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

By

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I C R I S A T

HYDERABAD, INDIA

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

B.A. Krantz[1] and Associates[2]

INTRODUCTION

At ICRISAT, cropping patterns are considered as one program segment which, when synthesized with many other segments, form 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 is "resource centered" and "development oriented" 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 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.

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[1] Agronomist, Farming Systems Research Program, ICRISAT.

[2] Sardar Singh assisted in writing this paper and S.K. Sharma, P. Singh, K.L. Sahrawat and S.N. Nigam gave valuable suggestions.

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, some of which are represented by other speakers in this workshop.

II EVOLUTION OF TRADITIONAL CROPPING PATTERNS

In temperate regions the major physical constraint to the crop growing season 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 (monsoonic period).

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

In some areas, factors such as malaria and other diseases in the lowland, 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 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 unsuitable lands is resulting in lower yields due to soil fertility depletion, soil structure degradation and soil erosion.

III TRADITIONAL CROPPING PATTERNS IN THE MAJOR AREAS OF THE SEMI-ARID TROPICS

There are a multitude of factors which have influenced farmers in the development of 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 (1974). Therefore, 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 due to excessive rainfall and from drought due to 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 (1974). This discussion will emphasize properties as they relate directly to the development of the cropping patterns. Due 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 throughout ancient times.

To optimize production and to reduce risk of crop failure due 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 relationship to climate, soil conditions and socio-economic patterns.

1. <u>India</u>

Most cropping patterns followed in the SAT of the country are based on the traditional system 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 evaluation 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 relative 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% of the net sown area in the country, covering about 47 million hectares.

Table 1 - Cropping pattern in the low rainfall-unirrigated areas of India[a] (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
Chickpea (*Cicer arietinum*)	6.27	6.66	31.51
Pigeonpea (*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	
Totals	100.00	100.00	

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

The data in table 1 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, pigeonpea and chickpeas. The respective percentages of All-India acreages for these five crops are 74, 64, 61, 47 and 31. However, there are wide inter-regional variations in cropping patterns. In the case of sorghum, five districts in Maharashtra average 42.9% of land in sorghum while the average for the 84 districts shown in table 1 was only 22.9% (Kanwar 1968). Likewise, in the case of pearl millet and groundnut, in some districts in Gujarat and Andhra Pradesh the percentage of land in the crop is 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 soils (also called black cotton soils) are formed from a variety of rocks which include traps, granite and gneisis, particularly those rich in lime feldspars. Thus they are usually rich in bases including potassium, calcium and magnesium. In the black soils the montmorillinitic and beidelite types of clay predominate and impart the characteristic swelling and shrinking properties. The soils have a high water holding capacity which provides encouraging potentialities for relay or double cropping. The pH ranges from 7.0 to 8.5 and the lime content from 1 to 10%. Due to their formation under

SAT conditions, the soils are low in organic matter (0.4 to 0.8%) 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 rainfed (non-irrigated) area (J. Singh 1974). A recent survey (IARI 1970) shows that 57.2% 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% of the black soil falls in this group (J. Singh 1974). The most common cropping mixtures and sequences are as follows:

Sorghum + pigeonpea + sesamum (intercrop)
Pearl Millet + pigeonpea + sesamum (intercrop)
Sorghum + pigeonpea - fallow (2 year rotation)
Sorghum + pigeonpea - groundnut (2 year rotation)
Sorghum + pigeonpea - cotton (2 year rotation)
Cotton - sorghum + pigeonpea - groundnut (3 year rotation)

The pigeonpeas which are grown in mixtures with sorghum are usually 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% of the cultivated black soil is fallowed during the monsoon season and then cropped during the post-monsoon season. This would amount to a total of more than 15 million hectares[1]. However, the amount of monsoon fallow has been reducing in recent years due to population pressures (J. Singh 1974).

Common cropping mixtures and sequences grown in these areas are:

Fallow - sorghum + oilseed mixture (intercropping)
Fallow - chickpea (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% 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

[1] Preliminary observation at ICRISAT indicate that if suitable soil, water and crop management systems are used, a substantial increase in food production could be realised 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).

2. Red Soil

The red soils are usually developed from ancient granites or gneisees. Due to the type of parent material and soil formation processes under SAT 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 pigeonpea, pearl millet, castor and cotton.

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

Cotton + setaria (intercropping)
Sorghum + pearl millet + pigeonpea (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.

3. Alluvial Soil

These soils usually possess good physical condition, are easily tilled and are moderately permeable. The water holding capacity is relatively low compared to 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, chickpea, 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	- chickpea	(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)

B. <u>Africa</u>

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 while 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.

