EVALUATION OF DIFFERENT CROPPING SYSTEMS FOR ALFISOLS AT DIFFERENT FERTILITY LEVELS ON AN OPERATIONAL SCALE

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EVALUATION OF DIFFERENT CROPPING SYSTEMS
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ON
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by

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CERTIFICATE

This is to certify that the thesis entitled "Evaluation of different cropping systems for Alfisols at different fertility levels on an operational scale" 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 out by Shri Joseph K. Kimemia under my guidance and subversion. 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. Published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

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CERTIFICATE

Shri Joseph K. Kimemia has satisfactorily prosecuted the course of research and the thesis entitled "Evaluation of different cropping systems for Alfisols at different fertility levels on an operational scale" submitted is the result of original research work and is of sufficient high standard to warrant 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

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ABSTRACT

A number of different cropping systems are practised by farmers in the semi-arid tropics. Research has been carried out on individual cropping systems for some time. This present study was taken up to compare the various cropping systems possible under alfisol situation. Seven intercropping systems, two sequential, one relay and one ratoon cropping systems were evaluated in the rainy and postrainy season 1982/83 at ICRISAT research farm. Two fertilizer levels, 80-22-0 and 20-12-0 N.P.K. were used. The research was carried out on an operational scale, with individual plot size being 210 m^2. Planting, fertilizer application and intrarow cultivation were done using a bullock-drawn implement.

There was a response to high fertilizer application in terms of yield, but land equivalent ratios were higher under low fertility, however, the net monetary returns were higher under the high fertility level.

Intercropping proved to be the superior cropping system, and in this intercropping of long duration crops was better than that of short duration crops in terms of better light utilization, land equivalent ratio and net returns. Sorghum/pigeonpea, millet/pigeonpea and groundnut/pigeonpea were the best having a yield advantage of over 50%, and net returns of over Rs 2500/ha. Sequential cropping was also a feasible cropping system giving a net return of about Rs 2500/ha. However, relay cropping in fact gave negative returns, and also a lot of problems were experienced while planting the relay crop without damaging the first crop and harvesting the first crop. Ratoon cropping was also not economical.

INTRODUCTION

INTRODUCTION

The Semi-Arid Tropics (SAT) where precipitation exceeds the potential evapotranspiration from 2 to 7 months (Trol, 1966) represents diversity of soils, climate and people. The soils, particularly red soils (Alfisols) which are predominant, are low in organic matter, and have low moisture holding capacity. The rainfall is erratic and undependable, mostly occurring in high intensity torrents and the rainfall season rarely exceeds 150 days (Virmani, 1976). The farmers are poor and illiterate, the farm holdings are small, the main source of power is the bullock, and the source of labour is mostly their own family members and there is little capital investment. All these summed up make agriculture in the SAT a very difficult task, and it is not surprising that most of the regions under SAT are faced with food shortage in one part of the year or throughout the whole year (Norman, 1974). In addition, the population of most SAT countries has doubled in the past thirty years. Farmers have attempted to double agricultural production by increasing the size of land under cultivation. Due to population pressure, there is now very little land or no land to expand, and the only alternative left is to increase the cropping intensity or improve the traditional cropping systems or introduce new ones.

Faced with these problems, farmers have developed their own traditional cropping systems, and have attempted to maximize returns by using the family labour and limited resources that they have. Despite, the importance of these traditional cropping systems, very little research had been carried out on them. However, recently interest has been shown on this aspect in both national and international programs (Norman, 1974). Some of the common traditional cropping systems have been outlined by Aiyer (1949) and Krishnamoorthy (1978). Some preliminary work on these cropping systems has been carried out at ICRISAT (ICRISAT, 1976-1981) and has shown that it is possible to improve them by using improved varieties and cultural practices.

Fertilizer application is an integral component of improved cropping systems, but most farmers in the dryland situations rarely apply any fertilizer to their fields (ENSP, 1980). According to ENSP Fertilizer Information Bulletin No.13 (1980), fertilizer represents one of the key inputs for raising the yield of dryland crops. So it is important to conduct research, mainly to see how these improved cropping systems perform under different fertility levels. As legumes are known to fix nitrogen (Agboola and Fayemi 1972) that would benefit a non-leguminous crop in association with the legume (Rao 1980), then it would be advantageous to include a legume(s) in the cropping system, either as an intercrop or as part of the rotation.

Another very important aspect of an improved cropping system is the choice of crops and varieties (Kanwar, 1970) and also crop combinations that will lead to higher yield advantages.

It was with this background information that the present experiment was taken up on an operational scale, and at different fertility levels. This experiment entitled "Evaluation of different cropping systems for Alfisols under different fertility levels on an operational scale" was designed with the following objectives.

1. To examine the productivity and profitability of different cropping systems based on a research watershed on an operational scale.
2. To find out how an improved system would perform under different fertility levels.
3. To find out the major operational problems associated with the different cropping systems.

REVIEW OF LITERATURE

2 LITERATURE REVIEW

2.1 Definitions

2.1.1 Cropping System

Cropping system was originally defined by Andrews and Kassam (1976) as the cropping pattern used on a farm and their interaction with farm resources, other farm enterprises and available technology which determine their make up. Later on, Willey (1977) defined it as the combination of crops in space and time with an objective to provide high and stable returns.

2.1.2 Mixed Cropping

Mixed cropping was defined by Aiyer (1949) as the practice of growing two or more crops simultaneously in the same field, with no distinct row arrangement. Crop intensity is increased in both time and space.

2.1.3 Intercropping

This is defined as the growing of two or more crops simultaneously on the same piece of land, in a distinct row arrangement. There is both inter and intra-crop competition during all or part of the crop growth. Crop intensification is both in time and space dimensions (Andrews and Kassam, 1976).

2.1.4 Sequential cropping

Growing two or more crops in sequence on the same piece of field per year (one farming year is assumed to be 12 months except in very arid areas where one crop can be grown every 2 years) is known as sequential cropping (Andrews and Kassam, 1976). The succeeding crop is planted after the preceding crop has been harvested. Crop intensification is only in time dimension alone, and there is no intercrop competition.

2.1.5 Relay cropping

This is the practice of growing one or more crops smultaneously during part of the life cycle of each.i In most cases, a second crop is sown after the first one has reached its senile phase, but before it is harvested (Andrews and Kassam, 1976).

2.1.6 Ratoon cropping

This is the cultivation of crop regrowth after the completion of harvest of the main crop. It is commonly practised in sugarcane and pasture grasses. In food crops, it is more common in sorghum. Utilizes apical dominance phenomenon (Plucknett, et al, 1970)

2.1.7 Sole cropping

This is growing one crop variety alone in pure stand at normal density in one growing season.

2.2 Traditional Cropping Systems

In regions of low rainfall (300 mm), short growing season (2 months) and shallow soils, grass is the principal crop (Arnon, 1972). With increasing rainfall and growing season, the dominant cereal changes from pearl millet, through sorghum to maize. Mixed cropping dominates and is mainly combinations of relatively long duration crops like pigeonpea and sorghum (Krishnamoorthy, 1978). Relay and sequential cropping are practically unknown (Krishnamoorthy, 1978; Okigbo, 1976). According to Kanwar (1970), traditional varieties grown in drylands are of long duration and invariably suffer much moisture stress. Natural selection operated in favour of survival rather than productivity, so that these crops hardly respond to inputs and high level of management (Kanwar, 1970). Hence, these traditional cropping systems are characterized by low and unstable yields (Krishnamoorthy, 1978).

Krishnamoorthy (1974) recognizes 3 types of cropping systems for the drylands:

2.2.1 Cropping system for aberrant weather

This mainly includes adjustments for:

a. delayed onset of the rains
b. long gaps in rainfal, and
c. early stoppage of the rains.

The principles involved are the choice of alternate crops, ratooning, thinning and possibly crop life saving irrigation.

2.2.2 Cropping systems for minimizing fertilizer use

These involve:

a. improving the efficiency of fertilizer use, split application in relation to crop needs and available moisture, placement and in specific cases foliar application;

b. development of suitable cropping systems. The inclusion of a legume in the cropping system saves on nitrogen and increases phosphate use.

2.2.3 Cropping systems for risk minimization and distribution

Traditional cropping systems are characterized by low risk and low yield. The problem is how to combine low risk with high yield. This can be achieved by:

a. developing a cropping system to meet aberrant weather;

b. combine low monetary inputs with high level management, e.g. selection of crops and varieties, choice of sowing date, plant population, crop geometry and weeding;

c. supplementing the natural resources with monetary inputs such as fertilizer, ground water etc.

Okigbo (1974) while reviewing about the traditional cropping systems in Africa, reported that mixed cropping dominated. The studies indicate the following advantages of mixed cropping:

1. An efficient utilization of resources since compatible crops utilizing nutrients of various kinds at different levels could subsist mutually with one another.

2. An insurance against crop failure due to diseases, pests and other adverse environmental conditions.

3. A continuous cover of the soil throughout the year protecting it against erosion especially when crops are harvested at different times and their growth periods overlap.

4. The availability of a range of food stuffs at different times of the year, thus ensuring a more balanced diet and minimizing storage problems.

Baker (1974) reported that in many semi-arid regions, farmers with limited resources have traditionally inter-cropped their lands to minimize risks associated with monoculture and to assure a more stable subsistence in terms of food, nutrition and possible income.

Although the importance of mixed cropping in traditional agriculture was realised a long time ago (Nicol, 1935, Aiyer, 1949), it is only recently that the desirability to do research on mixed cropping under improved technological conditions has been realised.

Kanwar (1970) reviewed the role of traditional cropping systems in India, in increasing food production, alleviating poverty and also the problems associated with it (technical, economic, and sociological) and concluded that there were numerous potentials which have not yet been exploited.

Spratt et al (1978) and Krishnamoorthy (1978) separately concluded that as rainfall increases, cropping systems change from sole cropping to intercropping to double cropping. They gave the following recommendations, according to the amount of rainfall received per year.

500 - 625 mm - sole crop

625 - 715 mm - intercropping

750 - 900 mm - sequential cropping

2.3 Improved cropping systems

2.3.1 Intercropping

Willey (1977) stated that "in fact there is increasing evidence that yield advantage may be possible whatever the level of development and it can well be argued that intercropping should be seen as a crop improvement pathway as necessary and as potentially fruitful as monocropping".

For a long time, intercropping has been considered to be characteristic of poorly developed, traditional agriculture. A good illustration has been given by Norman (1974) in his studies of traditional agriculture in Northern Nigeria. The main controversy surrounding intercropping according to Charreau (1977) is whether it is possible at a higher level of technology where more inputs are available to farmers and either animal cultivation or tractor is used. The idea all along has been that sole cropping is the solution to the problems of the tropics. However, Baker and Yusuf (1976) reported that "it is the lack of knowledge of the principles underlying mixed cropping that has prevented the application of improved technology and the development of more productive mixed cropping systems".

Advantages of intercropping

With regard to productivity per unit area, intercropping superiority over sole cropping would arise from a better use of environmnet's resources : light, water and mineral nutrients (Charreau, 1977).

For a yield advantage to be obtained in the intercropping situation, there must be some "complementarity" between crops, reducing the intercrop competition (Willey, 1979).

The yield advantages shown in intercropping situations have often being attributed to temporal rather than spatial effects (Andrews, 1977, Osiru and Willey, 1977, Krantz et al 1976; Rao and Wiley, 1980). This seems especially true for light which cannot be stored (Baker & Yusuf, 1976, Natarajan and Wiley, 1980). In case of spatial complementarily a combined leaf canopy might make better use of light, or combined root systems make better use of nutrients and water (Fisher, 1976, Natarajan and Wiley, 1980, Reddy and Wiley, 1981).

Water is of primary importance in the semi-arid tropics and the main advantage of intercropping may be attributed to more efficient use, both spatial and temporal (Kurtz, 1952, Reddy and Willey, 1981). There is some evidence that intercropping root systems may exploit a greater volume of soil and that the roots of a later developing, deep rooting crop may be forced deeper by the presence of an earlier developing, shallow rooting crop (Willey, 1977).

There is evidence that intercropping can result in a greater intake of nutrients (Sharma, 1979). This may result from increased rooting depths or from temporal differences in nutrient requirements. Where the intercropping situation includes a legume, which is common, the nitrogen intake of the other non-leguminous component may be improved (Sarat et al, 1975; Ahmed et al, 1974; Rao, 1980; Searle et al, 1981). The benefit is likely to depend on the relative growth patterns. Shorter season legumes under long season non-leguminous crops may be beneficial. This is because the legumes excrete nitrogen (Agboola and Fayemi, 1971) which can be utilized by the long season non-legume (Sharma, 1979) either by current transfer of residual effects.

Other advantages attributed to intercropping include better protection of soil against erosion (Kampen, 1979), diseases (Mukiibi, 1980), weeds (Mugabe, 1980, Shetty et al, 1979). These benefits do not automatically occur in all intercropping situations, but they may certainly be observed for some mixtures of crops in a given climatic and soil environment.

When compared with sole cropping, the productivity is expressed in terms of monetary advantage (Willey, 1977) or Land Equivalent Ratio normally referred to as LER (Willey, 1979). Land Equivalent Ratio is the most common.

