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SOIL AND WATER CONSERVATION AND MANAGEMENT

IN

FARMING SYSTEMS RESEARCH FOR THE SEMI-ARID TROPICS

by

Jacob Kampen and Associates

INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS

Hyderabad - India

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SOIL AND WATER CONSERVATION AND MANAGEMENT

IN

FARMING SYSTEMS RESEARCH FOR THE SEMI-ARID TROPICS[1]

by

Jacob Kampen[2] and Associates[3]

I INTRODUCTION

Rainfed 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 evaporative demands 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 more effectively conserves and utilizes the rainfall and the soil, and new crop production systems which maintain productivity and assure dependable harvests are urgently required.

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1 A paper presented at the International Workshop on Farming Systems, ICRISAT, Hyderabad, November 18-21, 1974.

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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, over grazing 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.

Farming Systems Goals

The major goals of the Farming Systems Program are inherent in the primary objectives of 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 for 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 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 accellerating the attainment of its objectives.

II THE SETTING

Substantial diversity exists within the resource environments of different regions in the semi-arid tropics; a generalizing description therefore has inherent dangers. Insufficient data have been collected to arrive at well-defined classifications of similar sub-regions. Most examples referred to in this section are 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 4½ to 7 humid[2] months.

V4; Dry tropical climates with 2 to 4½ 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 are more common at sub-tropical or temperate latitudes.

Thus the semi-arid tropics are characterised 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 1500-mm (Fig. 1, 2 and 3); cooler tropical areas with somewhat less rainfall than 500-mm may still be considered semi-arid.

Cocheme and Franquin (1967) published a study of the agroclimatology 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% of the annual precipitation occurs during the rainy season[2] which generally lasts from 4 to 7 months (Fig. 1, 2 and 3).

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1 During an "arid month" 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. At least 1/3 and often more than 2/3 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[1] are two to four times 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 evaporative demand is relatively high during the four months preceding the humid season, potential evapotranspiration during this period often exceeds 40% of the annual amounts (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" and make farming in the seasonally dry tropics a hazardous way of life. The extended dry season during which no crops can be grown except on residual soil moisture or under irrigation represents another factor

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

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 "effective rainfall"[1] of 72% on average, ranging from 60 to 88% (Fig. 3). Most of the rainfall not used for evapotranspiration in the growing season is lost either as evaporation in the early rainy season or as runoff and deep percolation. However, long term averages overestimate effective rainfall in areas characterised by variable precipitation. Actual long term effective rainfall may be less than 2/3 and sometimes less than ½ 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.

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1 "Effective rainfall" is for the purposes of this discussion 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".

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% in the low rainfall areas and as low as 25% in high rainfall areas.

Rainfall use efficiency. Low effective rainfall has severe repercussions on "rainfall use efficiencies"[1]. Statistics on regional production indicate that e.g. 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 of e.g. 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

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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)".

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. 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 I illustrates that for six selected dryland districts in the Indian semi-arid tropics owner-operated farms generally account for more than 80% 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 rainfed areas is substantially larger than in regions where a significant proportion of the land is irrigated. As shown in Table I, often more than 75% of all farms in irrigated districts are smaller than two ha while in rainfed situations frequently more than 60% of all farms exceed two ha in size. In the selected districts 50% of all farms in primarily rainfed areas generally fall within the two to ten ha size.

Table I. Farm size distribution and irrigation and ownership status of farms in 12 districts of India (Source: Bureau of Economics and Statistics)

Size class (ha)	< 1	1-2	2-3	3-4	4-5	5-10	> 10	Owner operated[2]	Irrigated area[3]
	%[1]	%	%	%	%	%	%	%	%
"Rainfed" 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
"Rainfed" 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.

In rainfed districts the land area occupied by farms from 5 to 10 ha usually exceeds 25% 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 II shows that entirely irrigated farms in three selected, primarily rainfed districts in Andhra Pradesh measured on average less than .9 ha while partly irrigated and entirely rainfed farms on 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. In e.g. Adilabad, Mahboobnagar and Medak Districts in Andhra Pradesh the irrigated proportion of all cultivated land is 6, 9 and 15% respectively. Entirely irrigated farms account for 2, 2 and 3% respectively and consequently the irrigated land in partly irrigated farms accounts for only 4, 7 and 12% of the cultivated area. However, the cultivated area occupied by partly irrigated farms amounts to 46, 21 and 43% (Table II). This situation may be advantageous when efforts are made to introduce new technology aimed at the optimum use of water resources.

Table II. A relation of farm size to irrigation and the relation of the area in partly irrigated holdings to total cultivated area in three primarily rainfed 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 rainfed)	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 soiltypes are widely spread throughout the seasonally dry tropics, 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 is predominantly of the kaolinitic, non-swelling type.

The depth of the surface soil may vary from 0 to 30-cms and is often underlain by a more clayey subsoil. 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, 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, Northeast Brazil, North Cameroun, Chad, Dahomey, Ghana, Mali, Northern Nigeria, Sudan, Togo, Upper Volta and Zambia (Cochemé 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 underlain by 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%), 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 problems on these soils, particularly under fallow. Russell, 1970 stresses the potential for significant increases in production through improved drainage.

The profile is of varying depth (30 to 150-cms). The sub-soils are mostly clayey but sometimes sandy (Cochemé and Franquin, 1967). While 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 e.g. 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 in e.g. 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 due to lack of management. Kanwar, 1972 reports that in India alone 6000 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, between 100 and 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). Increased exposure of land resources to the hazards of wind and water erosion is the result. 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 rainfed 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, to increase infiltration, to prevent the soil from blowing and washing away, to control weeds, to improve soil structure and to increase crop yields. The yield increasing effect of mulches consisting out 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 system 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 to it (Swaminathan, 1973). This is not surprising: 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 rootzone. 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.