1. 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 in order 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 set 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 a sequence of cereals, legumes and root crops is grown, with small amounts of interplanted vegetables. Very commonly, pigeonpea 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 a fourth year.

2. East and Central Africa

In the 'chitemene' system practised on poor sandy soils in Zambia and 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 groundnuts 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 grown 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, Bambara 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 beans. Then, as in the previous season, weeding is done and subsidiary mounds containing buried weeds are again formed and are 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 pigeonpea, 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.

C. Northeast Brazil

The major food crops of the semi-arid tropics in northeast Brazil are maize, dry beans, casava and bananas. According to Patrick (1972) these crops are widely cultivated throughout the states of the northeast. He further states that during the period 1950 to 1969 the total cropped area in the northeast increased from 4.5 to 10.9 million hectares, which is a 4.8% annual increase in cultivated acreage. However, there was no appreciable increase in average crop yield in the northeast during this 19 year period.

Most of the maize, bean and cassava are grown either as mixed cropping (broadcasted) or intercropping (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 serious problems[1].

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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).

IV THE POPULATION EXPLOSION AND EXPANDING FOOD REQUIREMENT INFLUENCE CROPPING PATTERNS

During the past centuries, population growth was relatively slow and was in balance with the current capacity of the environment. Thus the farmers were usually able, by traditional methods, 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 food requirements. Also the supply of suitable lands for expansion has become exhausted in many areas. In India 44.6% 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% is in food grains and another 9.6% in food oilseeds. In the SAT of India, intensity of land use is even higher than that of the rest of the country. The survey of 84 districts in the SAT of India also showed that 57.2% of the total area in these districts was cultivated compared to 44.6% for the country as a whole (IARI, 1970).

Thus because of increasing population and land pressures in these SAT areas, 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 from growing productive forage crops than from growing sorghum, pearl millet or sunflower.

With the low yields per hectare in the SAT the most feasible approach to increased production is to increase 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 into productive perennial crops such as forage or tree crops. (This is particularly relevant in some of the hilly areas in shifting cultivation such as those found in Northeast 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.

V RESEARCH AIMED TOWARD THE IMPROVEMENT OF CROPPING PATTERNS FOR THE SAT

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 fibre 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 SAT water, not land, is the natural resource which is most limiting for crop production. Therefore, all cropping systems should aim towards 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 farmers' fields.

The resource development and management aspects are discussed in detail by Kampen (1974). At ICRISAT we are studying various aspects of crop production and attempting 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, relay cropping, double cropping, ratoon cropping and perennial cropping. Each of these cropping patterns are being or will be investigated at ICRISAT and elsewhere in the SAT. In developing alternative cropping patterns we are attempting to work with physical, biological and socio-economic scientists, in order 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 high yielding varieties of improved quality of different maturation periods. At ICRISAT vigorous breeding programs are underway on four of the major food crops of the semi-arid tropics including

sorghum, pearl millet, pigeonpea and chickpea. Recently it has been decided to add groundnut as a fifth crop. Close liason between the ICRISAT Crop Improvement Program and Farming Systems Program is essential in order 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 crops (agricultural, horticultural or forestry) which have potential to contribute to improved resource management and utilization. Therefore, we are starting to evaluate the most promising cultivars of many crops in order to select the proper species and varieties to best fit 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 for risk reduction. Recent intercropping studies under optimum technology by Harwood (1973), Rao (1974) and Krantz et al (1974) indicate substantial (50% or more) yield increases from various combinations of alternate row intercropping over those of two separate pure crop cultures. Andrews (1972) produced 70% 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 in the SAT. This work has been very beneficial in pointing out the potentialities, but in order

to more fully exploit the concept of intercropping, further basic investigations are needed along several 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 in order 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 species and varieties for height, canopy density and influence of shading and moisture competition during flowering and seed formation stage.

6. Screening of legume and non-legume crops to find combinations which would exhibit mutual production benefits, particularly at moderately low soil nitrogen levels.

7. Study of seasonal labor requirements and labor peaks of various crops in order to maximize labor utilization.

8. Investigations of the capital requirements, market feasibility and potential profitability of various species.

Preliminary observations indicate that pigeonpea is ideally suited for intercropping with a fast establishing intercrop. There are several reasons for this:

1. The slowly establishing pigeonpea seedling appears to be able to cope with considerable shading and plant competition by the intercrop in the early stages without serious reduction in final yield of the pigeonpeas.

2. During the seedling stage the pigeonpea growth is very slow and therefore seeding either by hand or mechanical methods must be spread over the long period of plant establishment. A fast growing intercrop will effectively compete with weeds while the pigeonpeas are becoming established.

