OF VARIABILITY



TRIANGLES REPRESENT PLACES IN WEST SENEGAL AND N'GUIGMI.

SOURCE: COCHEME, J., AND P. FRANQUIN. 1967. A STUDY OF THE AGROCLIMATOLOGY OF THE SEMI-ARID AREA SOUTH OF THE SAHARA IN WEST AFRICA. FAO/UNESCO/WMO INTERAGENCY PROJECT ON AGROCLIMATOLOGY. ROME.

area of West Africa. This is not only because countries like Mali, Niger, and Chad comprise within their boundaries both arid and semi-arid zones, but also because these two zones are largely complementary and because trade between herders and farmers has always existed from the beginning of settlement and will continue.

The second region extends from the 250 mm isohyet in the north to the 750 mm isohyet in the south. The duration of the rainy season ranges from 60 to 120 days; for a given annual amount of rainfall it is shorter on the Atlantic side (Senegal) than for the countries in the interior. This zone corresponds to all of the area cropped in Niger and between one-third and one-half of the area cropped in Senegal, Mali, Upper Volta, and Chad. It also includes a part of northern Nigeria and northern Cameroon. Without irrigation, potential productivity in this area is limited by the shortness of the rainy season and the variability of rainfall from one year to the next and its erratic monthly distribution. Also the soil is a limiting factor because about 15 percent of the soils are inadequate for agriculture owing to the shallow depth and iron pans. Due to the shortness of the rainy season, the number of species which can be cropped is limited. Rotations should include a resting period with grass fallow or green manure to plow under and incorporate vegetative matter into the soil atleast once in the rotation, however short the rainy season. Despite these adverse factors, improvements of varieties, cultural techniques, and mineral fertilization can give yields of cereals more than double of that frcm present systems as shown by examples in the preceding tables for Senegal. Increases in yields of legumes are, thus far, less and range from 20 percent to 80 percent. Moreover, good possibilities of irrigation exist in this zone in the plains of the Senegal and Niger Rivers and around Lake Chad. They involve more than 1,000,000 ha but require heavy investments for building dams and channels. Other sources of surface and ground water are more limited but should not be neglected.

The third region extends from isohyet 750 mm in the north to a southern limit which is better defined by the maximum duration of the rainy season (150 days), than by the mean annual rainfall. Depending on the region, this limit of maximum duration corresponds to a mean annual rainfall ranging from 1,000 to 1,300 mm. This region includes all of Gambia and most of the southern part of Senegal, Mali, Upper Volta, Chad, northern Nigeria and northern Cameroon. Important areas of soils with shallow depth to iron pans can also be found in this region, but the constraints of variable rainfall and duration in the rainy season are much less than in the foregoing region. The number of species which can be cropped is larger and continuous cropping is possible provided that good cultural techniques, application of sufficient mineral fertilization, and regular plowing under of crop residues are done. The present available technology is adequate to more than double the yields of the traditional cereals, pearl-millet and sorghum, and to multiply three to ten times the yiedls of cereals, that is maize and rain-fed rice, with high input requirements recently developed in this region. As for the cash crop, the yields of cotton can be more than doubled and the yields of groundnut can be increased from 10 to 80 percent. Examples of these increases are shown in Table 4 for Senegal.

Not only in the last two regions discussed above does the improvement in systems of cropping results in large increases of yields but it enablesone to maintain and even to increase the soil fertility, whereas the present systems of farming have led to a slow but steady degradation of the soil. This does not mean at all that the presently available technology is perfect and that no technical obstacles exist any longer. On the contrary, substantial progress can be expected from the development of new improved varieties, a better knowledge of the water-soil-plant relationships, a better understanding of the nature of organic matter in the soil, the practice of liming, the use of chemical herbicides, the management of soils with high potential productivity, such as the Vertisols, and many other factors.

But these technical obstacles seem to be of relatively little importance compared to the enormous economic obstacles resulting from the present general situation in these countries. The ratio of input to output, that is, manufactured products to price of crops, is very unfavorable in these countries even when products are manufactured locally because of the use of some imported products. So the use of manufactured products necessary for the improvement of agriculture, mainly fertilizers and mechanical equipment, is severely restricted everywhere. The general situation has recently worsened due to the energy crisis. Actually, in this context few countries in the region are able to make substantial progress in agricultural development with their own resources. Most of them urgently need increased help from industrialized countries. For the latter the question is whether it is better to give food periodically to these countries to prevent general starvation or to provide the means to enable them to make significant progress in food production. There is no doubt that the second alternative is much better than the first if only the interest of these African countries is considered.

In addition to economic obstacles, there are also human and sociological problems. In many cases special methodologies would have to be developed to extend new technology to the farmers more effectively. Sociological changes will result from the adoption of new technology. These changes will have to be foreseen and controlled to avoid social disorders.

To sum up, substantial increases in agricultural production are possible in these countries even in the less favorable regions but technical improvements will be of little or no effect if they are not accompanied by important efforts in the economic and human fields. It is hoped that this global effort will be expanded to correct the present serious situation in these countries and to reduce the increasing economic gap between them and the industrialized countries.

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ECONOMIC AND SOCIAL ASPECTS OF LABOR UTILIZATION IN THE SEMI-ARID TROPICS

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The semi-arid tropics does seem to display considerable homogeneity as regards overall ecological conditions, yet at the same time countries of major concern to ICRISAT range widely from areas of extreme drought (e.g., Chad) to those with recurring monsoons (e.g., India). These environmental factors fall outside my own sphere of competence and are being discussed by other participants at this Workshop. In my field of socio-economic development, we find an overall fairly homogenous framework within which there exists extreme diversity. The overall uniformity consists in the level of poverty, most of the people living in rural areas and deriving their meager livelihood from farming either as owner-cultivators and/or tenants, sharecroppers, shifting cultivators, tribute labor, landless laborers, etc.

Until recently it was generally believed that by trying to maximize a country's overall economic growth rate at least some of the benefits would reach even the poorest strata. Economic performance in the Third World since the last war has belied these beliefs: the poor have gained little, if anything at all. This realization seems to have encouraged some leading development economists, planners, politicians and others to re-evaluate growth strategies. Numerous reasons are being discovered for believing that the previously alleged conflict between growth and employment has been exaggerated (Cassen, 1974). This new thrust of 'Development with Equity' is discussed in a forthcoming book (World Bank and Instt. of Development Studies, Redistribution with Growth). It is of great significance to this Workshop in assessing the pros and cons of alternative agricultural development strategies for the semi-arid tropics so as to insure that the new technologies help to reduce, rather than increase, the gap between the rich and the poor of this world. In some cases this may involve providing altogether different technologies for different regions; in others it may mean combining the same new technology with different institutional arrangements, etc.

Each continent and each region has its own kinds of peasant communities, (Tax, 1963). This great diversity, which is usually stressed by

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social anthropologists and emerges from their many microstudies, often causes despair amongst researchers, planners and administrators whether they would ever be able to design new technologies which would be generally applicable to all Less Developed Countries (LDC). It certainly seems much easier to develop new high-yielding varieties of seeds than to insure that they are uniformly adopted by the many different farming communities in LDCs. The human society is a much more complex organism than any plant breed. Yet I hope to show in this paper that regularities do exist, a realization of which should help developers.

Much has been written already on the importance of insuring that the right quantities of appropriate inputs reach the farmer at the right time and at reasonable prices, that credit should be made available to those farmers who need it, etc. to facilitate the adoption of new technologies. Less attention has so far been paid to the more general social variables, as distinct from purely economic ones, which affect farmers' response. Since there are other economists present, I think it best if I concentrate on the social aspects of labor utilization. At the end of each section I am giving the conclusion which developers may find useful.

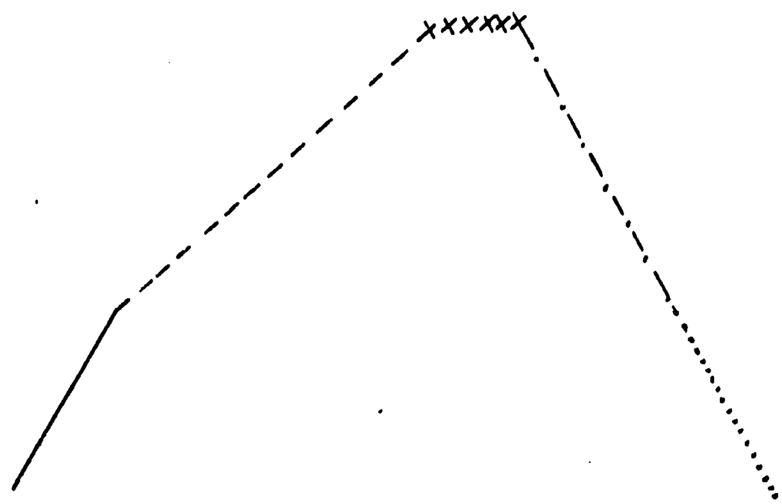
AGRICULTURAL LABOR

Family Farms

In most agricultural economies, the household is the primary production unit (Firth, 1970). "In conditions where capitalist farms would go bankrupt, families could work longer hours, sell at lower prices, obtain no net surplus, and yet manage to carry on with their farming, year after year"(Thorner, 1966). The household's composition, which obviously changes during the different phases in its life cycle influences its performance. The normal life cycle starts with (a) the establishment of a separate farm unit either on the marriage of a young couple, or after the birth of their first child or after the partition of a joint family; it continues to expand (b) by procreation and/or including kin of wider genealogical connection until it reaches its peak (c) after which adult offsprings begin to get married and fission (d) sets in and the household continues to decline (e) until it finally ceases to exist altogether with the death of either one or both of its founding partners (Fig. 1).

The predominance of unpaid family household labor in peasant societies led Chayanov to postulate that "the degree of self-exploitation is determined by a peculiar equilibrium between family demand satisfaction and the drudgery of labor itself"(Chayanov, 1966 a). His theory of peasant economy is based on conditions that prevailed at about the turn of the last century in certain parts of rural Russia where "statistics

Fig. 1. NORMAL FARM FAMILY CYCLE



——— = Establishment (a)

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xxxxxx = Peak Phase (c)

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confirmed that the size of a farm is not so much the determining factor of peasant activity as it is the expression of this activity" (Kerblay, 1966). Such simple relationship between the utility of income and the disutility of labor in farming can exist only under a number of important and limiting conditions, such as a fairly static demand horizon, access to uncultivated land whenever the size of a household increases, absence of capital intensive cultivation techniques, production and consumption decisions vested in the same social unit, etc. To what extent do these conditions exist in the semi-arid tropics of today and what lessons can be learned from the general proposition to which they have given rise?

In much of the rural Africa demand levels are changing very slowly; land is vested in kin or tribal units and shifting cultivation is practised using labor rather than capital intensive methods. Thus the individual farmer is normally in a position to extend the acreage he cultivates provided he can rally the necessary additional labor required -- except in certain areas where there are pockets of land already under extreme pressure from population. For large tracts of Africa, therefore, it may be true to say that the area cultivated by any one farm unit is a function of its labor supply and its consumption needs, which obviously vary for the different phases through which each household passes.

A study of Bugandan (Uganda) farmers, by taking the life cycle phase of farm units as the determining variable in agricultural performance, has provided new insight into family farming in Africa (Robertson). It shows that as the farm unit passes through its developmental phases, its size at first increases together with its needs for both cash income and food crops, so that acreages are extended and/or land is cultivated more intensively while its cropping pattern changes; gradually assets are accumulated until children get married and leave home, when decumulation begins. "Thus every family, depending on its age, is in its different phases of development a completely distinct labor machine as regards labor force, intensity of demand, consumer-worker ratio, and the possibility of applying the principles of complex co-operation" (Chayanov, 1966b). If a Bugandan farmer is successful and can afford to be polygamous he takes a second or further wives which strengthens his subsistence labor as well as his demand for greater output. The same applies to some tribes in Kenya, such as the Ribe, where a man's "shrewd investment within the traditional economy in the form of marrying five wives who in turn convert their labor into wealth, enabled him to take advantage of the new opportunities resulting from the growing cash economy" (Mkangi).

Large families with favorable age and sex composition seem to be a necessary, though not sufficient, condition for success in African agriculture. The Buganda study pointed out a number of other variables affecting agricultural performance such as off-farm employment; the group of farm units occupying the peak in the domestic life cycle also had the highest income from employment; moreover, the household heads of many of them having left urban jobs and returned to full-time farming. Even though this Bugandan group of farmers had the largest availability of family labor, the intensity of their farming activities was so much above the general average as to require substantial hired labor. The input of hired labor, however, directly reflects the patterns of cultivation intensity and cash cropping, as one would expect, since labor is very rarely hired for agricultural operations on home-consumed crops. Outside employment does seem to supply a farmer not only with the necessary capital to reduce the risk in experimenting with cash crops but also, and possibly even more important, with the incentive to do so. This Bugandan group of peak life-cycle farmers also had the greatest number of children away at school, which required them to earn sufficient money to pay the substantial school fees, and thereby increased the demand for more income (Hughes, 1974). Accounts of other than African societies also show that marginal members of farming societies are more likely to be innovators than their socially fully integrated colleagues (Epstein 1972).

Thus Farm Units Within Their Peak Life-Cycle Phase, or Approaching it, can be Expected to be Most Receptive to New Technologies, Provided they Constitute Feasible Economic Propositions. Men who have been in Employment Outside Their Village and who send at least one or Other of Their Children for Higher Education are the Most Likely Innovators.

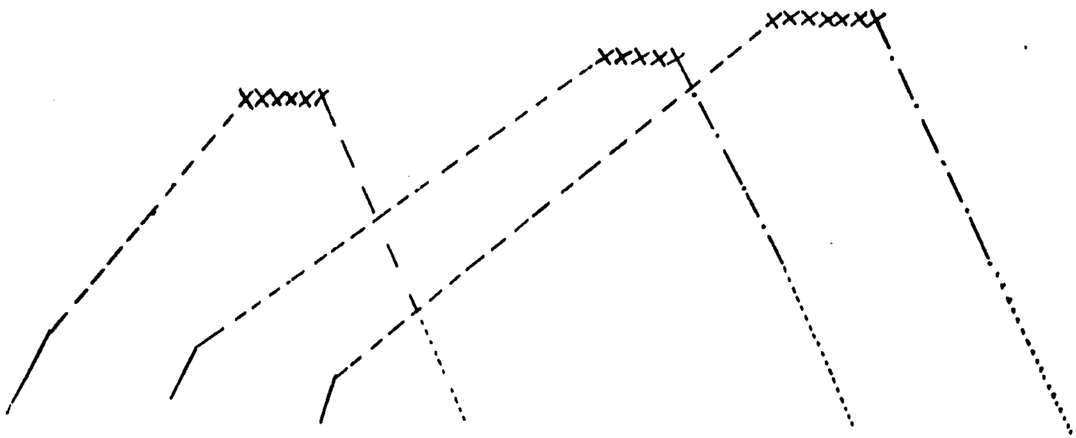
This is particularly important in view of the rapid population growth in many LDCs (e.g., Kenya 3.5 percent p.a), which means that the family life-cycle takes longer time to complete and an increasing proportion of farm units can be found within their expansion and peak phase (Fig. 2). All of the expansion-phase families among the Haya of Uganda were, for instance, cultivating beans and other food crops, but unlike all other Haya families they were also growing plantains and coffee (Reining, 1970). More research is needed on the impact of the domestic development cycle on lineally extended families, such as e.g., the Indian joint family.