Emergency measures. During crises large sums of money are often spent for hastily conceived programs in various types of disaster relief. 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.

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 though timely irrigation have been reported (Hiler, 1974). On black soils at Bellary, Karnataka sorghum yields of 527-kg/ha were obtained under entirely rainfed conditions; two supplemental irrigations (of 12-cm each) increased yields to over 2700-kg/ha (Das and Tejwani, 1974). Crops like sorghum and millet are not normally provided with supplemental water in the seasonally dry tropics. Due 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 due 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 through 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 rainfed farming by irrigated paddy cultivation.

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 rainfed 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 rainfed agriculture. In India, the All India Coordinated 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 ICRISAT in 1972.

III 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 apparent that insufficient data are presently available with ICRISAT to permit a well documented and precise determination of priorities for research and development. A program to collect and analyse information for 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 unit) 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 is of moderate size, new management technology therefore should be applicable to small units or mechanisms for people to cooperate 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 realise 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 in their eyes - out of necessity - more important than the productive potential of their resources in the next decade.

Due 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 human tragedy. The farmer is in his decisions guided 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 in order for farmers to be able 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 is 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 cooperation 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 to cooperation 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 fulfill the partially conflicting requirements. Initial research at ICRISAT supports the contention that ridge and furrow systems can be used to manipulate runoff and to reduce erosion. Earlier research established the surface drainage function of ridges and furrows (Choudhury, 1971; Krantz and Kampen, 1973).

The ridges function as a very close **succession** of "mini bunds". Each furrow runs under a slope which is 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 rootzone 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; (c) No further land development is necessary to facilitate the application of supplemental water

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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 holds back water which otherwise would run off.

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.

2c The development of waterway systems which safely convey excess water from the land with minimum interference for 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 on upland crops, resulting in increased benefits through stabilizing rainfed agriculture and by lengthening 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 due to the relatively high evaporative demands. New technologies in water use which decrease 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 equipment and the feasibility of cooperative arrangements.

In some regions substantial development of ground and surface water resources has taken place while in other areas 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 earth movement to created capacity ratios for runoff storage units cooperation in construction may be necessary. Particularly on flat land pumping of runoff water into above ground reservoirs will be investigated.

IV 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 land slopes vary considerably. This diversity provides valuable opportunities to simulate a wide range of conditions in the semi-arid tropics at ICRISAT. However, it does not eliminate the need for associated research at other locations in the world region of interest. 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 production factor investigations involves studies of 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 through field trials. Although some of these experiments will not give complete answers on questions of actual implementation on a farm scale or on 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 relay cropping[2]. The last two cropping systems extend over both seasons. Krantz (1974) discusses the 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.

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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.

[2] 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.

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 during a number of years:

a) Traditional practice: After 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 any preceding year the land will be cultivated to incorporate the stubble and weeds. Following this the land will be ridged leaving a rough cloddy seedbed during the remaining part of the dry season. At the beginning of the monsoon the land is ready for planting or fallowing[1].

The comparisons have been initiated for the relay cropping systems and for 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 on the red soil experiments 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

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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.

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 those 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 successful only if the implement phase is 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 related to the development of land and water do not lend themselves well to conventional experimental designs. Examples are comparisons of different bunding systems and studies on the effects of alternative slopes of ridges and furrow systems on water use, erosion and runoff; the optimum development and utilization of ground

ing is necessary

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 ICRISAT a number of natural watersheds has 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 and 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.

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 field 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% and of systems with and without runoff water storage facilities for "life saving" supplemental irrigation. Table III 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 while 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.

Monitoring the water regime. On each watershed unit an effort is made to continuously monitor the water regime with the objective of selecting optimum systems for agricultural production. A number of recording and non-recording rain gauges has been installed. Runoff data are obtained from Parshall flumes with continuous recorders. Samples of eroded material are collected regularly. Soil moisture measurements are made both gravimetically 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 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 systems 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).

Table III: Soil and water management and conservation practices on black soil watersheds.

Unit No.	Cropy 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]
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 South Optimum	Bullocks Improved Tractor Improved[8]	Monsoon and Post-monsoon	Ridges and furrows at .8% and graded terraces	Deep storage tank Piped to circle[9]	Mechanical

[1] Crop system technology defines primarily the level of fertilizers applied.

[2] Cropping in a second season will each year 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.

Table III: Soil and water management and conservation practices on black soil watersheds (Continued)

Unit No.	Crop system technology	Power source Implements	Cropping Season(s)	Land and water management technology under testing	Runoff storage Application method	Means development
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
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[1]	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[2] and grasses	Flat planting in levelled fields	Pump storage tanks[3] Gravity supply below	Mechanical

[1] Gravity supply below; After lifting water is provided to the area below the tank.

[2] The area in BW8C is saline, a paddy and grass crop will be applied for sometime to reclaim the area.

[3] At times of drainage flow, water will be pumped into a storage tank.

THE INTERNATIONAL PROGRAM

The third and fourth components of the Farming Systems Program are: Cooperative 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 program because of the site specificness of many problems. The agro-climatic environment at 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.

Selection of bench marks. 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 agroclimatic conditions, 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 physical 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 IV this very preliminary and simple classification would result in eight regional descriptions with distinct 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 IV: 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

[1] A precise definition of the boundary limits of each situation will not be attempted until additional data have been collected and analysed. For illustrative purposes 750-mm might be thought of as the divide 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%.

The development of associated research programs at representative locations is urgent, particularly in view of the critical food problems 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 regions in classes 1 and 3 (Table IV) would provide opportunities in this regard.

