EVALUATION OF DIFFERENT CROPPING SYSTEMS ON SHALLOW BLACK SOILS IN SEMI-ARID INDIA

Thesis submitted to the
Andhra Pradesh Agricultural University
in partial fulfilment of the requirements
for the award of the
Degree of Master of Science

By

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Rajendranagar, Hyderabad 500 030
Andhra Pradesh, India

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CERTIFICATE

Mr Abdulkadir Mohamed Abikar has satisfactorily prosecuted the course of research and the thesis entitled "Evaluation of different cropping systems on shallow black soils in semi-arid India" submitted is the result of original research work and is of sufficient high standard to its presentation to the examination.

I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any University.

Major Advisor

M R Rao

Date: [illegible]

Dr. M.R. Rao
Agronomist
ICRISAT

<u>CERTIFICATE</u>

This is to certify that the thesis entitled "Evaluation of different cropping systems on shallow black soils in semi-arid India" submitted in partial fulfilment of the requirements for the degree of Master of Science in Agriculture of Andhra Pradesh Agricultural University, Hyderabad, is a record as the bonafide research work carried by Mr Abulkadir Mohamed Abikar under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

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ABSTRACT

An experiment was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), located 25 Km northwest of Hyderabad, in 1984-85 with an objective of evaluating alternate cropping systems and identifying the most promising systems for shallow black soils (Inceptisols). Four sole cropping systems (sole sorghum, sole pearl millet, sole pigeonpea and sole groundnut), four intercropping systems (sorghum/pigeonpea, pearl millet/pigeonpea, groundnut/pigeonpea and pearl millet/groundnut), three sequential systems (mung followed by early pigeonpea, safflower or setaria) and a ratoon cropping system with a short-duration pigeonpea cultivar were evaluated in a randomized block design with three replications. All operations except harvest and threshing were carried out by animal-drawn wheeled tool carrier.

Intercropping systems showed higher land productivity than sole cropping. Pearl millet/pigeonpea was 36% more productive, pearl millet/groundnut-32%, and groundnut/pigeonpea-23% more productive over their respective sole crops. Sorghum/pigeonpea showed somewhat lower advantages at 14% over sole cropping.

Groundnut among sole crops and groundnut/pigeonpea among intercrops were the most remunerative cropping systems with net profits of Rs 3867 and Rs 3700 ha^{-1} respectively.

Other promising systems that gave profits about Rs 3000 ha^{-1} were sorghum/pigeonpea, pearl millet/groundnut and sole sorghum.

The sequential cropping systems with returns of only Rs 1756 to Rs 2202 ha^{-1} were significantly less profitable than some of the most promising intercrop or sole crop systems. Although the ratoon system with early pigeonpea (cv. ICPL 87) gave better returns (Rs 2576 ha^{-1}) than the sequential systems, it was still less remunerative than sorghum or groundnut-based systems. Establishment of pearl millet in sole cropping and intercropping with pigeonpea got delayed due the failure of the first planting and consequently they gave very low returns.

The wheeled tool carrier was a versatile equipment. It can be used for all operations including land preparation, broadbed-and-furrow formation, sowing of different cropping systems, and interculturing without any difficulty. However, care must be taken while planting small seeded crops such as millets which require shallow planting.

It can be concluded that full season sole crops such as sorghum, groundnut or intercropping systems with pigeonpea are the best options for shallow black soils.

INTRODUCTION

Insufficient and erratic rainfall is the general characteristic of the semi-arid tropics (SAT). Rainfall is confined to only a limited period of 3 to 4 months, leaving rest of the year relatively dry. More than 70% of the cultivated area of India is lying in the SAT (Ryan *et al.*,1974). Crops in much of this area are grown only on rainfall. As a result, agricultural production in this region is highly dependent on rainfall and its distribution.

Soils vary widely in the semi-arid India, but in the Deccan plateau black soils of different depth (deep, medium and shallow) and Alfisols (red soil) are the predominant soil groups. Cereals such as sorghum, pearl millet and setaria, and legumes such as pigeonpea mung bean and chickpea are the major food crops; groundnut is the chief cash crop. Intercropping involving these crops is widely practised. Cropping on lighter soils is confined to the rainy season but on heavy deep black soils, that hold more than 200 mm of available moisture, crops are grown only in the postrainy season on the stored moisture. Thus, cropping intensity in either case is low. Crop yields generally are very low (500 to 700 Kg ha^{-1}) because of poor management and supply of little or no inputs (El Swaify *et al.*,1985).

Rainfed agriculture has been receiving a great deal of attention in recent years at the international and national levels. The International Crops Research Institute for the Semi-

Arid Tropics (ICRISAT) has been working in the past twelve years to develop improved crop production systems for different agroclimatic regions of the SAT India. Their approach is on a watershed basis integrating improved soil, water, and crop management technologies for increased and stable crop yields. The technologies for deep black soils consisted of graded broadbed-and-furrow system, cropping in the rainy and postrainy seasons, and execution of operations by an improved animal-drawn wheeled tool carrier and its accessory equipment. The improved technology has been found to give about 4 t ha^{-1} of crop yields or six times greater income than the traditional system of single postrainy season crop (Ryan and Sarin,1981). Intercropping of long duration crops such pigeonpea or double cropping by sequential planting of two short duration crops such as maize or sorghum followed by chickpea or safflower were found to be the most profitable cropping systems (Reddy and Willey,1982). Studies have shown that on Alfisols a combination of flat cutivation on grade, intercropping with pigeonpea or sole crops of castor, sorghum etc. and good crop management can improve crop yields substantially (El Swaify et al.,1985; Randhawa and Venkateswarlu,1981). Improved cropping system was a key component of the new technology on both the types of soils and was generally readily accepted by farmers(Virmani et al.,1985).

Shallow black soils (Inceptisols) constitute nearly one third of the Vertisoil group (27.1 million ha) in India. Because of light texture and shallow depth (15 to 30 cm), they hold less available moisture (50 to 100 mm) in the profile . Inspite of some physical differences these soils closely resemble Alfisols in terms of moisture environment, and like Alfisols they are also cropped only in the rainy season. Whenever there are long dry spells during the rainy season, crops are subjected to moisture stress. The rainfall is generally more than sufficient for a single crop but may not be sufficient for planting another crop in sequence. There is a need to explore alternative cropping systems to effectively utilize the seasonal water. Intercropping based on long season crops such as pigenpea or ratoon cropping that extend cropping beyond the rainy season may be more important for these soils. Double cropping with two full season crops may not be possible but sequential planting with very early maturing crops such as mung, setaria may be possible. The shallow black soils have not received enough attention at ICRISAT and the national Programs. Thus, there is a need for identifying efficient cropping systems for these soils to improve returns for the beneficial of large population that live on these soils. Hence the present experiment was conducted with the following objectives:

1) to explore the possibility of increasing the cropping intensity on shallow black soils by intercropping, sequential and ratoon cropping systems,
2) to identify promising cropping systems for shallow black soils, and
3) to identify operational problems associated with the practice of different cropping systems.

REVIEW OF LITERATURE

Various terms of cropping systems used in this thesis are first defined to avoid confusion in understanding them. These definitions are based on the most widely accepted opinions (Andrews and Kassam, 1976; Willey, 1979).

2.1 Definition of Cropping Systems

1. Sole Cropping

It is defined as growing of one crop variety in a pure stand in a given season at the recommended rate of plant population.

2. Multiple cropping

Growing of two or more crops on the same field in a given year in time or space . It extends cropping beyond one season and allows to harvest more than one crop.

a) Intercropping - Intercropping is growing of two or more crops simultaneously on the same area of land. The crops are not necessarily sown and harvested at the same time, but usually involves a substantial period of overlap in their growing period. Crop intensification is both in time and space dimensions. Intercropping would have a distinct reproducible spatial arrangement which is not the case in mixed cropping.

b) Relay cropping - This is the system where a second crop is sown into a standing crop shortly before its harvest. The system is distinguished from intercropping by the short period of overlap which may not cause of any significant crop competition.

c) Sequential cropping - This refers to a sequence of two sole crops grown one after the other, where the second crop is sown immediately after harvest of the first crop with minimum turn around. Crop intensification in this system is in time dimension.

d) Ratoon cropping - The practice of removing the apical bud of crop plants and activating their lateral buds to produce a new crop is known as ratoon cropping (Plucknett et al. 1970). The ratoon growth can be managed for grain or for fodder.

2.2. Improved Cropping Systems

2.2.1. Sequential Cropping

The productivity per unit area per unit time can be increased by increasing the cropping intensity. This could be achieved by a suitable combination of crops in sequence (Singh et al., 1980; Hedge and Patil, 1981). Each crop in a multiple cropping system need not give the maximum yield but should be such that the combined yields of all components in the system should give maximum production or return per unit of the cropped area (Lal and Ray, 1976).

Sequential cropping in rainfed is frequently observed where rainfall exceeds 1000 mm and on soils having a storage capacity of 150 to 200 mm of available moisture (Krishnamoorthy et al., 1978; Spratt and Choudhury, 1978). However, recent studies showed that double cropping was possible even in slightly lower rainfall areas by using short duration varieties and improved soil and water management practices (Krantz et al., 1978; Suraj Bhan and Khan 1981. Timely crop establishment is very crucial in sequential cropping (Rao and Willey, 1980).

2.2.2. Intercropping

Intercropping has been an age-old practice associated with subsistance agriculture in developing countries of the tropics (Aiyer, 1949; Okigbo and Greenland, 1976). There has been a growing interest in intercropping as a potential system for increased crop production and for achieving greater yield stability in drylands (Rao and Willey, 1980; Singh and Jha, 1984; Wade and Sanchez, 1984; Willey, 1979). If one crop fails or grows poorly, the other crop might compensate and avoid total crop failure. Such a compensation would not be possible if crops are grown separately (Willey, 1979; Rao and Willey, 1980; Pearce and Edmondson, 1982).

A guiding principle for developing improved intercropping systems should be to maximize complementarity and minimize competition between the component crops (Willey, 1979). Greater yield advantages are likely to occur when the growth pattern of the component crops differ in time, so that crops make their major demand on growth resources at different times of the season/year (Rao and Willey, 1980).

Intercropping for a long time was considered appropriate only to low input agriculture and many expressed doubts about its worthiness for high input conditions (Charreau 1977). Nevertheless, recent work has shown that intercropping offers substantial yield advantages even under medium to high levels of technology(Beets, 1975, Krantz,1981, Singh,1981). Baker (1974) expressed that the system could lend itself to mechanization, at least for sowing and weeding during the early stages of crop growth. Most of the operations in intercropping experiments conducted at ICRISAT including planting and interculturing have been carried out using bullock-drawn implements (ICRISAT, 1983). Cereal/legume intercrops are particularly important because such systems provide the calories and proteins required for subsistance farmers, and the presence of legumes may also help economizing nitrogen needs of crops that follow in rotation (Agboola and Fayemi, 1972); Ahmed and Gunasena, 1979; Agboola and Fayemi, 1972).

a) Intercropping Systems Based on Long Duration Crops

The slow growing and late maturing crop such as pigeonpea provides an excellent opportunity to grow short season crops in the inter-row space before they cover the ground(Rao and Willey, 1983). Pigeonpea is intercropped with cereals such as sorghum, maize or millet and legumes such as groundnut or cowpea. Sorghum/pigeonpea is widely grown in the semi-arid Deccan Plateau of India on a variety of soils (Aiyer, 1949). This system has received a great deal of attention in recent years at ICRISAT and national research centers . The findings were that i) an arrangement of 2 sorghum: 1 pigeonpea is most appropriate, ii) both crops should be planted at their respective sole crop optimum population (i.e. about 150000-180000 plants of cereal and

40000 to 50000 plants ha^{-1} of pigeonpea), and iii) the improved genotypes are appropriate to intercropping (Rao and Willey, 1983). The improved system yielded 90 to 100% of sorghum and 50 to 60% of pigeonpea giving about 50% yield advantage over sole cropping. Intercropping of pigeonpea with pearl millet was better than with other cereals in low rainfall and lighter soils (Rao and Willey, 1983; Rao et al., 1982). This system also required a row arrangement of 2 pearl millet: 1 pigeonpea and additive populations. Since millet matured earlier than pigeonpea it was least competitive to pigeonpea and allowed a high proportion of the sole crop yield ; so the LER advantage of millet/pigeonpea was as high as 60 to 80% (Rao and Willey,1983).

Pigeonpea is widely intercropped with groundnut on red soils, shallow black soils and alluvial soils. In studies at ICRISAT, pigeonpea was spaced at 1.35 to 1.5 m apart and 5 groundnut rows were planted between 2 pigeonpea rows at a very close row spacing maintaining the sole crop optimum populations (ICRISAT,1982). The system yielded about 80% of each crop giving about 60% yield advantage over sole cropping. Several other workers also reported substantial yield advantage with pigeonpea/groundnut (Seshadri et al.,1956; Appadurai and Sevaraj, 1974; Veeraswamy et al., 1974).

Fertilization of cereal/legume intercropping systems particularly with nitrogen, has been a complex issue. Studies indicated that the intercropped cereal responds to nitrogen fertilization similarly as the sole crop. Therefore, a general strategy could be to apply phosphatic fertilizers as basal to both the components and top dress the cereal component later with additional nitrogen (Reddy et al.,1982).

b) Intercropping with Short Duration Annuals

Intercropping cereals with low canopy legumes or oil seed crops is widely practiced in the semi-arid tropics(Singh and Singh, 1978). The most predominant systems are sorghum or pearl millet intercropped with groundnut, soybean or cowpea. The temporal difference between the components in these systems is much less and complementary effects could be lower than that observed in the temporal systems described earlier. However, worthwhile yield advantages could still be possible due to spatial differences in leaf canopies and root systems (Willey *et al.*, 1982). Millet/groundnut was examined in detail at ICRISAT in India and also in African countries (Gunad, 1980; Yayock, 1981; Osiru and Kibira, 1981; Reddy and Willey, 1982). At ICRISAT,an arrangement of 1 millet: 3 groundnut planted in a replacement system (i.e 100% total plant population and each crop planted at the same within the row spacing as the sole crop) gave 50% millet and 75% groundnut, giving about 25% yield advantage over sole crops (Willey *et al.* 1982).

Gunad (1980) reported that in the Sahel of West Africa, millet/groundnut intercropping systems (millet - 10000 hills ha^{-1} and groundnut -166666 plants ha_{-1}) performed well in a good rainfall year, giving 2 t/ha of millet and 0.25 t/ha of shelled groundnut.

c) Resource Utilization by Intercropping Systems

Fewer studies have quantified the resource utilization by intercrops. Since light is fixed in any particular environment, efforts must be made to make efficient use of it. This may partly be achieved by mixed culture of crops having different canopies(Natarajan and Willey,1980). Reddy and Willey (1981) observed that millet/groundnut intercrop utilised light much more efficiently than sole crops. Their observations were further confirmed by Marshall and Willey (1983).