In many societies production and consumption decisions are vested in one and the same farm unit; yet this is not necessarily so. For instance, among the Bemba of Zambia, consumption is traditionally communal, whereas production decisions are made by each individual farmer. A Bemba cultivating alone usually clears four to ten acres of bush to make a millet garden of one acre. The millet produced lasts on an average for nine months of the year only. The Bembas constantly talk of hunger months. They value a reputation for giving rather than for having; to be permanently much more prosperous than the rest of the village would almost certainly lead to accusations of sorcery. Social sanctions among the Bembas discourage individual farmers from trying to extend the acreage they cultivate and make them aim at a very modest level of competence. Yet when taken out of their traditional environment and transferred to a modern setting, some Bemba farmers begin to display considerable enterprize. The isolation from their kin network and the gradual adoption of the use of money make for inequality in the standard of living between different households, which are not found in the traditional Bemba settlements (Richards, 1939).

Farmers in Societies, where Production is Individualistic but Produce is Shared are Unlikely to Use all Their Energies. Resettlement may Encourage Fuller Labor Utilization, but seems to Lead to Inequalities, which can however be Minimized with the Help of Appropriate Extension Services.

In much of Asia, and also in parts of Latin America, where almost

Fig. 2. POPULATION GROWTH AND FAMILY FARM CYCLES



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all cultivable land is already being farmed (unless deserts can be irrigated), population growth means that increasing numbers have to make do with limited acreages. "In farms greatly short of land the concern to meet the year's needs force the family farm to turn to an intensification with lower profitability. They have to purchase the increase of the total year's labor product at a lower price resulting in fall in income per labor unit" (Chayanov, 1966 a). Unless there are considerable economies of scale due to the use of costly and indivisible capital assets, it makes good sense not only in terms of social welfare but also for purely economic considerations to parcel out land to household subsistence cultivators whenever land is short and labor becoming increasingly abundant (Ryan, 1974). The official Ethiopian view that fragmentation greatly reduces agricultural output by wasting labor is not valid under present conditions, because most households have more labor than their land requires for cultivation (Hoben, 1972).

Cultivators using traditional farming techniques have developed over the years a system of division of labor by sex and age which enables them to cope up with the seasonal changes in agricultural labor requirements. It is also noticeable that the scheduling of the time spent on social, religious and other non-economic affairs are generally functions of wheat used to be the cycle of production activities, not the other way around (Peter, 1970). If new technologies exaggerate the seasonal labor requirements and/or multiple cropping poses labor problems which individual household farms have difficulty in coping with, (even those in their peak life-cycle phase) the adoption rate will necessarily be low. On the other hand, if new crops even out annual labor requirements, farmers will readily adopt them. For instance, in Sukuland, Tanzania, the steady increase in cotton output has been possible because the crop's peak labor requirements can be adjusted so as not to conflict with food crop production (Peter, 1970).

Thus it is essential for plant breeders to consider the distribution of annual farm labor requirements when deciding which particular seed variety to develop. This is important not only for family farms but also other types of rural labor.

Hereditary Labor Relations

In the past, Indian villages were largely self-sufficient and different families had different access to land. Within small rural communities individual households offered their appropriate caste services to their landowning patrons. Wiser called this system of interrelatedness in service the '_jajmani_ system'(Wiser, 1958). It involves hereditary relationships with strictly defined rights and duties as well as rewards in terms of fixed quantities, or fixed proportions, of agricultural produce. This _jajmani_ system is a mark of a stagnant economy where success in cultivation is largely determined by environmental conditions over which the farmer has no control. The customary system of rewards enables the land-owner to accumulate a surplus as a result of good harvests while it also provides a minimum of social security for landless laborers even in bad years. As soon as external forces break down the isolation of Indian villages and new economic opportunities are introduced, innovations and changes become important. However, since the same individuals continue to be involved, social relationships are often carried over into the changed economic environment. To give but one example, in Wangala, a South Indian village, land-owning farmers continue the hereditary labor relationships with their dependent landless A.K. laborers, whom they pay daily wages in addition to the annual rewards in kind. They employ them mostly in the cultivation of paddy, which is still largely conducted using traditional techniques rather than using the more productive Japanese method of paddy cultivation (Epstein, 1962). This behavior should not simply be attributed to conservatism, which in any case often indicates a recognition of diffuse benefits not seen on the surface. The very same farmers who rejected improved methods for paddy cultivation readily adopted modern techniques for growing sugarcane for which they now employ migrant labor. Sugarcane was a new crop to them and therefore there were no customary production techniques or traditional rewards associated with it (Epstein, 1967). Where the new technologies provide a manifold increase in productivity, land-owners adopt them readily and tend to break off the hereditary relationships with their clients. This is what happened in North India's 'green revolution' belt, where casual labor has replaced traditional labor relationships. The high-yielding varieties of wheat facilitated multiple cropping and increased peak labor requirements (Biggs and Burns, 1973). This led to investment in costly bulldozers, tractors and even combine harvesters by the larger landholders, thereby reducing their demand for unskilled farm labor and causing the displacement of large numbers of landless workers. Some of India's scarce capital resources have thus been used to increase the numbers living below the proverty line.

Therefore in Areas with Customary Systems of Reward it is Important to Remember that (a) If the New Technologies are not Dramatically more Productive, it may be Easier to Improve Productive Efficiency by Introducing Entirely New Crops Rather than by Attempting to Provide New Technologies for Traditionally Grown Crops; and (b) Where the New Technologies are Many Times more Productive and cause Sharp Increase in Peak-Labor Requirements, Farmers are Tempted to Mechanize, thereby Reducing Demand for Labor and Depriving the Landless of the Minimum Social Security they Enjoyed Under the System of Hereditary Labor Relationships. This is Particularly Serious in Times of Rapid Population Growth.

Household Servants

In South Indian villages hereditary indebtedness by landless laborers to local land-owners frequently resulted in one or another of the laborer's sons being pledged to act as household servant for the creditor. This so-called '<u>jeeta</u>' arrangement involved the servant being at the beck and call of his patron in recognition of which he received his daily food and one set of clothing per year, whereas his annual wage was supposedly written off against the hereditary debt. The servant was obviously in no position to bargain over his annual remuneration. This traditional <u>jeeta</u> service is still being exploited by some of the bigger farmers in South India, as well as by some small-town moneylenders (Epstein, 1973).

In Order to Protect the Poorest Strata from Extreme Exploitation, Some Welfare and Legal Measures are Essential; Otherwise they fall Prey to the Wealthy and Powerful in Rural Society.

Contract Work

In developing the rural infra-structure, the Public Works Department -- at least in India -- frequently engages local entrepreneurs as contractors. These local entrepreneurs are normally leading men in their home villages. They use their influence over their clients to exploit them by paying a miserly rate for the job while they themselves make a handsone profit on the deal. The system of contract work is now beginning to be used by some shrewd farmers to organize gangs of migrant rural labor to perform certain tasks, such as for instance, harvesting wheat in the Punjab for which the contractor gets a fixed fee while the laborers, whom he employs and transports to do the work, get only a small proportion of it. This arrangement increases the monopoly power of the employer and severely reduces the workers' bargaining position. On the other hand, of course, it helpts to bring unemployed labor to places where there is demand for it.

To Increase the Mobility of Rural Labor while Protecting it from Exploitation, it may be Necessary to make Institutional Arrangements, such as Dispersed migrant labor camps, where farmers in need of labor could Request Help and Workers could Organize Themselves into Labor Gangs, thereby Eliminating the Contractor's Profit Margin.

Casual Wage Labor

Casual agricultural labor is paid either a rate per day or per job done; in both cases the cash paid is usually accompanied by one or two meals given to the laborer in the course of his work performance. Daily wages seem the far more common practice; piece rates appear to be paid only in cases where either a whole group of workers joins in one particular operation, as for instance the women's gumpu does in transplanting acres of paddy in Mysore villages (Epstein, 1962), or when a package of service is hired, for instance the plowman in North India, who brings his own bullocks and plows the land-owner's land (Biggs and Burns, 1973).

He who hires out his labor is regarded as subordinate to him who hires it. Social status may in fact be considered as an economic asset in itself (Firth, 1970). Economic dependence, social inferiority and the dispersed nature of agricultural employment impede the formation of labor unions and weaken the workers' bargaining position. Particularly in India their plight is becoming worse. Economic expansion is lagging behind the rate of population growth resulting in excess rural labor supply, which in times of rapid inflation is reflected not only in a falling real wage rate, but also in fewer days worked per year by individual laborers. To make matters even worse, since women receive a considerably lower daily wage than men, farmers tend to substitute female for male labor, wherever feasible (Epstein, 1973). The many attempts in India at minimum rural wage legislation have invariably failed, real wages have continued to decline. By contrast, wherever rewards are paid in kind, as is for instance normally done at harvesting time, the quantities the worker receives per day worked have remained the same even in periods when cash wages have greatly declined in real terms. This led me to suggest experiments with minimum rural wage legislation expressed in real rather than cash terms, as part of a package of palliative measures for South India's development (Epstein, 1973).

New Technologies have to be Labor Intensive to Insure that Demand for Labor keeps Pace with Increasing Numbers, Otherwise Real Wages Fall and the Gap Between the Rich and the Poor Widens.

This brief discussion of the socio-economic aspects of labor utilization in the semi-arid tropics has, I hope, shown that every farming society represents a system; any change in one of its segments affects all other elements to some degree. Development planners view economies as systems: e.g., they expect repercussions throughout the whole economy if for instance the rate of interest is changed. However, what does not yet seem to be generally realized is the fact that every economy constitutes only a sub-system of an overall social system. The rate of interest affects productive activities, so do for instance religious beliefs: the Bemba commoner believes that the productive capacity of the land depends entirely on the beneficience of the tutelary deities associated with it and the goodwill of these supernatural beings can only be secured by the prayers of the chief and his observance of a particular way of life (Richards, 1939). This belief encourages commoners to perform tribute labor for their chief.

Some innovations require a minor adjustment and seem therefore to be more readily acceptable. A higher-yielding seed strain (synthetic maize in Kenya for instance) is often welcomed by many farmers and causes little disturbance. But the introduction of oxen or ox-drawn equipment can cause considerable tension (Wharton, 1970). For example, many Gambian farmers do not and cannot follow the advice on cattle care. Their recently introduced bulls should be fed millet in large amounts during the season of heavy work. Late millet is a major food grain for most villagers, and therefore bulls compete with farmers' claims and stored millet (Weil, 1970); it is doubtful that Gambian farmers who produce even double the subsistence level will consider giving spare grain to their livestock (Haswell, 1963).

All this indicates that a SYSTEM APPROACH is necessary to insure the successful implementation of new technologies.

It Seems Essential that Farming Societies are Given a Unified Service, where One Organization Handles All Aspects of Extension (Farmer Training, Supply of Inputs, Credit, Marketing, etc.) in a Particular Area and Keeps in Close Touch with Research Activities. This may Involve a Change from Individual Crop Research to a Focus on 'Farm System' Research.

Note: This paper was written weeks before the workshop. I still think it can stand its ground by helping to explain the process of socio-economic change at village level. However, I want to put it on record that at the workshop I did not present a shortened version of my paper, but posed for more searching questions: "what are the major objectives of ICRISAT's research activities? Is it possible to streamline the new technologies so that they favor the poorer strata of society?" The discussion which followed my brief presentation of the fundamental problem in development justified my course of action: natural scientists are beginning to be concerned with the socio-economic implications of the new technologies they are developing under experimental conditions. This is a necessary beginning of applied research.

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RECOMMENDATIONS OF COMMITTEE III:

SOCIO-ECONOMIC RESEARCH IN FARMING SYSTEMS

J.S. Kanwar

1. Research policy. The socio-economics group should assist in the determination of an overall research policy in ICRISAT, especially with respect to questions relating to technology for small farmers, large farmers and their relationship to landless laborers.

2. Base data and constraint identification. Broad-based (macro) data collection should be done quickly but ICRISAT should not spend a major portion of its time in such activity. If more broad-scale data are needed by the Institute, it could be collected through sponsored research.

3. Village level studies. Village level studies should involve natural scientists as well as socio-economists. The field workers should be graduate students committed to the projects who can observe and identify problems and possible solutions. Only a small number of in-depth studies should be undertaken and they should be initiated to test hypotheses which are developed beforehand. For example, one hypothesis would be that risk aversion explains why farmers fallow land in the monsoon season in certain areas. A second would be that household consumption attitudes restrict market participation. Similar studies should commence in other semi-arid regions as soon as possible. Data should be carefully prepared for ease of later analysis, e.g., computer retrieval. Farms should be selected on an ownership basis, but the data could be used for interpretation on a watershed basis.

   Household, community and farming systems should be studied and their intrastructural constraints determined. Additional specific areas for study might include household fuel use, dry season fodder constraints for livestock and tree cropping systems. These studies need to relate to other agro-economic centers, either on a collaborative or sponsored basis. It may not be possible to test all hypotheses in any one study, and purposive selection may be required later. There may not be a sufficient number of farmers who crop in the kharif within the villages selected for the studies mentioned to make valid comparisons; further selection may be required to obtain needed data.

4. Evaluation of technology. Present-day technology must be understood to guide research efforts. These focal points should receive a

high priority:

a) Comparative systems of watershed management across countries need to be studied. This could be a sponsored research project.

b) The benefits and costs of watershed developments using farm data, if possible, or ICRISAT data appropriately adapted until such farm data are available, should be studied. When a viable watershed-based technology is developed, pilot studies to obtain appropriate economic information should be done in conjunction with national research institutions.

c) Pilot research studies in farming areas must be initiated as soon as possible to interrelate the prospective new technologies generated by ICRISAT with the existing farming systems. These studies should include both the watershed-based and independent innovations. An example might be a study of the role of increased mechanization in kharif fallowed areas and its effect on labor requirements, production and other variables.

d) Studies to anticipate the impact of technological change on market cost variables such as product prices, input prices, storage facilities etc., must be conducted. Attempts should be made to understand temporary economic and institutional conditions which may cause constraints to adoption of new technology.

Part IV

Transfer of Technology and Off-Site Research

TRANSFER OF TECHNOLOGY - OUTREACH PROGRAM OF ICRISAT

R.W. Cummings and J.S. Kanwar*

One of the stated objectives of ICRISAT, which we consider a basic purpose for the establishment of the Institute, is to help in significantly increasing crop production and stabilizing agriculture in the semi-arid tropics (SAT), through assistance to national and regional research programs and through co-operative outreach programs, and thus contribute to the welfare of the humanity struggling through life under harsh conditions in these regions of the world. Improvements in the SAT have lagged behind those in more favored regions and the chronic food shortages and the ever increasing gap between food production and demand has given new urgency to the problem. It is very important to develop a viable technology for increasing production in semi-arid tropics but the usefulness of such a technology can only be judged by the results produced on the farmers' fields. Thus the transfer of technology becomes especially an important consideration in achieving the goals set forth by the Institute.