As far as intercropping is concerned, yield advantages ranging from 10-17% compared with sole cropping have been reported (Natarajan and Willey, 1980; Rao and Willey, 1980; Reddi et al, 1980). It also appears that the largest increase in returns per surface unit are found in experiments where the growth patterns of the various component crops are clearly different (Andrews, 1972; Baker, 1974; Baker and Yusuf, 1976; Willey, 1979). This fact supports the assumption that the effects resulting from a better use of environmental resources the temporal aspects may be seen to be more important than spatial ones.

The performance of intercropping as compared to sole cropping with regard to fertilizer application is about the same, although the monetary advantage tends to increase when addition of fertilizer is increased (Rao and Willey, 1978).

Krantz et al (1976) showed that contrary to rather widespread opinion, it is possible to complete the cultural operations with animal traction in the intercropping situation, except harvesting. Hence it is more or less the simplicity of monocropping other than the sophistication of intercropping which hinders the progress of intercropping (Yusuf and Baker, 1976). According to Jodha (1977), the extent of mixed cropping is closely associated with quality and size of the resource base. Mixed cropping decreases and sole cropping increases with improvement in the resource base. Massive resource improvements orient the cropping patterns towards high value crops and tend to reduce the importance of intercropping.

Some common intercropping systems

i) Sorghum/Pigeonpea

This is an example of intercropping a long season pulse crop with a short or medium duration cereal crop. During the early trials, Krishnamoorthy et al (1978) obtained a land equivalent ratio of only 1.2.

This low yield advantage was attributed to an inadequate appreciation of the spatial and temporal attributes on crop population and poor choice of varieties.

Later on work carried out at ICRISAT (Rao et al, 1982) showed that intercropped sorghum yields were 89% of the sole crop and 59% in case of pigeonpea, giving a yield advantage of 48%. Natarajan and Willey (1980); and Rao (1980) have shown that it is possible to grow the intercrops at sole crop populations without affecting the yield severely, although pigeonpea growth is at first severely depressed by the sorghum, but it always recovers, compensates and gives a substantial additional yield at harvest.

ii) Millet/Groundnut

This illustrates the extent of yield advantage in closely maturing cereal/legume intercrop. In most cases, it is practised by the farmer to provide food and cash respectively (Baker, 1978). Punjab (1980) showed that the groundnut did not reduce the millet yield, while Reddy and Willey (1981) reported a yield advantage of 26% due to increased efficiency in converting light energy into dry matter.

Rao (1980) reported that when crops are sown at 30 cm rows, at a ratio of 1 millet: 3 groundnut using the same intra row spacing in the respective sole crops, groundnut produced 1505 kg/ha which is 77%

of its sole crop yield, while millet produced 1414 kg/ha which is 54% of the sole crop yield, in other words, the millet yield per plant was more than double. This gave a yield advantage of 31%.

iii) Pigeonpea/Groundnut

This is an example of a legume/legume intercrop. Kaul et al (1975) found that groundnut may reduce the yield of pigeonpea slightly as it occupies land for a longer time, but still a monetary advantage was achieved, whereas Gajendra (1978) found a yield increase of 46.7% when pigeonpea was intercropped with groundnut over sole crop. Ramdass (1980) reported similar monetary advantage. Rao (1981) reported on some ICRISAT trials, that when both crops are grown at 100% population, yields averaged 76% of sole groundnut plus 89% of sole pigeonpea, thus giving a yield advantage of 65%. This has been one of the best intercropping systems according to Rao (1982).

iv) Castor-based intercropping systems

This is an example of a deep rooted, drought resistant, long duration crop in an intercropping system.

Evans (1962) reported that intercropping in castor showed an overall increase in production per acre and never an overall loss. He further stressed that since castor is affected by insects that reduce yield drastically, intercropping will give a compensating yield of the other crops.

Prabhakra et al (1965) found that intercropping castor with legumes resulted in both yield and monetary advantages, as the castor benefitted from the nitrogen fixed by the legume. Intercropping castor with cereals did not prove profitable.

Rao et al (1975) found that intercropping in castor is economical over sole crop, as long as the intercrop matures before the primary spikes of castor start flowering.

Chinnappan and Palaniappan (1980) reported that growing of intercrops between rows of castor, reduced castor yield, but the loss was more than compensated by the yield of the intercrops. From their experiment, castor-mungbean gave maximum returns.

2.3.2 Relay cropping

Relay cropping is the sowing of a second crop into the later stages of growth of a first crop. It has also been termed as overlapping cropping (King, 1974) or interplanting (Bain, 1968). Although introduced only recently, the system has become very important in China (King, 1975-76) and has also established some importance in many irrigated areas of Southeast Asia (King , 1974). The overlap period is most often only 2-3 weeks but can be considerably longer. The basic concept is to establish the second crop during the period when the leaf area, and thus the degree of shading is decreasing in the first crop. In semi-arid regions, the main factor is probably the reduction of moisture loss. The most important aspect of this is that it may allow double cropping in areas where a natural sequence of two crops would be too marginal. In India, it has been suggested as a possibility in areas receiving 750-900 mm annual rainfall with reasonable soil water storage (Spratt et al, 1978). It must be added that the system is not without problems, since it tends to combine the difficulties of both intensive sequential cropping and intercropping.

Triplett (1976) has summarized the advantages and disadvantages of relay cropping as :

Advantages :

i) During the first 4-6 weeks of crop growth, young crops are not productive and have less canopy, during this period another crop can use its canopy to mature.

ii) Saves time in the sense that the second crop is given a longer growing period as compared to a sequential crop.

iii) Labour used in land preparation for a second crop is saved.

Disadvantages

i) Weed competition after the harvest of the first crop, as no land preparation will be carried out.

ii) Due to the difficulties involved in planting the second crop within the first crop, the resulting stand is usually poor.

iii) Some damage to the first crop while sowing the second and some damage to the second crop while harvesting the first.

Even though relay cropping is normally not practiced in rainfed semi-arid tropics, the development of high yielding short duration varieties has opened new avenues for relay cropping, particularly in black soils (ICRISAT, 1980).

2.3.3 Sequential cropping

The annual yield per unit area can be increased by increasing the cropping intensity. Each crop variety included need not give the maximum yield or returns during its growth period, but must be a suitable component in a crop sequence to give maximum production of net returns per unit area cropped out of the resources used over the appropriate time span (Lal and Roy, 1976).

Although it is a practice of a high rainfall area ($\geq$750 mm) and is commonly practised under vertisols of the semi-arid tropics (ICRISAT, 1980), it may be possible in lower rainfall areas, with proper choice of crops (Suraj, 1978) and of the rainy season crop is sown early, and better sowing methods used for the second crop (Spratt, 1978).

It can be achieved by complete land preparation before planting of a second crop or by planting the second crop in the crop stubbles after an inter-row cultivation to kill weeds.

Krantz (1979) recommended that the monsoon crop should be removed as early as possible and cultivate and plant between standing stubbles. This is time saving and it increases the length of the growing season for the second crop and conserves soil moisture for germination of the post-monsoon crop.

The time lag between harvesting and planting of the second crop is sometimes as much as 7 days according to the experience at ICRISAT (Krantz, 1979), and this is crucial as far as moisture conservation is concerned. Hence it is only advantageous over relay cropping under following conditions according to Krantz (1979).

i) in areas with high weed population

ii) where the post-monsoon crop seedlings are stunted by shading

iii) where the post-monsoon crops require more adequate seed bed preparation.

2.3.4 Ratoon cropping

Ratoon cropping can be defined as, the growing of a second crop from the stubble of a first crop, after harvesting most or all of the aerial parts of the latter (Plucknett _et al_, 1970).

The objective of ratoon cropping is, in many cases, in making maximum use of the growing season by fitting an extra crop. Although, ratoon cropping is an important and well established cropping system in a number of perennial crops, e.g. sugarcane (Plucknett, 1970), it is less common in annual crops. In case of sorghum, for example it is resorted to when there is not enough rain and the first crop is cut for fodder and then allowed to ratoon for grain (Reddy, 1968). It is possible to have several harvests from a single planting (Escalada et al, 1975). The ratoon crop is affected by the height, time of cutting (Escalada et al, 1974) and amount of nitrogen applied (Escalada et al, 1977). According to Escalada et al (1977), the best height for cutting is 8 cm above the ground which leaves enough nodal buds and sufficient carbohydrate reserves for establishment.

Based on his study (Escalada et al, 1977) found that ratoon sorghum responded high rates of N, upto 250 kg N/ha. The advantages of ratoon cropping which are often mentioned are :

- no pre-sowing tillage is necessary
- early growth is faster than from a sown crop
- flowers and matures earlier than the plant crop (Vijayakumar, et al, 1977)
- some crops like sorghum are very resistant to drought in their stubble stage and still have good regrowth when water becomes available (Plucknett et al, 1970).

- the ratoon crop can profit from existing root system. However, some evidence exists that the old root system cease to function after the harvest at least in sugarcane and perhaps in sorghum. Plucknett et al (1975) found a direct relation between ratoon performance of sorghum and the extent and vitality of new root development.

The major problem of ratooning sorghum is the attack by Shootfly (Atherigona indica) and unless proper control is taken, the crop may be completely destroyed (Trouchten and Martin, 1981).

Concluding from several experiments at ICRISAT, Krantz (1979) remarked that where ratoon crop of sorghum is planned, the heads should be harvested and stover cut soon after physiological maturity is reached.

2.4 Fertilizer interaction with cropping systems

Improved cropping systems respond well to fertilizer application (Reddy, 1982). But even though fertilizer application efficiency has been shown to be more efficient under intercropping systems (Sharma, et al, 1979), as compared to sole crops, the fertilizer application of any nutrient requires the farmer to gamble that the yield increase can be marketed at a price that will pay fertilizer cost plus profit (Rao and Willey, 1979). However, yield increases from fertilizer application are not always assured, and the farmer has no positive means of identifying those fields that would produce increased yields and optimum application rates to achieve these yields (Krantz, 1976).

Reddy et al (1982) recognized three different situation that arise due to introduction of an improved cropping system on nutrient requirements.

2.4.1 Nutrient requirement increased

This would occur where all the component crops of the cropping system require the nutrient. For example, in a cereal/legume intercrop, the phosphorous requirement may go up as it is required by both crops.

2.4.2 Nutrient requirement decreased

The inclusion of a legume in a cropping system reduces the nitrogen requirement (as fertilizer) due to their ability to fix nitrogen.

2.4.3 Nutrient requirement substantially unaltered

A cropping system may not require additional fertilizer if only one component crop requires fertilization and there is little competition between the component crops for this nutrient. For example, nitrogen fertilization of sorghum/pigeonpea intercrop, where nitrogen is only applied to sorghum and not pigeonpea, the response curves of both sole sorghum and intercrop is similar.

2.5 Role of legumes in cropping systems

Legumes have been playing an important role in traditional agriculture. Their ability to fix and excrete nitrogen was shown by Agboola and Fayemi (1972), and their beneficial effect in increasing the soil nitrogen status by Tiwari et al (1980). As a result, the cereal crops following them have produced higher yields than those grown after another cereal (Tiwari et al, 1980). Even in intercropping situations, there is enough evidence to show that the non-leguminous component crop may yield more than the sole crop (Saraf, 1975; Singh, 1977; Sharma et al, 1979; Searle et al, 1981).

Searle et al (1981) reported that the incorporation of a legume in a maize crop saves as much as 100 kg N/ha. Krantz et al (1976) found a yield increase of up to 100% in a cereal-pigeonpea intercrop. The yield of the legume is not reduced by the non-legume intercrop component (Saraf et al, 1975). Therefore, it seems that substantial amounts of nitrogen can be transferred to the non-legume, especially if the legume is early maturing (Ahmed and Gunasene, 1979; Rao and Willey, 1980).

Two mechanisms are postulated for the beneficial effects of a legume on other crops in a cropping system:

i) Current transfer : in which transfer of nitrogen from the legume to the non-legume occurs during the life of both crops (Pratap et al, 1977).

ii) Residual effects in which nitrogen fixed by the legume is available to an associated sequential non-legume after senescence of the legume and decomposition of its organic residues (Gajendra et al, 1979).

2.6 A note on broadbed and furrow systems

Since water is the most limiting natural factor in crop production in the semi-arid tropics, improving the management and conservation of water and soil for increased crop production becomes of primary importance (Krantz, 1978). Systems involving graded beds (150 cm) separated by furrows which drain into grassed watersways appear to fulfil this important function according to Choudhary and Bhatta (1971), and Krantz (1979). The beds function as 'mini bunds' and when runoff occurs, its velocity is reduced and infiltration opportunity time is increased.

The broadbed is more flexible than the normal ridge and furrow system for planting different crops according to their optimum spacing and populations (Krantz, 1974).

Rao (1982) reported that on Alfisols the broadbed generally increase runoff and soil loss and does not improve yields. He stressed the need for further research on this aspect before firm conclusions can be drawn.

2.7 Operational scale evaluation

Recent research has shown substantial benefits from intercropping at medium to high levels of technology, but due to several factors including lack of operational scale research, the potential benefits of improved cropping systems have not yet been confirmed (Krantz, 1979).