Many workers observed that intercrops take up more nutrients than the sole crops (Baldy, 1963; Dalal, 1974; Hall, 1974b; Natarajan and Willey, 1980a; Reddy and Willey, 1981). For instance, Hall (1974) reported a considerable increase in potassium uptake by intercropping of *Setaria* and *Desmodium*, whereas Dalal (1974), Natarajan and Willey (1980a), Reddy and Willey (1981) reported greater uptake of all the major nutrients by intercrops compared to sole crops.

Water is the most important limiting factor of crop production in the semi-arid tropics. Baker and Norman (1975) observed that advantage due to intercropping could be attributed in many instances to higher water use efficiency. Natarajan and Willey (1980b) in their studies on pigeonpea/sorghum noted that the total water use by sole pigeonpea and sorghum/pigeonpea intercrop which occupied the land for similar duration was nearly equal. Reddy and Willey (1981) observed that water use efficiency by a millet/groundnut intercrop was higher than with sole crops particularly in a dry season.

2.3.3. Ratoon Cropping

Ratoon cropping has some distinct advantages viz i) it avoids seed bed preparation for the second crop, ii) it produces a second crop in a short period, and iii) some additional yield is obtained even with less moisture and less fertilization(Plucknett et al.,1970). The major disadvantages are that i) pests and diseases would be more on the ratoon crop, and ii) it yields lower than the main crop. Sorghum amongst cereals and pigeonpea amongst pulses produce good ratoon growth which can be managed to produce a second harvest.

The success of ratoon cropping depends on i) soil moisture at harvest of the first crop, and ii) regenerative ability of the cultivar, (Sharma et al., 1978). Reddy and Willey (1982) reported that in good rainfall years ratoon sorghum produced grain yield equivalent to 50% of the first crop. They further observed that ratoon sorghum failed frequently due to drought and shootfly attack. The improved sorghum genotypes generally showed better ratoonability than the locals.

Ratooning of pigeonpea for grain is rather a new development. Sharma et al. (1978) observed that the short duration pigeonpea genotypes produced good ratoon growth and gave similar yields as the main crop . ICRISAT pigeonpea breeders developed early maturing pigeonpea (ICPL 87) which was shown to have good ratoon potential (ICRISAT, 1981) This variety produced under irrigation 2380 kg ha^{-1} in the first harvest and

2120 and 1000 kg ha^{-1} in the two subsequent ratoon crops giving a total of 5500 kg ha^{-1} over 213 day cropping period. However, the potential of this ratoon system was lower in dryland condition. Studies in ICRISAT Farming Systems Program showed that yield of the rainy season crop was as good as any other legume but the ratoon yield was not very high compared to other postrainy season crops(ICRISAT,1985).

2.4. Influence of Cropping System on Weeds

The canopy of an intercropping system covers the ground quickly because of the presence of two or more crops, and it facilitates to suppress weeds. Several workers reported that the weed density and weed growth were less in intercropping than in sole crops (Kondap, 1981; Moody and Shetty,1981). Several biological factors such as spacing, crop variety, density and fertilization influence weed growth in a cropping system (Moody and Shetty,1981). Spreading genotypes, close spacing, and high plant density and fertilization generally reduced weed growth in intercropping. Rao and Shetty (1976) noted that weeding requirement can be reduced in widely spaced and slow growing crops such as pigeonpea by introducing quick growing intercrops. Shetty and Rao (1981) observed that weed growth in an intercropping system of very contrasting crops would be intermediate to that observed in the respective sole crops. They found that in a millet/groundnut intercropping, the row arrangement of 1 pearl millet : 3 groundnuts resulted in optimum weed suppression and maximum intercrop advantage.

Light is one of the important factors in the crop - weed balance; therefore, manipulation of light should be one of the approaches for better management of weeds (Moody and Shetty, 1981; Mugabe et al., 1982; Patterson,1982); They found that by choosing suitable components, it was possible to manage certain weeds. Furthermore, their work indicated that shading suppressed propagation of certain weeds, for instance, Cyperus spp.

2.5. Methods of Evaluating Cropping Systems

Since crops differ in different cropping systems, indices used to evaluate them should be such that they enable to combine the yields of the component species in the systems (Rao and Willey, 1978).

Several methods have been developed to assess intercropping systems. The Competition Index developed by Donald (1963), the Relative Yield Total suggested by De Wit and Van Den Bergh (1965), and the Competitive Ratio by Willey and Rao (1980) help to assess the competition between species in intercropping. The Land Equivalent Ratio (LER) suggested by IRRI (1974), helps to quantify whether or not an intercropping system is advantageous over sole cropping, and if so, by how much. LER is defined as sum of the relative land areas required as sole crops to achieve the same yields as from 1 ha of intercropping (Willey, 1979). It is calculated as follows:

$$LER = La + Lb = \frac{Ya}{Sa} + \frac{Yb}{Sb},$$ where La and Lb are

LERs of the individual crops. Ya and Yb are the individual crop yieds in intercropping, and Sa and Sb are the respective sole crop yields. A ratio > 1 indicates an advantage for intercropping, and a ratio < 1 indicates a disadvantage for intercropping. LER indicates the biological efficiency of growing two or more crops together in intercropping in a given environment. LER is a ratio and large values could be obtained simply because of low yields of sole crops; so sole crops should be managed very well to obtain the potential yields. Some doubts have been expressed on whether LERs follow normal distribution and they can be analysed. However, Oyejola and Mead (1982) observed that LERs tended to be normally distributed if sole crop yields averaged over all replications are used for calculation of individual plot LERs. They suggested that LERs calculated on that basis can be subjected to analysis of variance. Willey (1985) reviewed the merits and demerits of LER and other methods of evaluating intercropping systems.

Yields of crops in intercropping can be combined on the basis of nutritive value of component crops such as calorie, fat, crude protein, lysine, and methionine (Beets, 1977) or on monetary basis (Willey,1979).

Monetary returns is the most practical method of evaluation when different types of systems are to be compared (Perrin *et al*.,1979). One limitation of this method is that since prices vary frequently over time and space, relative ranking of systems may not remain the same. However, to avoid this problem cropping systems may be compared at different price ratios of crops so that inferences can be drawn quickly for any price situation (Perrin *et al.*,1979; Reddy *et al.*,1982). While comparing cropping systems the practical difficulties encountered in the field should also be taken into account. Other criteria worth considering are labour demand and operational expenses.

2.6.Comparison of Cropping Systems in Semi-Arid India

The choice of a cropping system at any particular location is dependent on the length of the available moisture period. The moisture period itself is dictated by the rainfall and soil type. In traditional cropping systems there are periods when the land is kept fallow or underutilized. The local varieties are also late maturing and occupy land for a greater part of the season leaving less scope for double cropping (Swaminathan and Rao,1970). However, the availability of early-maturing genotypes coupled with improved soil and water management and agronomic practices enabled to intensify cropping even in the drylands (Swaminathan and Rao,1970; Krantz *et al.*,1978).

Medium to deep black soils in high rainfall areas (>750 mm) provide 6 to 7 months of cropping period. This can be utilized effectively by either intercropping based on long duration crops such as pigeonpea and cotton or sequential cropping where two crops are grown one after the other (Krishnamorthy *et al.*,1978). Studies at ICRISAT showed that instead of keeping the land fallow as in the traditional system a rainy season crop of maize can be successfully grown on these soils without greatly affecting the postrainy season crop. Sequential system of maize followed by chickpea, safflower, or a short-duration pigeonpea were also found to be very productive giving about 3 t ha^{-1} of maize and about 1 ton ha^{-1} of a pulse or oil seed crop (Reddy and Willey,1982). Sorghum was also examined as a possible rainy season crop. Although it was a good alternative to maize, the postrainy season crops following sorghum were less productive compared to those after maize especially in a relatively low rainfall year. Other double cropping systems examined were mung-sorghum, mung-chilli, sunfflower-chickpea etc but the productivity of these systems was lower than some of the systems mentioned earlier. Crops such as sorghum, pigeonpea or chilli generally showed positive response to early sowing in the postrainy season, so relay sowing of these crops 2 to 3 weeks before harvest of the rainy season crop increased their yield. Although relay sowing was feasible when carried out in small-plot experiments, it was not practicable in operational-scale experiments. Promising double cropping systems in high rainfall areas (e.g Madhya Pradesh) were rice or soybean in the rainy season followed by wheat, lentil, chickpea or safflower in the postrainy season (Willey et al.,1985).

Cereal/pigeonpea intercrops have been found to be very successful cropping systems on Vertisols. These were grown at an arrangement of 2 rows cereal: 1 row pigeonpea with populations of each crop the same as the recommended sole crop population. On average, cereal yields were about the same as in sole cropping and pigeonpea yields were approximately similar to the yield of chickpea in a sequential system.

Comparison of several cropping systems in operational scale testsindicated that on medium to deep black soils the pigeonpea-based intercropping systems were more remunerative than sequential systems particularly in years when the rains end early. In such years establishment of the postrainy season crops becomes difficult due to the drying out of the surface soil. Since both crops in intercropping are planted in the beginning of the rainy season there is no risk in the establishment of the postrainy season crop. Studies have also indicated that operational expenses were less in intercropping as it avoids cultivation and fertilization for the second crop, and that returnsfrom intercrops were less variable (RaoandWilley, 1980, Ryan and Sarin,1981, Singh Jha,1984). Ratoon systems with sorghum did not compare very well with other 2-crop systems but ratooning of early pigeonpea appeared to be promising (ICRISAT, 1985).

Shallow black soils and other lighter soils provide only 4 to 5 months of cropping period. The types of cropping systems appropriate for this environment are i) intercropping of short duration crops (e.g.pearlmillet/mung orgroundnut), ii) intercropping with long duration crops (groundnut/pigeonpea, cereal/pigeonpea), iii) full season sole crops (sorghum, groundnut, castor etc.) and iv) ratooning of sorghum or pigeonpea. There is little scope for double cropping with full season crops but however, there might be some possibilities with very short duration crops/cultivars especially by resorting to relay planting, transplanting of cereals etc. (Reddy and Willey, 1985).

Some possible cropping systems options for red soils were evaluated at ICRISAT Center in small-plot and operational-scale plot experiments. Intercropping systems of pigeonpea or castor with groundnut were the most remunerative followed by cereal/ pigeonpea systems. Pearl millet/groundnut intercrop gave comparable returns as some cereal/pigeonpea intercrops in high fertility but it gave higher income than cereal/pigeonpea systems under low fertility. It was possible to grow drought tolerant and short duration crops such as cowpea or horse gram (Macrotyloma uniflorum) in normal and above normal rainfall years following an early pearl millet but these sequential systems were not as profitable as intercrops. Ratoon systems with sorghum or pigeonpea gave some extra yield but again the total returns were not as high as those from intercrops(ICRISAT,1984,1985).

Evaluation of a limited number of cropping systems was carried out on shallow black soils. Sorghum/pigeonpea, mung bean/castor, groundnut/pigeonpea intercrops gave high returns which in some years compared very well with those from medium to deep black soils (Rs 6000 ha^{-1}). The early pigeonpea did not compare well with the medium duration pigeonpea. Mung bean/sorghum intercrop was the least productive system under nil fertilizer and its returns with fertilizer averaged only half of those from sorghum/pigeonpea. The potential of double cropping systems for shallow black soils was not explored (ICRISAT,1984 and 1985). Thus the results highlight the importance of intercropping systems for the red and shallow black soils.

MATERIALS AND METHODS

3.1 Location

The experiment was conducted at ICRISAT Center about 25 km northwest of Hyderabad (17^{o}N, 500 m elevation) during the rainy (*Kharif*) and postrainy (*Rabi*) seasons of 1984 - 85 (from June 1984 to February 1985).

The experimental plot was of a shallow black soil (Inceptisol) that has low water holding capacity (about 75 mm of available water), and hence subjected to rapid moisture depletion. The physical and chemical characteristics of the soil are given in Tables 1a and 1b. The mechanical composition of the soil was determined according to the conventional schemes of the International Society of Soil Science (ISSS) for classification of textural fractions of soils. Total nitrogen content of the soil was determined by the Kjeldahl method as described by Bremner (1965). Available phosphorus was determined by the Olsen's method (Olsen and Dean 1965) and available potassium by atomic absorption spectro photometer.

Table 1a: Physical properties of the soil under experimentation.

Depth (cm)	Mechanical Composition				
	Gravel	course sand	Fine sand	Silt	Clay
	(%)				
0-15	16	22	24	11	27
15-30	54	8	6	9	23
30-60	58	8	6	9	19

Table 1b: Chemical properties of the soil under experimentation

Depth (cm)	pH	EC m mhos/cm	Organic carbon (%)	Total N	Available P	Available K
				(ppm)		
0-15	8.3	0.15	0.63	740	4	178
15-30	8.3	0.14	0.40	569	2	100

The soil was shallow in depth which generally varied from 0 to 30 cm. There was a murrum layer below 30 cm which is a hardened layer of gravel and clay. This can restrict the growth of the roots. The gravel content increased to >50% below 15 cm. The soil can be classified as a gravelly sandy clay loam. The nutrient status of the soil was low, particularly in respect of nitrogen and phosphorous. It was medium in available potassium. Therefore, crop yields would be extremely low if nutrients are not supplemented through fertilizers. The soil was alkaline in reaction.

3.2 Climate

The climate of ICRISAT Center is typical of a semi-arid tropics characterized by short rainy season (3 to 4 months) and a prolonged dry weather (8 to 9 months). The normal rainfall of the site, averaged over 60 years data, is 760 mm. About 86% of this rainfall is received during the rainy season - June to October. An average of 53 mm of pre-monsoon showers are received during the month of April and May. The postrainy season is relatively dry. The mean annual maximum temperature is 35.5 C and the minimum is 18.5 ^{o}C. The average daily pan evaporation varies from 3.8 to 12.3 mm.

The total rainfall received during the period of experimentation from June 1984 to February 1985 was 599.5 mm; 510.9 mm of that rain was received from June to September and 88.6 mm from October to February. About 31 mm was received during the pre-monsoon period from April to May 1984. The rainfall from June to December was 15.6% less than that of the normal (719 mm) rainfall for this period. Mean Maximum and minimum temperatures were 30.4 and 17.2 ^{o}C respectively. The average daily pan evaporation was 5.2 mm/day from July to December 1984. Climatological parameters from June 1984 to February 1985 are given in the Appendix I and Fig.1.