The results of research conducted at Hyderabad will have to be tested, evaluated and spread in the entire semi-arid tropical region of the world. On the success of this activity will depend the success of the Institute in bringing a revolution in agriculture in the semi-arid tropics.

For proper discussion of our philosophy of outreach, it will be necessary to first define our area of operation. After carefully considering various definitions of semi-arid tropics, ICRISAT scientists have accepted Troll's classification for general delineation of the regions of our major concern. The areas with 2 to 4-1/2 wet months and the rest as dry months are called semi-arid dry tropics. The areas with 4-1/2 to 7 wet months and the rest as dry months are semi-arid tropics with wet climate. Water is the major limiting factor for crop production in this region. Thus the characteristic feature of semi-arid tropical region is 5 to 10 dry months and only a short wet period. The possibilities of development of conventional irrigation facilities are limited. It is unlikely that more than 20 percent area in the whole region will be brought under irrigation projects in the near forseeable future. Thus most of agriculture in SAT is and will continue to be dependent on natural rainfall and the vagaries of weather. Any technology for crop production in this region has to aim at maximizing the efficiency of utilization of

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the rain water and not to depend on irrigation water transported from other areas.

High-yielding seed has been a major vehicle for the green revolution. Seed with high yield potential under rain-fed conditions of semi-arid tropics is absolutely essential for obtaining breakthrough in agricultural production in the region. ICRISAT will lay great emphasis on the 'seed improvement research' but simultaneously carry on 'resource-centered research' to find ways of managing the crop, soil, climate and total environment to maximize dependable returns from the farming system.

INTERNATIONAL OUTREACH PROGRAM

Quite often the terms outreach program and international program are used interchangeably. Athwal and Brady in a paper presented at the meeting of Directors of International Centers, March 4-7, 1974, CIAT, Columbia, stated that the term outreach should be used in a restricted sense for services or assistance rendered to national programs through special projects or co-operative country projects whereas the international program should be used in the broadest sense to include all activities that are carried out at locations other than those which require continuing direct supervision of headquarter's staff. This definition would also include location-specific research programs which are integral parts of the core research program and are directed to generate new information for general use rather than to help a national program. It could involve an extension of core program in places or centers away from the headquarters of the Institute. It may entail the involvement of the Institute's headquarter research staff to varying degree but generally is dependent on the help of the location-based staff of co-operating Institute, country or organization.

We feel that the entire activity of the Institute must be internationally orientated and the resident research which is carried out by its headquarters staff must have an international outlook. We prefer to refer to the Institute's activities away from the headquarters as international co-operative programs. Some of these activities would be essential as complementary to the research efforts of the international institute at the headquarters. The others will be necessary for spreading the new technology, adapting and evaluating it and utilizing it for increasing crop production in the region proposed to be served by the Institute. It can take various forms including:

(i) Collection of indigenous germplasm and information on traditional production practices and tools;

(ii) international testing nurseries;

(iii) general consultative and advisary assistance to the countries and institutes in the region;

(iv) location specific researches;

(v) regional research programs having elements common to two or more countries;

(vi) collaborative research on problems requiring a range of environmental interactions;

(vii) specific country programs of adaptive research and application, etc.

None of these activities can be carried out without the active support and involvement of the national organizations. It is a sort of symbiotic relationship in which both the partners are intertwined and by their interaction the effect becomes synergistic.

HOW TO TRANSFER TECHNOLOGY

The international outreach activities as mentioned under items 1 to 6 aim at generating new technology and studying its adaptation to a particular environment. In these projects the transfer of technology or its extension is secondary and not the primary objective. The country programs on the other hand can have both the research part as well as the extension part. It will concern the adaptability and applicability of a technology and tailor it to the local needs.

For the success of a technology, it is essential that it should be viable, easy to adapt and fulfil the felt need of a place, country or region. The availability of trained staff for its transfer and necessary inputs and infra-structure are absolutely essential for its success. However, the application of rain-fed farming technology has a large element of local specificity and thus the local factors are very significant in determining its success.

The Institute will have two types of technologies to transfer:

1. Seed-based technology in which seed is the prime mover.

2. Resource-based technology in which seed is only one of the ingredients and there is integration of the various aspects of technology aimed at efficient utilization of local natural

resources such as land, water, climate and man. This comes under the general term Farming System.

For the success of both these elements of technology, well trained and dedicated staff is necessary. Thus training is essential for the transfer of technology from the ICRISAT. Some training can be given at the ICRISAT headquarters but much of it may have to be arranged at different regional centers which simulate the local conditions most efficiently. Thus a net-work of training centers may be required for the success of the training program. Strong centers of excellence in the countries to be served are absolutely essential. The ICRISAT can undertake the job of training the staff who may have to train actual field workers required for the implementation of the program in their countries.

We are concerned with the improvement of sorghum, pearl-millet, pigeon-pea, chick-pea and groundnut. A first step is the breeding of most promising varieties or hybrids, which can give high yields consistant with quality under rain-fed conditions of the semi-arid tropics. Our scientists feel that they will start testing the material at early generation stages and making it available to the national programs in various countries so that the local scientists can make choice based on their local experience and judgement. We do not contemplate limiting ourselves to giving them the finished product but rather we wish to encourage them to take the promising material at early stages of development. For acquainting the different researchers with the material, we will start testing the material under different environments in semi-arid tropics. It will require the co-operation of the agricultural scientists working in different countries of the semi-arid tropics. It thus follows that the benefits from the crop improvement program can be obtained by different countries depending on the strength of their national research organizations or in other words strong national centers are absolutely vital for the success of ICRISAT's mission.

Perhaps the most difficult part of ICRISAT's program is the farming system, which is the theme of this workshop. It is only a very difficult technology to develop and reduce it to principles of broad applicability but its transfer is even much more difficult. Its application will have to be made location specific and its success will depend on many factors - physical, climatic and socio-economic. At the ICRISAT headquarters we can develop certain concepts of this technology making use of the special feature of the locality, but the use of these concepts for fashioning out technology suitable to a given situation will require adaptive researches under different environments. A number of watersheds providing reference points for the entire range of the semi-arid tropics will be needed and farming systems suitable for them evolved.

In India itself there are many different agroclimatic regions of the semi-arid tropics and we do not think that the package of any given technology could be equally successful under all these conditions. Under the All India Co-ordinated Research Project on Dryland Agriculture, the ICAR has identified 24 distinct regions, out of which at least two-thirds are located in the semi-arid tropics. What may be excellent for Hyderabad may not necessarily be good for Indore, where the average rainfall is higher, minimum winter temperatures are lower, and soils are somewhat different.

Our approach will be to work closely with the national programs. We hope to achieve this goal in stages.

1. The first stage is the experiments at ICRISAT on watershed to develop suitable technology. These are on two widely contrasting soils - heavy balck cotton soils and lighter textured red soils. These studies aim at concept building.

2. The second stage is to analyze these in terms of a farm holding scale using the watershed approach, socio-economic considerations and simulating farmers' conditions. The data from these studies will be subjected to economic analysis.

3. The third stage is testing and adaptation of the technology under different agroclimatic regions in India and other countries, both on experiment stations and on actual farmers' holdings on pilot scale.

For achieving this goal, Ryan and Associates are initiating some village studies in a few selected districts of India representing the black soil and the red soil of the semi-arid tropics. This is to understand the problems better and select representative watersheds for adaptive research. We anticipate that this may be carried out in collaboration with the national programs. This can provide a two-way traffic for the flow of information about new technology to the farmer and feed-back of the problems to the scientists in the ICRISAT Farming Systems Research. The exact shape this program may take is difficult to visualize at this stage, but there will certainly be no rigidity in the program which would rather be extremely flexible. In these programs we will enlist the support of the local agricultural research organizations and work in closest co-operation with the All India Co-ordinated Research Project on Dryland Agriculture, as well as the local agricultural universities and departments of Agriculture.

OUTREACH PROGRAM IN AFRICA AND LATIN AMERICA

Next to India, the African region of semi-arid tropics is a high priority region for ICRISAT's program. As pointed out by Ryan and Associates in their paper, the most important countries from the point of view of acreage and population in the semi-arid tropical region of Africa are Nigeria, Senegal, Mali, Upper Volta, Ivory Coast, Niger, Tanzania, Uganda, Sudan, Kenya, etc.

The ICRISAT has appreciated the urgency of an outreach program in the African belt. Director, ICRISAT, and Dr. Doggett have visited western and eastern African countries in the last one year. They have developed proposals on co-operative programs for West Africa which will be financed in part by UNDP and will enlist participation and support from several additional sources. The objective of this program is to co-operate with and to strengthen existing West African agricultural research to develop improved varieties of sorghum and millet with the characteristics of consistent, reliable yield and improved food quality and to co-operate in the development of improved farming systems for rain-fed areas.

It is proposed to organize the West African outreach program with two main centers, viz, The Centre National de Recherche Agronomique, Bambey, Senegal, and the Institute of Agricultural Research, Samaru, Nigeria.

The Bambey centre will lay greater emphasis on problems of the more northerly shorter season zone where millets predominate while the Samaru station would concentrate on the more southerly longer season zone where sorghums predominate. Both these stations would however be concerned with both the crops as they get into their respective regions.

Samaru and its associated station at Kano would place primary emphasis on sorghum with a secondary emphasis on longer season millets, while Bambey would place primary emphasis on Pennisetum millet with a secondary emphasis on short-season sorghum.

Both the stations will pay special attention to groundnut which is an important crop of the region.

Although pigeon-pea is not an important crop in that region at present, both the stations would make plantings and observations on the performance of promising varieties identified by ICRISAT.

A Plant Breeder/Agronomist will be posted at Bobo-Dioulasso station (Farako-Ba) to help support the screening and testing work and take responsibility for the trials in Upper Volta, Dahomey and Togo. At least one Field-Trial Officer would be located in each of the countries of the semi-arid zone in due course. It is anticipated that the field trial officers now located at Dakar, Senegal; Maroua, Cameroons; Tamale, Ghana and Kano, Nigeria, which are provided by the French and British governments, will be linked up with the proposed UNDP program for West Africa and their functions defined more sharply. They will be linked up with the research centers at Samaru, Bambey and Bobo-Dioulasso. Additional field-trial officers in other countries are planned.

The main centers would be developing new and improved crop varieties and farming practices. They would distribute promising material to the national research stations, which would carry out further improvement in adaptation to local needs. Much of this material would need testing regionally, to identify varieties with a genotype x environment interaction, and to ensure that new farming practices are realistic and beneficial. The entries for the series of uniform trials required throughout the region would be decided by consultation between these co-operating centers and the various national agencies. The field-trial officers would organize these trials, and also report on their conduct and the behavior of the crops by inspecting at appropriate intervals. They would see that the results are properly collated, relate anomalies to their field observations, and supply all this information to the co-operating centers.

It is anticipated that scientists at the ICRISAT's main center in India would periodically visit the West African projects and would be available for consultation there as needed. Likewise, scientists from this regional program would be expected to visit ICRISAT from time to time and participate in the central as well as regional research planning. Trainees and scholars would be selected to spend longer periods at the ICRISAT.

In addition to conducting field trials, these officers would gather information on local customs in food uses, on the indigenous varieties grown and their attributes according to local opinion, and local farming practices. They would gather seed of as many varieties of these crops as possible within their areas, and send it to the national stations and the ICRISAT co-operating centers. In this way, the germplasm of this region would be made available for the use of the whole world. The field-trial officers would not only have a promotional function within the West African network, they would also have an essential feed-back function, supplying material and information to the stations of the network which will be of the greatest value in ensuring that the research policies and programs relate in the most practical manner to the needs of the people in the area.

An overall project leader located within the region will be required for organizing and providing guidance and surveillance to the project and for maintaining close liaison with the ICRISAT central staff and program. The ICRISAT expects to have an Associate Director at the Hyderabad Center for training and co-operative activities in other countries who would give special attention to this program and its relationships to the program at the ICRISAT headquarters.

At the stations at Bambey and Samaru, the following staff would be posted to serve the regional program for sorghum and millet improvement:

Bambey (with substation at Louga)

1 Plant Breeder (millets & sorghum)
1 Agronomist
1 Plant Physiologist (drought & plant efficiency)
1 Entomologist (millet pests)
1 Plant Pathologist (millet diseases)

Samaru*

1 Plant Breeder (sorghum)
1 Plant Breeder (millet)
1 Agronomist (culture & trials)
1 Physiologist (nutrition & Plant efficiency)
1 Entomologist (sorghum pests)
1 Plant Pathologist (sorghum diseases)
1 Striga Physiologist

Discussions at Samaru emphasized that to get good work from international staff, each senior staff member needs 2 assistants at intermediate level, 4 junior level assistants, and about 5 laborers.

At Bambey, keen interest has been expressed in the intensification of work already underway at that station on farming systems, including work of the type now underway in ICRISAT on improving the effectiveness in managing the rainfall moisture, soils and cropping patterns, sequences, and cultural practices to maximize the return from water which falls on the land and improving dependability of harvests. In fact, this would appear to hold much promise throught the region. The following additional staff at Bambey would be required for this work: 1 Economist, 1 Agro-climatologist, and 1 Agronomist.

Certain portions of the program outlined above are already being supported at least in part by governments and agencies of the U.S.A., U.K., and France and related projects have had support from the European Community and the International Development Research Center of Canada. Additional support is anticipated from the United Nations Development Program and possibly from the Netherlands. The Scientific and Technical Research Council of the Organization for African Unity has assisted in the implementation of a major cereals research project in West Africa concerned with sorghum, millet and maize, and in performing liaison functions with the various national governments. The ICRISAT proposes to develop contracts with the various respective donor agencies for support to this project and to work out co-operative agreements with the Governments and Institutions concerned for the implementation of the project.

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* Since it is anticipated that USAID support to Project JP-26 on major cereals in West Africa may terminate in 1975, this list includes staff now assigned to sorghums and millets under this Project.

Under the direction of an Associate Director for Training and Offsite Co-operative Programs, it is proposed to designate an overall project leader who would be posted at a suitable location in Africa, to supervise co-ordinate, and administer the project. Periodic planning conferences will be required, involving the leading participants in the project and other officials responsible for national agricultural development activities. In addition to providing supervision and guidance to the project in the region, the project leader would be responsible for seeing that close liaison is maintained with the ICRISAT headquarters program, for arranging for the regular transfer of new genetic materials and technology from ICRISAT to the regional program where applicable, for the collection of genetic materials in the region and its incorporation into the world germplasm bank, for utilizing the services of scientists from ICRISAT headquarters in the regional program, and for seeing that appropriate scientists and technicians in the regional and national programs are provided opportunities for training and professional development.