Sarin _et al_ (1980) showed a wide gap between experimental yields and farmer yields, and one of the reasons given was that research at experimental stations is always carried out in small plots under carefully controlled operations and the more complex interactions are not manifested.

A good example shown by Krantz (1979) is that experimental results have shown that alternate row arrangement of intercrops such as a cereal and pigeonpea give great yield advantage. However, this system may present many problems on an operational scale such as :

i) inefficiency of applying needed nitrogen or plant protection to one row of cereal and not to pigeonpea.

ii) the problem of hand harvesting the cereal at physiological maturity without damaging the pigeonpea, which has spread out and is at the flowering stage.

iii) the problem of handling sorghum regrowth which competes with pigeonpea for residual moisture in the soil at the critical reproductive stage.

2.8 Criteria for evaluation

In any cropping system, different types of crops are used. Hence when comparing one system against another, yield *per se* cannot be used (Price, 1978). Several methods have been used particularly for comparing intercrop systems.

2.8.1 One of the earliest methods was to convert the yield of the component crops to a standard farm, either convert the yield of one crop to equivalents of the other (Nicol, 1935), or convert the yields to starch, fat or protein equivalents (Beets, 1977).

2.8.2 Willey (1977) introduced the use of Land Equivalent Ratio (LER). This defined as the relative land area required as sole crops to produce the same yields as intercropping. It is in fact analgous to the Relative Yield Total which has been used for many years in competition studies (de Wit and van den Bergh, 1961). In simple notation, it can be written as:

$$LER = L_A + L_B = \frac{Y_A}{S_A} + \frac{Y_B}{S_B}$$

where L_A and L_B are the LER's for the individual crops, Y_A and Y_B are the individual crop yields in intercropping and S_A and S_B are their yields as sole crops (Mead and Wiley, 1979).

The main advantages of LER according to Mead and Wiley (1979) are:

- it puts crops on a standardised basis so that they can be added to form 'combined' yields. This makes comparison between different situations and different crop combinations easy.

- comparison between individual LERs can indicate competitive effects (Willey, 1979).

- total LER can be taken as a measure of the relative yield advantage.

The main setback of LER is that because it is defined as a ratio, large values of LER can be obtained not only because of large yields or intercropping but also because of small yields in corresponding sole crops (Mead and Willey, 1979).

Another problem of LER is that it varies depending on which value of sole crop yield is used - the best sole crop yield, the average sole crop yield, etc. (Oyejola and Mead, 1982).

2.8.3 Monetary advantage

This was introduced by Willey and Rao (1978) and written as

$$\text{Monetary Advantage} = \text{Gross Returns} \ \frac{\text{LER}-1}{\text{LER}} .$$

The above outlined methods are only useful for intercropping situations. When other cropping systems are involved, the net monetary benefit is the best criteria (Perin et al, 1979). This is obtained by substracting the variable cost from the gross returns. Net benefit comparisons have been used successfully (Perin et al, 1979; Reddy et al, 1982).

MATERIALS AND METHODS

MATERIALS AND METHODS

1. LOCATION

The experiment was carried out at the ICRISAT Research Center in a watershed (RW3C) during the rainy (kharif) and postrainy (rabi) seasons of June 1982 to January 1983. The farm is situated 25 km northwest of Hyderabad town at a geographical bearing of 18°N and 17°E and an altitude of 500 meters above the sea level.

2. CLIMATE

The rainfall season extends from June to September and the postrainy season extends upto January. The average maximum and minimum temperatures were 30°C and 25°C respectively. During the crop growing season of this experiment, a total of 527 mm rainfall was received.

The meteorological data is shown in Fig 1 and Appendix 1.

3. SOILS

The experimental area was a medium deep red soil falling under the classification of Alfisols in the 7th approximation of USDA soil nomenclature. The physical and chemical properties of the soils are shown in Table 1a and 1b.

Table 1a. Physical properties of the soil in the experimental field

Depth (cm)	Gravel (%)	Mechanical composition (%)			
		Coarse sand	Fine sand	Silt	Clay
0-15	8.6	45.9	35.3	5.2	13.3
15-30	49.0	40.0	27.0	5.8	27.3

Fig. 1. Meteorological data collected at ICRISAT Center meteorological station from July 1982 to January 1983

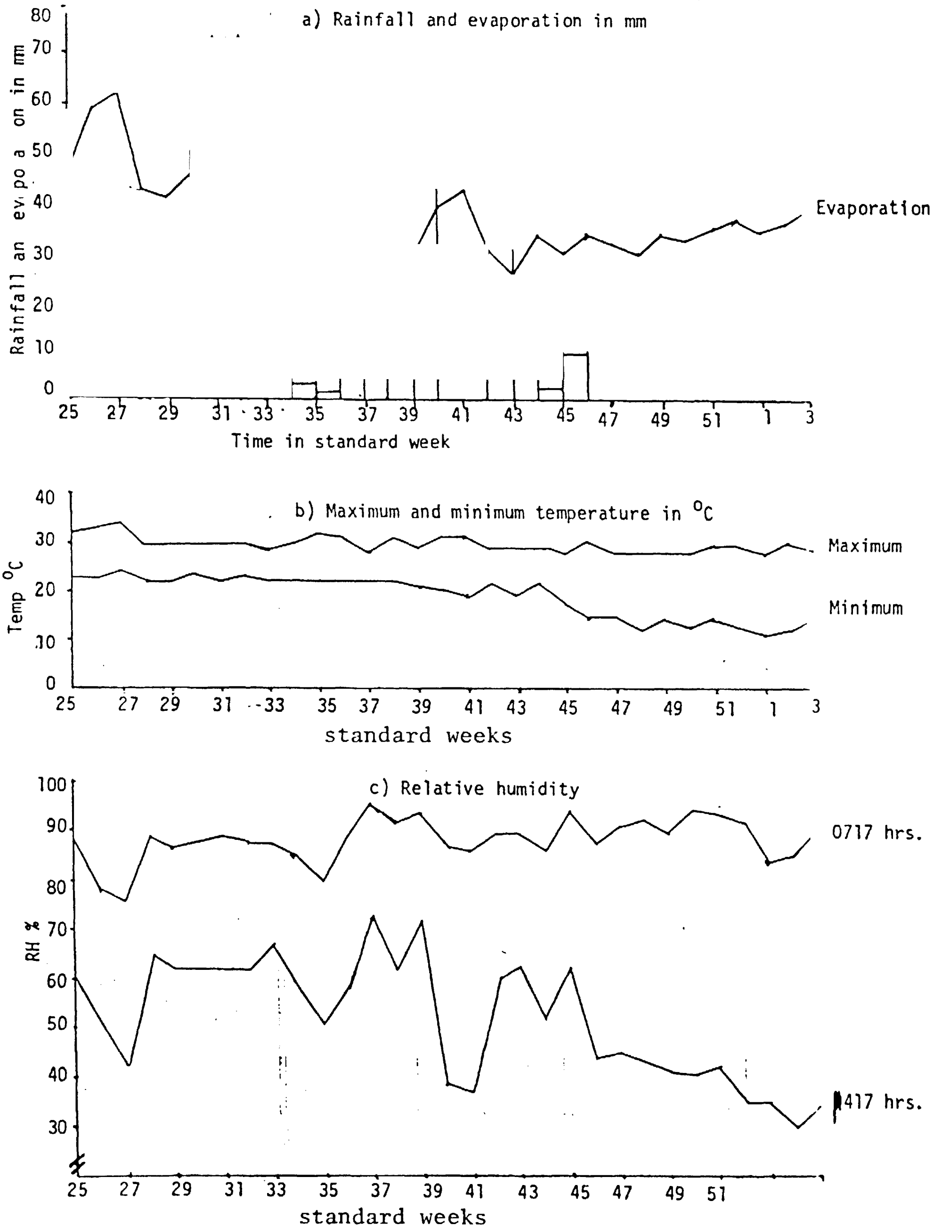


Table 1b. Chemical properties of the soil in the experimental field

Depth (cm)	pH	EC m mho/cm	Organic carbon (%)	Available N (%)	Available P (%) ppm
0-15	5.93	0.15	0.69	1.19	4.5
15-30	5.53	0.15	0.32	0.55	1.0
30+	5.84	0.15	0.35	0.61	1.0

The available N was determined by Alkaline Permanganate method, while available P was estimated by Olsen's Method.

PREVIOUS CROPPING HISTORY

The crops and fertilizer used in this field during the past four seasons are shown in Table 2 below:

Table 2. Previous cropping history of the experimental field

Year	Cropping system	Types of fertilizer used	Rate of fertilizer used or applied (kg/ha)
1978	Sorghum/pigeonpea	DAP (18-46-0)	100
	Sorghum	Urea (56% N)	120
1979	Sorghum/pigeonpea	Gromor (28-28-0)	100
	Sorghum	Urea	75
1980	Sorghum	Gromor	100
		Urea	75
	Ratoon sorghum	"	75
1981	Pearl millet/pigeonpea	Gromor	100
	Pearl millet	Urea	75

3.5 EXPERIMENTAL DETAILS

3.5.1 DESIGN

Split plot design with two fertility levels as the main plots and 15 Cropping Systems as the subplots were replicated thrice. The gross plot size was 210 m^2 comprising of four broadbeds of 1.5 m width, i.e. from centre of furrow to the centre of the next, but the effective planting width was 90 cm. The plot length was 35 metres. The net harvested plot size was 90 m^2 : two broadbeds of 30 m length. The total experimental area was about 2 ha. The field layout and the individual plot pattern are shown in Fig 2 and 3 respectively.

TREATMENTS

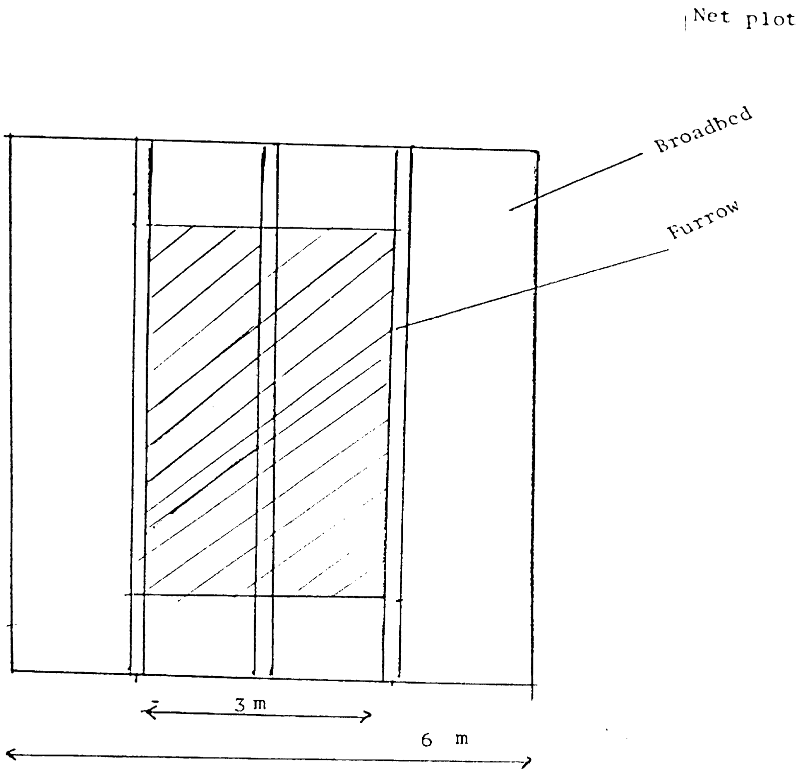
Main plot treatments : Fertility levels - 2

	N-P-K	Notation used
1. High fertility	80-22-0	HF
2. Low fertility	20-12-0	LF

Subplot treatments: Cropping Systems - 15

1.	Sorghum/pigeonpea intercrop	(2:1)	T1
2.	Pearl millet/Pigeonpea intercrop	(2:1)	T2
3.	Pearl millet/Groundnut intercrop	(1:3)	T3
4.	Pigeonpea/groundnut intercrop	(1:4)	T4
5.	Pearl millet/castor intercrop	(2:2)	T5
6.	Mungbean/castor intercrop	(2:2)	T6
7.	Sorghum/cowpea intercrop	(2:2)	T7
8.	Mungbean + relay castor		T8
9.	Millet + sequential horsegram		T9
10.	Millet + sequential cowpea		T10
11.	Sorghum + ratoon sorghum		T11
12.	Sole pigeonpea		T12
13.	Sole groundnut		T13
14.	Sole cowpea		T14
15.	Sole castor		T15

Fig. 2 : Individual plot pattern



CROPS AND CROP VARIETIES

Crops that are drought-tolerant and are normally grown in the red soils of the rainfed semi-arid tropics were chosen for this experiment. Four of ICRISAT mandate crops were selected. These are sorghum, pearl millet, groundnut and pigeonpea. The other crops used were cowpea, greengram, castor and horsegram. Improved hybrids or varieties that have been recommended for cultivation were used. Local variety of horsegram was used as no improved varieties were available. The hybrids or varieties used are shown in Table 3.

Table 3.