To arrive at superior land and water management technology under conditions basically different from those at 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 IV). A second "bench mark" location might be selected in regions of high rainfall, good soils and steep topography (class 2 in Table IV) and a third in areas with low annual rainfall, good soils and steep topography (class 6 in Table IV).

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 Cooperation".

Improved resource management will require 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 due primarily 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 while 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 the most essential importance in the development of sound soil and water management and conservation practices.

Economically viable technology for the exploitation and utilization of surface and groundwater resources on 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. In addition, 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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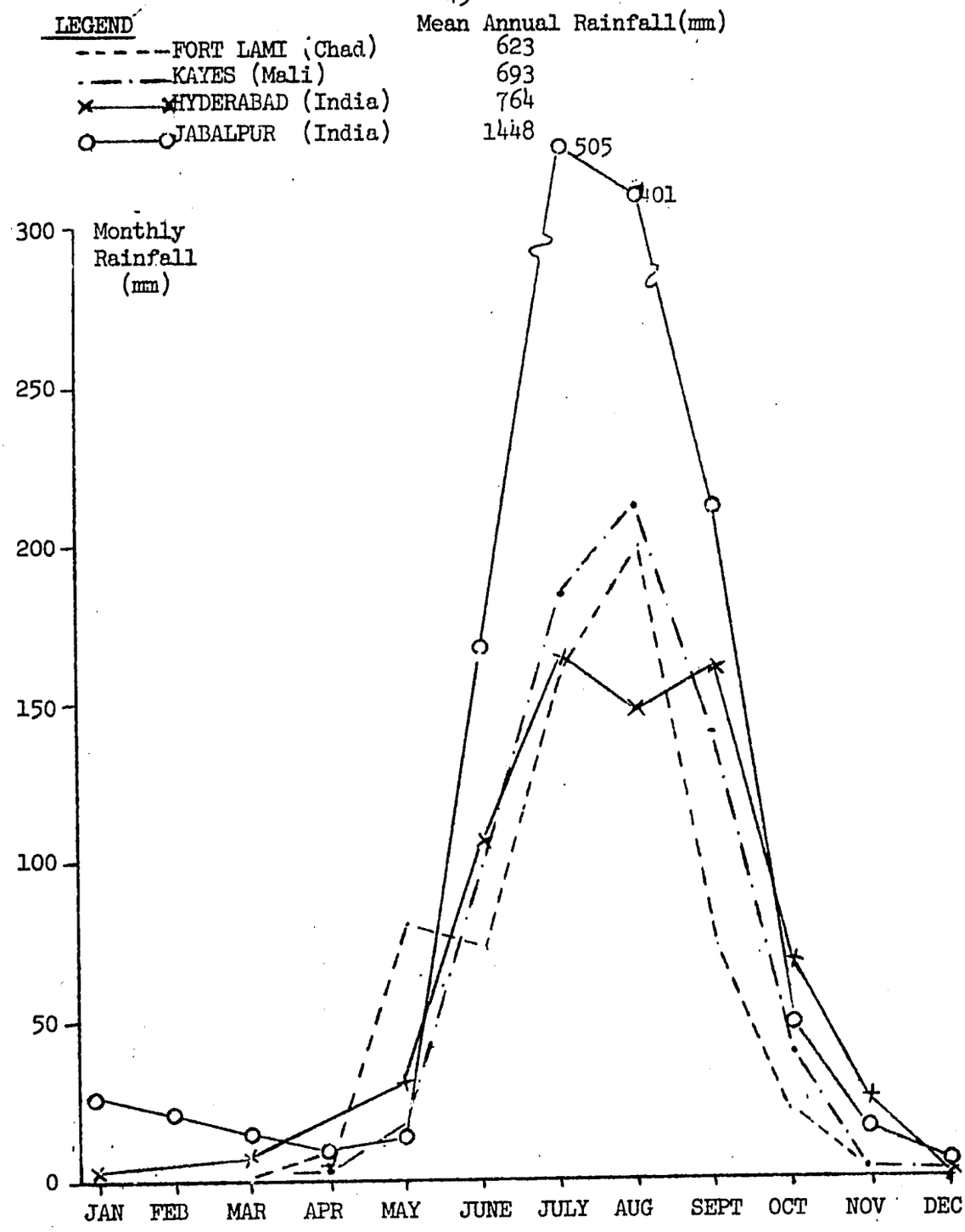


FIG. 1 ANNUAL RAINFALL DISTRIBUTION AT 4 LOCATIONS IN THE SEMI-ARID TROPICS OF THE NORTHERN HEMISPHERE (Compiled from "The Climates of the World"; Reid, 1941)