OUTREACH PROGRAM IN LATIN AMERICA

In Latin American countries, parts of Brazil and Argentina and a substantial area in Mexico and central America fall within the semi-arid tropical classification. Director, ICRISAT, has made two visits to Brazil in the last one year to develop a suitable approach to the outreach program in that country. Dr. Krantz also visited it once. It is evident that the research organizations in Brazil are undergoing a significant change. The entire agricultural research program is coming under EMBRAPA, an apex organization having some features similar to ICAR in India. It is developing co-ordinated projects on major commodities and a few regional resources centers. The North-east region of Brazil is the real semi-arid region of the country where sorghum, millets, and pigeon-pea would seem to have considerable scope for the future. Argentina and Paraguay have considerable area of semi-arid tropical climate. We have not yet made any studies in this area nor in Mexico and central America concerning specific lines of co-operation. It is however expected that in the near future some co-operative international links will begin to take shape in Latin America.

OUTREACH PROGRAM IN SOUTH-EAST ASIA

The South-east Asian region has sizeable areas in Thailand and Burma which are representative of the semi-arid tropics. Besides a co-operative program on sorghum, we feel that consideration of improvements in farming systems will be a very important concern of this region. We are closely watching the experience of IRRI, The Rockefeller Foundation, The Ford Foundation and the IDRC in their projects on multiple cropping and soil and water management. We hope that in near future we may be able to explore more fully the appropriate role for ICRISAT in this region. The expert consultation sponsored by FAO should help in identifying more sharply the needs of rain-fed agriculture in the region. We have had keen expressions of interest in co-operation with ICRISAT from representatives of Thailand, especially in relation to the development problems of the north-eastern portion of the country.

TRAINING PROGRAM

We realize that the first prerequisite for transfer of a technology is that it should be capable of giving a spectacular payoff to the farmers. Unless a technology can produce really impressive results, it may have difficulties in becoming acceptable. Secondly the technology of crop production for the rain-fed areas should provide reasonable insurance against risks. Thirdly, it should be very flexible and more location specific. Fourthly, it should be transferred by the people who understand the aspirations and difficulties of the local farmers and can motivate them to increase the agriculture production and stabilize the yields. Knowledge of local conditions, language and customs is very essential.

Inadequacy of trained personnel for manning research, extension, education and development activities for rain-fed areas is keenly felt in all the semi-arid tropical countries. Thus for the transfer of technology, training is the most important link. The training requirements also vary from country to country and job to job. These may be classified as follows:

1. Practical training in research methodology of crop improvement, crop production, farming systems and watershed management. It may be of a few months or one crop season or one year's duration.

2. Practical training in crop production and farming systems. It may be one crop season or one year duration.

3. Training leading to postgraduate degrees such as M.Sc. and Ph.D. in different subjects with emphasis on rain-fed farming technology. This may take 2 to 3 years depending upon the background of the candidates.

4. Short-term training in special projects.

We believe that the transfer of technology will be as fast as we are able to build teams of well trained scientists and extension workers in the countries of the semi-arid tropics. The adaptive and location-specific research will depend on the locally available potential research workers who after a suitable training can take major responsibility in collaboration with a few expatriate scientists who may be available for short periods. No large scale transfer of agricultural technology can be affected by expatriate experts only. A hard core of well trained local staff is absolutely essential for the purpose. Some of the training may be imparted at the ICRISAT headquarters in Hyderabad (India) but most of it particularly location-specific training may have to be given in the countries concerned.

Since there are various levels of indigenously available expertise, the training needs have to be carefully assessed and a training program to meet the local situation designed. Quite often the efforts made on training do not produce commensurate results due to lack of critical evaluation of the local needs and competence of the trainees and the practical experience of trainers specific to the situation to which the results are to be applied. We feel that in the case of rain-fed areas of semi-arid tropics this is a crucial factor and we have to be very specific in training programs.

Training in farming systems particularly will need too much location-specific stress and will be more meaningful if the research data from different environments become available. The ICRISAT is developing a strong training program to meet the specific needs of Africa, Latin America, South Asia and India.

We are also developing suitable links with the Andhra Pradesh Agricultural University for postgraduate training with specialization in rain-fed agriculture in semi-arid tropics. We hope to develop a joint program of research and teaching by pooling our resources together. Similar links with other institutions are also likely to be developed in due course of time.

In conclusion, it may be stated that the ICRISAT is conscious of the need for a relevant technology for the different environments and is developing a suitable strategy for the transfer of technology for increasing crop production in the semi-arid tropics. We know it is a difficult and challenging job but it is a job of highest priority.

AID'S CONCERN FOR AGRICULTURAL DEVELOPMENT IN REGIONS OF LIMITED RAINFALL

Donald L. Plucknett*

During the past several years we have seen enormous human suffering brought about by drought and its consequences in arid and semi-arid areas, with much attention having been given recently to the Sahelian zone of Africa. While this suffering has been dramatized and has made urban people or more fortunate persons aware of such problems, the truth is that people of semi-arid regions have always existed with a tenuous hold on life and sustenance, and that threats to food supply for man and animals will be perpetual there. One great challenge to mankind is to find ways to make food production more secure and reliable under rain-fed conditions. AID is focusing most of its efforts to help meet the need for more food and for better human nutrition, and is currently reconsidering its approach to rain-fed agriculture.

At present almost 85 percent of the cultivated lands of the world depend entirely upon precipitation to supply water for plant growth. The remaining 15 percent of the world's cropped lands which is under irrigation produces more than a quarter of the world's agricultural produce. If the problem of hunger is to be solved and increasing food demands met, then more and more of the semi-arid subtropical regions of the world -- comprising a major part of the world's arable land -- will have to produce more food.

Current Aid Programs and Actions in Semi-Arid Regions

Emergency aid. For many years AID has provided emergency help to distressed countries suffering from drought, famine, floods or other disasters. In the Sahelian countries emergency relief has been provided to prevent loss of life. Food, medical supplies, and other materials or services were provided along with support for certain activities designed to assist in short-term recovery; such activities included seed multiplication, fertilizer purchase, providing irrigation for seed farms, etc. Longer term needs are met through bilateral or multilateral aid projects.

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* Chief Soil and Water Management Division, Office of Agriculture, Bureau for Technical Assistance, Agency for International Development.

Support for international agricultural research centers. To help provide a long-term approach to meeting world food needs, AID (through its membership in the Consultative Group for International Agricultural Research) provides funds to support the work of the international centers, including ICRISAT. It is hoped that such long-term support will provide new crop varieties, cultural practices and production technology to materially increase world food production.

Development projects (bilateral or multilateral assistance). These projects are funded and implemented by the Regional Bureaus or missions to individual countries. Technical, short-term teams are used to design and evaluate the projects which may run for 5 years or more. Most projects in agriculture are orientated toward food production or integrated rural development.

Research programming. This is the responsibility of the Office of Agriculture in the Technical Assistance Bureau. AID-supported research is contracted to universities or government agencies. It must be focused on key problems of developing countries, and must have a strong possibility of bringing about increased food production. Except for crop improvement and irrigation, little of this research applies directly to semi-arid areas. This deficiency is being remedied.

Current research includes on-farm water management (Utah State University in Latin America and Colorado State University in Pakistan and Vietnam), management of tropical soils (North Carolina State University and Cornell University), benchmark soil research to evaluate technology transference methodology (University of Hawaii and University of Puerto Rico), new fertilizers for tropics and subtropics (TVA), sorghum and corn improvement (Purdue University), wheat improvement (University of Nebraska), barley improvement (University of Montana), soybean improvement (University of Illinois), weed control (Oregon State University), aquaculture (Auburn University and University of Rhode Island) and various agricultural economics projects. A new project on symbiotic N-fixation in tropical legumes is about to begin.

AID's 211 (d) grants to universities to build competence in specific fields. AID provides grants to selected universities in order that they can build their competence in specific fields which bear on problems of developing countries. Grants in the soil and water field include a tropical soils consortium, consisting of five universities (Cornell, Hawaii, North Carolina State, Prairie View A&M, Puerto Rico); a water management consortium consisting of four universities Arizona (watershed management), Colorado State (delivery and removal systems), Utah State (on-farm water management) and California-Riverside (dryland farming in summer-rainfall tropics and subtropics). A new grant is contemplated to build competence in dryland farming in Mediterranean climates (winter rainfall). These universities are charged with the responsibility of conducting 'state-of-the-art' studies and analysis, building a knowledge and information base in their assigned area, increasing training and educational capacities and opportunities, and increasing their competence to do research and provide general technical assistance on problems of developing countries.

Planned, Suggested or Desired Activities in Dryland Farming

'State-of-the-Art' studies are needed to determine practices now being used or which could be used to make dryland farming more predictable and productive. Such studies include literature surveys, which alone are not enough. There is also a need for inventory practices now in use and to determine whether they can be adapted to production systems elsewhere. This could be an excellent opportunity for international co-operation, for in some countries practices which have been used for thousands of years might have value elsewhere. Perhaps this workshop should consider how such an international co-operative effort could be organized and operated. Survey data should be analyzed and evaluated by expert groups and the conclusions should be published. 'State-of-the-art' studies are a major part of AID's 211(d) grant program. Both of our 211(d) grant institutions in dryland farming will be asked to conduct such studies and we hope that they will be able to co-operate with a number of institutions represented at this workshop in completing this task.

'State-of-the-art' surveys in dryland farming should include practices such as tillage, land-forming or shaping, mulching, cropping patterns, cropping systems, management of untilled lands surrounding arable lands used for dryland farming, water management practices such as water-harvesting, etc.

Land capability mapping is needed for many dryland areas to determine those lands most suited for cropping as well as others most suited for cultivated pastures or rangelands. Such studies do not consist of just soil classification; rather, they take into account the suitability of lands for various agricultural uses. Resources of most countries are too limited to allow unplanned land use or investment in marginal lands, unless absolutely necessary. A number of African countries are moving rapidly to finalize land capability maps, especially of rangelands, and it is our belief that more countries will follow.

<u>Research to find species or varieties of crops better suited to low energy needs, or to severe soil-stress or to soil-water stress conditions</u>. Much of our crop improvement work in recent years has been done under high soil-fertility conditions and/or low water stress. This approach has resulted in varieties which while well suited to low-stress conditions may perform poorly when grown in difficult soils or during drought. AID will co-sponsor a workshop in 1975 to review research progress in finding varieties which can grow in soils with high soil

aluminium, low soil phosphorus, or other stress conditions. Low-input varieties would be especially useful in dryland farming where risks are great and management alternatives are limited.

Need to Improve Dryland Farming and Management of Natural Grasslands

To raise agricultural production on semi-arid lands will not be easy. To do so, we will have to focus on a long-term program in dryland farming and grassland management. Wherever the total amount or seasonal distribution of rainfall is a principal limiting factor in rain-fed crop production, farming practices should emphasize two objectives.

1. Conservation of rainfall by reducing runoff losses, and by storing as much as possible in the soil profile for use by crop roots.

2. Invoking appropriate farm practices to make the most efficient use of the soil water by crop plants, and by the forage species of permanent grasslands.

In some cases the technology to apply these two principles is not available; therefore, research to develop new practices or to adapt old ones will be necessary.

It is clear that both objectives of dryland farming which are stated previously should be dealt with, to be of greatest benefit to cultivators and herdsmen. Several questions can be raised concerning water conservation and use in dryland farming systems. What adjustments in land and crop management are needed to fully utilize the available water resources? What is the potential production value of normal amounts of seasonal rainfall under temperature, humidity and evaporation conditions of the tropics and subtropics? What are the soil water relations of local soils, particularly the infiltration rates and water storing capabilities? What kinds of crops are best adapted to local climate and soil conditions, measured in terms of the most productive varieties of each species? What feasible changes in local cultural practices for individual crops and in farming systems can be made to fully exploit the improved knowledge that should flow from detailed research?

On the basis of achievments in temperate zone dry regions, one may predict great improvement in productivity of tropical and subtropical dry regions as the fruits of research become available; but this is contingent on imaginative, dedicated, and successful attacks on the problems involved. The foregoing prediction is based on experience in the subhumid and semi-arid regions of the U.S. Although periodic, cyclic shortages of rainfall still occur, their impact has been cushioned by the application of knowledge gradually acquired since about 1900. However, most of the advances that have resulted in much greater total productivity and less disastrous crop failures have occurred since the infamous 'dust bowl' days of the mid-1930s. At that time a comprehensive soil and water conservation program was invoked and supported by the U.S. government, in which technical advice was provided to land-owners and operators without charge, and the government provided cost-sharing financial support for certain recommended practices. Over a 20 to 30-year period, a large percentage of arable lands and permanent grasslands were placed under conservation programs. The U.S. still has droughts, but the former misery and suffering have been effectively reduced. How much of the experience and expertise acquired in drier regions of the U.S. or in Australia is applicable to the tropics and subtropics? A program of adaptive research on technology borrowed from developed regions would appear to be useful in tropical regions.

1. Management systems. The development of improved soil and water management systems for the arid and semi-arid tropics would appear to involve the following components:

a. Valid inventories of the kinds of land forms (topographic), the inherent characteristics of regional soil groups, and the parameters of the climate, including rainfall amounts and distribution, temperature patterns, humidity and evaporation rates, and the directions and velocities of winds. In short, what are the natural resources available in specific major areas?

AID is much concerned about the possibility that such inventories can provide a basis for decisions as to whether (1) there has actually been a recent (or current) change in climate in certain continental regions, such as sub-Sahara in Africa, or (2) whether the combination of normal cyclic variations in rainfall, in association with the proliferation of people and their livestock that has produced unbearable pressures on a fragile environment, constitute the basic cause of drought distress and human suffering. External assistance agencies, as well as national governments, can hardly go beyond current relief and rescue operations without some implicit assumptions as to the quantity and quality of the natural resource base of drought afflicted regions. For example, can national governments develop programs for restructuring agriculture and rural life on the mere assumption of a fundamental change in continental climate? The land and soil resources of a region should be stable, except for the degradation caused by unwise use; therefore the planning may be focused on those climatic factors which constrain effective utilization of lands.

b. A second component to consider in developing improved management systems would be an evaluation of current agricultural management practices, in relation to the anticipated rainfall situation, the conservation and storage of rainfall in the soil profile, and the effectiveness in use of soil water to support plant growth (State-of-the-Art). A preliminary survey of drought-stricken regions in the tropics and sub-tropics suggests that many of the principles believed important in developed, temperate zone countries are largely unknown in the less developed countries. Would it be feasible and rewarding to develop comprehensive soil and water conservation programs by individual developing countries?

c. A third component of prime importance includes the complex of social-economic-political constraints that affect present agricultural management systems. Borrowing an Australian philosophy, is agriculture regarded as a 'primary industry' of the nation? The influence of such a concept would greatly facilitate the changes needed to place agriculture on a more stable and fruitful basis. Cultivators and herdsmen should be supported through research, education, development of a suitable infra-structure, access to credit, supplies of inputs, and rational pricing of agricultural commodities, etc., so that these rural operators can be rewarded for prudent use of the nation's natural resources. Farmers and herdsmen, as custodians of resources, are indispensable producers of essential commodities.

d. There are additional basic requirements to be met in formulating improved agricultural management systems. Are they within current capabilities of small cultivators, under the skilled guidance of extension advisors? Will their results be sufficiently dependable to assure cultivators that they are not taking additional risks in subsistence and survival?