Crop	Variety	Approx. days to maturity
Sorghum (Sorghum bicolor)	CSH-6	105
Pearl millet (Pennisetum americanum)	BK 560	80
Pigeonpea (Cajanus cajan)	ICP 1	180
Groundnut (Arachis hypogaea)	Robut 33-1	110
Cowpea (Vigna unguiculata)	C 152 *EC 6216	60
Mungbean (Vigna radiata)	S 8	60
Castor (Ricinus communis)	Aruna	180
Horsegram (Dolichos uniflorus)	Local	70

*Cowpea variety used in the sequential cropping

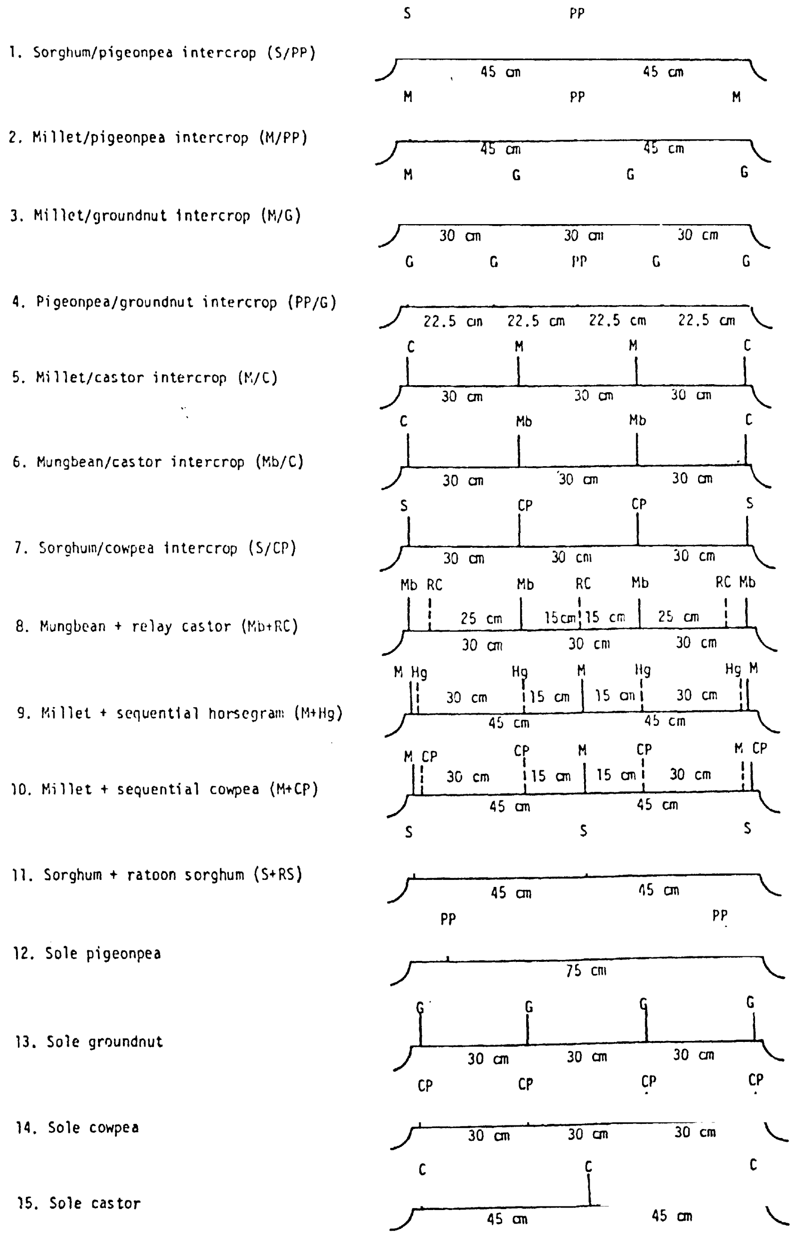
3. SPACING AND POPULATION

Optimum sole crop populations were maintained both in sole and intercrops. In the intercrop, it was achieved by adjusting the intrarow spacing. The only exceptions were in millet/groundnut intercrop where a 25:75 replacement series was used; in cowpea and mungbean intercrops where 50% of the sole crop population was maintained in the intercrops. The spacings used are shown in Table, and the row arrangement on the broadbed is shown in Fig 4.

Table 4. Spacing and intended populations maintained for the different sole and intercrop treatments

Crop	Inter-row spacing (cm)	Intra-row spacing (cm)		Population in '000 plants/ha	
		SOLE	INTERCROP	Sole	Intercrop
Sorghum	45	11	7	180	180
Pearl millet	45	9	6	222	222
Pigeonpea	75	22	11	60	60
Castor	45	33	22	100	100
Groundnut	30	8	8	333	333
Cowpea	30	6	6	555	250
Mungbean	30	6	6	555	250
Horsegram	30	6	-	555	-

Fig 4 Row arrangement and spacing on the broadbed (dotted lines represent rabi crops)



3.5.6 FERTILIZER

A basal dose of 80 kg/ha diammonium phosphate (18-20-0) was applied at the time of sowing to the high fertility treatments. This provided 14 kg N and 16 kg P/ha respectively. At 20 days after emergence a starter dose of 75 kg/ha of gromor fertilizer (20-12-0) wasaapplied to all plots (both and high fertility treatments). This provided 20 kg N and 12 kg P/ha respectively. The cereal crops and castor and castor in the high treatment were later on top dressed with urea (46% N) at the rate of 100 kg/ha. The overall fertilizer application for the different cropping systems was :

Low fertility	20 kg/ha N and 9 kg/ha P
High fertility	80 kg/ha N for all cereals and castor 34 kg/ha N for all legumes 25 kg/ha P to all crops

In case of relay and sequential crops, 80 kg/ha of Diammonium phosphate was applied at the time of sowing to the high fertility plots, and relay castor was later on top dressed wtih 100 kg/ha urea. Ratoon sorghum in the high fertility treatments was dressed soon after harvest, with 90 kg/ha of urea.

FIELD OPERATIONS

1. Land preparation:

Ploughing was done on 21st June 1982 using a tropicultor. After ploughing, bed formation and levelling followed. For the sequential crops, the concerned plots were ploughed soon after the harvest of pearl millet.

2. Sowing:

Sowing of all crops was done using a planter mounted on a tropicultor, on 24th and 25th June. Both seeds and fertilizer were drilled at the same time with the fertilizer shoe arranged in such a way that the fertilizer was placed 3 cm deeper than the seed and 5 cm to the side of the seed furrow. By putting different seeds in the appropriate seed box, intercrops were sown without much problem. Different seed plates were used to give the required spacing and population. No thinning was done afterwards. Some plots of millet and sorghum were gap-filled due to some poor germination.

3. Weeding:

An interrow cultivation by the tropicultor was done 15 days after emergence. This was followed by 2 handweedings at 25 days and 50 days after emergence respectively. The sole cowpea and sole millet plots were not weeded for the 2nd time because there were less weeds and the crops were weeded, so as to reduce weed competition for the relay castor that was to follow. Both relay and sequential crops were weeded once at 35 days after emergence.

3.6.4. Topdressing :

A starter dose of 75 kg/ha gromor fertilizer (28-12-0) was given at 20 days after emergence to all crops due to an initial poor growth. Later, at 27 days after emergence the cereals and castor in high fertility treat-ents were topdressed with 100 kg/ha urea. This brought the overall amount of nitrogen applied high fertility treatments to 80 kg/ha.

3.6.5 Relay planting :

The relay castor was sown in between mungbean rows, 15 days before the mungbean harvest, using a Nikart mounted planter (Nikart has more clearance than tropicultor). Fertilizer was applied at the same time. There was some damage to the mungbean plants while sowing.

3.6.6 Sequential plant :

The sequential cowpea and horsegram were planted 7 days after the pearl millet harvest with due land preparation.

3.6.7 Ratooning :

The sorghum crop was harvested at physiological maturity to allow more time for the ratoon crop. The stubbles were cut 3 cm above the ground. Urea (90 kg/ha) was applied at the high fertility treatments.

3.6.8 Plant protection :

Plant protection for both pests and diseases were carried out when the level of infestation was above the economic level of damage.

Crop	Pest	
Cowpea	Aphids (Aphis craccivora) Stem fly (Melangromyza phaseoli)	Rogor 30 EC @ 0.75 l/ha
Castor	Castor semilooper (Achara janata)	Thiodan 35 EC @ 1.5 l/ha
Groundnut	Jassids (Empoassa kevi) Thrips (Frankliniela schuttzei), (Scirtothrips dorsalis)	Rogor 30 EC @ 0.75 l/ha Thiodan 35 EC@ 1.5 l/ha
Pigeonpea	Pod borer (Heliothis armigera)	Thiodan 35 EC @ 1.5 l/ha
Ratoon sorghum	Shoot bug (Perigrinus maidis)	Thiodan 35 EC@ 1.5 l/ha Metasystox @ 0.5 l/ha

9. Harvesting and threshing:

The various crops were harvested as they matured, and the time taken is shown in Fig 5. The harvested material was sundried and then threshed manually.

OBSERVATIONS RECORDED

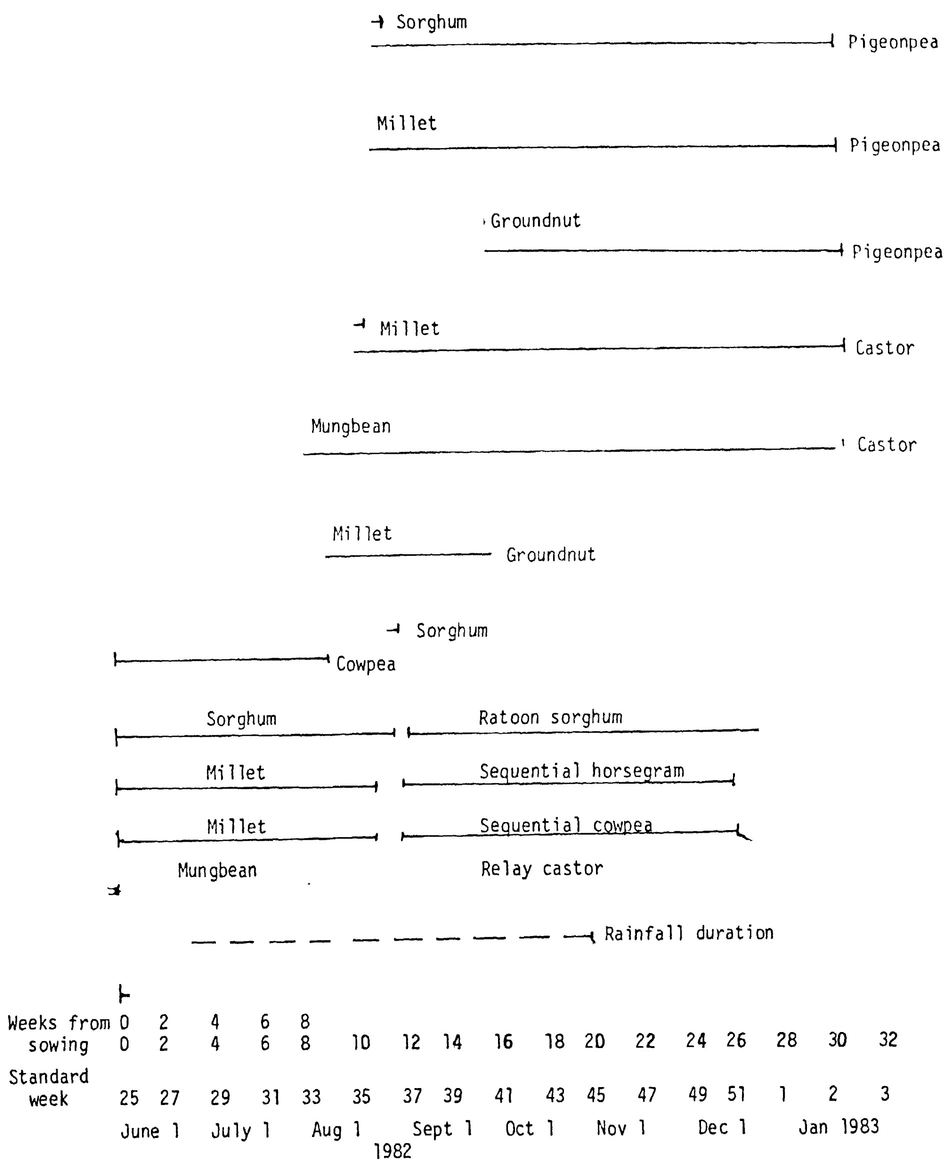
1. Days to emergence:

This was counted from the date of sowing till 90% of the seedlings had emerged.

2. Light interception:

A 'T' meter developed by Williams and Austin (1977) at the Plant Breeding Institute, Cambridge was used. It consists of horizontal bar bearing photocells for insertion into the crop, a control mounted on top of the crop and a counter. The photo electric cells

Fig. ,5. Crop duration in weeks.



are mounted beneath filter to cut out long wave radiation. Diffusers titled over each cell reduce errors due to bearing and sky conditions. It gives a digital display of percentage transmission of photosynthetically active radiation (PAR).