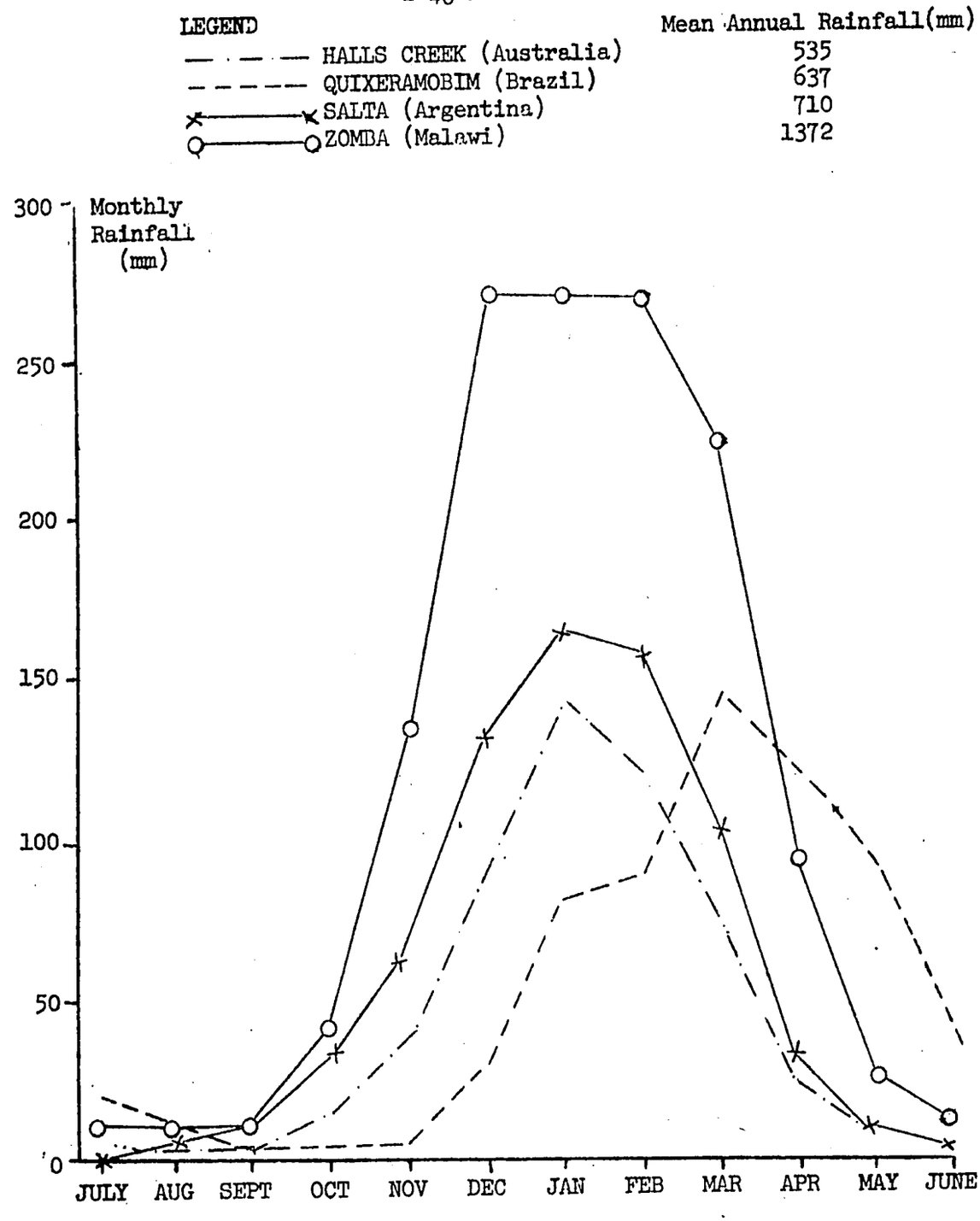


FIG. 2 ANNUAL RAINFALL DISTRIBUTION AT 4 LOCATIONS IN THE SEMI-ARID TROPICS OF THE SOUTHERN HEMISPHERE
(Compiled from "The Climates of the World"; Reid, 1941)