3. The bare soil area between the slowly establishing pigeonpea plant is subject to raindrop impact and soil erosion problems when pigeonpeas are planted as a pure crop.

For these reasons it appears that pigeonpea should be grown with an intercrop which establishes itself quickly. Preliminary observations at APAU and 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 pigeonpea 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 maximising the use of farmers' resources of land, water and time. Early observations on relay planting at ICRISAT indicate encouraging potentialities for effective soil and water resource utilization and increased yield.

Although relay cropping is normally not practised in the rainfed SAT, the development of high yielding short-season varieties has opened new avenues for the possibility of relay cropping in the SAT especially in the black soils. 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 SAT by the use of animal-drawn relay planters. In order 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 establishment of a post-monsoon relay crop on either red or black soil during various periods in 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 of 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 SAT.

Since most farmers in the SAT 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. Observations at ICRISAT during the 1974 season indicate that inter-cultivation between the monsoon crop stubble will kill all weed seedlings and prepare an adequate seedbed for planting of the post-monsoon crops. Further investigations are planned under a wider range of crop and soil conditions. Crops in which stubble regrowth is a factor present 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 would be favored over 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 in order 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 distinctly 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. Venkataswarlu (1974) has shown that in case of severe mid-monsoon season drought it may be desirable to make a "mid-season correction" by harvesting the pearl millet or sorghum for fodder, thus saving the crop. Then after the rains come a ratooned 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 SAT 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, hardpan soils and waterlogged depressional 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 has representatives 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.

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 ICRISAT is crop oriented, we in the Farming Systems Program recognize the essentiality of consideration of livestock in the farming systems of the SAT. Livestock provide the means of producing food from forage crops, fodder crops and residues of agronomic crops which would otherwise be wasted. In the SAT livestock furnish much 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 potentials of high yielding varieties and the available water resource are well known. However, the farmer of the SAT 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 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 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 SAT. The SAT is characterized by a hot-dry period during the four to five months preceeding 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 Azatobacter 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 sequences of grain legumes and non-legumes. 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 turnover to improve soil workability and water infiltration and recycle needed nutrients into the fertility pool in the soil. 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 the 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 amount 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 ICRISAT indicate that sorghum, sunflower and pearl millet are far more responsive to phosphorus application than are chickpeas and pigeonpeas (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 more 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 loss 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 and available equipment and power source. Since animal power is the main power source of the farmers of the semi-arid tropics,

the Farming Systems Program (FSP) at ICRISAT will likewise develop farming systems around the animal power source.

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 recognition 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 and tillage cost, considerable research is being conducted upon "zero-tillage" (Baeumer and Bakersman 1973).

Since the long hot dry period preceeding the monsoon is normally not cropped under rainfed conditions, this "hostile" weather period provides an opportune time to apply tillage and other cultural practices for the reduction of pest populations, particularly insects and perennial weeds. This aspect will be investigated at ICRISAT.

Experimentation underway and future plans at ICRISAT will emphasise 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 and surface storage for water. (Larson (1964) reported that on slopes of less than 2%, 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 until 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 get out of hand 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 herbicides 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 in order to avoid deleterious build-ups of weed problems. Herrera and Harwood (1973) pointed out that weed problems were reduced with intercropping due to the rapid closing of the intercropping canopy and the 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 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 cooperation 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 cowpeas than following maize. Likewise, mung beans 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 potatoes, mung beans, cowpeas and soybeans in spite of additional fertilizers and the maintenance of good soil structure. At 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 (1974). Economic evaluations of cropping patterns will include the following phases:

1. Evaluation of food, feed and fibre 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 SAT.

II. 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 experimentation in which many of the problems facing farmers emerge and can be identified and solutions developed. In addition to the field-scale strips simulating field-scale situations, 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 Maize Deccan Hybrid	Relay chickpea Relay safflower
c) Pigeonpea (Hy-3) intercropped with sorghum - CSH-5 Pigeonpea (Hy-3) intercropped with setaria (One row of pigeonpea and one row of intercrop on each ridge 25 cms apart)	
d) Setaria	a) Sunflower b) Sorghum

[1]Each of the four monsoon season crops will occupy one quarter of each watershed unit arranged from botton to top in the following order: Sorghum, maize, pigeonpea-intercrop and setaria.

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 onset of monsoon.

1. Sorghum
2. Pigeonpea - sorghum
3. Maize

b) After sufficient rain to provide 15 cms of moist soil, harrow or reshape ridges to kill weeds and plant immediately.