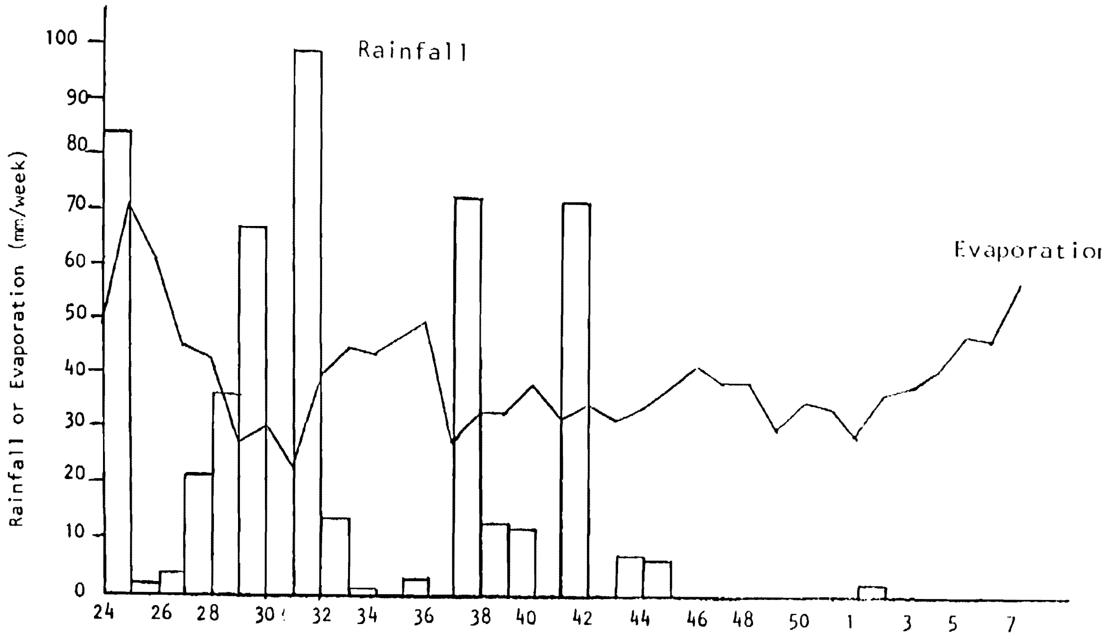
3.3 Cropping History

The experimental plot for the past three years was under a cover crop (maize or sorghum) during the rainy season and fallow during the postrainy season. The crops were fertilized uniformly with about 75 kg/ha of diammonium phosphate applied before planting and with 42 kg N/ha top dressed after interculture. General management was not at a high level, so weed infestation had increased over years in the field. The area was cultivated into 150 cm broadbed-and-furrows.

3.4 Experimental Details

Twelve different cropping systems were evaluated for their biological and economic performance on shallow black soils. The

a) Rainfall and Evaporation



b) Relative humidity

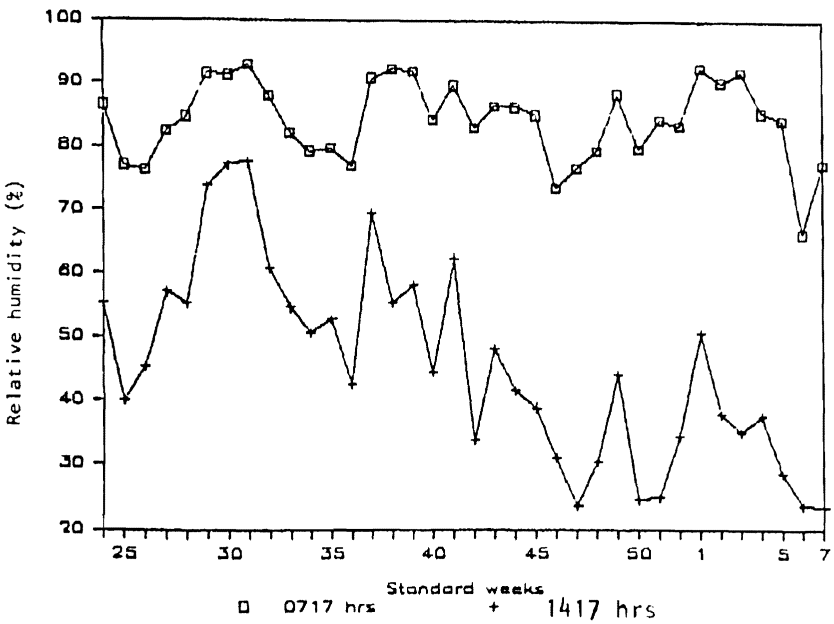
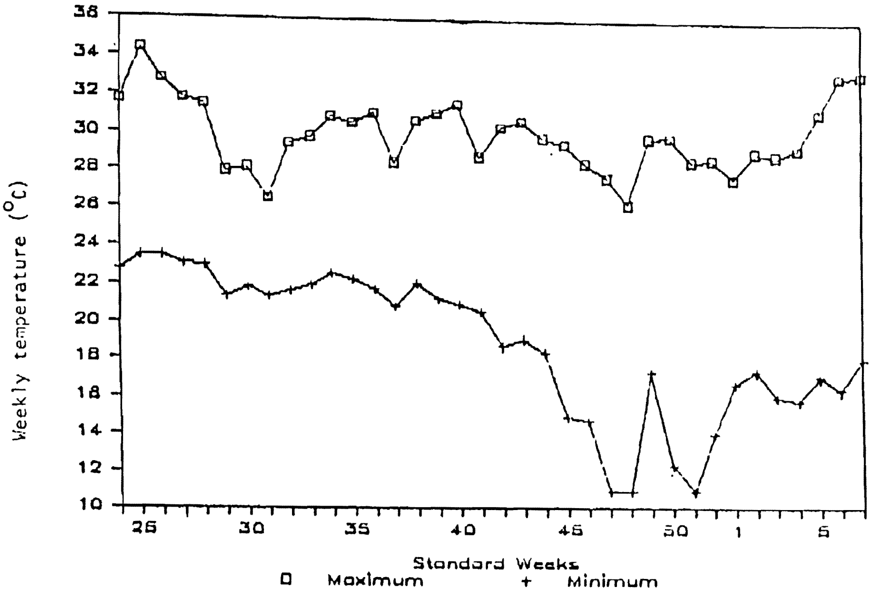


Fig.1: Meteorological data collected at ICRISAT Center from June 1984 to February 1985.

c) Maximum and minimum temperature



d) Solar radiation

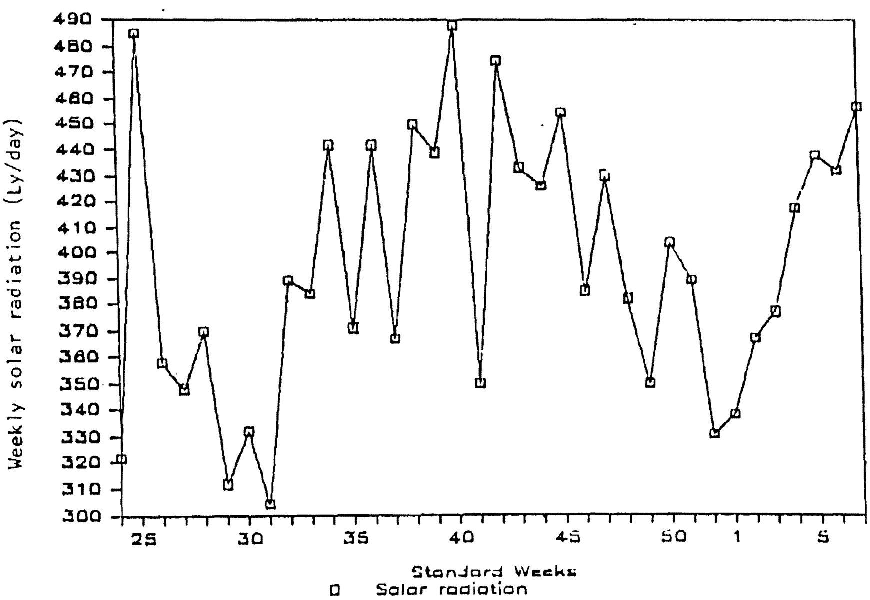


Fig.1: Meteorological data collected at ICRISAT Center from June 1984 to February 1985

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details of the systems are as follows:

Sole Crop Systems

1. Sorghum
2. Pigeonpea
3. Groundnut
4. Pearl millet

Intercrop Systems

5. Sorghum/Pigeonpea
6. Pearl millet/Pigeonpea
7. Groundnut/Pigeonpea
8. Pearl millet/Groundnut

Sequential Systems

9. Mung - Early Pigeonpea
10. Mung - Safflower
11. Mung - Setaria

Ratoon System

12. Early Pigeonpea-Ratoon

The systems involved only the most commonly grown crops of the region. Four ICRISAT mandate crops, sorghum, groundnut, pigeonpea and pearl millet were included. Sorghum, groundnut and pearl millet were grown as full season sole crops in the rainy season and also as intercrops with a long duration crop such as pigeonpea. Early maturing and drought avoiding crops such as mung bean, early pigeonpea, safflower and setaria were considered for sequential double cropping systems. Crops were grown entirely under rainfed conditions. Crop varieties used in the systems and their approximate duration are furnished in Table 2.

Table2: Crops and crop varieties and their approximatedays to maturity

Crops	Varieties	Approximate days to maturity
Sorghum (*Sorghum bicolor*)	CSH 9	100
Pearl millet (*Pennisetum americanum*)	BK 560	80
Groundnut (*Arachis hypogaea*)	R-33-1	140
Pigeonpea (*Cajanus cajan*)	ICP 1-6	170
Mung bean (*Vigna radiata*)	PS-16	65
Safflower (*Carthamus tinctorius*)	Mangira	100
Setaria (*Setaria italica*)	STA 326	75
Early pigeonpea (*Cajanus cajan*)	ICPL-87	120

The above twelve treatments were examined in a Randomized Block Design having three replications. The plot size was 120 m^2 consisting of four broadbed-and-furrows, each of which was 1.5 m widthand 20 m long.The total experimental area was about0.5ha.

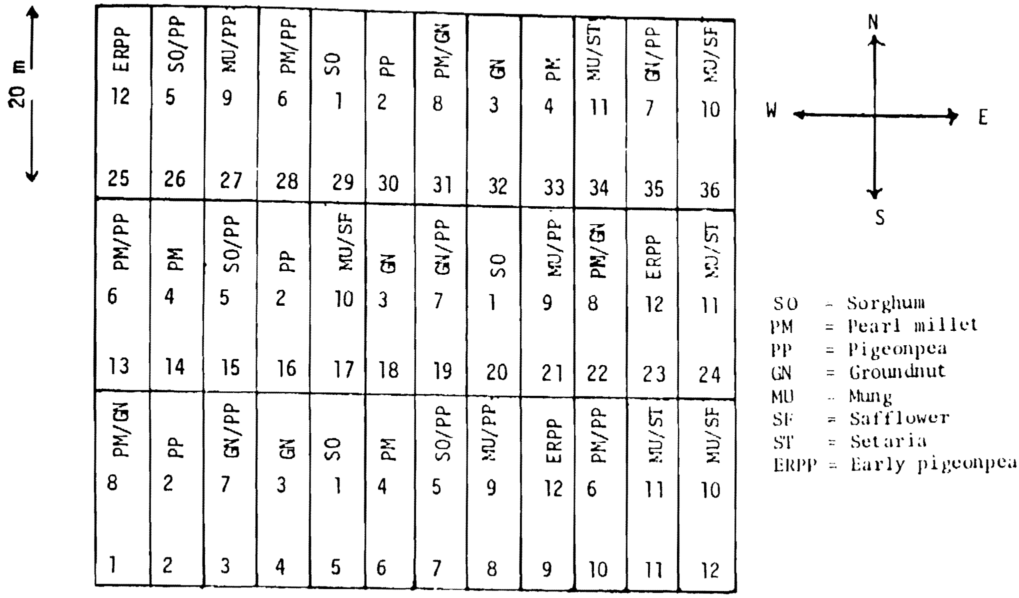
Sixteen meter length of the plot was kept free from weeds by periodical weeding, and an area of 4 m length was left unweeded after one initial weeding for observing the competitive effects of weeds on different cropping systems. Out of the 16 mlong weed-free plot, one bed on either side of the plot and 2 m area on either end were removed as border. The central two beds (3.0m) of 12 m long were harvested for final yield and dry matter estimation. Of the 4m unweeded portion, the central two beds (3.0 m) measuring 2 m were harvested for yield leaving one meter as head border. The layout plan of the experiment in the field and harvest details of an experimental plot are shown in Fig. 2.

3.5 Crop Culture

Plowing, levelling, sowing of crops and interculture were carried out with the help of animal-drawn wheeled tool carrier (Tropicultor) and its accessory equipment(ICRISAT, 1977). The broadbed-and-furrow system existing in the experimental field was also laid out with tropicultor six years ago and since then the system was maintained by restricting the cultivation only to beds. The field was plowed on the beds by attaching right-and left-mould board plows to the tool bar of the tropicultor. Then the beds were cultivated, stubbles removed and finally they were shaped with the help of a bed shaper. The broadbed-and furrows provided a 100-cm bed area where the crops were sown and 50 cm furrow which provided the track for animals and wheels of the tropicultor.

Crops were sown on 14 June 1984 with the help of two to four planters mounted onto the tropicultor each of which have independent seed metering mechanism. These enabled to plant varying numbers of rows or intercropping systems having different configuration on the bed. Appropriate seed plates were used in the planters for metering of seeds of different crops to obtain the required plant density (Table 3). However,millet/groundnut system was planted manually because of wide difference in the

A. Field layout of the experiment



B. A plot showing the harvest area in weeded and unweeded parts.

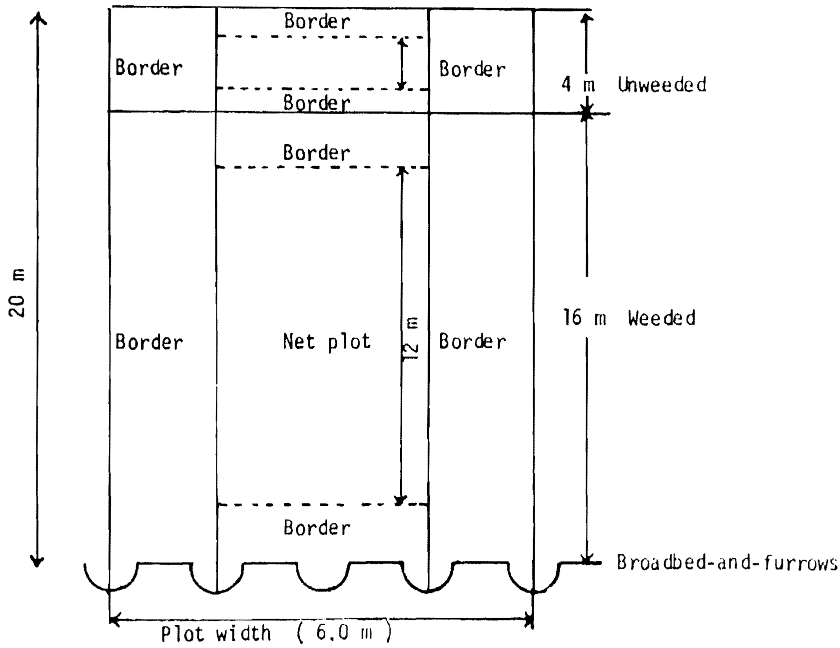


Fig. 2. Field layout plan of the experiment and details of harvest area in an experimental plot.

seed size of millet and groundnut. Spacing varied with the crops. The rows per bed and the spatial arrangement of crops in different systems are shown in Fig.3.