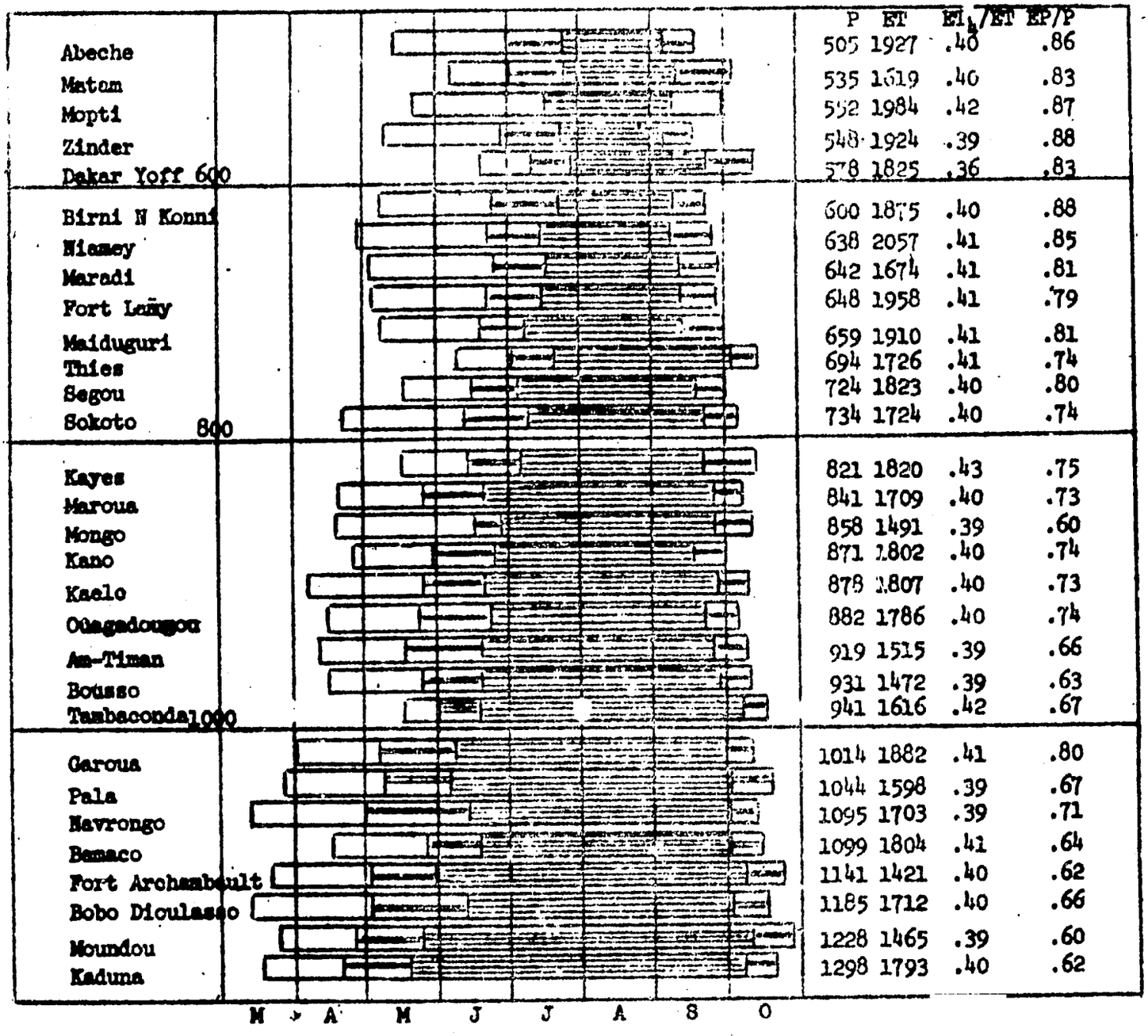
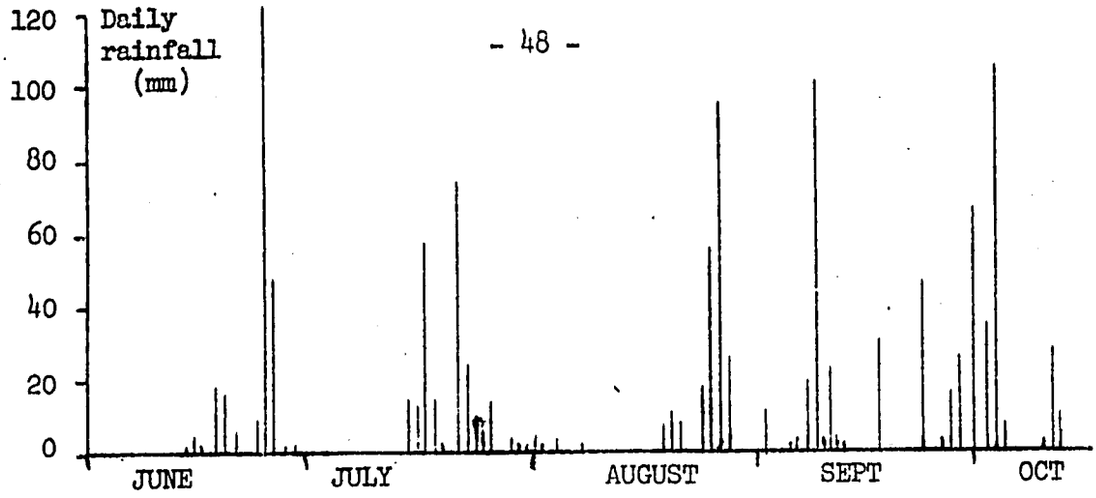
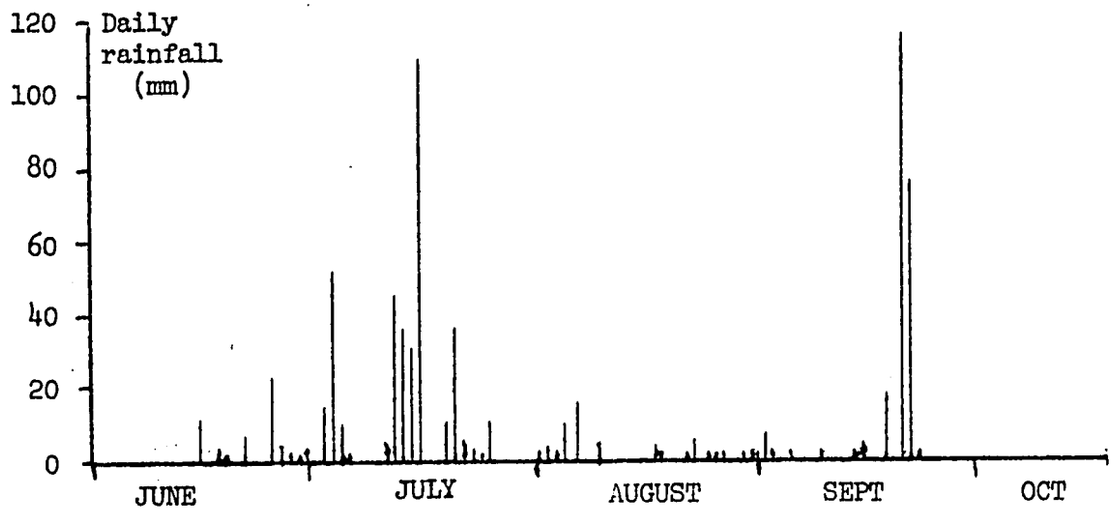