2. Types of situations. Any comprehensive program of soil and water management in regions of limited rainfall appears to fall in distinct categories:

a. Those pertaining to arable lands.

b. Those pertaining to non-arable lands in dry farming regions, particularly the grazing lands that support communal or migrating livestock herds.

c. Those pertaining to permanent grasslands outside of farming communities, usually consisting of dry range lands supporting livestock enterprises.

It may not be improper to seriously question the viability of agricultural systems that do not involve the interaction and mutual support of all three of these categories. For example, in the absence of expensive or scarce chemical N fertilizer, is it possible to maintain continuously productive arable lands without use of balanced farming systems which include livestock, especially cattle? Can small dryland farms maintain adequate soil N for crop production through biological fixation without sacrificing one or more cropping seasons or stored soil water to produce leguminous crops? Is it feasible to expect dry rangelands to support both breeding herds and the growth and finishing of marketable animals on the slender forage resources of dry permanent grasslands? Would not both types of agriculture be more dependable and profitable by a combination of the two systems?

3. Research needs. Obviously, research programs should be designed to explore crucial problems of agriculture believed mos appropriate and promising for longer-term agricultural development. One means of orientating research that has some merit is to establish pilot or demonstration farms to test the application of currently known technology to actual production under local conditions, and to identify problems that are beyond the scope of current technology. The use of controlled farming tests would supplement the observations of research specialists as to the constraints to better production noted on local farms and grasslands.

Whatever the methods of identifying specific research problems, it is probable that the following studies will be desirable:

a. Measurement of water intercepted and stored in the soil profile, for representative situations on both arable lands and permanent grasslands. Feasibility of soil profile modifications to increase intake rate and soil water capacity; land forming including conservation terraces; alternate crops, fallow cropping systems, stubble mulch systems, etc.

b. Effectiveness in use of stored water by economic plants as measured by:

(i) Yields of different species;

(ii) Yields of improved varieties compared to those of common unselected types within each species;

(iii) Changes in crop production per unit of soil water (water-use efficiency).

(iv) Yield responses obtained by correction of soil deficiences in essential nutrients -- nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, or 'trace' elements.

(v) Effects of date of planting, methods of planting, and plant population on crop yields, per unit of soil water utilized.

(vi) Effects on efficiency of plant production per unit of water from control of weeds, insect pests and diseases.

(vii) Influence of the time of harvest on production under the currently available soil-water supply.

c. Low-risk farming systems. A third type of research may be to evaluate the merits of combining several enterprises into a system in order to distribute risks and to maximize returns and thereby provide new stability not possible with a single crop system. Hopefully, a system made up of several compatible enterprises may cushion the impact of abnormal rainfall deficiencies and improve the opportunity for maintenance of soil productivity (as by including legumes for nitrogen supply), and soil structure (by sod crops and/or green manures) to minimize soil erosion and rainfall runoff losses. If a system is effective, it should enhance the farmer's net income, and assist in distributing both labor and energy needs over the year.

d. Continuously productive land. The need for developing continuously productive systems of agriculture is by no means limited to the humid tropics, in order to substitute planned management for the traditional 'shifting cultivation.' Such systems are just as urgently needed for subhumid arable lands and for permanent grasslands in both subhumid and semi-arid ecological zones. Mankind cannot afford continually to reduce **soil fertility** or to otherwise degrade these lands. Farmers of the temperate zones did not have continuously productive farming systems until recently. Gradually, over the centuries, the accretion of knowledge from experience and experimentation has led to the development of continuously productive lands. Will it be possible to duplicate these successes in the tropics and sub-tropics, at a much accelerated pace? This should be a challenge to the researchers at the ICRISAT as well as to other research groups within the tropics and sub-tropics. AID hopes to contribute to this effort through its soil and water management research projects and 211(d) grant programs.

e. Guidance to cultivators and herdsmen. The tasks of the research agency may not be completed when new technical knowledge has been acquired. The application of that knowledge to actual production involves an effective means of transfer from the researcher to the cultivator. Are there unique methods for accomplishing effective transfers of technology pertaining to dryland farming on arable land and effective production and utilization of forage on permanent grasslands? If we assume that a co-operative system between herdsman and cultivator offers the greatest stability and productivity in subhumid and semi-arid regions, how can adoption of such a system be fostered? How far can we go in the necessary restructuring of agriculture in dry regions by concentrating solely on a few crop species in less developed societies.

f. Will research on individual crops really pay off? The answers to such questions require some valid estimates of total costs to produce a commodity under present conditions, and equally valid estimates of costs per unit of the commodity when new technology is applied. Or to revert to an old useful system, what are the total costs (except for labor), with and without the new technology? By whatever method, it would be most helpful to have the results of applied technology expressed in monetary values or in some measure of productivity. Such data would supplement other values such as better distribution of labor, more effective use of power (animal and mechanical) and machines, and the stability of the agricultural system.

TRANSFER OF CROP PRODUCTION TECHNOLOGY

FROM INTERNATIONAL RESEARCH CENTERS IN DEVELOPING COUNTRIES

R.D. Havener*

After noting that several experts have been invited to comment on this subjects I would restrict my comments to certain aspects of this problem. Recently, there has been considerable discussion concerning the need for and organization of regional programs which, by serving a relay function, might make the services of international centers to national agricultural programs more efficient and effective. The ALAD program, with which I am affiliated, attempts to perform this role for CIMMYT, CIP and ICRISAT. Perhaps the most useful contribution I can make in the time available is to relate some of our observations concerning the relative merits and problems of this approach.

Services Provided by International Centers

It may be useful to review briefly some of the services normally provided by international centers to national agricultural programs. This was recently done rather succinctly by Dr. Lowell S. Hardin of the Ford Foundation**. His list included the following:

1. Developing of and training in modern, problem-solving research procedures;

2. generation of complete commodity 'production packages'with suggested procedures for adaptive testing and modification to suit local conditions;

3. provision of genetic materials;

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** Paper on 'International Agricultural Research & Training Institutes and National Programs', presented at the Round Table Organizing and Administering National Agricultural Research Systems, Beirut, December 1-8, 1973, by Lowell S. Hardin.

4. international testing of materials and practices with associated data retrieval and analysis;

5. consulting services;

6. seminars and workshops;

7. publications; and

8. direct technical assistance through contracts for special outreach projects.

Presumably then, regional programs functioning as relay centers for international institutes attempt to provide the same services, achieve better results or similar results more effectively. While reserving ultimate judgement on the comparative value of regional agricultural development programs, the points which follow seem worthy of consideration.

Advantages of a Regional Approach

Perhaps the underlying premise, which justifies a regional approach to strengthen national agricultural research and production systems, is that it should be more economic than attempting to establish similar programs in each individual country. This appears to be the case. More data are needed, however, which compare not only the cost efficiency but the relative cost effectiveness of investments in international centers, regional research and development activities and in attempts to directly strengthen national programs.

There are, however, many small countries which may not be able to attract major inputs from external assistance agencies to strengthen their national programs. Even with a regional approach, not all countries in the region are equally important in terms of their potential to expand agricultural productivity and/or contribute to world food supplies. But regional programs appear to be a relatively effective way to service the needs of small countries.

By building a system of pre-screening trials and a network of regional co-operative nurseries, incorporating the best materials from national programs in the region, it should be possible to broaden the base of adapted germ-plasm available to each of the countries at an accelerating rate. There are preliminary indications that this is the case in the ALAD/CIMMYT wheat and barley improvement programs. Likewise, it may be more efficient, particularly when serving the smaller national programs, to introduce exogenous materials into one or two regions for incorporation into the general germ-plasm base than to attempt to do so in each individual country. Varieties developed through this system should prove more precisely adapted to a particular set of agro-climatic conditions and more resistant to locally important pests and pathogens than varieties developed elsewhere.

Training programs, particularly in fields which tend to be location-specific such as agronomic practices, crop protection etc, can be more specifically orientated toward the problems which are most important in the region. The subjects addressed in workshops and conferences can also be more sharply focused.

For any given staff size, the diagnostic skills of regional specialists can be more closely atuned to problems shared throughout the region. Their visits to individual countries can be more frequent and, over time, provided that regional experts are highly qualified in scientific and inter-personal skills, a strong collegial relationship can evolve. Travel time and the burden it places on families of international scientists can be minimized in regional programs.

At any given level of available resources, it is likely that a regional approach may allow an organization or an agency to assemble a critical mass of highly qualified scientists with a wide disciplinary base to address the problems limiting agricultural production in a given area. Their activities can also be more closely co-ordinated.

A strong desire on the part of national governments is a pre-requisite for any successful effort by outside agencies to strengthen national programs. There are numerous examples where expatriates have been resident in countries for several years with no perceptible effect because sufficient local interest did not exist to change the present bureaucratic systems. A regional program allows one to focus resources on the countries in the area which place high priority on strengthening their research and production programs. At the same time, it is possible to provide modest services to those governments who are not yet eager for change or already have a relatively highly developed system. There may be useful 'spill-over' effects on neighboring countries when some programs in a region are highly successful.

Possible Weaknesses of a Regional Approach

There are certain inherent weaknesses in a regional approach to strengthen national agricultural systems. Some are manageable, others may be less so. Even when operating within a region, senior scientists spend considerable time involved in the logistics of travel arrangements. Their time is valuable and expensive and might be better utilized in conducting their own research projects.

It is also difficult to plan a schedule which will allow the scientist to be at the right place at the time when observations should be taken or when problems arise. Daily contact with the research program is not possible. Therefore, the observations of the visiting scientist may be too superficial or inaccurate and recommendations may be incorrect.

The regional visiting scientist may tend to spend too much time with senior officials and administrators and too little with junior scientists and research workers. He may even compete with the latter for the time and attention of their supervisors. The visiting expert may overshadow or claim partial credit for the accomplishments of local scientists. There is also the danger that the visiting scientist may become a critic of local efforts rather than a collegial participant.

It is possible that the research interests of the regional scientists are not exactly coincidental with the need of a particular country. Thus, they may effect priorities and funding within the national program in ways which may not be in the best interest of that country at a given time.

At least at present it is not envisaged that regional programs <u>per se</u> will have the staff strength or depth which has been assembled in the commodity-oriented international centers. Likewise facilities may be inadequate. Thus, the ability to perform more fundamental research is limited and the diagnostic skills of the team of regional scientists may lack competence when compared with those of the international center. (The ALAD program attempts to overcome this deficiency by formal and informal linkages with the existing international centers and consultants from other resource bases).

One of the advantages of a regional program carries with it a weakness. Working on facilities and with staff provided by host governments, while inexpensive, limits the scientists' ability to control the quality and perhaps even the nature of experimentation. The results achieved and data derived may be significantly inferior to what might have been accomplished if the program had full control over research resources. When programs expand while funds and facilities remain limited, tensions arise between the national and regionally orientated scientists. The process of reconciling these conflicting priorities can be difficult.

If the regional staff have no facilities of their own and have limited opportunity to conduct their own research projects, it may be difficult to attract and retain first class scientific personnel. It may also be difficult for them to maintain the cutting edge of their scientific skills.

Bricks and mortar plus laboratories and support staff bring stability. It may prove difficult to mobilize and sustain adequate funds to maintain regional programs. When resources become scarce or funding agencies bored, regional programs with their low level of built-in fixed costs and political clientele are likely to be the first to suffer.

Summary

In summary, regional activities or programs designed to strengthen and service national research programs can be effective. They are relatively inexpensive, have flexibility and offer one way to bring some direct assistance to smaller countries. On the other hand, they may have insufficient technical depth and breadth, be unable to mobilize adequate funds and lack permanence or stability.

Finally, and perhaps most importantly, one could imagine the evolution of a series of regional programs which would capture funds which might otherwise be available to directly assist national programs. It is much easier and more attractive to invest funds with a multinational organization, free from bureaucratic encumbrances and national politics, than to become involved in the slow and difficult job of providing direct assistance to national programs. The comparative effectiveness of this approach in the absence of strong national programs remains to be proven.

TRANSFER OF TECHNOLOGY FROM INTERNATIONAL RESEARCH CENTERS IN THE DEVELOPING COUNTRIES - THE CIAT EXPERIENCE

C.A. Francis*

The challenge of technology transfer is of increasing concern to CIAT, as crop and animal programs mature and begin to turn out results which have direct application to the farm. To work together with national agencies to develop technology, design alternative systems, test these on the farm, and assure that appropriate technology is adopted by the farmer is a complicated and difficult process, and requires a special orientation for each group involved in these activities. Many research organizations, both national and international (including CIAT), have dismissed this concern in the past as a responsibility of other agencies, particularly the extension services and recently the rural development agencies, which are charged by their governments with the task of communicating results to the farmer.

It is our concern in CIAT that the center's objectives are met--to increase productivity and production in the lowland tropics of Latin America, and thus to stimulate economic development and improve human nutrition in the zone. To achieve this goal, we must understand and function within the total process which leads from (1) problem identification to (2) research solution and finally to (3) application of these results on the farm. We are not an extension agency nor would it be possible or desirable to attempt to supplant the efforts of national agencies across the lowland tropics in this awesome task. It is essential that we maintain a clear, objective and evolving concept of what the most limiting factors are in the zone, which also limit our center from reaching its objectives. The technology and other solutions which we generate must be relevant to solving problems in the field, and we can only assure success by understanding and keeping in touch with the entire process which leads to adoption on the farm and by monitoring the impact of that adoption. There are at least three ways in which an international center can influence production in its zone of interest and responsibility: (1) generate technology and transfer this to countries and to the farm (e.g., new varieties), (2) transfer resources for generating technology (e.g., trainees), (3) influence decision-making

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processes concerning national policy or research resource allocation (e.g., workshops of special training courses).

CIAT has a number of activities which are directly concerned with transfer of technology, and these will be discussed as (1) the programs of research, communications and training at the center and (2) the direct activities of the newly formed systems team.

COMMODITY PROGRAMS - COMMUNICATIONS AND TRAINING

The basis for communications and training is a series of strong commodity programs which are well orientated to solve the serious problems limiting production of each crop and animal species. Establishment and organization of germ-plasm banks of major species (cassava and field beans in CIAT), and subsequent screening and multiplication, provide a wide range of genetic material to researchers throughout the tropics. Promising new varieties of crops are available to researchers, while established superior varieties can be moved into government or commercial channels if they have been adequately tested (rice is an example in Latin America). The CIAT in-service training program, in which young professionals from countries in the tropics work with specific scientists, provides another channel through which we can introduce improved germplasm and other technology. The crop and animal production courses attract professionals who have adequate technical knowledge but lack practical orientation and experience in the field. These training programs in Colombia aim at developing capability to identify and solve problems with available technology, rather than teaching how to apply a specific technological package for one crop or animal species.

A logical extension of this production training concept is the establishment of training centers and programs in countries as an integral part of the national research and development organizations. A course in maize production has been held in Ecuador, and one is planned in beef production in Paraguay. Plans are progressing for establishing crop production training centers in Guatemala, the Dominican Republic and Ecuador. Much of our co-operative research is conducted in collaboration with national programs throughout the zone, and this requires and assures periodic visits by CIAT senior staff personnel to national programs - an additional avenue for communication of technology.