In intercropping both crops were planted simultaneously. In sequential systems the postrainy season crops were established on 21st September 1984 following a shower of 51 mm . One shallow cultivation was given immediately after the harvest of rainy season mung to facilitate planting of the postrainy season crops. One hundred Kg ha^{-1} of diammonium phosphate (18-46-0) was applied at planting time using a fertilizer drill mounted onto the tropicultor. Top dressing was done only to cereals with 42 Kg N ha^{-1} after weeding.

One intercultivation was given in all systems 15 days after the crop emergence by attaching duck-foot sweeps onto the tool bar of the tropicultor. Interculturing could have been continued by tropicultor in widely spaced crops, but however, weeds in later stages were controlled manually in all systems.

All crops were monitored periodically for the incidence of pests and diseases, and whenever pests became serious appropriate control measures were taken in consultation with the ICRISAT plant protection officer. Insecticide sprays were generally given so as to provide an economic level of protection Groundnut was sprayed with 0.2% Rogor (dimethoate) to control leaf minors and thrips in the early stages and with 0.35% Thiodan (endosulphan) to control leaf eating caterpillars at later stages. Pigeonpea was sprayed with 0.35% Thiodan in pod

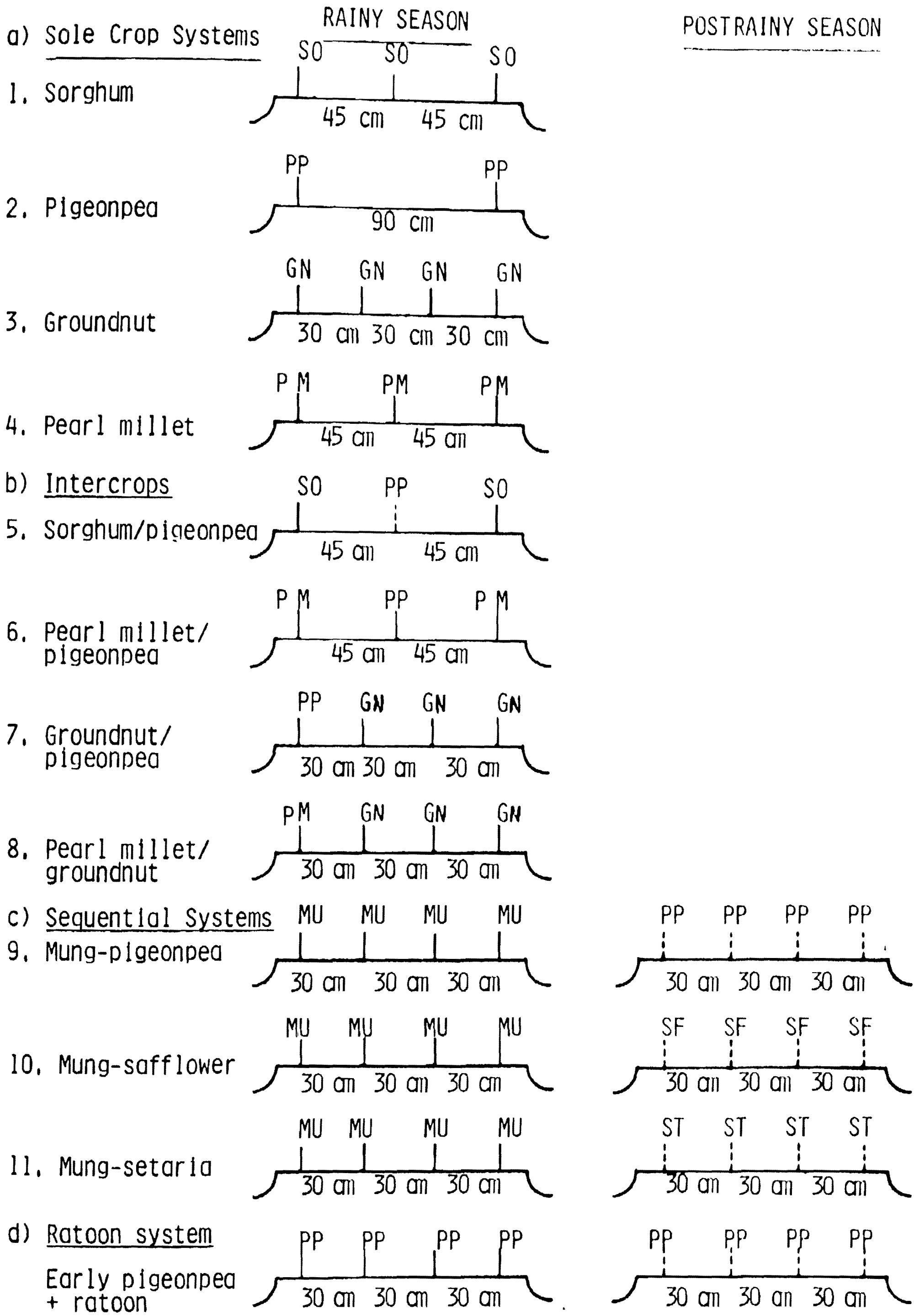


Fig. 3. Row arrangement of crops on broadbed-and-furrow system in different cropping systems.

formation stage to control *Heliothis* pod borer. Other crops did not show any major pest problems.

3.6 Observations Recorded

1. Initial soil fertility

Twelve random soil samples were taken from 0 to 15 cm and from 15 to 30 cm depths by using a scaled soil auger. Soil from the same depth was pooled over different samples and about half a kg of composite soil sample was prepared for determining the mechanical composition and the initial fertility status (Table 1a and 1b).

2. Date of planting

This is the date on which crops were planted in the field.

3. Date of crop emergence

Date on which about 90% of the seedlings had emerged.

4. Days to 50% flowering

This was recorded from the date of emergence to when 50% of the plants in the plot had flowered.

5. Days to maturity

This was recorded from the date of emergence to physiological maturity.

6. Crop stand

Stand count was taken immediately after the emergence of crops. Another count was taken at the time of harvest.

7. Plant height

This was measured from the ground level to the top of the plant (cm).

8. Number of hand weedings

Number of weedings given in each cropping system and the time taken for weeding were recorded. The cost of weeding was considered in economic evaluation of the system.

9. Weed growth

After giving an initial weeding, an area of 4 m was marked at one end of each plot which was not given any further weedings. Weed samples were collected thrice from 1m^2 within this area on border beds. After removing soil particles and other inert material attached to weed roots, the samples were dried out in an oven at 70°C and weighed to a constant weight.

10. Approximate time required for various cultural operations with tropicultor

Bullock and labour-hours required for plowing, planting and interculture were recorded while executing these operations in each cropping system. Costs for these operations were computed proportionately using the prevailing charges for hiring of bullocks and the equipment.

11. Light interception

Light observations were recorded at a weekly interval after the crops were thinned out to the required stand. Observations were made only in a few selected intercrops (sorghum/pigeonpea,

pigeonpea/groundnut) and their respective sole crops. Measurements were taken with the help of a T-meter at two randomly chosen spots in the net plot area. At each spot readings were taken covering the total width of the net plot (2 beds).

The T-meter is a 1m long tube containing the required photocells to measure the photosynthetically active radiation. The other components of the instrument include a vertical stand with a photocell to measure the total incoming radiation (i.e control) and an integrator to calculate the percentage light transmitted through the canopy. The long arm of the T-meter is placed across rows below the crop canopy to measure the light transmitted to the ground . Per cent light intercepted by the crop can be obtained by substracting the per cent transmision from 100.

12. Yield Components

Head length of cereals was measured on ten plants.

Branches and pods per plant of pigeonpea were measured by taking counts on ten plants. Test weight (or seed weight) was determined in all crops on the grain obtained from the net plot.

13. Grain and dry matter yields of crops

Grain and total dry matter yields were recorded for each crop, in Kg/ha . Grain yield was adjusted to 12% moisture in the case of cereals and 10% in the case of legumes. Moisture content was determined immediately after harvest and again at the time of weighing the samples. The non seed-dry matter was reported on oven dry weight basis. For this purpose,the stover of cereals, and haulms and sticks of legumes or oil seeds were weighed and moisture content of the material determined at the time of weighing in the field.

14. Land Equivalent Ratio (LER)

Productivity of intercropping systems was compared with that of the respective sole crops by calculating land equivalent ratios as defined in the earlier section.

15. Harvest Index

Harvest index was calculated as the ratio of economic yield to the total biological yield.

16. Economics of different cropping systems

The costs of variable inputs such as fertilizer, seed, insecticide, weedings, harvesting, and threshing, and of fixed costs involved for land preparation and sowing were computed for different cropping systems using the costs of inputs (or operations) as observed at ICRISAT Center(Appendix II and III)

Net profit from each cropping system was computed by substracting the operational costs (ie.variable costs and fixed costs) from the gross value of the produce. Prices as realized at two months after harvest of crops were used in estimating the gross value of the produce. In addition to the value of grain, the value of fodder and other byproducts was also considered for computing gross returns.

3.7 Statistical Analysis

The results were analysed according to the analysis of variance scheme for the Randomized Block Design (Cochran and Cox, 1957). Summary of the analyses of variance for different parameters is presented in the Appendix IV. Wherever the 'F test' was significant, least significant difference (LSD) was computed at 5% significance level for comparing the treatment differences.

4. RESULTS

The results of evaluation of twelve cropping systems on shallow black soils (Inceptisols) are presented below, after carrying out the analysis of variance .

The tables were arranged such that each table contains the data of one character measured on a particular crop(crops) in different cropping systems. Standard errors (SE$\pm$) and coefficients of variation (CV%) were presented for each parameter. Values of LSD (0.05) were given wherever the 'F' test showed significant differences among treatments.

4.1 Plant Stand

The plant stand of crops in different cropping systems as noted near harvest is given in Table 3.

Plant population of sorghum in sole cropping was slightly above 121 000 plants ha^{-1} whereas the stand in intercropping with pigeonpea was about 100 000 plants ha^{-1}. Although we aimed for a higher stand (150 000), the desired level could not be achieved because of operational difficulty in working with a bullock-drawn planter. However, in view of the observations that sorghum yield was affected little by plant population in the range of 90 000 to 180 000 plants ha^{-1} (Freyman and Venkateswarlu,1977; ICRISAT,1979), the stand achieved in the sole and intercropping could be regarded as sufficient for getting the potential yields.

Table 3. Crop stand in different cropping systems as observed at harvest time.

Cropping Systems	Sorghum	Pearl millet	Medium Pigeonpea	Early Pigeonpea	Groundnut	Safflower	Setaria	Mung
	(X 1000 plants ha-1)							
Sole Crop Systems								
Sorghum	121.3 (150)a							
Pearl millet		157.2 (150)						
Pigeonpea			84.4 (50)					
Groundnut					257.7 (300)			
Intercrop Systems								
Sorghum/Pigeonpea	99.5 (150)		41.4 (50)					
Pearl millet/Pigeonpea		115.1 (150)	39.3 (50)					
Pearl millet/Groundnut		51.4 (45)			178.0 (225)			
Groundnut/Pigeonpea			45.8 (50)		158.7 (225)			
Sequential Systems								
Mung - Early Pigeonpea				391.1 (300)				176.0 (300)
Mung - Safflower						180.0 (180)		199.9
Mung - Setaria							356.1	180.1
Ratoon System								
Early Pigeonpea-Ratoon				206.5 (300)				
SE(±)	3.9	4.2	1.8	12.5	11.7	-	-	8.1
LSD(0.05)	-	16.7	6.2	76.2	46.2	-	-	-
CV%	6.2	6.8	6.0	7.3	10.3	-	-	7.6

a Numbers in parentheses refer to the expected stand ha-1.

Similarly, pearl millet population in sole cropping was at the recommended level, but the stand in intercropping with pigeonpea was at 115 100 plants ha^{-1}. Considering the wide plateau in the yield-population relationship of millet (Lima, 1983), the stand could be considered as satisfactory in intercropping also. The density of pearl millet in intercropping with groundnut was at the required level.

The pigeonpea plant population in intercropping systems was in the required range of 40 000 to 50 000 plants ha^{-1}, but the stand in sole cropping was almost double of that in intercropping. While this excess stand may not give any positive benefit to grain yields over the generally accepted level of 40 000 to 50 000 plants ha^{-1} (ICRISAT, 1979 and 1980), it may considerably improve the stalk yields. The stand of early pigeonpea in the ratoon system was about 30% lower than the recommended density. But the crop planted in the sequential system was well above the recommended level.

Groundnut stand in sole cropping as well as in intercropping with millet was about 15 to 20% lower than the recommended level. The stand in intercropping with pigeonpea was 30% lower than the recommended level. The required stand could not be achieved even in the case of mung bean which is generally planted at a fairly high density. However, differences in the stand among systems was not marked; therefore, comparisons were unlikely to be affected by these differences. However, this points out the difficulty of maintaining proper stand with bullock-drawn planters in the case of crops that require high plant population density.

Safflower and setaria established very well and they required thinning to get the normal stand.

4.2 Plant Height

Data relating to plant height recorded at harvest are tabulated in Table 4.

Sole sorghum grew to a height of 159 cm, but in intercropping with pigeonpea it grew 10 cm shorter than in sole cropping.

Millet height was not affected by different cropping systems, and on average it grew to a height of 113 cm. The medium maturity pigeonpea attained a height of 138 cm in sole cropping. The intercrop of groundnut did not affect the height of pigeonpea, but the cereal intercrops slightly reduced its height. The early pigeonpea grew up to a height of 69 cm in the rainy season, whereas the same cultivar in the postrainy season reached to only a height of 48 cm.

Safflower also grew to a height of only 48 cm but setaria attained a height of almost one meter.

4.3 Days to 50% Flowering

Days taken by each crop to reach 50% flowering in different cropping systems are given in Table 5.

Table 4. Plant height measured at final harvest of crops in different cropping systems.

Cropping Systems	Sorghum	Pearl millet	Medium Pigeonpea	Early Pigeonpea	Safflower	Setaria
			(cm)			
Sole Crop Systems						
Sorghum	159					
Pearl millet		117				
Medium Pigeonpea			138			
Intercrop System						
Sorghum/Pigeonpea	149		128			
Pearl millet/Pigeonpea		111	129			
Pearl millet/Groundnut		114				
Groundnut/Pigeonpea			132			
Sequential Systems						
Mung-Early Pigeonpea				48		
Mung-Safflower					48	
Mung-Setaria						94
Ratoon System						
Early Pigeonpea-Ratoon				69		
SE(±)	2.7	4.4	6.4	3.3	-	-
LSD(0.05)	-	-	-	-	-	-
CV%	3.0	6.7	8.4	-	-	-

Table 5. Days from emergence to 50% flowering of crops in different cropping systems.