The horizontal bar was inserted under the crop in such a way as to cover all the crops on the broadbed. Light readings were taken at four locations per plot (only on the two inner beds comprising the net plot). The average light transmission per plot was calculated. From this, the percentage light interception was calculated from the formula:

% light interception = 100 - % light transmission.

3. Days to 50% flowering:

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

4. Plant height:

Plant height was measured from the ground to the tip of the plant (earhead in case of sorghum and millet) at the time of harvest. A 2 meter scale was used and the plant height measured to the nearest centimeter.

5. Plant population:

The number of plants in the net plot were counted at harvest time, then converted to plants per hectare.

6. Yield and yield components:

At harvest time, 10 plants in each crop were randomly sampled from the plot and analysed for yield components.

After harvest of the net plot, the grain yield, dry straw yield and total dry matter per plot were recorded and then converted to yield per ha. This was recorded as kg/ha and to the nearest kg.

Yield and yield components taken for each crop were:

1. Sorghum and millet

   a. The weight per earhead in grams
   b. Number of grains per earhead
   c. 1000 seed weight in grams
   d. Grain yield in kg/ha
   e. Straw yield in kg/ha
   f. Total dry matter in kg/ha

2. Cowpea, Mungbean and pigeonpea

   a. No. of pods/plant
   b. No. of seeds/pod
   c. 100 seed weight in grams
   d. Grain yield in kg/ha
   e. Straw yield in kg/ha
   f. Total dry matter in kg/ha

3. Groundnut

   a. No. of pods/plant
   b. No. of seeds/pod
   c. 100 seed weight in grams
   d. Pod yield in kg/ha
   e. Hulm yield in kg/ha
   f. Total dry matter in kg/ha

4. Castor

   a. No. of racemes/plant
   b. No. of capsules/raceme
   c. 100 seed weight in grams

d. Yield of capsules in kg/ha
e. Yield of beans in kg/ha
f. Straw yield in kg/ha
g. Total dry matter in kg/ha

7. Land Equivalent Ratio (LER):

This was calculated using the equation given by Mead and Willey (1979).

$$LER = \frac{YA}{SA} + \frac{YB}{SB}$$ Where,

YA and YB are the individual crop yields in the intercropping and SA and SB are the yields of the sole crops. Sole crop yield in each main plot was used to calculate LER for all the intercrops in that particular main plot.

8. Economic Calculations:

8.1 Variable cost

The variable cost for each cropping system was calculated. All the costs of inputs were provided by ICRISAT Economics Program. The variable costs included:

Material inputs - seeds, fertilizer and pesticides

Labour - land preparation, sowing, fertilizer application, weeding, harvesting and threshing

The variable cost for each cropping system in Rs/ha is shown in Appendix VII.

8.2 Gross and net returns

Gross returns were calculated by multiplying the economic yield by the market price one month after harvest (Perin *et al*, 1979). Local market prices were used and the prices provided by ICRISAT's Economic Program is shown in Appendix VI.

Net returns = gross returns - variable cost (Perin *et al*, 1979)

9. Statistical analysis:

Analysis of variance for a split plot design was used (Fisher and Yates, 1948). The analysis was carried out for light interception, days to 50% flowering, plant height, yield and yield components, land equivalent ratios and the net returns.

RESULTS

RESULTS

The results of the observations that were made are presented below after analysis of variance was carried out. To make the tables more clear without inclusion of so many figures, some short from method was used to present the SE (interaction). The SE interaction throughout is represented by SE (C x F). The SE for comparing different cropping systems at the same fertility level is presented as SE_1, while SE for comparing the two fertility levels at the same cropping system as SE_2.

CD at 5% significance level is given in brackets beside the SE for only the statistically significant effects.

4.1 The number of days to emergence and plant population at the time of harvest are shown in Appendix II and III respectively.

4.2 Days to 50% flowering

This was counted from the date of emergence till the time 50% of the plants in the net plot had flowered in the different treatments.

Sorghum reached 50% flowering at 56 and 60 days after emergence in high and low fertility respectively. The two means were statistically significant (SE ± 0.22 days). The treatment and interaction effects had no significant effect on the date of flowering (Table 6).

Millet attained 50% flowering at 45 and 50 days in high and low fertility respectively (SE ± 0.5). Intercropping millet with pigeonpea and castor increased the time to 50% flowering (SE ± 0.72). The interaction effects were not significant (Table 7).

In case of pigeonpea, high fertility treatments, reached 50% flowering at 126 days from emergence while those under low fertility, flowered at 131 days from emergence (SE ± 0.5). Component crops in the intercrop increased the time to 50% flowering significantly (SE±0.8). Groundnut had the greatest effect (6 days increase), while sorghum had the least effect (Table 8).

Groundnut days to 50% flowering were only affected by the fertility level, being 28 and 31 days for high and low fertility respectively (SE±0.11). The component crop effects and interaction effects had no effect on the time to 50% flowering (Table 9).

Table 6. Sorghum - Days to 50% flowering

	Days to 50% flowering			
	HF	LF	Mean	SE of Mean
Sorghum	55	60	57	± 1.7
Sorghum (cowpea)	56	61	58	
Sorghum (pigeonpea)	55	57	56	
Mean	55	59		
SE of mean	± 0.22 (0.96)			
SE_1 (C x F)	± 2.3			
SE_2 (F x C)	± 1.94			
CV %	6.0			

Table 7. Millet - Days to 50% flowering

	Days to 50% flowering			
	HF	LF	Mean	SE of M
Millet (pigeonpea)	45	49	47	± 0.72 (1.53)
Millet (groundnut)	47	51	49	
Millet (castor)	45	50	48	
Millet (sole)	44	48	46	
Mean	45	50		
SE of Mean	± 0.52 (2.24)			
SE_1 (C x F)	± 1.02 (2.16)			
SE_2 (C x F)	± 1.05 (2.79)			
CV %	5.5			

Table 8. Pigeonpea - Days to 50% flowering

	Days to 50% flowering			
	HF	LF	Mean	SE of M
Pigeonpea	125	130	127	$\pm$ 0.8
Pigeonpea (sorghum)	125	129	127	(1.75)
Pigeonpea (millet)	126	131	129	
Pigeonpea (groundnut)	130	136	133	
Mean	126	131		
SE of mean	$\pm$ 0.5 (2.2)			
SE_1 (C x F)	$\pm$ 1.13			
SE_2 (C x F)	$\pm$ 1.1			
CV %	1.08			

Table 9. Groundnut - Days to 50% flowering

	Days to 50% flowering			
	HF	LF	Mean	SE of M
Groundnut	28.3	29.3	29	$\pm$ 0.84
Groundnut (millet)	29.0	30.0	30	
Groundnut (pigeonpea)	28.3	31.0	30	
Mean	28.5	30.1		
SE of mean	$\pm$ 0.11 (0.48)			
SE1 (C x F)	$\pm$ 1.2			
SE_2 (F x C)	$\pm$ 0.97			
CV %	4.95			

Both in cowpea and mungbean, the days to 50% flowering were not affected by either the fertility level nor by intercropping. Mungbean flowered at 32 days and cowpea at 45 days after emergence respectively (Table 10).

In case of castor, 50% flowering was attained at 58 days and 64 days after emergence for high and low fertility respectively (SE±0.59). Intercropping castor with millet and increased the time to 50% flowering significantly (SE±1.18). The interaction effects between cropping system and fertilizer had no effect on time taken to reach 50% flowering (Table 11).

4.3 Light interception

Light interception was measured at 15 day intervals using a T-meter, and the percentage light interception of photosynthetically active radiation (PAR) for each of the different cropping systems is shown in Table 12. For simplicity reasons, the different cropping systems were grouped into five groups, namely sorghum, millet, pigeonpea, groundnut and castor based cropping systems and are shown in Fig 6, 7, 8, 9 and 10.

The first light readings were taken 35 days after emergence. At that time, the amount intercepted was significantly different for the different cropping systems (SE ± 10.23) and

Table 10. Mungbean - Days to 50% flowering

	Days to 50% flowering			
	HF	LF	Mean	SE of Mean
Mungbean	32.7	31.7	32.12	± 0.47
Mungbean (Castor)	31.3	32.3	31.8	
Mean	32	32		
SE of mean	± 0.5			
SE_1 (C x F)	± 0.67			
SE_2 (C x F)	± 0.68			
CV %	2.55			

Table 11. Castor - Days to 50% flowering

	Days to 50% flowering			
	HF	LF	Mean	SE of Mean
Castor	56	63.3	59.7	± 1.18 (2.73)
Castor (millet)	62	67.7	65.0	
Castor (mungbean)	56	62.7	58.8	
Mean	58	64.2		
SE of mean	± 0.59 (2.5)			
SE1(C x F)	± 1.67			
SE_2(C x F)	± 1.48			
CV %	3.34			

Table 12. LIGHT INTERCEPTION (%)

Cropping System	Days from emergence																			
	35		50		65		80		95		110		125		140		155		165	
	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
Sorghum/pigeonpea	19	25	37	56	35	39	42	49	52	60	55	66	63	71	62	74	62	71	59	67
Millet/pigeonpea	27	58	58	82	37	39	24	46	22	52	33	57	66	74	59	67	52	60	47	56
Groundnut/pigeonpea	25	36	45	70	36	42	47	53	66	74	58	73	36	67	32	66	30	66	25	60
Millet/Castor	32	67	67	85	44	51	27	40	25	28	27	31	27	25	24	25	20	24		
Mungbean/castor	24	58	48	76	38	44	31	46	79	51	32	54	30	55	29	53	28	48		
Millet/Groundnut	30	36	71	73	48	37	48	42	48	45	42	43								
Sorghum/cowpea	49	61	69	81	41	49	37	45	36	44										
Sole sorghum	16	31	31	58	33	40	31	35	27	32										
Sole millet	40	76	57	84	46	53														
Sole cowpea	62	69	67	77	18	24														
Sole mungbean	40	44	51	63	23	29														
Sole pigeonpea	22	17	34	31	31	29	52	51	82	78	88	82	91	90	82	82	74	70	68	68
Sole castor	17	40	31	72	35	42	46	42	59	46	55	46	53	43	50	42	48	40		
Sole groundnut	28	30	57	54	36	36	40	42	54	51	48	49								

L = Low Fertility H = High Fertility

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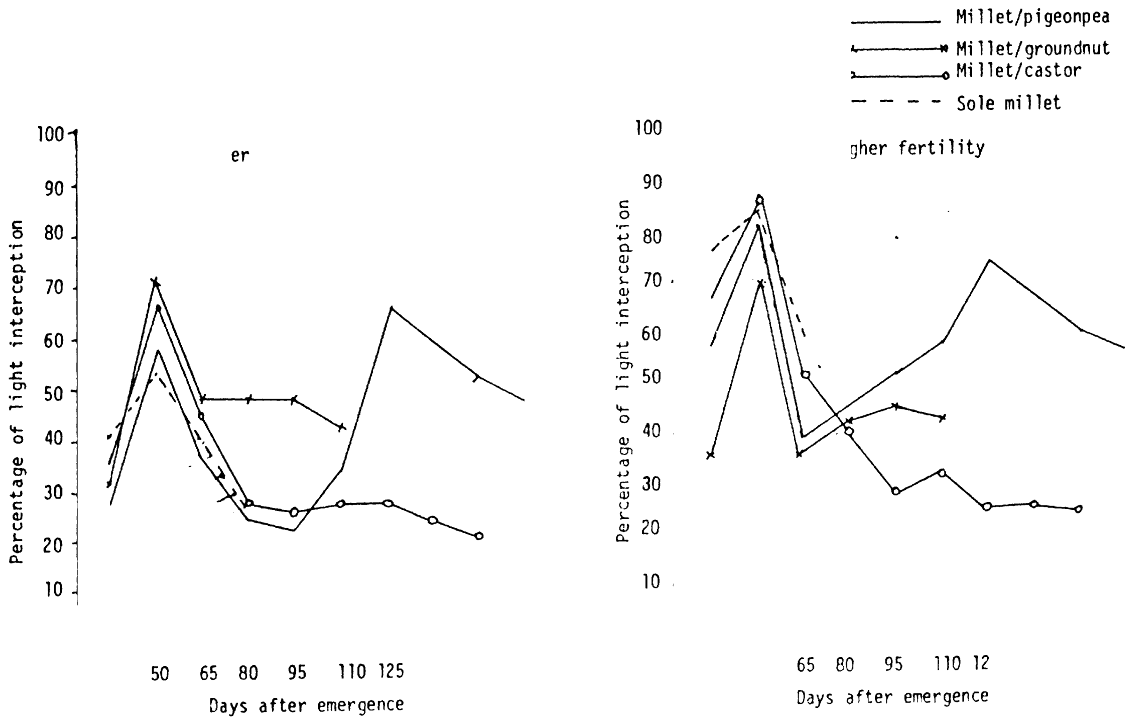