Special major workshops have already been held in CIAT on rice blast, rice policy, cassava, beans, plant protection in maize, beef, swine, and tropical soils: others schedule for this year are on bean rust and allocation of research resources. The maize program annually sponsors a workshop for researchers in the Andean zone, and the site of this meeting is rotated among the five countries. A regional newsletter is published by the Maize Program to publicize recent advances in germ-plasm and technology, and keep ideas moving among programs in the Andean zone. CIAT has established an information service for research personnel, including abstracts and copies of requested publications at nominal cost, for cassava, beans, animal health and agricultural economics. All these activities of the center are designed to select, organize, and move ideas, germ-plasm and technology into national programs and onto the farm in the humid low-land tropics.

SMALL FARM SYSTEMS PROGRAM

A description of the objectives and some activities of the CIAT Systems Team was presented in the previous paper, 'Impact of Technology on Small-Farm Agriculture'. This new program is specifically concerned with the relevance and applicability of new technology to solve the most serious problems limiting production and economic development of the farm sector in the low-land tropics. Of equal importance is the effectiveness of existing agencies in identifying limiting factors, designing practical alternatives, and moving technology to the farmer for adoption.

To satisfy this concern and assure the relevance of our present research and training programs, the systems team works to integrate available information and physical inputs in specific development zones in collaboration with national programs. Methodology and other elements of this program have been described. As with the CIAT training programs, the emphasis is on developing and teaching a process for problem identification, and not the recommendation of any specific multiple cropping or crop/animal scheme as the patently 'best' solution for increasing production in all zones.

Through these specific program activities and the full-time efforts of the systems team, the CIAT is dedicating a significant portion of its available resources to working with national programs in developing technology and transfering these results to the farm. Experience will indicate which among these several activities has the greatest impact on production, and proves most effective in communicating information to the farmer. It is essential that we focus on real farm problems which are susceptible to solution, and assure that these solutions do move onto the farm. This is the most direct route which will allow international centers to meet their objectives, increase production and stimulate development in the tropics.

ILCA AND THE SYSTEMS OF ANIMAL PRODUCTION IN SEMI-ARID ZONES OF AFRICA

Georges Tacher*

The International Livestock Center for Africa is an international organization with the same status as ICRISAT. It has been set up in Addis Ababa in Ethiopia.

Its main objectives are:

(i) to promote the development and demonstration of improved livestock production systems, optimizing the use of human and natural resources in Africa;

(ii) to promote training activities which will increase regional competence in a systems approach to livestock production and development; and

(iii) to serve as a multi-disciplinary documentation center for the livestock industries of Africa.

In carrying forward its program, the Center will develop close linkages with the national and regional organizations undertaking research and training activities in the same or closely related fields of interest,

In furtherance of its objectives, the Center will:

(i) retrieve, assemble and make available in both English and French all relevant information on animal production in tropical Africa;

(ii) engage inter-disciplinary research staff to study existing animal production systems (embracing the whole complex of animal, plant, environmental, social and economic factors, and including production, management, marketing processing) and thence to develop new or modified systems of production and define priorities for other research;

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(iii) support, supplement and co-operate with existing national and regional research stations or programs in developing a fully co-ordinated program of production and rangeland research which is related to the urgent needs of livestock development;

(iv) develop research programs in specific aspects of livestock production which are appropriate to an international center;

(v) organize, or assist in organizing, seminars technical conferences and training courses for staff engaged in livestock research, extension, planning and production, particularly to increase regional competence in the inter-disciplinary systems approach to livestock research and development;

(vi) engage in such other activities as may be found necessary in the furtherance of its objectives.

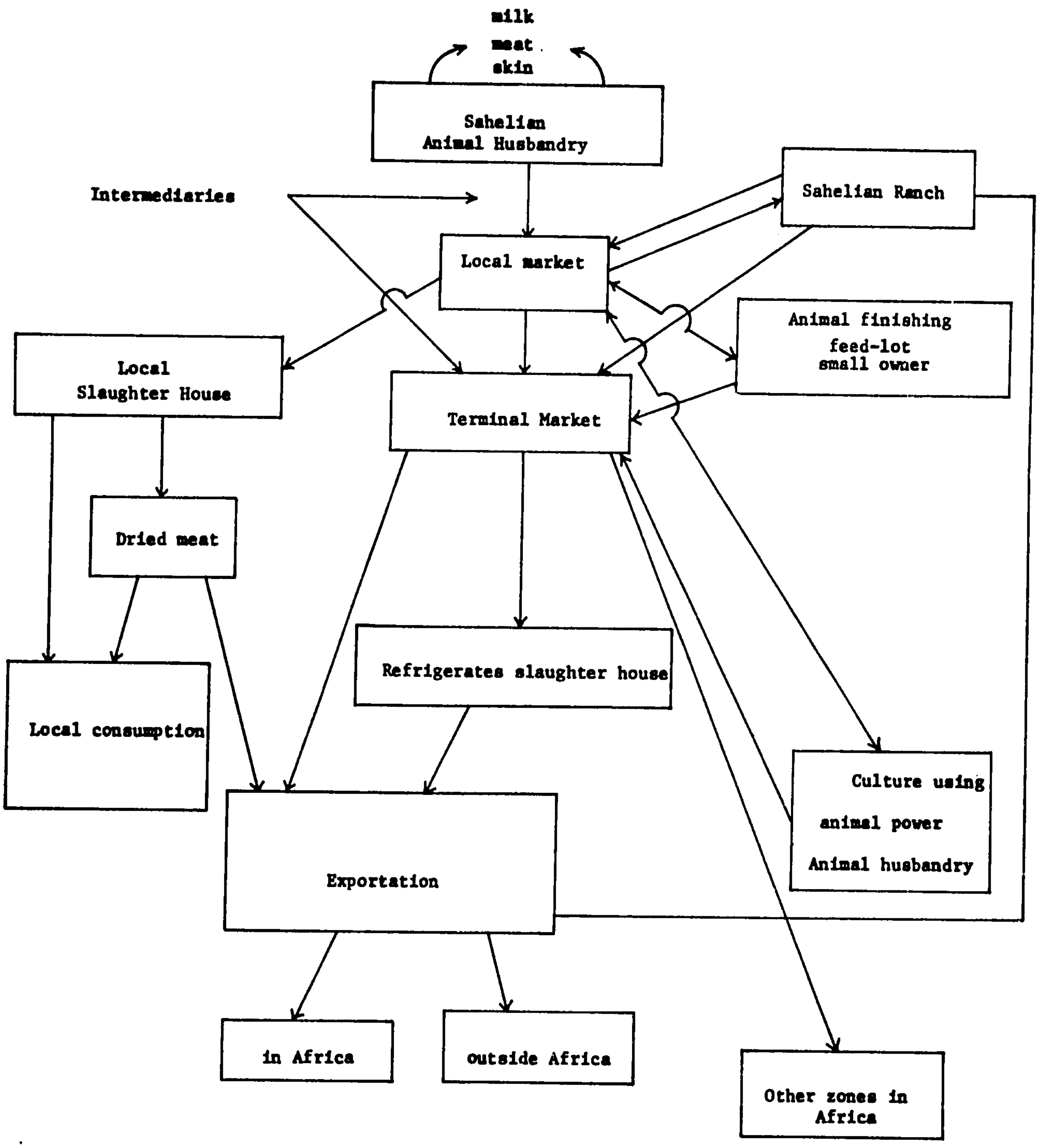
In developing and executing these programs, the Director of ILCA is required to maintain close liaison with the Director ILRAD (International Livestock Research on Animal Diseases), located in Kenya.

In the field of research, the multi-disciplinary system approach is essential for an international center. The centers are generally orientated around one or more specific crops, and find it adequate to concentrate to a large extent, on breeding improved genetic material. Moreover, their co-operative programs were built mainly on the distribution of this improved plant material. ILCA, on the other hand, cannot be as selective in its operations, nor will it have anything as tangible as new crop varieties or commodities on which to base a co-operative program. Instead it will need to spread its research activities over several localities, representing different ecological and socio-economic conditions, and to use the research program itself as a means for establishing linkages with national and regional authorities. Unlike other international centers, therefore, ILCA will not concentrate its research program at one headquarter site but will, over time, build up a network of research activities. It will be a decentralized center.

For carrying out this research program, it will have:

<u>Concerted programs</u>. In this kind of program, the ILCA will provide the opportunity to research workers interested in a specific program to concentrate on their work by themselves. They will co-ordinate their speciality with other workers and use the same techniques of observation and analysis so that there could be a common evaluation of results, i.e. project leaders of national projects on intensive grazing working in East Africa and West Africa will meet each year under the sponsorship

Fig.1. SAHELO SUDANIAN DIAGRAM OF SYSTEMS OF ANIMAL PRODUCTION



of the ILCA. They will meet successively in the different experimental areas to compare their results and to test their methods. Their objectives will be to present their findings in such a way that fruitful comparison could be made of research results at the different locations.

Associate programs. In these programs, the ILCA will strengthen those national programs whose scope of research and application exceeds the boundary of the country in which the national research program is being conducted. It is our expectation that findings through these programs will be of very great importance to Africa.

The defining of responsibilities and of the procedures to be followed will be detailed in an agreement between the ILCA and the authorities in charge of sponsoring the project, i.e. a government. It may decide to begin a program of research on the possibilities of certain techniques of irrigation to be used, it may become an associate to this program bringing experience of its own research workers and additional assistance in personnel, equipment, etc.

Conducted programs. The Board of Trustees on the proposal of the program committee may decide that a research program of great interest for Africa will be conducted by the ILCA research workers under their own responsibility and with only ILCA resources.

These programs will consist generally of long-term research areas concerned. The location of the research experiments will be chosen by the ILCA and agreements will be reached with the government of the countries in which ILCA workers will conduct their research.

ILCA's research which is of specific interest to this workshop is the animal system of production in the Sahelo Sudanian area, which is described diagrammatically in Fig.1.

Concerning the top portion of this diagram, agriculture in the Sahel area is characterized by pearl-millet and sorghum cultivation but only for the family consumption. Animal husbandry is the main resource of the people. It is characterized by a low rate of productivity. Fertility is about sixty percent and the rate of mortality is very high. It is generally admitted that 40 percent of the calves die during their first year of life. The percentage of animals coming from the herd, which become commercially productive, is about 12 percent. The production is about fifteen kilogrammes per animal, and thus the rate of growth of the herd does not go beyond three percent. The main constraints of this sub-system which the ILCA will have to study are:

(i) Sociological, such as the basic social unit of production or the rate of stockage of animals according to the risks anticipated by the cattle-breeders, etc.

(ii) Economic, such as the level of prices and the optimum age at which the animals should be taken out of the herd.

(iii) Zootechnical, such as the techniques of reducing the mortality and increasing the fertility, etc.

(iv) Environmental, such as pastures including perhaps fodder cultivation by irrigation with ground water, surface water collected from the river or lakes in this part of Africa; water management is very important. The recent drought has brought out the acuteness of this point and the necessity to undertake research on this aspect on a priority basis.

(v) Political, such as taxes per head of cattle or on its commercialization, or credit policies, etc.

The ILCA intends to study each point described above and each step of the diagram adopting a multi-disciplinary approach.

Cattle coming from the Sahel are sold in local markets where intermediaries intervene to group the animals which are then bought by the cattle buyers.

One of the problems of Sahelian animal husbandry is the instability of the quality of animals (During the dry seasons animal lose from ten to twenty percent of their weight). Sahelian ranches were, therefore, developed, where a rational management of pasture and water helps in maintaining the animals coming from Sahelian region in good condition in every season and this contributes to regularize the sub-system.

Then, the local market provides the local slaughter house for local consumption, or the terminal market where animals are taken either to the refrigerated slaughter houses or they are exported.

The different types of export are: animals on hoof, transportation by trucks or by railway; and transportation by airplane of refrigerated carcasses.

For each type of transportation there are problems, such as the establishment and management of cattle trails, choice of special trucks for animals on hoof, or refrigerated meat and so on.

But principally the two following points will interest the delegates because each point would enable one to integrate agriculture with animal husbandry.

The first is animal feeding either with feed-lots, or by small owners. As regards feed lots, many experiments have been carried out throughout Africa. They were done by utilizing grains, by-products or fodder. The two last ones are more interesting. But they are often restricted because by-products are often rare and the government of the countries having them are attracted by the high prices given by the developed countries where the prices of meat are higher than those of Africa and because we have to demonstrate the economic productivity of fodder cultivation.

Concerning small owners in Niger and Nigeria, for instance, the habit of fattening one or two oxen with crop residues or by-products of the farm is already a custom. The problem is that during some parts of the year, the labor does not have much work whereas during some months, for example while harvesting, they are overworked and hence hardly have time to look after their animals.

The second is to introduce animals coming from the Sahel into areas where they do not exist or where they are very few because of numerous diseases such as trypanosomiasis transmitted by tsetse fly, streptothnicosis, helminthiasis and so on and where not much interest has been shown in animal husbandry. A good way of introducing it is by importing oxen for animal power. After their working period, animals are fattened and sent to a slaughter house. In this way Chadian farmers have a third ox which they use as a spare wheel which enables them to increase the potentiality of meat production. Another way is to introduce animal husbandry in the farming system this way described by Professor Ruthenberg in his paper and I agree with what he says.

I have tried to summarize as briefly as possible the problems which will arise in the semi-arid zones of Africa and with which ILCA will have to deal and I think that ICRISAT and ILCA will gain in co-operating in this field.

TRANSFER OF CROP PRODUCTION TECHNOLOGY FROM INTERNATIONAL RESEARCH CENTERS IN DEVELOPING COUNTRIES - THE IRRI EXPERIENCE

R.R. Harwood*

The International Rice Research Institute (IRRI) experience has shown that whereas genetic materials, machinery, biological principles ideas may be transferred from an international center, production technology developed on the center usually does not go very far. This is especially true if an attempt is made to package and wrap it as for a box of seeds, and then mail it out to 'eager' recipients.

While many, if not most, of the ingredients may originate at the center, the 'package' should be assembled by research scientists in the environment where it is to be used. IRRI's entire cropping systems program, as presented earlier, is based on this concept, which necessitates a minimum of 'transfer' of ingredients in the package.

Functional Model

Based on an identification and classification of key environments in our target area, locations are being selected as test centers for production technology. Such a center is illustrated in Fig.1. The Batangas site is located about 40 kilometers from IRRI in an upland rice growing area characterized by a deep, well-drained silty-clay loam classified as a Vertisol. There is no irrigation available and rainfall is 1800 mm/year with 6 months having more than 200 mm/month and 3 months with less than 50 mm/month. The cropping systems team makes its basic research trials on cropping systems and on the component parts at this site for the agro-climatic zone. There will be three such zones in the Philippines.

Funding is planned through a national agency for support to the national research agencies for praticipation in the project. The Bureau of Plant Industry will join IRRI in basic and developmental research at each site. The Weather Bureau will plot areas of equal water availability and the Bureau of Soils will classify the major zones and their soils.