Cropping Systems	Sorghum	Pearl millet	Medium Pigeonpea	Early Pigeonpea	Groundnut	Safflower	Setaria	Mung
Sole Crop Systems								
Sorghum	57							
Pearl millet		42						
Medium Pigeonpea			128					
Groundnut					37			
Intercrop Systems								
Sorghum/Pigeonpea	57		135					
Pearl millet/Pigeonpea		42	132					
Pearl millet/Groundnut		33			37			
Groundnut/Pigeonpea			129		36			
Sequential Systems								
Mung-Early Pigeonpea				32				35
Mung-Safflower						78		35
Mung-Setaria							40	35
Ratoon System								
Early Pigeonpea-Ratoon				70				
SE(±)	-	-	0.7	1.2	0.6	-	-	-
LSD(0.05)	-	-	2.3	7.2	-	-	-	-
CV(%)	-	-	0.9	4.0	2.9	-	-	-

Sole cropped sorghum flowered in 57 days after emergence. Intercropping sorghum with pigeonpea did not influence the time taken for 50% flowering of sorghum, so the intercropped sorghum also flowered at the same time as sole cropped sorghum. Similarly, pearl millet in sole cropping and in intercropping with pigeonpea flowered at the same time (42 days), about a fortnight earlier than by sorghum. But millet in intercropping with groundnut flowered much earlier, in 33 days.

The sole crop of medium-maturity pigeonpea flowered in 128 days. While intecropping with groundnut did not affect the time taken for flowering of this cultivar, intercropping with cereals such as sorghum and pearl millet significantly delayed flowering. The early maturing pigeonpea planted in the rainy season flowered in 70 days, but the same cultivar planted in the postrainy season flowered in 32 days. This was because of the photosensitivity of the crop. Low temperatures prevailing in the postrainy season reduced the overall growth of the crop, and short days forced the crop to flower early and mature early (Narayanan and Sheldrake,1979).

Flowering of groundnut was not affected by cropping systems, and it flowered in 37 days. Mung bean flowered in 35 days. Setaria and safflower in the postrainy season flowered in 40 and 78 days respectively.

4.4 Light Interception

Patterns of light interception (photosynthetically active radiation) by sorghum/pigeonpea and pigeonpea/groundnut intercrops and their respective sole crops are shown in Figs.4 and 5 respectively.

Sole sorghum intercepted more light than sole pigeonpea and the intercrop , and it reached the peak interception value of 89% by 50 days after emergence . Light interception remained quite high until 71 days but it declined thereafter to 83% at harvest. Light interception by sole pigeonpea was low up to 70 days. The crop improved the interception thereafter to reach a peak value of 92% at 127 days . Light interception declined from 127 days until maturity of the crop , when it intercepted only 81%. Light interception by the intercrop followed similar pattern as that of sole sorghum until harvest of sorghum but at a slightly lower level . Soon after sorghum harvest , the intercropped pigeonpea intercepted a very low value of 62%. However, the interception increased to reach a maximum of 70% by 141 days as the crop compensated in growth later. The intercropped pigeonpea reached the peak interception a fortnight later than the sole pigeonpea, but even at this stage the interception by the intercropped pigeonpea was 20% lower than that recorded in sole pigeonpea . This difference between sole and intercropped pigeonpea remained until harvest.

Differences in light interception by sole groundnut , sole pigeonpea or their intercrop were small until 85 days. The

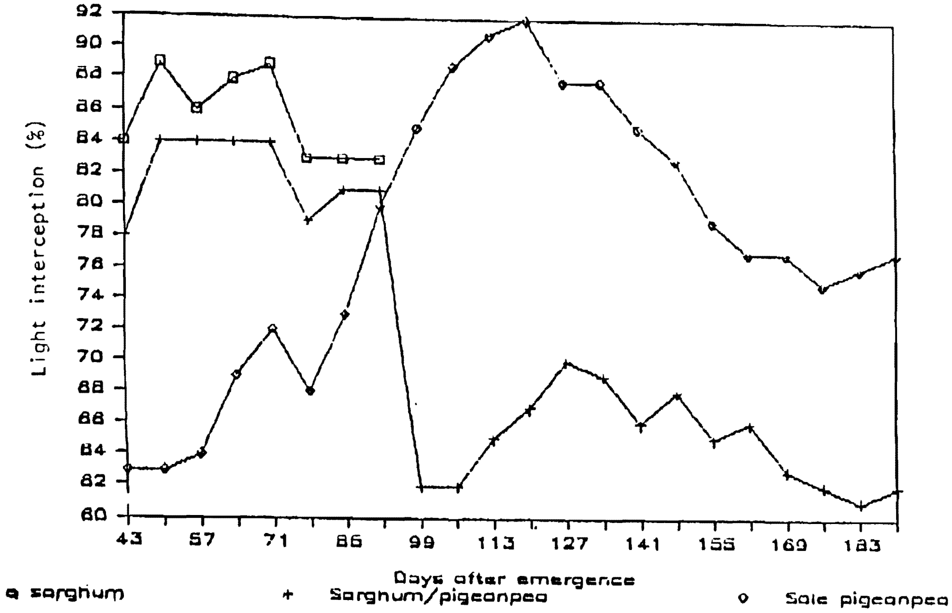


Fig.4: Light interception in sole crops of sorghum and pigeonpea and their intercrop system.

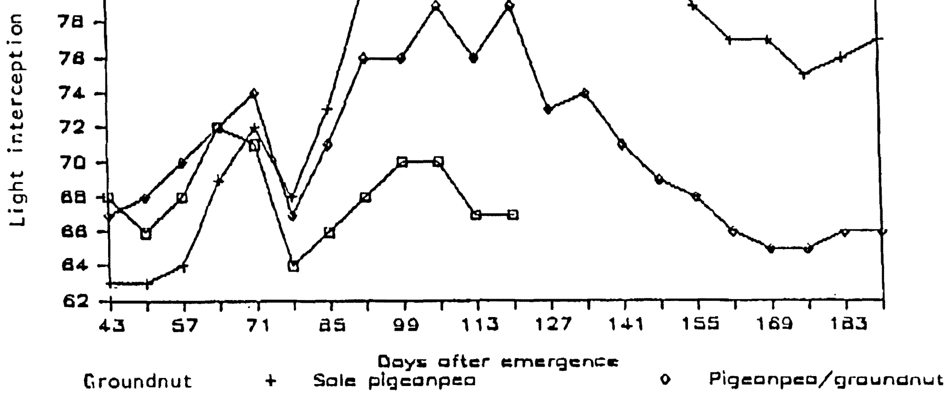


Fig.5: Light interception in sole crops of pigeonpea and groundnut and their intercropping system.

interception by sole pigeonpea was generally lower than with other systems until 70 days but from then onwards it intercepted more light than the others . It intercepted a maximum of 92% of the incident light at 127 days but the interception declined thereafter to record 78% at harvest. Sole groundnut reached the peak interception (73%) early by 64 days, but the interception soon dropped to 64%. However , the crop improved the light interception again to record 70% during 106 to 113 days . The depression in interception for about 3 weeks from 71 days was due to the effect of moisture shortage. Light interception by the pipeonpea/groundnut intercrop followed similar pattern as that of the sole pigeonpea until groundnut harvest but interception later was about 15% lower than that observed in sole pigeonpea.

4.5 Influence of Cropping Systems on Weeds

Dry matter of weeds measured on three occasions in different cropping systems are presented in Table 6.

Amongst all cropping systems , sole sorghum recorded the lowest weed dry matter throughout its growth. The sorghum/pigeonpea intercrop also showed very low weed growth, probably because of the presence of the competitive sorghum . Weed growth was also less in the early stage (at 62 days) in sole groundnut and pigeonpea/groundnut intercropping which had a high proportion of the space planted to groundnut. But in course of time weeds over-grew the low-canopy groundnut crop and at 99 days the weed dry matter in these systems was as high as in the cropping systems with pearl millet . Weeds came up well from the

Table 6. Weed dry matter in different cropping systems measured at three different stages.

Cropping Systems	Days After Emergence 62	99	141
	---------(g m^{-2})-----------		
Sole Crops			
Sorghum	34	106	-
Pigeonpea	80	324	315
Groundnut	61	229	-
Pearl millet	80	217	-
Intercrops			
Sorghum/Pigeonpea	42	104	205
Pearl millet/Pigeonpea	98	378	422
Groundnut/Pigeonpea	58	245	301
Pearl millet/Groundnut	78	211	-
Sequential Systems			
Mung-Pigeonpea	77	-	-
Mung-Safflower	61	-	-
Mung-Setaria	88	-	-
Ratoon System			
Early Pigeonpea-Ratoon	113	358	416
SE (±)	19.5	44.8	39.0
LSD(0.05)	-	134.4	120.1
CV(%)	46.8	32.2	21.4

beginning in the slow growing and widely spaced sole pigeonpea , the low canopy mung bean, sole pearl millet , and the two intercrop systems with pearl millet viz, pearl millet/pigeonpea and pearl millet/groundnut . The high weed infestation in pearl millet- based systems was due to the late establishment of millet following poor stand in the first planting . Weeds got established during this phase and persisted throughout the crop cycle. Thus , we find that weed dry matter at the time of second observation in these systems was 2 to 3 1/2 times to that observed in sole sorghum or sorghum/pigeonpea intercrop.

Differences in weed infestation among intercrop systems continued even after the harvest of the early maturing crops . At the time of the third observation, pigeonpea intercropped with pearl millet recorded the highest weed dry matter which was twice that recorded in pigeonpea intercropped with sorghum and 140% of that recorded in pigeonpea intercropped with groundnut.

The short duration pigeonpea recorded very high weed growth from the beginning to the harvest as was the case with sole crop of medium duration pigeonpea. This was because i) the short duration pigeonpea did not establish very well, and ii)the crop canopy did not fully cover the ground due to moisture stress in later stages.

Considering the sole versus intercropping there was no appreciable difference between the two systems and weed growth in intercropping closely resembled that in the sole crop of the dominant component.

A visual observation was carried out on 20 September to identify the most prevalent weed species and their approximate composition in different cropping systems (Table 7). Digitaria ciliaris and Celosia argentea were prominent in all cropping systems. While Indigofera glandulosa was prevalent in addition the above in most sole crops, Cynodon dactylon became important in intercropping systems. The composition of weeds was different with different cropping systems. Digitaria constituted more than 50% of weeds present in sole milllet, sole groundnut and intercropping systems with these crops. Weed flora in sole sorghum consisted of only Indigofera, Digitaria and Celosia. Their presence even under the thick canopy of sorghum suggests their persistent nature. The perennial weed Cynodon dactylon also survived under the canopy of sole pigeonpea. The sorghum/pigeonpea intercrop showed Lagasca mollis in addition to all those weeds observed under the two sole crops. Interestingly, this new species constituted fairly a high proportion compared to Digitaria and Celosia. There were a number of other species such as Lavandula, Phyllanthus, Tridax, Alysicarpus and Dicanthium which were not observed under sole crops but were noted in intercropping systems to a lesser degree.

4.6 Yield Components of Crops in Different Cropping Systems

Yield components measured in certain crops are given in Table 8,9 and 10.

Head length and grain weight of sorghum and millet were unaffected by cropping systems. This suggests that their yield

Table 7. Visual assessment of the occurance of weed flora in some sole crops and intercrops on shallow black soil (Inceptisols), 20 September 1984.

Weed Flora	Sole Crops				Intercrops			
	Sorghum	Pearl millet	Pigeonpea	Groundnut	Sorghum/ Pigeonpea	Pearl millet/ Pigeonpea	Pearl millet/ Groundnut	Pigeonp Groundn
	(%)							
Indigofera glandulosa	45	6	37	10	24	3	2	3
Digitaria ciliaris	20	64	18	50	13	48	45	67
Celosia argentea	35	26	32	13	6	20	25	13
Cynodon dactylon	-	2	13	3	31	23	16	17
Lagascea mollis	-	2	-	20	20	-	-	-
Iseilema spp.	-	-	-	4	-	-	-	-
Lavandula spp.	-	-	-	-	5	-	-	-
Phyllanthus maderaspatensis	-	-	-	-	1	2	-	-
Tridax procumbens	-	-	-	-	-	2	-	-
Alysicarpus spp.	-	-	-	-	-	2	5	-
Dichanthium aristatum	-	-	-	-	-	-	7	-

Table 8. Head length of sorghum and millet crops in different cropping systems.

Cropping Systems	Sorghum	Pearl millet
	(cm)	
Sole Crop Systems		
Sorghum	21	
Pearl millet		17
Intercrop Systems		
Sorghum/Pigeonpea	20	
Pearl millet/ Pigeonpea		17
Pearl millet/Groundnut		18
SE($\pm$)	0.4	0.9
LSD(0.05)	-	-
CV%	3.5	9.4

Table 9. Some measurements on yield components of medium and short-season pigeonpea.

Cropping Systems	Medium Pigeonpea			Early Pigeonpea
	Branches per plant		Pods per plant	Pods per plant
	Primary	Secondary		
Sole Crop System				
Pigeonpea	6	20	95	-
Intercrop Systems				
Sorghum/Pigeonpea	4	16	74	-
Pearl millet/Pigeonpea	5	18	114	-
Groundnut/Pigeonpea	5	17	138	-
Sequential System				
Mung-Early Pigeonpea				14
Ratoon System				
Early Pigeonpea-Ratoon				27
SE(±)	1.7	0.3	22.6	0.9
LSD(0.05)	-	-	-	5.7
CV%	16.0	10.9	37.3	7.9

Table 10. Test* weight of crops in differnt cropping systems.

Cropping Systems	Sorghum	Pearl millet	Medium-Pigeonpea	Early-Pigeonpea	Groundnut	Safflower	Setaria	Mung
	(g)							
Sole Crop Systems								
Sorghum	68							
Pearl millet		55						
Medium Pigeonpea			95					
Groundnut					29			
Intercrop Systems								
Sorghum/Pigeonpea	68		98					
Pearl millet/Pigeonpea		55	94					
Pearl millet/Groundnut		56			28			
Groundnut/Pigeonpea			94		27			
Sequenial Systems								
Mung-Early Pigeonpea				75				
Mung-Safflower						55		25
Mung-Setaria							3	25
Ratoon System								
Early Pigeonpea-Ratoon				90				
SE(±)	0.7	0.6	1.8	3.7	1.0	-	-	0.4
CV%	1.8	1.9	3.3	7.7	6.0	-	-	2.7

*It refers to the weight of 1000 seeds except for groundnut in which case it refers to the weight of 100 kernel weight.

in different systems was determined mostly by head numbers.

Pigeonpea produced lower branches per plant in intercropping than in sole cropping (Table 9). The sorghum intercrop was more competitive than others, and consequently, pigeonpea intercropped with sorghum produced fewer branches per plant than that intercropped with pearl millet or groundnut. Pods per plant also reflected similar trend but results of this character should be considered carefully because of high coefficient of variation. Weight of 1000 seed from sole cropped pigeonpea was 95 g, and intercropping did not cause any significant change in the seed weight.

The early pigeonpea cultivar ICPL-87 had only one fourth the pods per plant (27) of the medium cultivar. The pod number decreased further to only 14 per plant when it was grown in the postrainy season. The seed size of this cultivar was slightly smaller than that of ICP1-6. The seed size became much smaller when grown in the postrainy season.

Intercropping did not affect the seed weight of groundnut. This suggests that groundnut yield in intercropping was probably dependent on plant stand and pods per plant.