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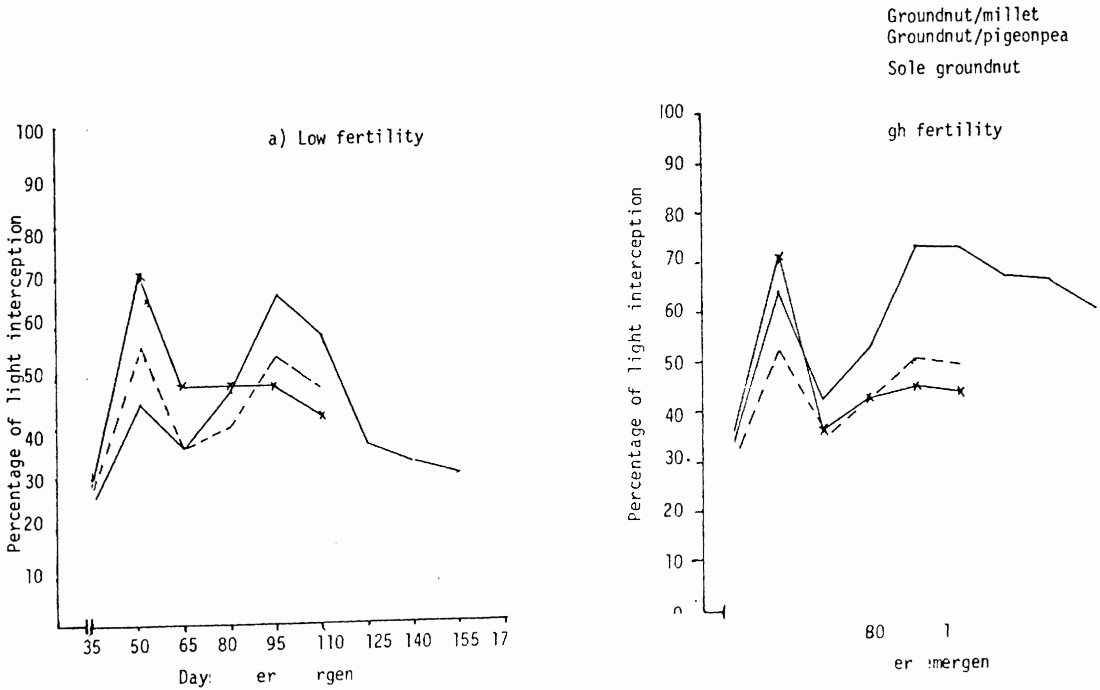
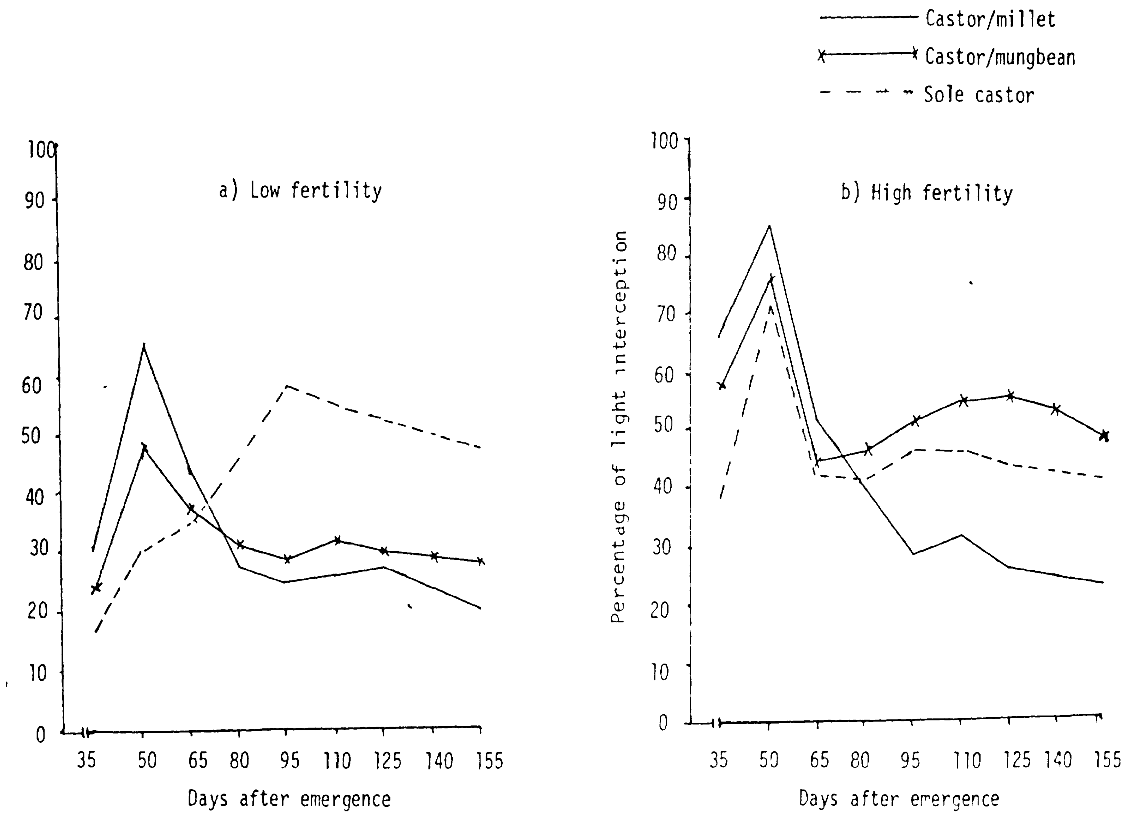


Fig. 9. Light interception in castor based cropping systems.



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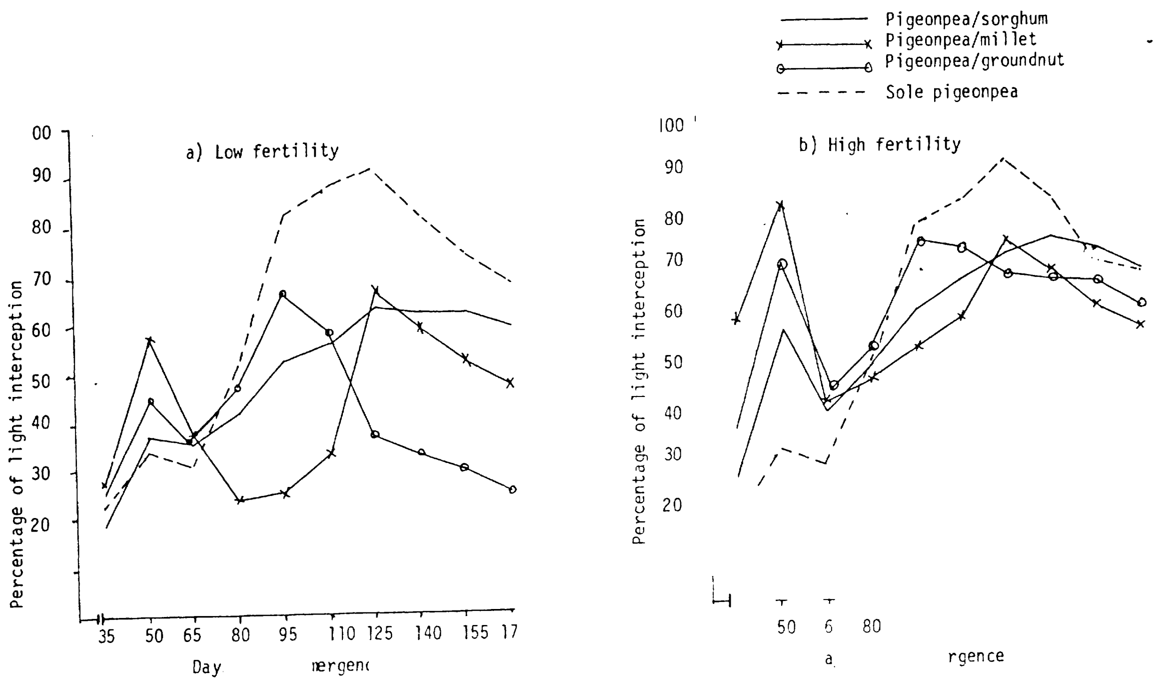


fertility levels (SE $\pm$ 10.07), indicating the nature of canopy cover. Sole millet was intercepting the maximum light (67%) under high fertility treatments, and sole pigeonpea the minimum (17%). Under low fertilizer situation, sole cowpea was intercepting maximum light (67%) and sole sorghum the minimum (16%).

Among the different intercropping systems, sorghum/cowpea and millet/castor were intercepting maximum light under high fertility situation, mainly due to the rapid growth of cowpea and castor. Sorghum/cowpea was the only intercrop intercepting more than 49% light under low fertility situation.

Where short duration crops were involved, the light interception rose steadily reaching the peak at 50 days after emergence with millet/pigeonpea, sorghum/cowpea, millet/castor sole millet and sole cowpea, intercepting over 80% light under high fertility and 50% under low fertility treatments.

At 65 days after emergence, there was a sharp decline in light interception for all the cropping systems due to two main reasons:

a. The crops suffered from severe moisture stress for about two weeks resulting in severe wilting. This is standard week 34 and 35 (2-16th September) shown in Fig 1.

b. Some early maturing crops such as cowpea and mungbean were already harvested, and other like millet were senescing, hence poor canopy and the low light interception.

After the harvest of one of the component crops, the amount of light interception declined, and only picked up in case of the long duration crops like pigeonpea (Fig 6). In some systems like millet/castor, where millet was intercepting more light, light interception continued to decline after its harvest, even though castor is a long duration crop (Fig 7 and 9).

At harvest, most of the cropping systems were intercepting about 20-50% of incoming light, except pigeonpea (in all pigeonpea-based cropping systems) which was still intercepting more than 60% of incoming light.

The amount of light intercepted by some cropping systems were affected by some cultural factors:

1. Poor crop stand, as in the case of sorghum based cropping systems and millet-intercropping systems, where both sorghum and millet germination was very low and hence the crop canopy was not well developed.

2. Disease and pests. In case of cowpea, it was attacked by stem fly (Meladogromyza spp.) which destroyed most plants, thus reducing the crop plant population. In groundnut, it was attacked by tikka leafspot (C. arachidicola), which destroyed most leaves thus damaging the crop canopy.

4.4. Plant Height

The plant height at harvest time was generally more affected by the fertility level than the cropping systems.

The sorghum plant height was not affected significantly by either the fertility level, or the component crop in the intercrop and had a mean height of 130 cm (Table 13).

Sole millet had a mean height of 153 cm, millet in castor intercrop 135 cm, in groundnut intercrop 100 cm, and in pigeonpea intercrop 148 cm (SE $\pm$ 9.4 cm). These different plant height means were statistically different. The effects of fertility level was not significant (Table 14).

In case of pigeonpea, plant height was greatly influenced by fertilizer effects, 140 cm and 120 cm (SE$\pm$ 3.4 cm) for high and low fertility situations respectively. There was no significant reduction in plant height of pigeonpea in the different intercropping systems (Table 15).

Table 13. Sorghum plant height at final harvest time

	Plant height in cm		Mean	SE of mean
	HF	LF		
Sole sorghum	127.7	126.3	127	+ 6.07
Sorghum (Pigeonpea)	128.6	119.7	124	
Sorghum (Cowpea)	142.0	122.0	132	
Mean	132.8	128.7		
SE of mean	+ 2.42			

SE_1 for comparing different cropping systems at same fertility level ± 8.5
SE_2 for comparing different fertility level for the same cropping system ± 7.4
CV% 8.23

Table 14. Millet plant height at final harvest time

	Plant height in cm		Mean	SE of mean
	HF	LF		
Millet (Pigeonpea)	140	148	144	± 9.4(20)
Millet (Groundnut)	110	100	105	
Millet (Castor)	132	135	133	
Millet (sole)	160	153	157	
Mean	135.5	134		
SE ± of mean	±1.3			

SE_1 for comparing different cropping systems at same fertility level ± 13.35
SE_2 for comparing different fertility levels for same or different cropping system ± 11.99
CV % 7.15

Table 15. Pigeonpea plant height at final harvest time

	Plant height in cm HF	LF	Mean	SE of mean
Pigeonpea (Sole)	144	146	145	± 11.28
Pigeonpea (sorghum)	153	119	136	
Pigeonpea (millet)	134	112	123	
Pigeonpea (Groundnut)	128	104	116	
Mean	140	120		
SE Of mean	± 3.44 (14.8)			

SE_1 for comparing different cropping systems at same fertility level ± 15.9
SE_2 for comparing different fertility level at same or different cropping system ± 14.2
CV % 10.75

Table 16. Castor plant height at final harvest time

	Plant height in cm HF	LF	Mean	SE of mean
Castor (sole)	72	71	72	± 9.1
Castor (millet)	79	55	67	
Castor (mungbean)	89	71	80	
Mean	80	66		
SE of mean	± 1.3 (5.6)			
SE_1				± 12.9
SE 2				± 10.7
CV %	12.7			

Castor attained a height of 80 cm and 66 cm (SE±1.3 cm) for high and low fertility situations respectively. The millet and mungbean intercrops had no significant effect on plant height (Table 16). Cowpea plant height was not affected by either fertility level nor the sorghum intercrop, while mungbean plant height was comparatively reduced at low fertility treatment.