1. Setaria
2. Setaria - pigeonpeas

B. Red Soil

After 20-25 cm of soil has been moistened by rain, harrow or reshape ridges to kill weeds and plant immediately.

VI THE INTERNATIONAL PROGRAM

In addition to the farming systems research conducted at Hyderabad, a major facet of our program involves cooperative research with national and state organizations and extension and outreach activities through national and state agencies.

The soil and climatic conditions at 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 fit 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 1974). Principles of cropping patterns for various

regions will be investigated at these benchmark locations. It is hoped that the information developed at ICRISAT can 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 patterns 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 in order to evolve optimum farming systems for a given area.

Since much of the SAT 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[1]. To be successful, an emergency food production program must be based on the best available research information and be oriented 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. Gibbons (1974) suggests

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[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.

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 heavy 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 the proper amenities in the community. Any long-term development program must also include emphasis upon family planning or the population explosion will negate all other efforts toward development and improved economic status of the people.

VII 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 SAT 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 the SAT has been the erratic and undependable nature of the rainfall.

4. To optimise 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 expanded food and feed requirements by expanding cultivation and grazing of 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 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 combination 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 ICRISAT.

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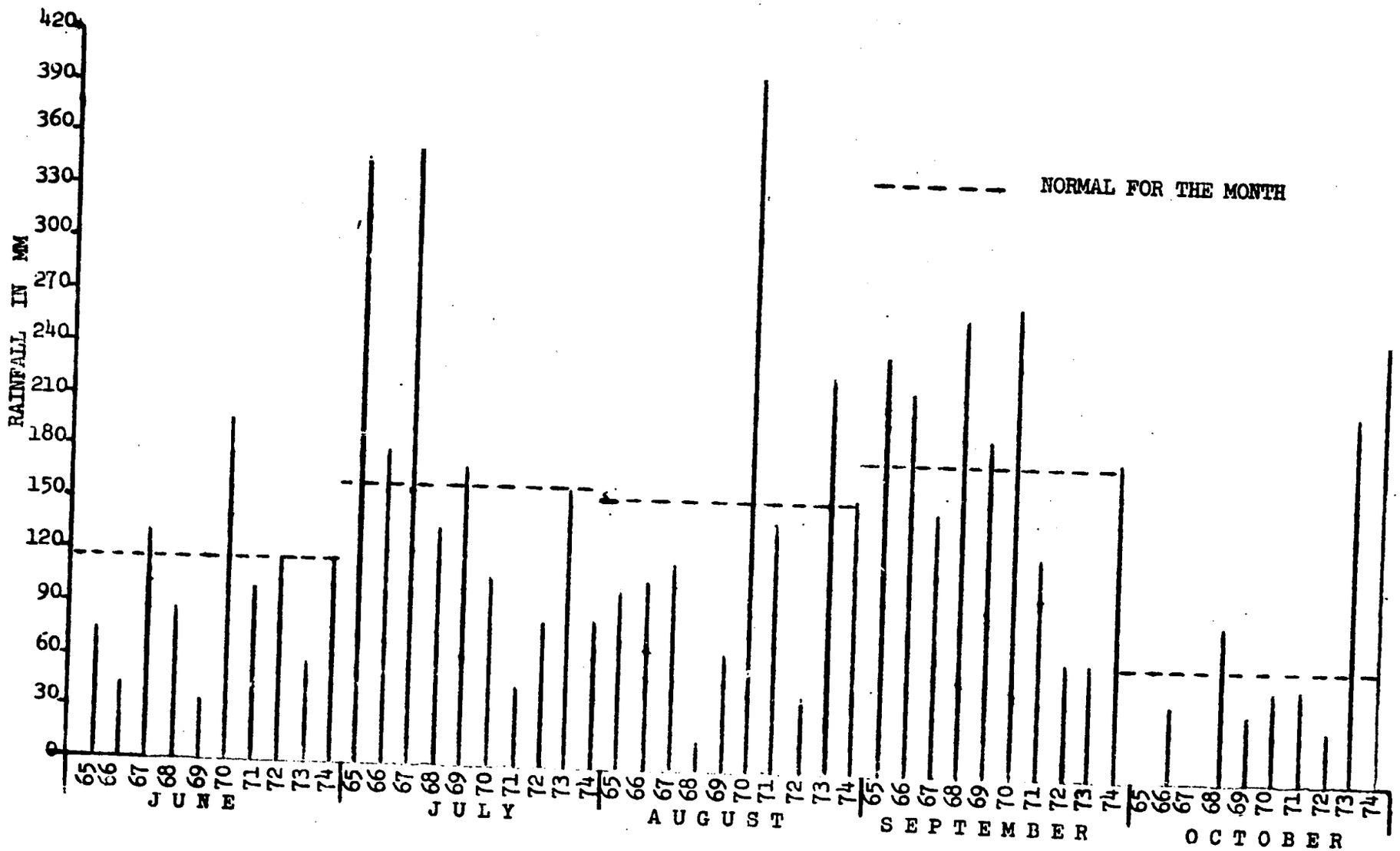

Figure 1. The variability in monthly rainfall during the monsoon period from 1965 to 1974.