4.7 Weeding VS Non Weeding on Pigeonpea and Groundnut Yields in Different Cropping Systems.

Only yields of pigeonpea (ICP1-6) and groundnut were measured from the unweeded portion in different cropping systems (Table 11).

Table 11. Grain yield or pod yield of medium duration pigeonpea and groundnut in different cropping systems as affected by weeds.

Cropping Systems	Medium Pigeonpea		Groundnut	
	Unweeded	Weeded	Unweeded	Weeded
	(Kg ha-1)			
Sole Crop Systems				
Pigeonpea	356	1112		
Groundnut			1139	1225
Intercrop Systems				
Sorghum/Pigeonpea	192	401		
Pearl millet/Pigeonpea	246	730		
Pearl millet/Groundnut			710	825
Groundnut/Pigeonpea	467	715	646	718
SE(±)	57.6	105.2	72.6	68.5
LSD (0.05)	-	363.9	284.8	269
CV%	31.7	24	15.1	12.9

Weeds drastically reduced the yield of the slow growing and widely spaced pigeonpea, whereas they affected the low canopy and quick covering groundnut very little. Yield from unweeded pigeonpea was only about one third of that from weeded pigeonpea. Weeds were less competitive to intercrop systems, so their detrimental effect was somewhat less pronounced in intercropping. Thus, while the intercropped pigeonpea in weed free treatment averaged 55.4% of sole crop yield, the same in the unweeded area was 85% of the respective sole crop. Of the three intercrops pigeonpea yield with groundnut was highest. This high yield cannot be attributed solely to the good weed smothering affect of groundnut, but could be due to the combined effect of weed smothering and less competitiveness of groundnut to pigeonpea. The cereal intercrops were competitive to weeds as well as pigeonpea, so the pigeonpea yield in association with them was low.

As mentioned earlier, weeds reduced the groundnut yield only marginally in sole cropping. The competitiveness of weeds remained unaffected by intercropping and they reduced the intercropped groundnut yield similarly as in sole cropping.

4.8 Grain Yield of Crops in Different Cropping Systems

Data pertaining to the grain yield of crops in different cropping systems are given in Table 12.

Sole sorghum produced a reasonable yield of 2457 kg ha^{-1}, whereas the sorghum intercropped with pigeonpea yielded 22% less

Table 12. Grain or pod yield of crops in different cropping systems.

Cropping Systems	Sorghum	Pearl millet	Medium Pigeonpea	Early Pigeonpea	Groundnut	Safflower	Setaria	Mung
	(Kg ha^{-1})							
<u>Sole Crop Systems</u>								
Sorghum	2457							
Pearl millet		791						
Pigeonpea			1112					
Groundnut					1225(812)a			
<u>Intercrop Systems</u>								
Sorghum/Pigeonpea	1924		401					
Pearl millet/Pigeonpea		556	730					
Pearl millet/Groundnut		513			825(567)			
Groundnut/Pigeonpea			715		718(486)			
<u>Sequential Systems</u>								
Mung-Early Pigeonpea				327				334
Mung-Safflower						416		335
Mung-Setaria							836	327
<u>Ratoon System</u>								
Early Pigeonpea-Ratoon				1035				
SE(±)	238.6	132.0	105.2	89.9	68.5(50.1)	-	-	42.5
LSD	-	-	363.9	547.3	269(198)	-	-	-
CV%	18.9	36.9	24	22.9	12.9(14.0)	-	-	22.2

a Numbers in parentheses are kernel yield of groundnut ha^{-1}

than that in the sole crop (1924 kg ha^{-1}). Pearl millet as a sole crop produced much lower yield (791 Kg ha^{-1}) than that of sorghum. Millet intercropped with pigeonpea gave 556 kg ha^{-1}; and that intercropped with groundnut also yielded similarly at 513 kg ha^{-1} despite the fact that millet population in this system was only one fourth of that in sole cropping. On average millet yield in intercropping represented about 67% of that in sole cropping. However, differences were not significant partly because of high variability and less error degrees of freedom for treatment comparison.

The medium-maturing pigeonpea (cv ICPl-6) gave a good yield of 1112 kg ha^{-1} in sole cropping. It suffered considerably in intercropping with sorghum, pearl millet or groundnut and consequently produced significantly lower yield than in sole cropping. Competition from sorghum intercrop was much greater than with pearl millet or groundnut intercrop. So pigeonpea in association with sorghum recorded the lowest at 401 kg ha^{-1} (36.1% of sole crop), whereas in association with pearl millet or groundnut it recorded a little over 700 kg ha^{-1} (about 65% of sole crop).

The short duration pigeonpea (cv ICPL-87) gave almost similar yield (1030 kg ha^{-1}) as the sole crop of the medium maturing genotype (1112 kg ha^{-1}). This genotype was allowed to produce regrowth in the ratoon system, but regrowth was so poor due to low moisture status that no worthwhile yields were obtained from the ratoon crop. However, the same cultivar planted in the postrainy season in sequence with mung bean gave 31.6% of that produced in the rainy season.

Sole groundnut yielded 1225 kg ha^{-1}. Intercropping reduced the groundnut yield significantly irrespective of the plant population maintained in the system and the crop with which it was associated. Competition from pearl millet intercrop was lower than from pigeonpea intercrop. Hence, groundnut intercropped with pearl millet, inspite of having only 3/4 of the sole crop population, gave slightly better yield than that intercropped with pigeonpea. Interestingly, the kernel yield of groundnut followed similar pattern as the pod yield indicating that the shelling percentage remained unaffected by cropping systems. The reduced yield in intercropping was therefore primarily due to the reduction in growth of groundnut and not due to any effect on kernel filling.

The short duration mung crop in the three sequential systems gave only a little over 300 kg ha^{-1}. The sequential crops planted after mung established well but their growth was not good due to low residual moisture. Thus, safflower gave 416 kg ha^{-1} and pigeonpea cultivar (ICPL-87) gave 327 kg ha^{-1}. But seteria gave slightly better yield at 836 kg ha^{-1}.

4.9 Stover or Stalk/Haulm Yield of Crops in Different Systems

Yield of non-seed dry matter of crops in different cropping systems is presented in Table 13.

The effect of cropping systems on stover/haulm yield was similar to that on grain yield. Sorghum produced 3685 kg ha^{-1} of stover in sole cropping and 82 % of that in intercropping with pigeonpea.

Table 13. Stover or haulm yield of crops in different cropping systems.

Cropping Systems	Sorghum	Pearl millet	Medium Pigeonpea	Early Pigeonpea	Groundnut	Safflower	Setaria	Mung
	(Kg ha^{-1})							
Sole Crop Systems								
Sorghum	3685							
Pearl millet		1123						
Medium Pigeonpea			3722					
Groundnut					2236			
Intercrop Systems								
Sorghum/Pigeonpea	3027		1025					
Pearl millet/Pigeonpea		742	1955					
Pearl millet/Groundnut		566			1614			
Groundnut/Pigeonpea			1674		1331			
Sequential Systems								
Mung-Early Pigeonpea				599				440
Mung-Safflower						844		421
Mung-Setaria							1361	421
Ratoon System								
Early Pigeonpea- Ratoon				1390				
SE($\pm$)	247.6	126	314.3	161.9	150.8	-	-	65.9
LSD(0.05)	-	-	1087.7	-	592.1	-	-	-
CV%	12.8	26.9	26.0	28.2	15.1	-	-	26.7

Pearl millet in sole cropping produced only one third of stover produced by sorghum; stover yield went down further in intercropping to record only 742 to 566 kg ha^{-1}.

Stalk yield of pigeonpea (cv ICPI-6) in sole cropping was 3722 Kg ha^{-1}, which was as high as the stover yield of sole sorghum. This clearly shows the potential of pigeonpea in biomass production compared to cereals. The cereal and groundnut intercrops were very competitive to pigeonpea, as a result of which, the stalk yield of pigeonpea was significantly reduced in intercropping. Sorghum was much more competitive to pigeonpea than pearl millet or groundnut and caused a maximum reduction of 72.5%. Pearl millet and groundnut were equally competitive and affected pigeonpea similarly.

Although the early pigeonpea (cv ICPL-87) gave as good grain yield as the medium maturing pigeonpea, its stalk yield was only 37.4% of that of ICP1-6. This shows the small overall growth of ICPL-87. The growth of this genotype was further reduced in the postrainy season to result in only 599 Kg ha^{-1} of stalk yield. The quality of stalks also differed between the two cultivars, the stalks of ICP1-6 were thick and sturdy compared to those of ICPL-87.

Sole cropped groundnut produced 2236 Kg ha^{-1} haulms whereas the intercropped groundnut produced significantly lower yield of 1614 and 1331 Kg ha^{-1}.

Haulm yield of mung bean was lowest (428 Kg ha^{-1}) among all legumes examined in the trial. Straw yield of setaria in the postrainy season was better than that pearl millet in the rainy season. The stalk yield of safflower was 844 Kg ha^{-1}.

4.10 Harvest Index of Crops in Different Cropping Systems

The harvest index of cereals was very high (40% or above) compared to that of other crops (Table 14). The harvest index of sorghum and pearl millet was very similar in sole cropping and in intercropping with pigeonpea. But pearl millet intercropped with groundnut showed higher harvest index (48%) than in other systems, probably due to low plant population at which it was planted in this system. The harvest index is generally improved at low plant population(Stoskopf,1981).

Harvest index of sole pigeonpea (cv ICP1-6) was 23% but that of intercropped pigeonpea varied from 27% to 30%. Pigeonpea improved its harvest index in intercropping probably because of reduction in the early vegetative growth due to the competition from intercrops. The lower harvest index of pigeonpea compared to that of cereals suggests that this long season crop was inefficient in converting dry matter into economic yield. However, harvest index of the short duration pigeonpea (cv ICPL-87) was higher than that of the medium duration cultivar. It showed 43% when grown during the rainy season and 35% when cultivated during the postrainy season . The harvest index of groundnut was relatively unaffected by different cropping systems.

Table 14. Harvest index of crops in different cropping systems.

Cropping Systems	Rainy season crop	Postrainy season crop
Sole Crop Systems		
Sorghum	0.40	
Pearl millet	0.41	
Pigeonpea		0.23
Groundnut	0.35	
Intercrops		
Sorghum/Pigeonpea	0.39	0.28
Pearl millet/Pigeonpea	0.43	0.27
Pearl millet/Groundnut	0.48/0.38	
Groundnut/Pigeonpea	0.35	0.30
Sequential Crops		
Mung - Early Pigeonpea	0.35	0.35
Mung - Safflower	0.36	0.33
Mung - Setaria	0.36	0.38
Ratoon Crop		
Early Pigeonpea-Ratoon	0.43	

Amongst other crops, the harvest index of mung bean was 36%, that of safflower 33% and setaria 38%.

4.11 Land Productivity of Different Intercropping Systems

Mean land equivalent ratios of different intercropping systems are given in Table 15.

Intercropped sorghum averaged a LER of 0.78 and pigeonpea a LER of 0.36 . Combining the LERs of the two crops , we observe that the sorghum/pigeonpea intercrop was 14% more productive than either of the sole crops. Total LER in the case of pearl millet/pigeonpea was 1.36 indicating that this intercrop was 36% more productive than the respective sole crops. Greater productivity of pearl millet/pigeonpea intercrop over sorghum/pigeonpea was due to higher pigeonpea yield in intercropping with pearl millet than with sorghum . The groundnut/pigeonpea intercrop showed more or less similar LER for the component crops, 0.59 for groundnut and 0.64 for pigeonpea totaling a LER of 1.23 for the system. Thus, of the three intercropping systems based on pigeonpea , pearl millet/pigeonpea showed the maximum land productivity advantage (36%) followed by groundnut/pigeonpea (23%) while the lowest advantage (14%) was with sorghum/pigeonpea . A common feature of these systems was that the component crops were planted at 100% of their respective sole crop optimum populations. The observed LERs of rainy season crops were very much lower than generally have been reported for these crops in intercropping with pigeonpea (Rao and Willey,1983; Reddy and Willey,1985). Besides lower plant stand there might be other factors that were responsible for low LERs.

Table 15. Land Equivalent Ratio(LER) of different intercropping systems calculated on the basis of grain yield.

Intercrop Systems	Land equivalent ratio Rainy Season crop	Postrainy Season crop	Total LER
Sorghum/Pigeonpea	0.78	0.36	1.14
Pearl millet/Pigeonpea	0.70	0.66	1.36
Pearl millet/Groundnut	0.65	0.67	1.32
Groundnut/Pigeonpea	0.59	0.64	1.23
SE(±)			0.1
CV%			14.6

which would be discussed later.

Pearl millet and groundnut in intercropping might have yielded 25% and 75% of their respective sole crops if the interspecies competition was similar to that of intraspecies competition. But the intercropped groundnut produced 59% of sole crop yield and pearl millet 64% of its sole crop, thereby showing 23% advantage for this intercropping over the sole crops.

4.12 Gross Monetary Returns

Gross returns and net profits are shown in Table 16 and Fig.6. The input and output costs considered for calculating monetary returns are in Appendix II. Details of variable costs for different systems are given in Appendix III.

Amongst the sole crops, gross returns were highest with sole groundnut which differed significantly from other sole crop systems. Sole sorghum and sole pigeonpea gave similar returns which were about 74% of the returns from sole groundnut. Sole pearl millet showed the lowest gross returns.

Comparing the intercropping systems, groundnut/pigeonpea gave significantly higher returns (Rs 6003 ha^{-1}) than other intercrops. In fact, this system gave slightly higher returns than the sole groundnut. The sorghum/pigeonpea and millet/groundnut produced similar returns at Rs 4928 and 4825 ha^{-1} respectively which were about 81% of those observed with groundnut/pigeonpea. The returns from sorghum/pigeonpea were only 12.9% higher than those from sole crops. Though the returns from

Table 16. Variable costs, gross returns, and net profits of different cropping systems.

Cropping Systems	Variable Costs	Gross Returns	Net Profit
		(Rs ha^{-1})	
Sole Crop System			
Sorghum	1177	4362	3185
Pigeonpea	1297	4226	2929
Groundnut	1908	5774	3867
Pearl millet	1115	1411	296
Intercrop Systems			
Sorghum/Pigeonpea	1572	4928	3356
Pearl millet/Pigeonpea	1510	3685	2175
Pearl millet/Groundnut	1865	4825	2960
Groundnut/Pigeonpea	2303	6003	3700
Sequential Systems			
Mung - Early Pigeonpea	1196	2952	1756
Mung - Safflower	1209	3411	2202
Mung - Setaria	962	2747	1785
Ratoon System			
Early Pigeonpea- Ratoon	1049	3625	2576
SE(±)		365.5	361.3
LSD (0.05)		1072	1061
CV%		15.8	24.9

pearl millet/groundnut were about three times higher than those from sole millet, they were significantly lower than those from sole groundnut.The pearl millet/pigeonpea system gave significantly lower returns than all other intercrop systems. These returns were also lower than those of sole pigeonpea by 12.8%, but they were about 161.7% higher than those of sole millet.