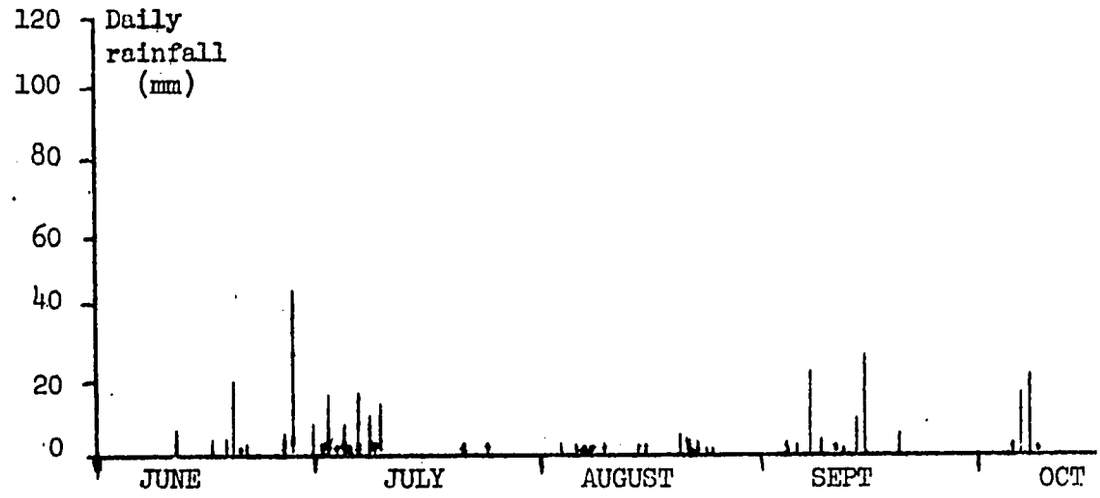
FIG. 3 THE MONSOON AT 30 STATIONS IN THE WEST AFRICAN SEMI-ARID TROPICS (The non-shaded bar gives the preparatory season (P> 1/10 ET) the light shaded portions the intermediate seaons (P> ½ ET) and the dark shaded part the humid season (P> ET). Column "P" gives mean annual rainfall, "ET" the mean annual 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 Cochemé and Franquin, 1967)



a. Monsoon rainfall in 1915; 1275 mm



b. Monsoon rainfall in 1965; 776 mm



c. Monsoon rainfall in 1972; 340 mm

FIG. 4 RAINFALL EXTREMES AT HYDERABAD

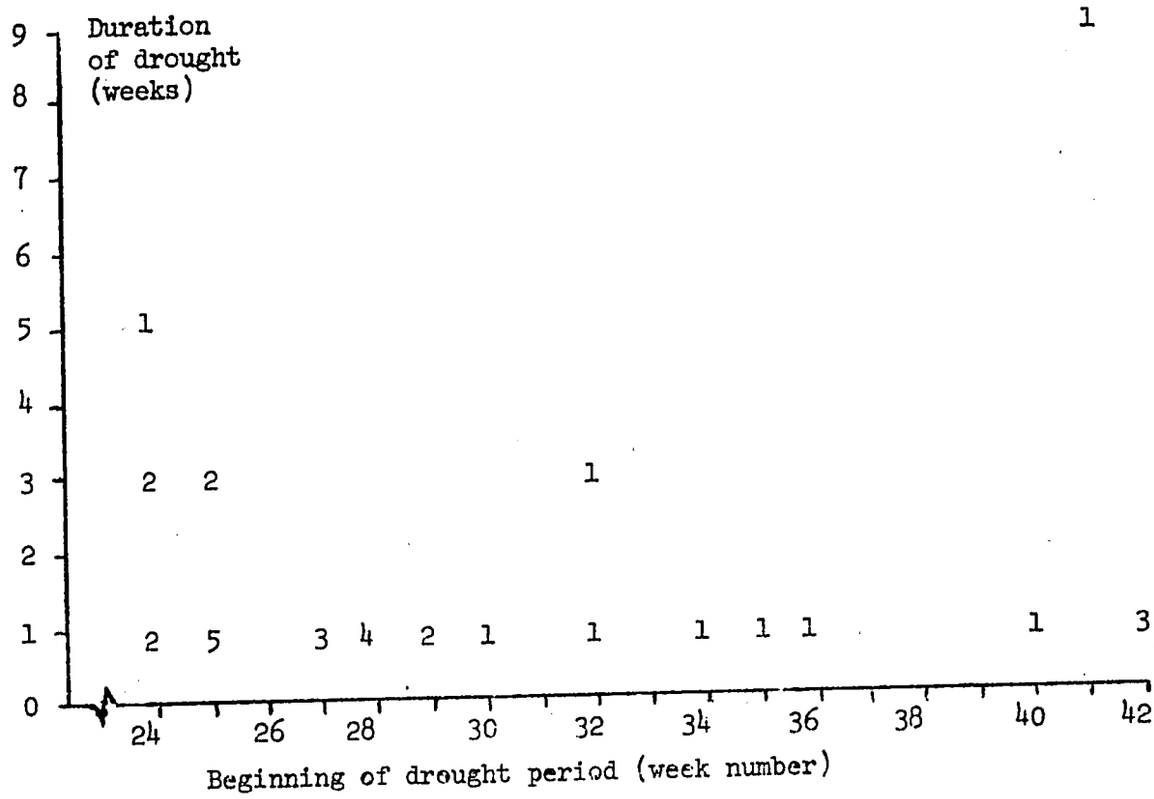


FIG. 5 OCCURRENCES OF DROUGHT FROM 1901 TO 1970 IN HYDERABAD (Hyderabad climatic data were used for analysis and estimation of soil moisture regimes. A "drought" period here is defined as a period during which no significant rain falls while the available moisture in the profile (estimated at 100 mm)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