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IRRI's applied research group in co-operation with the Bureau of Extension conducts applied trials on a nationwide scale to confirm or modify the results. The applied research locations will focus on zones similar in production potential to the central test sites.

An example of the effectiveness of this approach can be given by the direct-seeding production program in 1974 when 52,000 hectares converted from single crop rain-fed paddy to a direct seeded two-crop system.

International Network

With senior staff stationed in three countries and co-operative programs in several other countries, a South-east Asian network is being organized (Fig.2). IRRI has a senior scientist co-ordinating the network. A series of agro-climatic test sites are being established, around which applied research programs are being built. The sites are selected to represent major agro-climatic zones and cropping systems. Agencies with national responsibilities for research are selected in each country through which these sites are run. The methodologies used at each site follow the same pattern, but are adjusted to the environment and capabilities of the host institution.

A three-year program is organized at each site as follows:

First year: Baseline study of the farming systems (50 farmers, 1 village)

Second year: Continued systems study and addition of new technology, replicated across farms and to put production curves defined. (85 farmers, 3 villages).

Third year: Widespread applied research across the agro-climatic zone by extension specialists.

In all cases at least a portion of the junior research staff lives in the villages. This methodology gives a common approach in different regions and permits comparison of different farming systems across those regions and zones.

IRRI's training programs in cropping systems, both degree and non-degree, are aiming at the development of national staff for this network.

Annual workshops at IRRI will bring the staff together for reporting and planning.

Fig. 1: MODEL FOR A KILLAG RESEARCH LABORATORY
Batangas Philippines Cropping Systems Studies

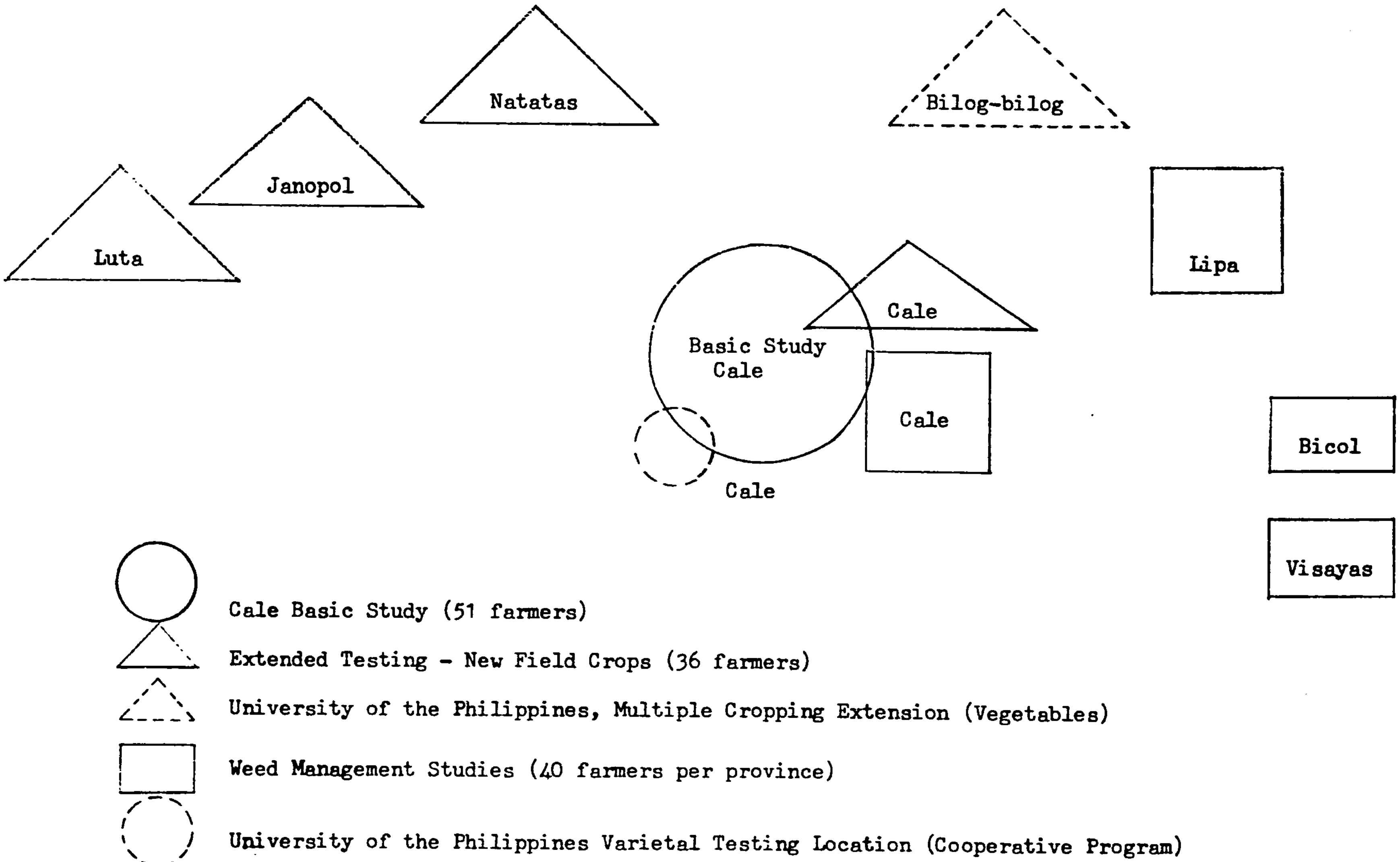
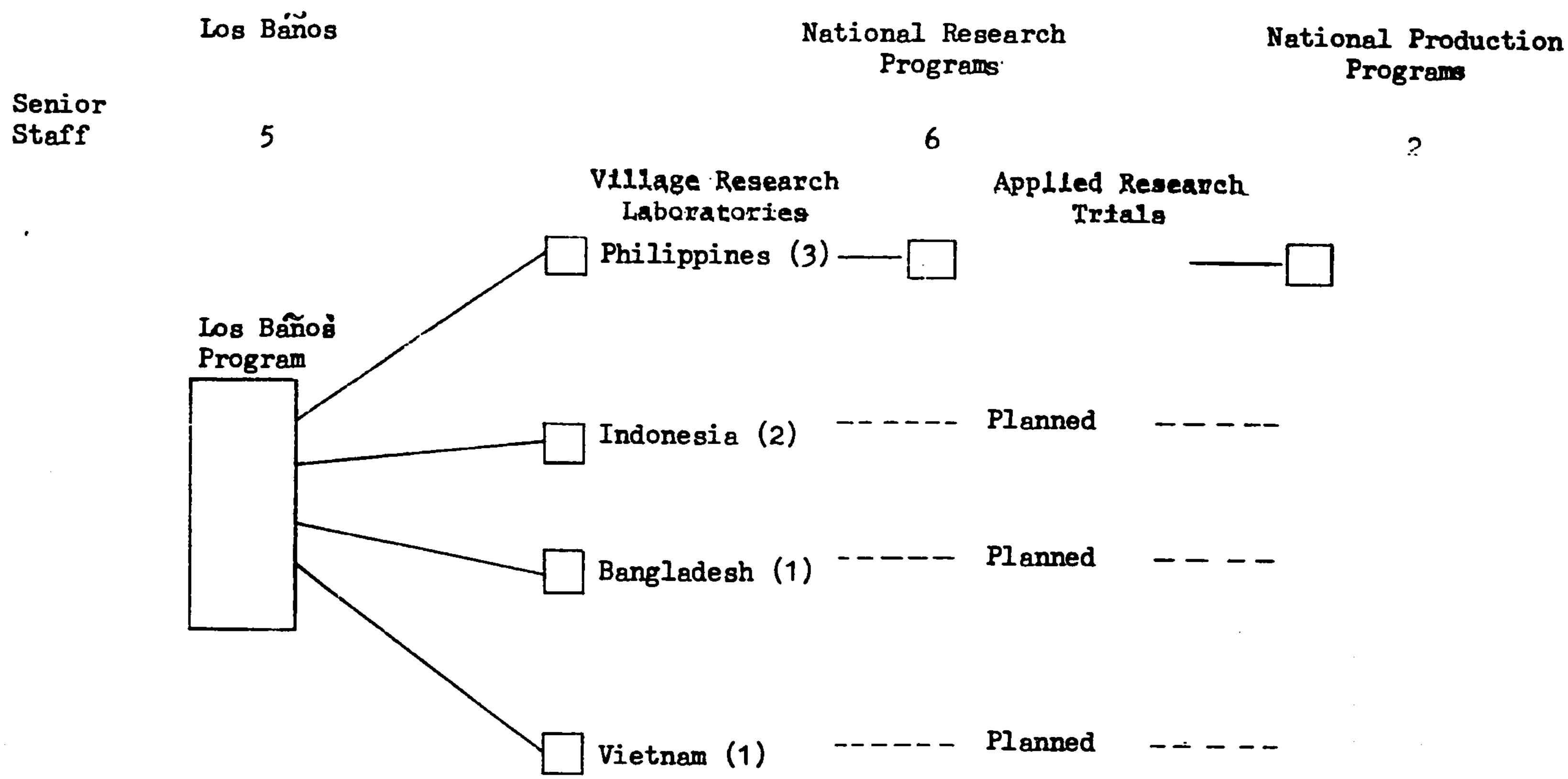


Fig 2: IRRI CROPPING SYSTEMS OUTREACH PROGRAM



IRAT APPROACH TO DEVELOPMENT OF INTENSIVE SYSTEMS IN PEASANT AGRICULTURE

A Case Study in Senegal

R. Tourte

The aim of this paper is to review the approach followed by IRAT in Senegal to development and introduction into the rural sector of production systems likely to change traditional agriculture without questioning the fundamental values of the rural community. Therefore, it only outlines the research methods and organization which enable the agronomists to reach already intensive technologies in an area where conditions are not very favorable.

In this paper, the attention is focused more on the ways of communicating with the farmer with a view to formulating his farm development plans which must indicate his land potentialities; use his means to best advantage and take account of his constraints; respect his ideas and attitudes; take account of the national objectives and realities; and define as far as possible the elements of an agricultural policy complying with these different conditions and constraints.

This paper is more a working document to be used as a basis for discussion than a true review document of the work and results obtained in Senegal, but its scope can probably be extended to cover a large part of the West African semi-arid area.

The Natural Environment

The physical environment of the Sudan-Sahelian zone of West Africa is characterized by:

<u>A severe climate</u>

- two constrasted seasons

  . a 7-9 months dry season
  . a 3-5 months wet season

- high temperatures

  . annual mean : 27-28^{o}C
  . minimum-maximum mean : 20 and 35^{o}C

- rainfall varying from 300 to 1,200 mm, with irregular distribution, often torrential or aggressive causing problems of serious erosion and runoff

- exceptional sunshine (always exceeding 200 days) resulting in a high potential plant photosynthesis

- high potential evapotranspiration (PET) varying from 4 to 6 mm by day in the wet season and 7 to 9 mm in dry season at peak times of drought.

Generally poor soils

- sandy to sandy-clay in the uplands, with very unfavorable structure and poor fertility.

- often high clay content, and low fertility in the lowland soils.

Traditional Agriculture

The 'traditional' agricultural systems are characterized by the often excessive exploitation of two factors from which any wealth springs, the land and labor, the part played by capital being generally very small. The other features of these systems are as follows:

(i) Cultivation, which was first extensive, and semi-shifting, has become more and more permanent as the density of population increased and system of fallowing disappeared

(ii) Hand cultivation prevails though animal drawn cultivation comes into rather general use for few small operations (sowing and hoeing); this leads to a lack of balance at the farm level which prevents actual increase in productivity owing to an always inadequate mechanization rate (0 to 30%)

(iii) Inputs are low and even absent

(iv) Labor organization is generally poor in the farm divided into sub-units, autonomous for the commercial crops, depending on the farm manager for the food crops

(v) Labor exchanges, more particularly, depend largely on old social habits, are not adapted to the requirements of technological progress, both as regards their quality, quantity and distribution

(vi) At the farm level the division into sub-units and the superposition of some technical innovations on old practices result in different systems existing simultaneously and more or less well specified in concentric areas from the farm center.

These characteristics involve or imply

(i) inadequate clearing;

(ii) extensive cultivation and low technical level, surface tillage, low amount of organic matter returned to the soil and inadequate weed control;

(iii) small cultivated area per worker generally not exceeding 1 to 2 ha; and

(iv) very limited use of fertilizers and pesticides.

This leads to

(i) a reduced possible action on the environmental conditions and therefore a great difficulty in diversifying crops, low income per caput ranging from \$ 60 to 100 to \$ 80 to 140 per worker.

(ii) very low labor efficiency (A worker devotes 700 to 900 hours/year to agricultural work and one man-hour yields 1-2 kg of produce-cereals or groundnut).

Technical Results of Agricultural Research

Technical improvements are being attempted mainly in the following fields:

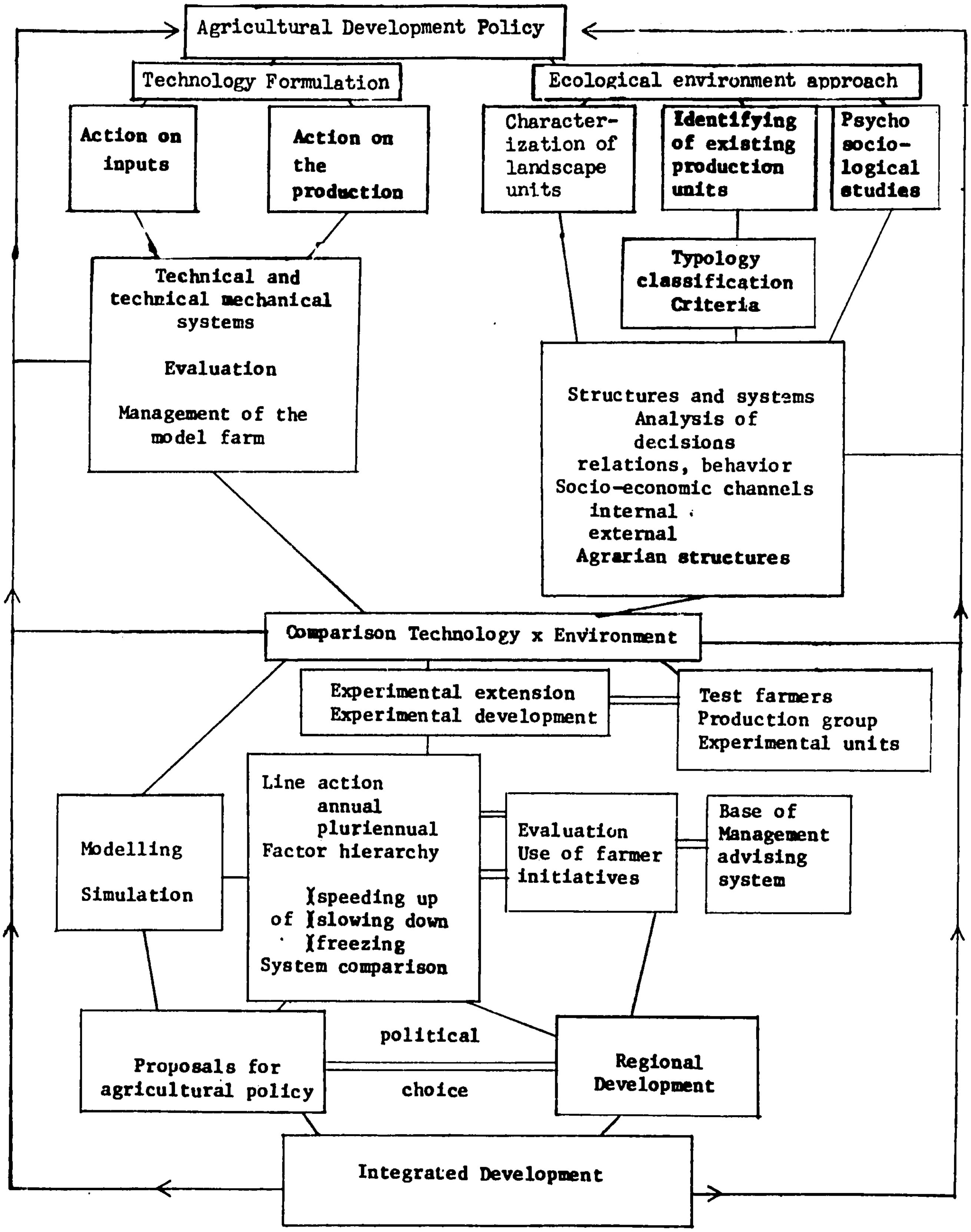
(i) the farmer's mechanical equipment, the options being generally but not exclusively: ox-draught cultivation for the uplands and mechanized post-harvest and farmhouse operations, and/or motorized cultivation in the lowlands especially for rice growing

(ii) the development and extension of high yielding and diversified plant material (groundnut, millet, sorghum, rice, maize, cotton, cowpea, sugarcane)

(iii) the introduction of phyto-sanitary methods

(iv) irrigation in the lowlands which is still on a very reduced scale (less than 100,000 ha out of 2,000,000 ha of flooded or

Fig.1: INTEGRATED RESEARCH SYSTEM IN A DEVELOPMENT PROCESS



irrigated area in Senegal under crops). In every case, water from surface flows is used (mainly river floods).