4.5 Yield and yield components

4.5.1 Sorghum

The sorghum panicle weight, 23.97 gm and 14.54 gm (SE ± 2.7 gm) for high and low fertility treatments respectively was significantly different. The component crop in the intercropping systems and their interaction with fertilizer did not affect the panicle weight significantly.

The number of grains per panicle was also not influenced by either the fertility level or the component crop or their interaction and the mean was 1194 grains per head. However, the 1000 grain weight was statistically different. It was 18.38 gm for high fertility treatments and 15.39 gm for low fertility treatments (SE ± 0.64 gm). Intercropping sorghum with other crops did not reduce significantly the 1000 grain weight (Table 17). The sorghum yield was quite low throughout the experiment due to poor crop stand. The mean grain yield was 1659 kg/ha for high fertility treatments and 742 kg/ha for low fertility treatments (SE ± 93.5 kg).

Table 17. Yield components of sorghum

	Head weight (gm)				No. of grains/head				1000 grain weight (g)			
	HF	LF	Mean	SE of mean	HF	LF	MEAN	SE of mean	HF	LF	Mean	SE of mean
Sorghum	22.57	17.13	19.85		1304	1156	1230		17.33	15.01	16.17	
Sorghum (cowpea)	22.36	12.79	17.58	± 3.11	1148	795	972	± 193.4	19.44	15.84	17.64	± 0.55
Sorghum (Pigeonpea)	27.00	13.70	20.35		1490	899	1194		18.39	15.32	16.85	
Mean	23.97	14.54			1314	950			18.38	15.39		
SE of mean	± 2.7 (11.69)				± 206				± 0.64 (2.79)			
SE_1 (C x F)	± 4.4				± 273.6				± 0.77			
SE_2 (C x F)	± 4.5				± 380				± 0.9			
CV %	27.9				29.5				5.64			

SE_1 = SE for comparing different cropping systems at the same fertility level

SE_2 = SE for comparing different fertility levels for the same or different cropping systems

Table B. Sorghum grain yield, fodder yield and total dry matter in kg/ha

	Grain yield (kg/ha)				Fodder yield (kg/ha)				Total dry matter (kg/ha)			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of M
Sorghum	1806	767	1287	±121	2196	1050	1623	±291	4002	2319	3160	±389
Sorghum (cowpea)	1618	833	1225		1531	1200	1365		3149	2532	2841	
Sorghum (pigeonpea)	1554	626	1090		863	633	748		2417	1732	2088	
Mean	1659	742	1200		1530	961	1246		3189	2203	2696	
SE of mean	± 93.5				±105				± 191			
SE_1 (C x F)	± 173				± 411				± 551			
SE2 (C x F)	± 169				± 351				± 488			
CV %	16.5				17.84				20			

SE_1 = SE for comparing different cropping systems at the same fertility level

SE_2 = SE for comparing different fertility levels for the same or different cropping systems

Intercropping sorghum with either pigeonpea or cowpea did not reduce the yield significantly. The sorghum in sorghum/cowpea intercrop under low fertility situation gave more yield than the sole crop yield. The interaction effects between fertility level and cropping system were not significant.

The amount of fodder harvested was relatively reduced by the intercrop. Sole sorghum gave a mean yield of 1623 kg/ha, intercrop sorghum in sorghum/cowpea, gave 1365 kg/ha and intercrop sorghum in sorghum/pigeonpea yielded 748 kg/ha (SE ± 291kg). The total dry matter at harvest was affected by fertility levels only giving a mean of 3183 kg/ha under high fertility situations and 2203 kg/ha under low fertility situations (SE ± 191 kg/ha). The intercrops had no significant effects nor the interaction effects between cropping system and the fertility level (Table 24).

4.2.5. Millet

The earhead weight of millet was affected by the fertilizer application. Main effects being 12.4 gm and 8.3 gm for high and low fertility treatments respectively (SE ± 2.1gm) and by the intercrop giving a mean weight of 14.2 gm, 7.03 gm and 8.81 gm when intercropped with pigeonpea, groundnut, and castor respectively (SE ± 3.2). Sole millet had an earhead weight of 11.48gm. The interaction effects were also significant at 5% level (Table 25).

The number of grains per earhead were also affected by the fertilizer. Main effects being 1998 grains per earhead under high fertility situations and 1208 grains per panicle under low fertility situations (SE ± 363 grains). Sole millet had a mean of 1768 grains per earhead, and intercropped millet had 1500, 1066 and 2074 grains per panicle when intercropped with castor, groundnut and pigeonpea respectively (SE ± 465 grains). The 1000 grain weight was not affected by either the fertility level nor by the component crop (Table 18).

The grain yield was affected by both the fertility level, and the intercrop. The fertilizer main effect means were 1056 kg/ha and 577 kg/ha under high and low fertility respectively (SE ± 44 kg/ha). Sole millet gave a mean yield of 1159 kg/ha, in pigeonpea intercrop 715 kg/ha, in groundnut intercrop 256 kg/ha and in castor intercrop 354 kg/ha (SE ± 74 kg/ha). The interaction effects between fertility level and cropping system were also significant (Table 25).

Dry fodder yield was affected similarly to grain yield. The mean fodder yield at high fertility situation was 3300 kg/ha and at low fertility 2400 kg/ha (SE ± 365 kg/ha). Sole millet yielded 3742 kg/ha, while intercropped millet had a mean fodder production of 2322, 1955 and 3380 kg/ha when intercropped with castor, groundnut and pigeonpea respectively (SE ± 329 kg/ha). The interaction effects were not significant.

Table 19. Millet yield components

	Panicle weight (g)				No.of grains/panicle				100 seed weight			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Millet/pigeonpea	20.0	8.43	14.22	± 3.2	3048	1101	2074		6.4	7.59	6.99	± 0.53
Millet/Groundnut	8.56	5.5	7.03		1285	847	1066	± 465	6.8	6.73	6.76	
Millet/Castor	9.63	8.0	8.81		1831	1170	1500		5.4	7.12	6.24	
Millet	11.5	11.38	11.48		1825	1712	1768		6.4	6.68	6.54	
Mean	12.42	8.33	10.37		1998	1208	1603		6.2	7.03	6.64	
SE of mean	±2.14				±363				±0.33			
SE_1 (C x F)	±4.55				±658				±0.74			
SE_2 (C x F)	±4.59				±692				±0.74			
CV %	27.5				10.5				13.8			

Table 20. Millet grain yield, fodder yield and total dry matter in kg/ha

	Grain yield (kg/ha)				Fodder yield (kg/ha)				Total dry matter (kg/ha)			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of M
Millet/pigeonpea	1225	715	970	±74.25 (157.4)	3748	3013	3013	±328.5 (696)	5262	4144	4703	±382 (811)
Millet/groundnut	478	256	367		2167	1744	1955		2870	2144	2507	
Millet/Castor	781	354	568		2926	1718	2322		4087	2250	3168	
Millet	1740	983	1159		4357	3127	3742		7000	4511	5756	
Mean	1056	577	817		3300	2400	2850		4805	3262		
SE of mean	±44 (190)				±365 (1572)				±424 (1825)			
SE_1 (CxF)	±105(223)				±464				±541			
SE2 (CxF)	±104(263)				±553				±643			
CV %	13.89				18.78				15			

The mean total dry matter was 7000 kg/ha at high fertility and 4511 kg/ha at low fertility situations (SE ± 424 kg/ha). Sole millet had a total dry matter production of 5756 kg/ha and intercropped millet had 3168, 2507, and 4703 kg/ha when intercropped with castor, groundnut and pigeonpea respectively (SE ± 382 kg/ha). The interaction effects were not significant (Table 25). The fodder yield and total dry matter for millet intercropped with groundnut were low due to two main reasons:

1. The millet crop was poor due to poor millet germination; and
2. This being a replacement series, there was only one third sole millet population.

4.5.3 Groundnut

Among the groundnut yield components, it was only the number of pods per plant that was affected significantly by the intercrops (Table 19). Sole groundnut had 11.8 pods per plant, and when intercropped with millet and pigeonpea had 7.8 and 8.2 pods per plant respectively (SE ± 1.2 pods). The fertility level had no significant effect and the mean was 9.3 pods per plant for both fertility levels. The overall mean number of kernels per pod were 1.3 and the mean kernel weight 0.27 grams. Both of them were not affected by either fertility level or the intercrop (Table 19).

Table 21. Yield components of Groundnut

Cropping Systems	No. of pods/plant				No.of kernels/pod				Kernel weight (gm)			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Sole groundnut	14	9.6	118		1.33	1.56	1.45		0.26	0.26	0.26	
Groundnut/millet	7.3	8.3	7.8	±1.2 (3.96)	1.16	1.26	1.21	±0.23	0.32	0.31	0.31	±0.03
Groundnut/pigeonpea	7.0	9.3	8.2		1.23	1.5	1.37		0.23	0.24	0.24	
Mean	9.4	9.1	9.3		1.2	1.4	1.3		0.27	0.27	0.27	
SE of mean	±0.5				±0.23				±0.048			
SE_1(C x F)	±1.72				±0.23				±0.043			
SE_2(C x F)	±1.49				±0.3				±0.06			
CV %	11.6				21				19.46			

Table 22. Groundnut pod yield, kernel yield, hulm yield and total dry matter in kg/ha

	Pod yield (kg/ha)				Kernel yield (kg/ha)				Hulm yield (kg/ha)				Total dry matter			
	HF	LF	Mean	SE of M	HF	LF	Mean	SE of M	HF	LF	Mean	SE of M	HF	LF	Mean	SE of M
Groundnut	667	564	615	$\pm$48.6 (112)	454	380	417	$\pm$29.32 (67.6)	1403	1022	1213	$\pm$151.5	2070	1586	1828	$\pm$174.8
Groundnut/ Millet	400	420	410		265	270	270		1063	918	990		1463	1338	1400	
Groundnut/ Pigeonpea	329	521	425		213	356	356		1263	1062	1163		1592	1584	1588	
Mean	465	502	484		311	335	323		1243	1000	1122		1708	1502	1605	
SE of mean	$\pm$26				$\pm$18.04				$\pm$121				$\pm$146.7			
SE_1(C x F)	$\pm$68.7(159)				$\pm$41.48(95.64)				$\pm$224				$\pm$247			
SE_2(C x F)	$\pm$61.88(165)				$\pm$38.37(105.4)				$\pm$212				$\pm$249.5			
CV %	17.4				15.7				23.3				18.85			

The pod yield per hectare was significantly affected by the intercrop being 615, 410 and 415 kg/ha (SE ± 49 kg/ha) for sole groundnut, groundnut intercropped with millet and pigeonpea respectively. The fertilizer were not significant, but the interaction effects between fertility level and the component crop were significant (Table 26).

The dry hulms yield mean was 1122 kg/ha and the total dry matter mean was 1605 kg/ha. Both of these were not affected by either the fertility level or the intercrop or their interaction.

4.5.4 Pigeonpea

The number of seeds per pod and 1000-seed weight were not affected significantly by either the fertility level or the intercrop. The average was 2 seeds per pod, and 78 gms per 100 gms. However, the number of pods per plant were significantly affected by both the fertility level, the component crop and by their interaction (Table 20). The means for high and low fertility situations were 85 and 51 pods/plant respectively (SE ± 0.93). In case of sole pigeonpea, it had a mean of 45.9 pods/plant, 91.68, 56.61 and 78.33 pods/plant when intercropped with sorghum, millet and groundnut respectively (SE ± 8.3 pods).

The grain yield of pigeonpea was almost the same among the different cropping systems (650 kg/ha). There was no significant difference between these means. However, the difference in grain yield between high and low fertility means, 730 kg/ha and 588 kg/ha

Table 23. Yield components of pigeonpea

	Pods/plant				Seeds/pod				1000 grain weight (g)			
	HF	LF	Mean	SE of Mean	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Sole Pigeonpea	45.7	46.0	45.9		2.2	2.3	2.2		71.8	71.8	71.8	±9.3
Pigeonpea/sorghum	118.9	64.4	91.68	±8.3 (18.26)	2.0	2.1	2.04	±0.29	88.6	78.9	83.7	
Pigeonpea/millet	63.4	50.0	56.65		2.0	2.4	2.19		87.9	73.1	80.5	
Pigeonpea/groundnut	44.4	112.2	78.33		1.9	1.8	1.83		79.5	75.7	77.6	
Mean	85.07	51.22	68.14		2.0	2.15	2.07		81.93	74.9	78.4	
SE of mean	±0.93 (4)				±0.04				±6.69			
SE_1 (C x F)	±11.85(25.82)				±0.42				±13.15			
SE_2 (C x F)	±10.31(22.63)				±0.36				±13.21			
CV %	21.3				4				20.5			

Table 24. Pigeonpea grain yield and stalk yield in kg/ha

	Grains/ha				stalk yield			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Pigeonpea	1035	644	839		5847	5475	5661	
Pigeonpea/sorghum	630	681	655	±218	3828	3123	3476	±987
Pigeonpea/millet	649	651	650		2805	4026	3416	
Pigeonpea/groundnut	708	375	659		3299	2578	2939	
Mean	730	588	688		3945	3800	3872	
SE of mean	±97.13(417)				±397			
SE_1 (C x F)	±308(672)				±1396			
SE_2 (C x F)	±248(690)				±1272			
CV %	20				25			

respectively ($SE\pm97$ kg/ha) was statistically significant (Table 27). Within high fertility treatments sole pigeonpea had the maximum yield 1023 kg/ha, followed by pigeonpea in pigeonpea/groundnut intercrop 708 kg/ha. However, under low fertility pigeonpea in pigeonpea/sorghum intercrop had the maximum yield of 681 kg/ha, while that in pigeonpea/ groundnut intercrop had the least 375 kg/ha. This is the difference from what would be expected in the legume-legume intercrop, as there would be no competition for nitrogen since both crops are able to fix nitrogen. Hence some other factors might be expected.