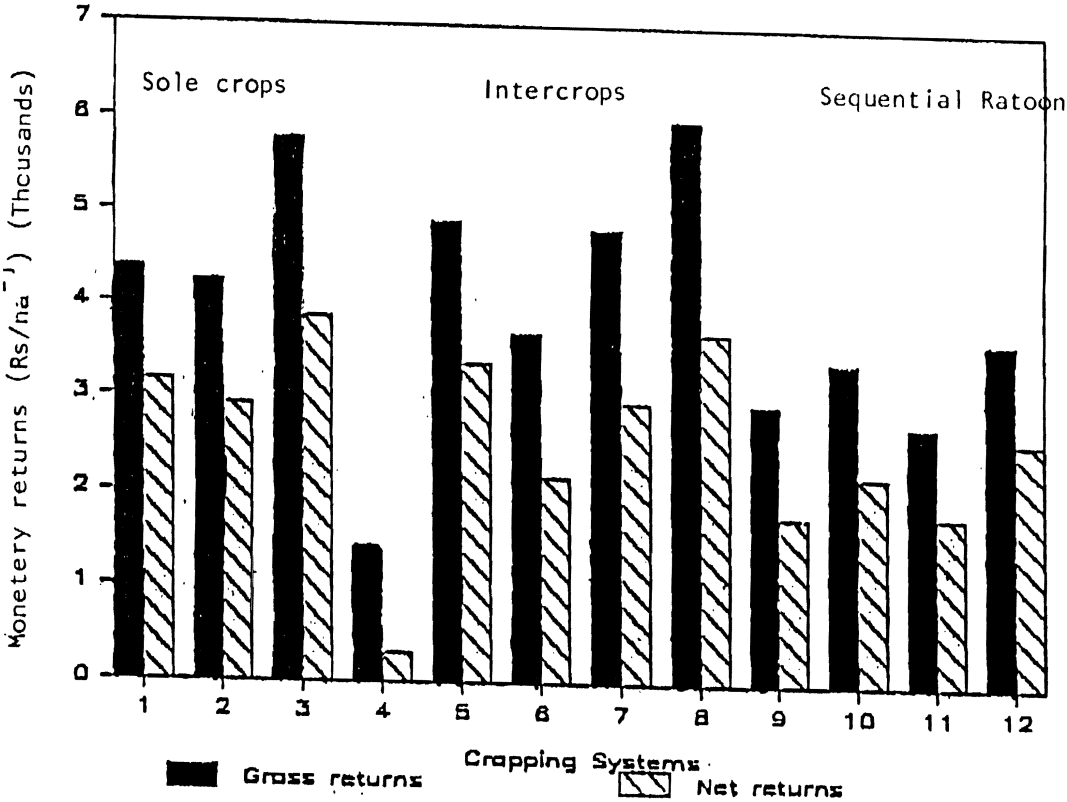
There were no appreciable differences in the returns of different sequential systems and the average returns were about 50% of those from groundnut/pigeonpea intercrop. The gross value of mung-safflower was higher than with other sequential systems by 16.5%.

The ratoon system of pigeonpea gave returns of Rs 3625 ha^{-1} which although were lower than from the promising intercrop and sole crop systems, they were substantially higher than with the sequential systems.

4.13 Net Monetary Returns

Table 16 and Fig.6 also show the net monetary returns of different cropping systems. Sole groundnut and intercropping of groundnut with pigeonpea were the most remunerative cropping systems with similar net profits (Rs 3867 and 3700 ha^{-1} respectively). Following them were sole sorghum, sole pigeonpea, sorghum/pigeonpea intercrop and millet/groundnut intercrop with returns varying from Rs 2960 to Rs 3356 ha^{-1}. Sole pearl millet gave the lowest net returns making this system least profitable.

Fig.6: Gross and net monetary returns from different cropping systems



1. Sorghum
2. Pigeonpea
3. Groundnut
4. Pearl millet
5. Sorghum/Pigeonpea
6. Pearl millet/Pigeonpea
7. Pearl millet/Groundnut
8. Groundnut/Pigeonpea
9. Mung - Pigeonpea
10. Mung - Safflower
11. Mung - Steria
12. Pigeonpea - Ratoon

Intercropping of pearl millet with pigeonpea improved the returns substantially but they were still lower than those obtained from other pigeonpea or groundnut based systems.

Sequential cropping systems gave significantly higher profits than sole millet but were not as profitable as some of the promising intercropping or sole crop systems. The mung-safflower sequence was comparable with millet/pigeonpea intercrop and was better than the other two sequential systems by about 19.6% .

The ratoon system with early pigeonpea gave higher returns than the sole pearl millet, pearl millet/pigeonpea intercrop or the sequential systems. Though its returns were significantly lower than those from groundnut/pigeonpea intercrop, they were only 12% lower than with sole pigeonpea.

5. DISCUSSION

5.1 Crop Stand and Crop Growth

There was no difficulty in sowing different rows or spatial arrangements of intercrops on broadbed-and-furrows with the wheeled-tool carrier. All crops established well except pearl millet in sole cropping and intercropping with pigeonpea which did not germinate well and required replanting. Obviously, the small-seeded pearl millet was placed at greater depth while it was planted simultaneously with other crops. Millet was replanted in these systems seven days later. This delay in establishment resulted in poorer growth of millet in these systems compared to that in pearl millet/groundnut. Crops in the latter system were planted by hand because of the apprehension that machine planting of such widely different sized seeds of millet and groundnut may not give good stand. The stand of intercrops in pigeonpea-based systems was lower than in their respective sole crops. These were required to be sown at 100% of their respective sole crop density by closer within-the-row spacing. Stand in intercropping could not be maintained similar to that in sole cropping because the seed metering plate used was the same in both systems. This points out that one must be careful while planting with machine of small-or large-seeded crops which require different depth of placement. However, plant population of crops in different systems was at reasonable level to permit valid comparison of the performance of the cropping systems. There was a 2-week dry spell soon after the crops emerged but the seedlings survived without any mortality.

Rainfall during the rainy season was only 510 mm (June to September) which was 18% lower than the normal. The deficit in the total seasonal rainfall may not be large but there was a 4-week long dry spell from 3rd week of August to 2nd week of September when crops were severly affected by stress compared to other crops. There were some good showers in the later part of September which facilitated to establish the sequential crops; otherwise the dry top soil might not have enabled to plant the postrainy season crops.

Inspite of the prevailing adverse conditions during the active crop growth period, sole sorghum performed well intercepting maximum light energy. This performance was probably due to better plant stand and ability of sorghum to withstand adverse climatic conditions. Light interception by sole sorghum declined from 71 days of emergence due to the commencement of senile phase (Fig. 4).

Sorghum/pigeonpea intercrop intercepted almost equal percentage of incoming radiation as that of sole sorghum. This agreed with the observations of Natarajan and Willey (1980b) that light interception by this intercrop was similar to that of sole sorghum until sorghum harvest. This was because the intercrop canopy was dominated by sorghum component. Light interception by the intercropped pigeonpea was much lower than sole pigeonpea because of the reduced growth due to sorghum competition. It compensated to some extent for the competition it had undergone earlier but the peak interception by the intercropped pigeonpea was lower than with sole pigeonpea. Sole pigeonpea intercepted 92% of the photosynthetically active radiation at 127 days after which the interception declined due to leaf fall.

Differences in light interception by different systems in pigeonpea/groundnut were small. The light interception values were not very high due to:

a) Insufficient plant stand, especially of the cereal in intercropping,
b) uneven distribution of rainfall causing moisture stress
c) poor water retention of the shallow black soil in the root zone, and
d) slow growth of crops such as pigeonpea.

Sorghum was the most competitive crop to weeds as well to pigeonpea in intercropping. Thus, the weed growth was lowest in sorghum-based systems. This agreed with the observations of Rao and Shetty (1976). The low-canopy and quick covering crops such as mung and groundnut also smothed the weeds well in the beginning of the season, but tall and hardy weeds such *Digitaria* and *Celosia* overgrew the crops in course of time and affected their growth. Similar observations were reported by Shetty and Rao (1981). Pearl millet in normal situation could be expected to suppress weeds similarly as sorghum but performance of millet-based systems was poor because of the delayed establishment of millet. Weed growth was highest from the beginning in sole pigeonpea because of wide spacing and its slow initial growth. Once the weeds got established they suppressed the crop and persisted throughout the crop growth.

The weed growth in intercropping systems was mostly determined by the type of the dominant component involved in the system. Although the intercropping did not show any additional advantage over the sole crop of the dominant component, they showed significantly lower weed growth compared to the sole crop of the weak component. The beneficial effect of sorghum in suppressing weeds early in the season in sorghum/pigeonpea intercrop system was carried forward until the harvest of pigeonpea (Table 7). Consequently, pigeonpea intercropped with sorghum recorded a high proportion of its sole crop (ie. 54%) in unweeded treatment compared to only 36% in weed-free treatment. Similar trends were noticed in other intercrop systems with pigeonpea. The yield of Intercropped groundnut as a proportion of sole crop was unaffected in weeded and unweeded treatments because weed growth in intercropping was determined by groundnut itself.

With regard to composition of weeds, Digitaria and Celosia were the most dominant weeds in all cropping systems. However, certain weeds were more specifically associated with specific cropping systems. For example, Indigofera was not prominent in intercropping systems, whereas Cynodon was not a major weed in sole crop systems. Similarly, a number of weeds noticed in intercropping systems were not present in sole crop systems. This points out that continued practice of a particular cropping system may encourage certain type of weeds which may become difficult to control later. While identifying the promising cropping systems one should, therefore, examine the possible shifts in weeds by long-term monitoring.

5.2 Crop yields

Given the unfavourable climatic conditions, sorghum yielded reasonablywell at 2.46 t ha^{-1} in sole cropping. Pearl millet produced only one third of the sorghum yield because of delayed establishment and also partly due to the suppression of the crop by weeds in the early stage. Sorghum suffered a yield loss of 22% in intercropping with pigeonpea. Pearl millet also suffered a yield loss of 30% in intercropping with pigeonpea. Earlier studies indicated that cereals intercropped with pigeonpea would under normal circumstances yield similarly as the sole crop if the intercrop was planted same as at the sole crop density (Natarajan and Willey, 1980; Rao and Willey, 1983; Shelke, 1977). However, in a below normal rainfall year, sorghum yield was significantly reduced in intercropping (ICRISAT, 1980). This was attributed to moisture stress and increased competition from pigeonpea to sorghum under such limited moisture conditions. The sizable reduction in intercropped sorghum and pearl millet in this study could be attributed to moisture stress that the crops had experienced during the dry spell. The dry spell coincided with flowering and grain formation of the cereals, where drought effects are generally more pronounced than at other stages (Seetharama et al., 1983). Under limited moisture the cereal/ pigeonpea intercrop may experience the stress effect more than the sole crops because of having additive populations.

Except the sole crops of pigeonpea and groundnut which gave above one tonne per ha all others produced very low yields. Mung bean produced only 332 kg ha^{-1} because of the dry spell during pod formation stage. The yields of postrainy season crops were also low because of small amount of stored moisture left in the profile at the end of the rainy season. In fact the postrainy season crops in sequential systems could not have been established but for 73 mm of rain received during September. For the same reason although mung was harvested on 20 August 1984, setaria and safflower were not sown untill 21st September. The performance of postrainy season pigeonpea was poor partly because of the limitation of moisture and the general reduction in growth of pigeonpea due to low temperature and short days (Narayanan and Sheldrake, 1979). There was very little moisture left in the profile after harvest of early pigeonpea, hence the ratoon growth was poor.

5.3 Land Equivalent Ratios

The yield advantage of cereal/pigeonpea intercrops was much lower (14% and 36%) than generally reported in previous studies (Natarajan and Willey, 1980a; Rao and Willey, 1980; Shelke, 1977). This was because of the reduced cereal yield in intercropping and relatively less contribution of pigeonpea than in normal circumstances. Pigeonpea yield as a proportion of its sole crop was only 36% in intercropping with sorghum and 66% in intercropping with pearl millet. Since the residual soil moisture in the postrainy season was very low, intercropped pigeonpea did not compensate for the loss of growth due to the competition of cereals in the rainy season. This was evident from the significantly reduced growth of intercropped pigeonpea compared to the sole cropped pigeonpea (Table 9). Between the two cereals, sorghum was much more competitive to pigeonpea than pearl millet, probably because of its height and longer maturity. Rao and Willey (1983) observed that these two plant characters mostly determined the competitiveness of cereals to pigeonpea. Hence, intercropping advantage was less with sorghum/pigeonpea compared to that with pearl millet/pigeonpea.

Pearl millet intercropped with groundnut, despite having only one fourth of the population, yielded same as the pearl millet intercropped with pigeonpea. This shows that the lower population of pearl millet was advantageous in a drought year. For the given pearl millet population in this system, the expected yield was only 25% (1 row millet : 3 rows groundnut) of the sole crop, but more than twice the expected yield indicated that the inter-species competition between millet and groundnut was lower than the intra-species competition. The increased millet yield was due to increased yield per plant as a result of increased tillering (Reddy and Willey, 1981). While the above could be the major reasons, however, it must be pointed out that the higehr relative yield of millet in this system could be partly due to low yield of sole millet which was replanted a week days later. Intercropped groundnut gave 67% of sole crop yield, only slightly lower than the expected 75%. The overall yield advantage of this intercrop system was 32% which was within the range of that reported by other workers (Reddy and Willey, 1981; Lima, 1983). The higher productivity of intercropping was due to the efficient use of the growth resources (Reddy and Willey, 1981). The relative yields of the component crops in groundnut/ pigeonpea intercrop were nearly equal, 59% in the case of groundnut and 64% in the case of pigeonpea. Although this pattern closely resembled that observed in previous studies (ICRISAT, 1980), the relative yields themselves were low, probably because of the determintal effect of moisture stress. Thus the overall advantage of 23% for this system was much lower than the 50% to 70% observed in normal years (ICRISAT, 1980). This intercrop system was also planted in additive populations as the cereal/pigeonpea systems and groundnut matured around the same time as sorghum. Lower relative yield of groundnut compared to sorghum or millet indicates that groundnut experienced greater competition from pigeonpea than the cereal intercrops.

5.4 Monetary Returns

Sole cropping of groundnut was the most profitable cropping system. This was because of its reasonable yield inspite of dry spell and high cash value of the produce. Groundnut/pigeonpea intercrop was also equally profitable. Gross returns were in fact higher for the intercrop, but net returnswere slightly higher for sole crop because of higher input costs required for the intercrop. Some alternatives to the above were sole sorghum, sole pigeonpea, sorghum/pigeonpea and millet/groundnut. Returns from these were only 11 to 22% lower than those from groundnut based systems. However, if we consider returns per every rupee invested sole sorghum was the most enterprising system (Rs. 2.71 Re^{-1}, Table 16). From economic point of view sorhgum/pigeonpea intercrop was only marginally superior to the sole crops requirement of increased operational costs by about Rs. 400 ha^{-1} made this system less attractive compared to either of the sole crops. However, intercropping still retains its advantage for farmers who would like to grow some of both the sole crops for subsistence needs.