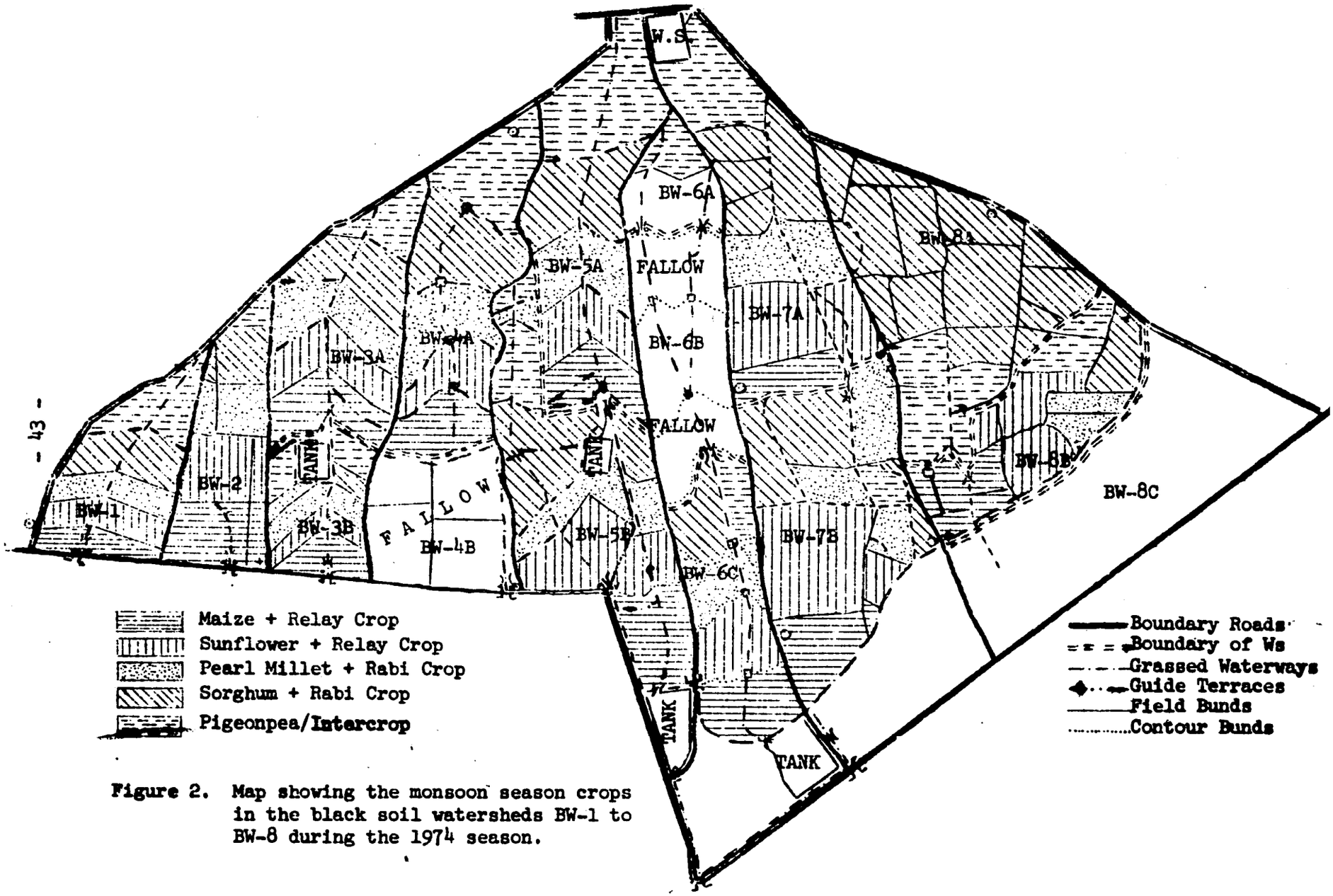

Figure 2. Map showing the monsoon season crops in the black soil watersheds BW-1 to BW-8 during the 1974 season.