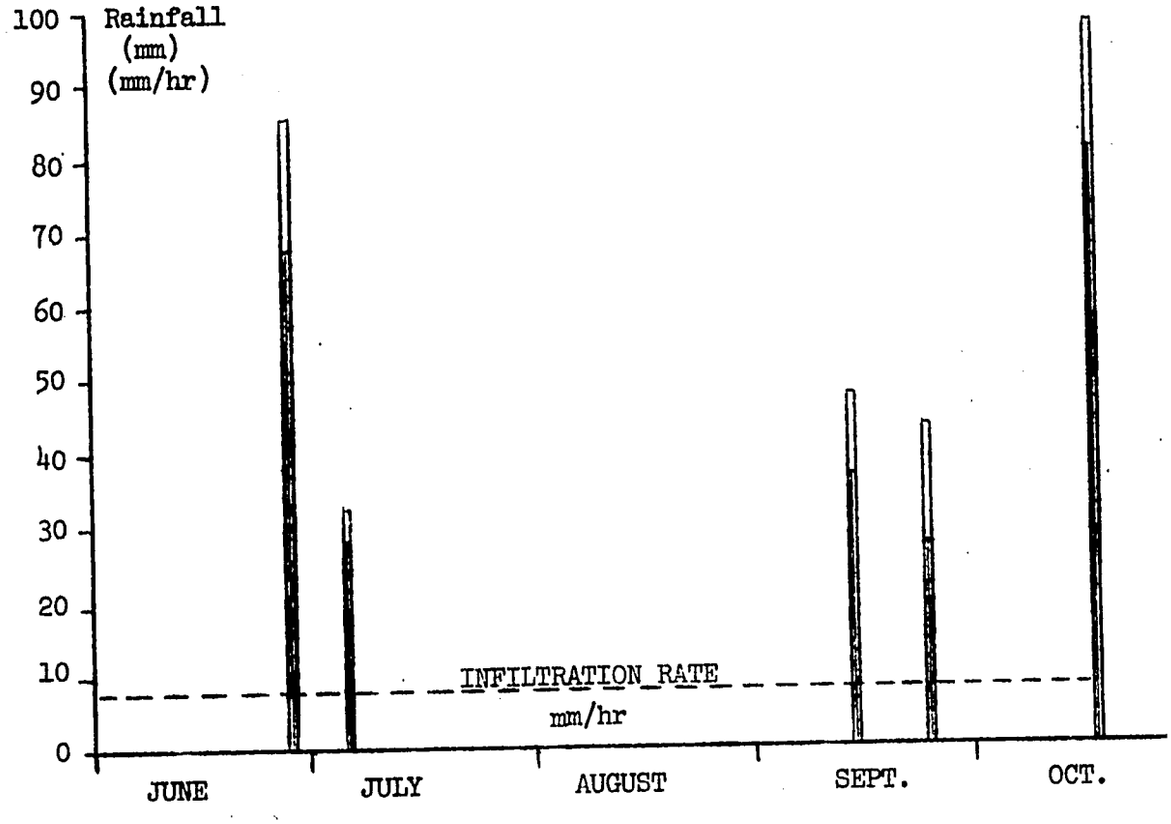


FIG. 6 RAINFALL INTENSITIES AND TOTAL RAINFALL OF FIVE SELECTED STORMS AT ICRISAT IN 1974
(The total storm rainfall is shaded dark, the maximum intensity observed during a minimum of 30 minutes is represented by the non shaded bar. An estimate of hourly infiltration rates measured on saturated black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