The early pigeonpea (cv ICPL-87) gave significantly lower net profits compared to groundnut systems but operational costs were so low for this system that return per investment was the second best (Rs. 2.45 Re^{-1}) after sole sorghum. This should be a good option for farmers who might have less resources. While this ratoon system has the advantage that it extends cropping beyond the rainy season and may provide partial second crop yield, one disadvantage compared to the medium pigeonpea was that it produced only one third the stalk yield of the medium cultivar (Table 13). Pigeonpea stalks have economic value as fuel wood material.

The sequential systems were less remunerative because of low yields of both the rainy and postrainy season crops (Table 12). The study demonstrated that sequential systems could be practiced with short duration crops on shallow black soils provided some showers are received during September/October. However, further studies are required to confirm their potentialities in relation to intercrop systems or full season sole crops. There is definitly some risk involved in establishing the postrainy season crops, particularly in years when the rains end early, and in such years the advantage of intercropping is highlighted.

The pearl millet/groundnut was less economical compared to sole groundnut because contribution from pearl millet did not compensate the loss in the high value groundnut. Comparison of intercrop with either of the most profitable sole crop is valid only when the farmer wants cash. But when he is interested on some of both sole crops then the intercrop should be compared with a shared sole system where the land is devided between the two sole crops. On that basis the intercrop turns out to be advantageous over sole cropping. However, since sole millet did not grow normally, further evaluation of pearl mille-based systems is required.

6. CONCLUSIONS

Inspite of thc environmental constraints faced during the conduct of the study, the following conclusions could be made.

1. Sole cropping of the cash crop groundnut and intercropping it with pigeonpea are the most remunerative cropping systems for shallow black soils.
2. Some alternative systems to the above are sole crops of sorghum or pigeonpea, and sorghum/pigeonpea or pearl millet/ groundnut intercrops.
3. Ratoon system with early pigeonpea(ICPL 87) could be regarded as a second level alternative. Eventhough the second harvest yield was not very encouraging and the total returns were not high it is worth considering from the point of low operational costs required for this system and less risks.
4. Although sequential cropping was feasible with very early-maturing crops, none of the systems examined in this study gave comparable returns as intercrops or full season sole crops because of the low productivity of the short season sole crops. However, mung-safflower system needs further examination.
5. The productivity of sole crop of pearl millet or pearl millet/ pigeonpea intercrop would not have been as observed in this study under normal circumstances. They need further assessment.
6. The wheeled-tool carrier can be employed to carry out all cultural operations except for harvest and threshing of crops. Care must be taken while planting of small-seeded crops such as pearl millet.

SUMMARY

An experiment was conducted at the International Crops Research Institute for the Semi-Arid Tropics(ICRISAT) during the rainy and postrainy seasons of 1984-85 on a shallow black soil. The objective of the study was to evaluate the performance of different cropping systems and identify the most profitable systems for shallow black soils.

The cropping systems included in the evaluation were four sole crops (sorghum, pearl millet, groundnut and pigeonpea), four intercrops (sorghum/pigeonpea, pearl millet/pigeonpea, groundnut/ pigeonpea, and pearl millet/groundnut), three sequential systems (mung followed by setaria, safflower or early pigeonpea cv. ICPL87) and a ratoon system with a short duration pigeonpea. The study was conducted in a randomized block design having three replications in fairly large plots (6.0X20 m). Crops were fertilized at a moderate level,a uniform dose of 100 kg ha^{-1} of diammonium phosphate as basal to all systems and 42 kg ha^{-1} of nitrogen as top dress later only to cereals. Most of the operations except harvest and threshing were carried out by an animal-drawn wheeled-tool carrier.

All crops established well except pearl millet which required replanting in sole cropping and in intercropping with pigeonpea. Consequently the comparison of these systems with others was vitiated. Seasonal rainfall in 1984-85 was 17% less than the normal. Low rainfall coupled with a four week long dry spell during August/September caused severe moisture stress and

affected crop yields.

The intercrops of sorghum/pigeonpea and groundnut /pigeonpea intercepted light similar as the sole crops of sorghum and groundnut respectively as long as these were associated with pigeonpea. The intecropped pigeonpea improved its growth later by compensation, but however, it intercepted less light than the sole cropped pigeonpea.

Sorghum was very competitive to weeds, so sorghum-based cropping systems showed very little weed growth. Weeds grew up well in pearl millet/pigeonpea intercrop similar as in sole pigeonpea because of the delayed establishment of pearl millet. Generally weed growth was high (especially in the later stage)in low canopy crops such as groundnut and mung, and slow growing pigeonpea.

Crop yields were generally low. Sole sorghum yielded 2.46 t ha^{-1} and intercropped sorghum averaged 78% of the sole crop (1.92 t ha^{-1}). Pearl millet produced only 0.8 t ha^{-1} in sole cropping and about 68% of that in intercropping with groundnut or pigeonpea. Sole cropped pigeonpea of medium cultivar (ICPl-6) and early cultivar (ICPL 87) yielded similarly at about one t ha^{-1}. The competitiveness of intercrops on pigeonpea was in the order: sorghum>groundnut=pearl millet. So pigeonpea intercropped with sorghum yielded only 36% of the sole crop compared to about 65% in intercropping with pearl millet or groundnut. Groundnut in sole cropping produced 1.2 t ha^{-1} while it averaged in intercropping 0.77 t ha^{-1}. The postrainy season crops gave low yields (0.32 to 0.42 t ha^{-1})except setaria which gave 0.84 t ha^{-1}.

Despite low pearl millet yields, the millet/pigeonpea intercrop showed higher LER advantage (36%) over sole cropping compared to other intercropping systems. Pearl millet/groundnut averaged 32% advantage, whereas groundnut/pigeonpea showed 23% and sorghum/pigeonpea 14% advantage over their respective sole crops.

Sole cropping of groundnut was the most remunerative system with a net profit of Rs 3867 ha^{-1}. This was followed by groundnut/pigeonpea intercrop(Rs 3700 ha^{-1}). Sorghum/pigeonpea intercropping and sole crops of sorghum or pigeonpea gave about Rs 3000 ha^{-1}, the intercrop showed only a marginal advantage over the sole crops. An intercrop of pearl millet/groundnut also gave similar type of profits. Because of poor pearl millet yield, the returns from millet/pigeonpea intercrop were low at Rs 2175 ha^{-1} which compared only with the sequential systems.

The ratoon system with early pigeonpea was more profitable than the sequential systems but this system was still less attractive compared to sole crop of medium pigeonpea.

Considering the limitations of the environment, it appears that sole cropping with full season crops such as groundnut, sorghum, or pigeonpea and intercropping with pigeonpea are the appropriate cropping systems for shallow black soils.

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Appendix I: Meteorological data collected at ICRISAT Center from June 1984 to February 1985.

(Standard week weather data from week Nos. 24 to 52 for the year 1984).

STD WEEK	RAIN mm	EVAP mm	MAX. TEM	MIN. TEM	R.HU 0717	R.HU 1417	WIND kph	SUN SHINE	SOL.RADIATION (LY/DAY)
24	85.3	47.8	31.7	22.8	86.6	55.4	19	2.2	322
25	2.4	72.3	34.4	23.5	76.9	40	25.2	8	485
26	3.8	62.1	32.8	23.5	76.1	45.4	20.2	4.3	358
27	21.6	46.4	31.8	23.1	82.3	57.1	20	3.7	348
28	36.8	43.5	31.5	23	84.7	55.4	10	4.8	370
29	68.1	27.6	28	21.4	91.6	73.6	14.6	2.9	312
30	25.2	30.7	28.2	21.9	91.3	77	11	3	332
31	149.6	22.9	26.5	21.4	93	77.3	12.9	3.3	304
32	14	40.4	29.5	21.7	88	60.6	14.9	5.3	389
33	0.3	46.3	29.8	22	82.1	54.6	14	5.1	384
34	0	45.2	30.9	22.6	79.1	50.7	9.9	7.1	442
35	3.2	48.4	30.6	22.3	79.6	52.9	12.1	5.3	371
36	0	50.5	31.1	21.8	76.7	42.7	9.8	5.5	442
37	73.5	27.9	28.5	20.9	90.9	69.4	7.2	5	367
38	13.4	33.9	30.7	22.1	92.3	55.4	4.6	7.3	450
39	12.3	34.3	31.1	21.3	92.1	58.1	4.5	7.9	439
40	0	40.1	31.6	21	84.3	44.4	6.9	8.7	488
41	73	33	28.8	20.6	89.7	62.3	6.8	5.5	350
42	0	36.3	30.4	18.7	82.9	33.9	4.7	9.3	475
43	7.4	33	30.7	19.1	86.4	48.1	4.3	9.4	433
44	6.4	35.9	29.8	18.4	86.3	41.6	5.6	9.4	426
45	0	39.1	29.5	14.9	85.1	39	5.6	9.8	455
46	0	42.6	28.5	14.7	73.3	31	6.4	6.9	385
47	0	39.6	27.7	10.9	76.4	23.6	6	10.5	430
48	0	39.8	26.3	10.9	79.3	30.4	7.7	9.2	382
49	0	31.2	29.8	17.3	88.4	44.1	5.5	8.1	350
50	0	36.3	29.9	12.3	79.7	24.6	4.2	10.5	404
51	0	34.7	28.6	10.9	84.3	24.9	4.7	10.3	389
52	0	36.9	28.7	14	83.4	34.5	5.8	9.8	331

STANDARD WEEK WEATHER DATA FROM WEEK NOS. 1 TO 7 FOR THE YEAR 1985

1	1.8	29.5	27.7	16.7	92.6	50.6	18.6	8	338
2	0	38	29.1	17.4	90.3	38	10.3	8.3	367
3	0	38.7	28.9	16	92.1	35.1	8.9	9.4	377
4	0	41.7	29.3	15.8	85.4	37.7	8	9.7	417
5	0	48.5	31.2	17.1	84.3	28.6	9	10.4	438
6	0	47.6	33.1	16.4	66.1	23.6	5.6	10.2	432
7	0	56.2	33.2	18	79.3	22.4	8	10.4	457

Appendix II. Input and output costs considered for different crops in working out the monetary returns of cropping systems.

1. Seeds	Seed rate (Kg ha^{-1})	Seed cost (Rs Kg^{-1})	Market value of the produce	
			Grain or pod	Stover
			(Rs Kg^{-1})	
Sorghum	10	9.00	1.40	0.25
Pearl millet	4	9.50	1.50	0.20
Pigeonpea	10	3.30	3.30	0.15
Groundnut (Kernels)	100(Kernels)	6.38	3.80	0.50
Mungbean	20	4.68	4.68	0.50
Safflower	20	3.95	3.95	-
Setaria	3	0.85	0.85	0.20

2. Fertilizer

- Urea Rs 2090/ton
- Diammonium Phosphate(DAP) Rs.3350/ton

3. Pesticide

Rogor 30 EC Rs 62.00/litre

Thiodan 35 EC Rs 62.00/litre

Appendix III. Variable costs estimated for different cropping systems .

Cropping Systems	Seed Cost	Fertilizer	Pesticides	Labour cost	Land preparation and planting	Total
	(Rs ha^{-1})					
Sorghum	90	111	-	846	130	1177
Pigeonpea	33	53	172	909	130	1297
Groundnut	639	53	240	846	130	1908
Pearl millet	28	111	-	846	130	1115
Sorghum/Pigeonpea	123	111	172	1036	130	1572
Pearl millet/Pigeonpea	61	111	172	1036	130	1510
Pearl millet/Groundnut	667	111	240	717	130	1865
Groundnut/Pigeonpea	672	53	412	1036	130	2303
Mung-Sequential Early Pigeonpea	156	53	172	625	190	1196
Mung-Sequential Safflower	169	53	172	625	190	1209
Mung-Sequential Setaria	94	53	-	625	190	962
Early Pigeonpea- Ratoon	64	53	172	630	130	1049

a = Values were adjusted to the nearest rupee.

Appendix IVa: Mean sums of squares from analyses of variance of different parameters of crops in different cropping systems.

	Sorghum			Pearl millet			Mung bean		
	DF	MSS	EMS	DF	MSS	EMS	DF	MSS	EMS
Crop stand(Plant ha)	1	7.129E8	4.763E7	2	8.512E9**	5.452E7	2	4.919E8	2.010E(
Days to 50% Flowering	1	-	-	-	-	-	-	-	-
Height(cm)	1	150.00	21.00	2	30.11	57.78	-	-	-
Test weight(g)	1	-	-	2	0.778	1.111	2	0.4444	0.4444
Head length(cm)	1	1.5000	0.5000	2	0.778	2.611	-	-	-
Grain/pod yield(kg ha)	1	426667	170741	2	67350	52309	2	62	5429
Stover/haulm/stalk(kg ha)	1	649446	183834	2	243889	47589	2	355	13025
Error D.F	2			4			4		

Appendix IVb: Mean sums of squares from analyses of variance of different parameters of crops in different cropping systems.

	Medium duration pigeonpea			Groundnut			Early pieonpea		
	DF	MSS	EMS	DF	MSS	EMS	DF	MSS	EMS
Crop Stand (Plants ha)	3	1.360E9**	9.919E6	2	8.259E9**	4.164E8	1	5.108E10**	4.713E8
Days to 50% flowering	3	34.306**	1.306	2	0.778	1.111	1	2204.167**	4.167
Height (cm)	3	63.2	123.1	-	-	-	1	604.67*	32.17
Test Weight (g)	3	11.000	9.917	2	1.444	2.778	1	337.50	40.50
Grain/Pod Yield(kg ha)	3	253533*	33152	2	214659*	14117	1	752604*	24272
Stover/Haulm/Stalk(kg ha)	3	3989951**	296195	2	643112*	68222	1	936940	78691
Primary Branches (kg ha)	3	0.9722	0.3056	-	-	-	-	-	-
Secondary branches(Plant)	3	8.750	8.333	-	-	-	-	-	-
Pods (Plant)	3	2216	1538	-	-	-	1	240.667*	2.667
Error D.F	6			4			2		

Appendix IVc: Mean sums of squares from analyses of variance of different parameters

	DF	Error DF	MSS	EMS
Weed dry matter at 62 days	11	22	1496	1143
Weed dry matter at 99 days	8	16	29245**	6021
Weed dry matter at 141 days	6	12	18827**	4553
Pigeonpea yield in unweeded area	3	6	44903	9944
Groundnut yield in unweeded area	2	4	215471*	15793
LER	3	6	0.03	0.05
Gross returns	11	22	5131481**	400754
Net returns	11	22	3076469**	392581

VITA

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I was educated at Afgoi Primary School and completed my Secondary School at Mogadishu in 1969.

I got my Bsc. degree in 1975 from the Faculty of Agriculture of the "Somali National University" at Afgoi district. Then I joined the Ministry of Agriculture.

I worked as a research officer from 1976 to 1978 at Jilib Agricultural Research Station in the Middle Juba Region. During the period from 1978 to 1979 I participated in a one year training course on "Dry Farming System in South Australia" at Roseworthy Collage under the sponsorship of FAO.

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