The catastrophic cycle of present drought calls for the intensification of research on irrigation of the upland areas with ground water.

The basic objectives of research are:

(i) The maintenance and improvement of land

(ii) Self-sufficiency in food

(iii) The development of continuous cultivation (because fallow is progressively disappearing)

(iv) The growing of crops as a pure stand because the short rainy season is badly adapted to the complex operations associated with mixed cropping

(v) Integration of cattle into mixed farming

(vi) Better use of labor (product increase and labor organization)

(vii) Research on regional agricultural productivities

(viii) Achievement of national production targets.

New Production Systems and Their Transfer to The Rural Sector

Thus the change in the traditional agricultural systems, which was necessary both technically and politically, was made possible and put into effect on the basis of new technical proposal within the framework of an integrated system of research-development. The pattern is described here by a double approach along two converging lines, the stages of this approach can be summed up as follows:

1. Technological approach: formulation, testing, evaluation of technical cropping and production systems, at the stations and experimental sites, and later on test-farmers' fields. It is indeed necessary, on one hand, to verify whether the elementary innovations are coherent and adapted to combination and, on the other hand, to assess their value and usefulness at the farm level particularly in the context of the national objectives and policies.

This approach is adopted both for physical patterns at several sites in the country and also for mathematical models.

In Senegal, it was possible with this approach to suggest a range of farm type-patterns for different areas, for farms with sizes varying from 3 ha (two rice crops by year) to 15 ha (rain-fed crops) and with the following economics:

- gross annual product : equivalent to $ 20,000 to 28,000

- gross monetary margin: $ 10,000 to 20,000

- margin per worker : $ 2,000 to 3,600

At the same time, these type patterns give an idea of the agricultural potentialities of the areas in which they are applied; these potentialities are one of the essential bases of planning.

We must point out here how particularly interesting it is to correlate or identify this technological approach to the main agricultural conditions of a country or of a zone so that a production system suitable to them may be identified and its potentialities determined.

This determination of farm type-patterns was recently followed in Senegal by experiments at the larger level of the landscape or production units (soils, irrigated rice-growing areas) studies on a watershed basis are under study. These experiments are expected to result in development patterns.

2. Socio-economic approach to existing production structures, including more particularly the characterization, structures and typology of the farms; the study of labor and its organization; the internal and external farm relations, and the factors of slowing down and short-term and institutional freezing, etc.

This approach is carried out in Senegal at two levels:

a) At the farm level, with sophisticated regular studies on the farm, its consistency, constraints, labor, economic analysis including the analysis of input use.

   By this study the identification and categorization of the criteria and characteristics, as well as an extensive knowledge of the basic organization of the Senegalese farm are possible.

b) At the landscape or production unit level, with sample surveys according to methods and criteria determined at the preceding level.

   By this study, a farm typology can be obtained which will provide the basis of farm management methods for extension; but this is possible only if the typology is judiciously formulated from criteria related to development factors (area, number of workers, equipment, draught animals, etc.).

3. A comparison of the technical production systems with the existing socio-economic structures resulting in socio-economic systems. This is an essential step. It has been for a long time the fundamental gap in the relations between research and extension.

It seems that it is principally on this aspect that efforts must be exerted.

Briefly, the point is to make the farmers adopt or correct or call into question, within the framework of a well concerted action of the researchers and extension officers, valuable technical systems but which must be adapted to the means, structures and mental habit of the community concerned.

Here again, two levels are possible:

a) The farm level. The innovation package, the new systems proposed to the farmers (the IRAT test-farmers in Senegal - about one hundred distributed throughout the area) who use them on the whole on a part of their farm and, by a feed-back process, show to researchers the difficulties and incoherence and consequently the new adaptation or research ways.

b) The socio-economic unit. The systems selected at the test-farmer level are considered as being likely to be extended and proposed to ordinary farmers but always within an experimental framework. They are aimed at replacing the farmers in their actual socio-economic environment, determining the external factors affecting speed of adoption and controlling and leading the extension and input supplying structures of the rural sector.

Taking into account these conditions in Senegal, the socio-economic units selected for experimenting the new production patterns were the co-operatives, the basic structure of agricultural development in Senegal.

In 1968, two experimental units were established which consisted of 150 to 200 farms each, having a total population of 4,200 inhabitants distributed over 12,000 hectares (7,500 cultivated).

After 5 years of operation, many useful lessons could be drawn from this experience in the field of research and extension:

(i) Introduction of ox-draught cultivation in 50 percent of the farms (+ 5 ha);

(ii)adaptation of equipment advices to all the farm categories;

(iii)adoption of cropping systems with 4 year rotations of the type cereals - groundnut (+ cotton) - cereals - groundnut. The basal dressing of phosphate and maintenance of fertility is essential. Ploughing in of straw and farmyard manure (oxen) helps with building soil fertility. There is also a possibility of integration of cattle into mixed farming through drought-oxen, diversification of crop production : cotton, maize, tobacco, introduction of mechanical post-harvest operations, and reforestation.

These adopted innovations cause a change in the economic results of the farms concerned.

Thus, from hand cultivation to semi-intensive ox-draught cultivation on 45 percent of the farm, the data per worker are as follows:

(i.) The total production value rose from $ 800 to 2,600

(ii)The agricultural income increased from $ 720 to 1,960

(iii)The net monetary margin rose from $ 350 to 1,480

There is another important point; it can be seen that the farmer had considered the highest possible increase in his production:

- The inter-annual income stability (preference for production of systems not very sensitive to climatic risks but suited to production ensured to be marketed).

- Staggered monetary resources through the year which are made possible, by vegetable crops, animal husbandry, etc.

In fact, the attractive character of the innovations caused deeper changes in the structures and farmer's mental habit, some of which are listed below:

1. A change in the nature and quality of work and exchange of work in the sub-farms of the same farm which can be seen, more particularly, in a better common use of the production machinery and some liberalization of the women status in regard to field work,

2. An awareness of the possibilities of the co-operative effort and acceptance of its rules and limitations and at the same time questioning of some traditional authorities and appearances of new leaders,

3. An attempt to improve life conditions (house, rural water supply), the state of knowledge (alphabetization) and health standard,

4. A possible land redistribution called for by the requirement of a new technology and changes in the agricultural systems,

5. Open discussion on some institutions : development agencies, marketing organization, price and credit policy, land tenure, etc.

It must be noted here that the three stages of the above approach were described separately for the sake of this statement but are in fact carried out simultaneously; one of the main IRAT ideas is that the analysis of the existing production structures assumes its actual value only in the evolutive dynamics of a rural sector made unstable by a new technology, the trends of the movement produced being more important to be known than a fixed situation in an old equilibrium.

Experimental Development

The action of experimental development carried out in the experiment units showed, if needed, the close relationship between the agricultural systems and the socio-economic environment of the farms.

More particularly, it identified and indicated the main retarding and speeding-up factors of agricultural development and all this at the micro-region level, and made it possible to know the attitudes and opinions of the farmers about their possible ways of development.

On the basis of the collected information about the inter-relationships of the endogenous variables (internal to the farm), production system and exogenous variables (activity systems and rural structures), it is possible to propose (to facilitate the guidance of agricultural production, for example) some change or 'manipulation' of the exogenous variables.

In other words, with such a knowledge of the mechanisms of rural activities the elements or bases of an agricultural development policy can be proposed.

After the first five years of the experiment unit operation, a series of political measures have been suggested to the Senegal Government, for example:

- price fixing, before the season, at calculated levels which take into account the development objectives and the compared production conditions (more particularly pricing of cereals and re-adjustment of cotton and groundnut prices),

- incentives to the adoption of post-harvest operations (threshing, stockage) for cereals,

- organization of a network for marketing cereals and meat,
- providing subsidy for the purchase of machinery, fertilizer subsidies and adaptation of the credit term to the type of machinery,
- education of young adults more particularly with a view to facilitating co-operative management,
- test operations of land improvement at the rural group or community level.

Besides these measures, it is suggested that research may be conducted into the methodology of close communication between research organizations and extension organizations on the spot with a view to studying and solving the problem of development.

It seems that this communication must be greatly favored by the fact that the extension organizations and bodies need information more and consult research not at the elementary research level, but in terms of production systems and farming structures also.

The experiment carried out in Senegal in this field is perhaps worthy to be extended to other countries and under other conditions.

RECOMMENDATIONS OF COMMITTEE IV:

TRANSFER OF TECHNOLOGY AND OFF-SITE RESEARCH

J.S. Kanwar

1. Need for off-site activities. The objectives of international centers are to increase food production, stimulate economic development and improve the nutrition of rural populations. This goal will not be achieved on any single experiment station or in any specific location. The battle will be won on the farm, and scientists working in the centers must be involved in the entire process of development from problem identification to generation of technology and transfer of technology to actual situations.

   Although ICRISAT may specialize in one or more areas of this process, it will need to understand and appreciate the full dimensions of the process, to keep its research sharply focused and priorities straight. It is not possible to generalize from a single experience in one location and there is a need to learn from the experiences of others from within as well as outside the zone of responsibility.

   Because of ICRISAT's focus on farming systems, research must be carried out as much off-site as on-site. Off-site research is not the transfer of technology or "extension" of ICRISAT, rather such research is an integral part of the core program.

2. Components of off-site activities. Conceptual models of farming systems must be developed in terms of the processes involved. The operational aspects need to be identified, studied and tested.

   ICRISAT should recognize that farming systems are more comprehensive than its mission which focuses on managing the soil, water and human resources for crop production. Other aspects of farming systems will be the responsibility of national programs and other organizations. ICRISAT's major efforts should:

   a) Generate technology and transfer it directly to other places in the semi-arid tropics. In the case of crops, this is obviously germplasm (varieties) and cropping practices. In farming systems this is more appropriately a "method for (1) identifying limiting factors, (2) for sharing available technology, (3) assembling the pieces into relevant and specific solutions for the farmer, (4) implementation of the change and (5) measuring the impact".

   b) Develop transfer resources for generating technology through trainees, publications, workshops and other activities.

c) Influence decision-making processes and national policy on research resource allocation throughout the semi-arid tropics by providing factual information through workshops, special consultation and training programs.

d) Build a conceptual model and data base for describing and, as far as possible, quantifying existing farming systems. These should be analyzed from different aspects and constraints and weakness identified.

e) Test in off-site locations the technologies emanating from research on location-specific problems.

Components of the system of crop production should be studied independently and in combinations so as to develop understanding of the basic physical, biological and socio-economic processes involved which may lead to generalizations and predictability. A continuing process of broad analysis, component identification, hypothesis formulation, testing and resynthesis is needed.

3. Mechanism for implementing off-site activities. A basic objective should be organizing national research systems, dealing with cropping systems of the semi-arid tropics and strengthening of their research capability. Many national research systems do not have the physical facilities required to obtain accurate results from field experimentation. ICRISAT should endorse efforts to strengthen national research systems throughout the region. Improvements in research station development, improved station management, better field plot technique and more systematic program planning, management and evaluation are preconditions for an effective "off-site" research.

4. Staff development. ICRISAT should assist in staff development of the national institutions through support of degree programs and by offering in-service training and opportunities for the exchange of staff among institutions.

Off-site research should be carried out through and with national research systems and should not be labeled as an "ICRISAT Program", rather it may be called "co-operative research program between ICRISAT and the collaborating center".

5. Priorities. Because off-site activities are as important as those carried out at the headquarters, identification of staff and the allocation of funds should reflect program priorities rather than location.

6. Criteria for off-site research. ICRISAT should develop a set of criteria to be used in selecting the institutions and the locations for its off-site activities.

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APPENDIX

ABSTRACT

AN ATTEMPT TO EVALUATE RISK OF FERTILIZER USE IN THE SEMI-ARID NORTHEAST OF BRAZIL - A STUDY OF CORN IN PERNAMBUCO

A.R. Teixeira Filho*

Using data from a set of fertilizer trials conducted in the semi-arid region of the State of Pernambuco, Brazil, this study assesses the production conditions under which fertilizer use is economical. The method used involves obtaining the frequency distribution of the internal rate of return achievable under several levels of fertilizer use.

Using an exponential type production function with varying coefficients, a response curve was obtained having rainfall as one of its arguments.

Since rainfall is a stochastic variable, yields and the calculated rates of return are also stochastic. Once the frequency distribution of rainfall is known, one can obtain the distributions of yields and of the rate of return. With these elements, optimal fertilizer doses were determined for a specific pattern of risk aversion.

Using Janvry's definition of risk aversion, the zero rate of return describes the fertilizer possibility frontier. This was determined for several combinations of prices, soil types, and rainfall levels and distribution.

Two major points are brought out by the study. The first is that one can be reasonably sure of getting positive returns from the application of fertilizer to corn in the semi-arid area of the State of Pernambuco. The second relates to the limited effects of policies which would tend to reduce prices paid for fertilizer.

Creation of new corn varieties is suggested as a natural way of improving the situation.

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