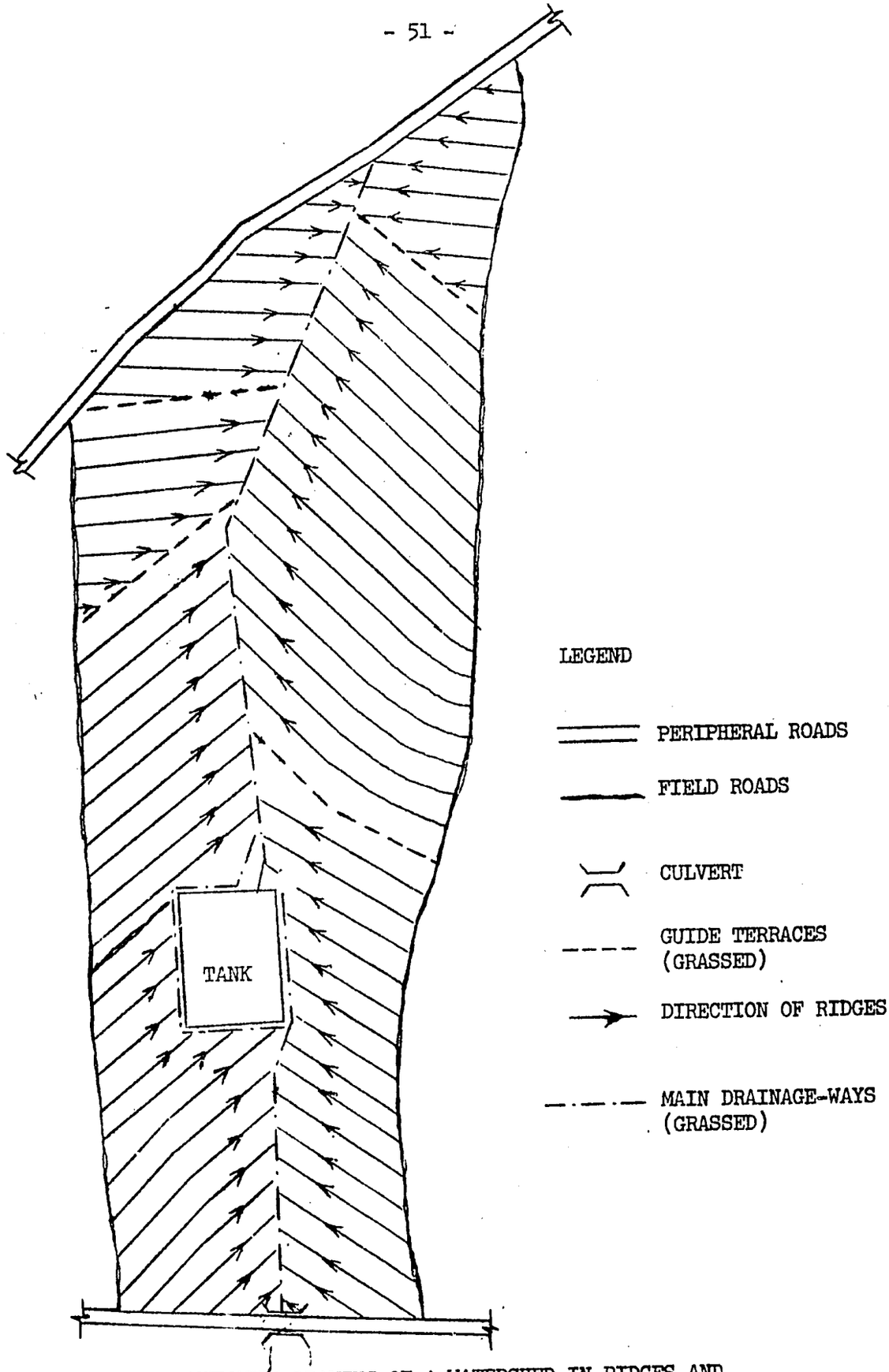
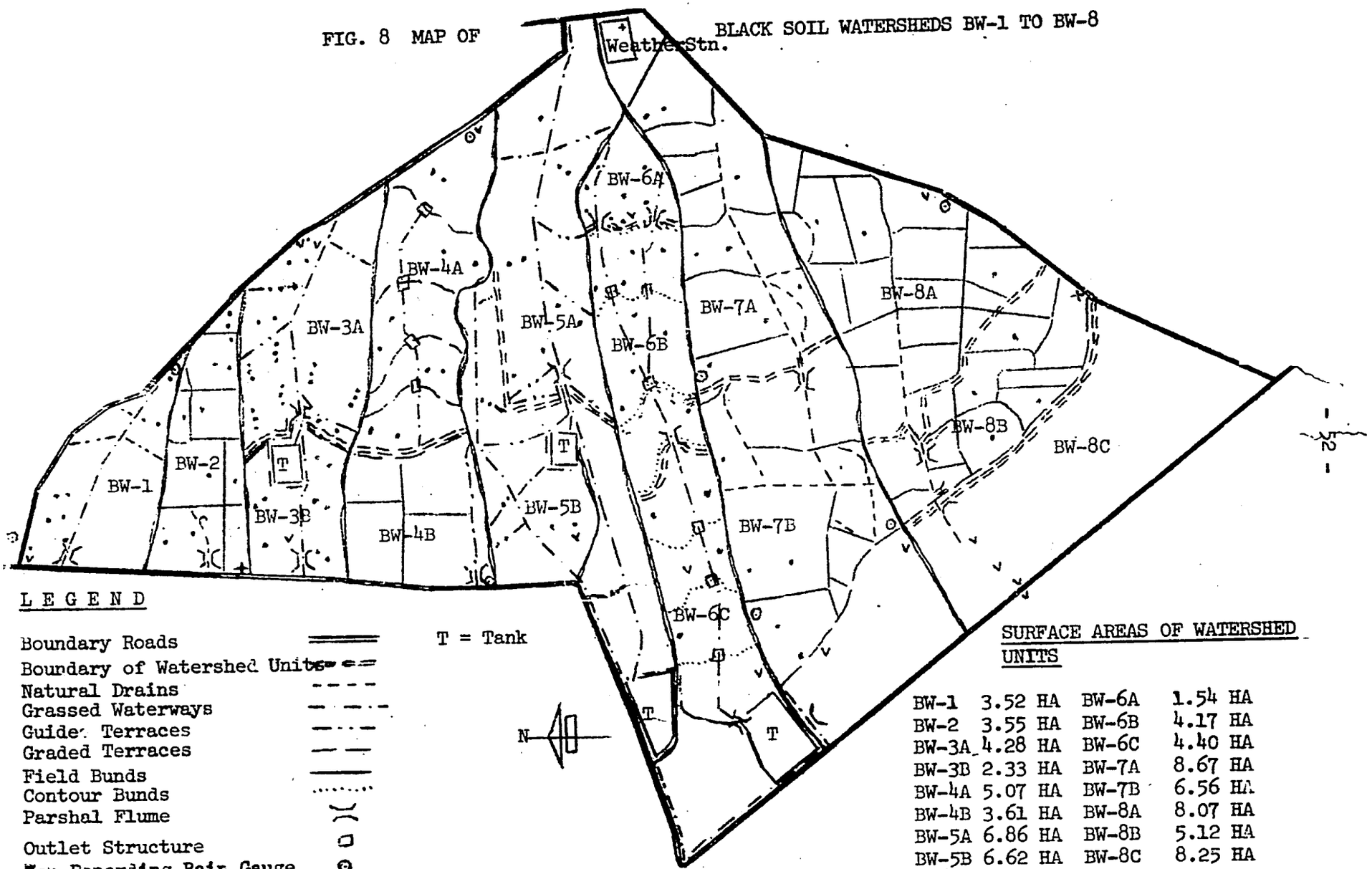


FIG. 7 SCHEMATIC DRAWING OF A WATERSHED IN RIDGES AND FURROWS WITH A RUNOFF STORAGE FACILITY.

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



LEGEND

Boundary Roads
Boundary of Watershed Units
Natural Drains
Grassed Waterways
Guide Terraces
Graded Terraces
Field Bunds
Contour Bunds
Parshal Flume
Outlet Structure
Non-Recording Rain Gauge
Neutron Probe Acces Tube
Recording Rain Gauge
Piezometer Tube

T = Tank

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