4.5.5 Cowpea

The mean number of seeds per pod and the 1000-seed weight were not affected by the fertility level nor by the sorghum intercrop. Cowpea under high fertility treatment produced 5.4 pods/plant and under low fertility 4.6 pods per plant ($SE\pm0.86$ pods/plant). However, the interaction effects between fertility level and cropping system were significant. Within each fertility level, there was a significant difference between sole and intercropped cowpea in the number of pods per plant ($SE \pm0.65$). In the intercropped cowpea, there was no significant difference between low and high fertility, but in sole cowpea, the difference was significant ($SE\pm0.98$) (Table 21).

The grain yield, fodder yield were all reduced significantly by the sorghum intercrop, but were not affected by the fertility levels.

Table 25. Yield components of cowpea

	No. of pods/plant				No. of seeds/pod				1000 seed weight (g)			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Cowpea	6.06	3.9	5.0	±0.46	9.4	9.76	9.58	±1.33	77.36	77.93	77.6	±10.2
Cowpea/sorghum	4.76	5.2	4.98		9.7	12.46	11.1		82.43	75.66	79.0	
Mean	5.4	4.6	5.0		9.6	11.11	10.3		79.9	76.8	78.4	
SE of mean	±0.87				±1.35				±0.75			
SE_1 (C x F)	±0.65(1.81)				±2.59				±0.29			
SE_2 (C x F)	±0.98(3.89)				±2.28				±0.77			
CV %	16				26.7				10.55			

Table 26. Yield of cowpea grain yield, and fodder yield in kg/ha

	Grain yield (kg/ha)				Fodder yield (kg/ha)			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Cowpea/sorghum	310	177	248	±54.8(152)	308	185	246	±39.08(108)
Cowpea	506	326	416		463	296	380	
Mean	413	252	332		385	241	313	
SE of mean	±65.5				±51.5			
SE_1 (C x F)	±77.6				±55.3			
SE_2 (C x F)	±85.5				±64.7			
CV %	15				21			

Sole cowpea yielded 416 kg/ha while intercropped cowpea yielded about half of sole yield, 248 kg/ha (SE ± 55 kg/ha) (Table 28). The low cowpea yields were due to the attack by stem fly (Melanogromyza spp.) already mentioned.

4.5.6 Mungbean

The number of pods per plant and 1000 seed weight were not affected by neither the fertility level nor by intercropping with castor. The number of seeds per pod were 8.5 and 8.8 for sole and intercropped mungbean respectively (SE ± 0.25); 9 and 8.4 for high and low fertility situations respectively (SE±0.25). The two main effects were not statistically significant, but their interaction effects were. For sole mungbean, there was no difference between low and high fertility treatments (8.5 and 8.6 seeds/pod, SE ± 0.46), but there was a significant difference for intercropped mungbean. Under high fertility situations, intercropped mungbean had more number of seeds/pod than sole mungbean, and the reverse was true under low fertility treatments (Table 27).

The grain yield was not affected by neither the castor intercrop nor the fertility level. The grain yield means were 227 kg/ha for high fertility treatments and 204 kg/ha for low fertility treatments (SE ± 22 kg/ha). Sole mungbean had a mean yield of 221 kg/ha and intercropped mungbean a mean yield of 211 kg/ha (SE ± 47 kg)(Table 29).

Dry fodder yield was not affected by either the fertility level or by intercropping with castor.

Table 27. Yield components of mungbean

	No. of pods/plant				No. of seeds/pod				1000 seed weight (g)			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Mungbean	7.93	7.63	7.78	±1.2	8.53	8.6	8.58		28.86	29.2	28.1	±0.14
Mungbean/castor	10.93	7.26	9.1		9.56	8.1	8.86		25.76	27.1	27.3	
Mean	9.4	7.45	8.5		9.05	8.4	8.7		29.01	26.4	27.7	
SE of mean	±0.56				±0.25				±0.2			
SE_1 (C x F)	±1.81				±0.36(0.998)				±0.2			
SE_2 (C x F)	±1.4				±0.46(1.76)				±0.25			
CV %	11.6				5.05				8.99			

Table 28. Mungbean grain and fodder yield in Kg/ha.

	Grain yield (kg/ha)				Fodder yield (kg/ha)			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Mungbean	235	206	221	±47	371	341	355	±74.8
Mungbean/castor	219	203	211		350	250	300	
Mean	227	204	216		260	296	328	
SE of mean	±17.4				±21.75			
SE_1 (C x F)	±66.59				±105.8			
SE_2 (C x F)	±50.2				±47.9			
CV %	13.9				11.4			

4.5.7 Castor

The number of racemes per plant were not affected significantly by either the fertility level or by the cropping system, but the interaction effects were significant. Castor intercropped mungbean had the maximum number of racemes (4.5 racemes/plant) under high fertility, followed by sole castor with 3 racemes/plant and castor intercropped with millet 2.7 racemes per plant (SE ± 0.69). The number of capsules/raceme was not affected by the fertility level or by intercropping (Table 23).

The castor yield was significantly affected by the fertilizer mean effects and by intercropping. The mean yield was 1140 and 711 kg/ha for high and low fertility treatments respectively (SE ± 104 kg/ha); 1277, 1579 and 921 kg/ha for sole castor, castor intercropped with millet and mungbean respectively (SE ± 88 kg/ha). The interaction effects were nonsignificant (Table 30).

4.5.8 Yield of ratoon, sequential and relay crops

The yields of ratoonn, sequential and relay crops are shown in Table 31.

Ratoon sorghum gave a mean grain yield of 510 kg/ha under high fertility and 323 kg/ha under low fertility treatments. This was 28% and 42% of the main crop yield for high and low fertility treatments respectively.

Table 29. Yield components of castor

	No. of racemes/plant				No. of capsules/raceme			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Castor	3.13	3.8	3.46	±0.5	18.2	13.4	15.76	±2.32
Castor/millet	2.73	2.3	2.53		10.0	10.6	10.3	
Castor/mungbean	4.53	1.9	3.22		14.2	15.2	14.7	
Mean	3.46	2.68	3.07		14.1	13.0	13.5	
SE of mean	±0.37				±0.41			
SE_1 (C x F)	±0.71(1.64)				±3.28			
SE_2 (C x F)	±0.69(1.98)				±2.71			
CV %	28				18.02			

Table 30. Yield of castor beans, and stalk yield in kg/ha

	yield of beans (kg/ha)				Stalk yield (kg/ha)			
	HF	LF	Mean	SE of mean	HF	LF	Mean	SE of mean
Castor	1457	1096	1277	±88 (204)	872	491	682	±87
Castor/millet	767	392	579		681	239	460	
Castor/mungbean	1197	646	921		678	341	509	
Mean	1140	711	926		743	357	550	
SE of mean	±104 (447)				±161			
SE1 (C x F)	±125				±123			
SE2 (C x F)	±146				±190			
CV %	16.5				27			

Table 31. Grain yield of rabi crops

Crop	Grain yield (kg/ha)	
	HF	LF
Ratoon sorghum	510	323
Sequential horsegram	1012	717
Sequential cowpea	806	657
Relay castor	404	314

Sequential horsegram gave a mean yield of 1012 kg/ha under high fertility treatment and 800 kg/ha under low fertility situations. Sequential cowpea produced a grain yield of 717 kg/ha under high fertility and 657 kg/ha under low fertility.

Relay castor yielded 404 kg/ha of dry beans under high fertility and 314 kg/ha under lower fertility treatments.

4.6 Land equivalent ratio (LER)

The land equivalent raios for the different intercropping systems are shown in Table 32 and Fig 11.

The mean LER was generally higher under low fertility treatments as compared to high fertility treatments.

Sorghum/pigeonpea and mugnbean/castor intercrops gave the highest mean LER, both gave a LER of 1.77, while millet/castor gave the lowest (0.86). The different LER means were significantly different (SE $\pm$ 0.29). The sorghum/pigeonpea intercrop under low fertility gave a LER 1.94 of which 1.3 was contributed by pigeonpea (Fig 11). The contribution of pigeonpea was only 0.9 under high fertility.

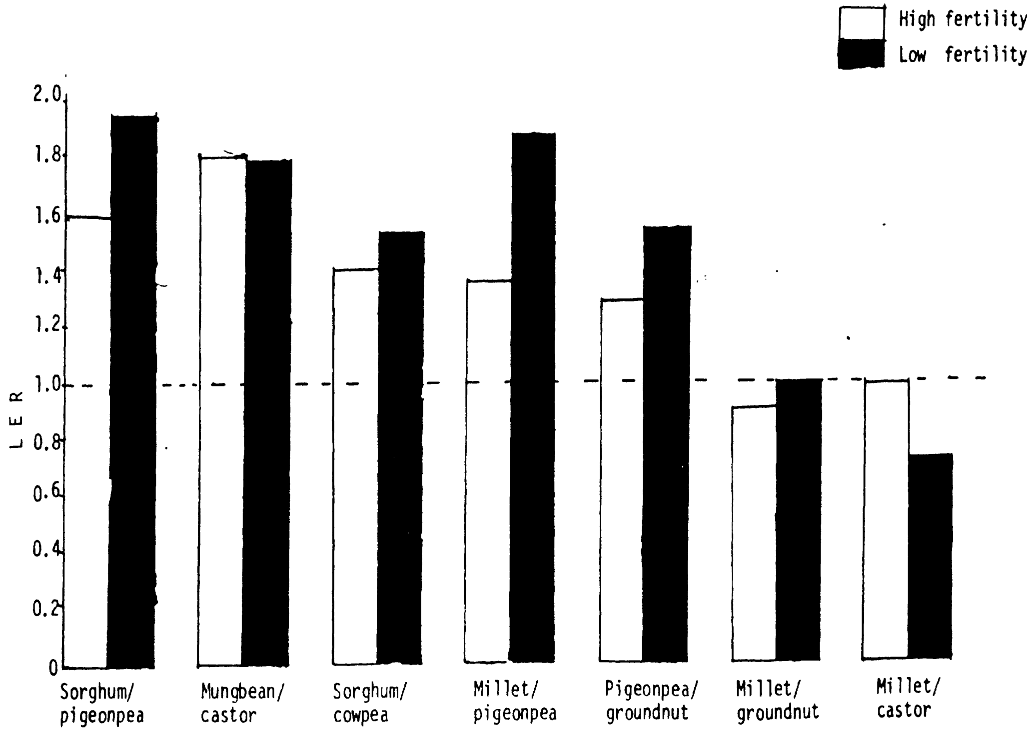
In mungbean/castor intercrop, mungbean contributed 1.0 of the total LER of 1.77. This indicates that mungbean was able to compensate and yielded as much as the sole crop, although it was at 50% of the sole population.

Table 32. Land Equivalent Ratios (LER) for the different intercropping systems

Cropping Systems	High fertility			Low fertility			Overal Mean LER
	LER of Crop 1	LER of Crop 2	Total LER	LER of Crop 1	LER of Crop 2	Total LER	
Sorghum/Pigeonpea	0.73	0.87	1.60	0.64	1.30	1.94	1.77
Sorghum/Cowpea	0.81	0.58	1.39	0.87	0.66	1.53	1.46
Millet/Pigeonpea	0.71	0.65	1.36	0.74	1.13	1.87	1.61
Millet/Groundnut	0.27	0.60	0.87	0.26	0.75	1.01	0.94
Millet/Castor	0.45	0.53	0.98	0.36	0.37	0.73	0.86
Mungbean/Castor	0.97	0.83	1.80	1.16	0.61	1.77	1.78
Pigeonpea/Groundnut	0.60	0.68	1.28	0.94	0.60	1.54	1.41
Mean			1.33			[illegible]	1.48

S.E.	± 0.058
$S.E._1$ (C x F)	± 0.41
S.E.[illegible] (C x F)	+0.39
C.V. %	24%

Fig. 11. Land equivalent ratios (LER) for the different intercropping systems.



In sorghum/cowpea, the sorghum contribution was 0.81 and 0.84 under high and low fertility treatments respectively, this being about one-half of the total LER.

In millet/pigeonpea intercrop, the millet LER was 0.7 under both fertility levels and pigeonpea contributed 0.65 and 1.17 under high and low fertility respectively.

In terms of yield advantage, sorghum/pigeonpea and mungbean/castor had the maximum of 77%. Millet/groundnut had no advantage in this experiment contrary to what has been reported (Reddy et al, 1982). Millet/castor also had no yield advantage.

4.7 Net returns

Net returns were calculated using the following formular

Net return = Gross returns - variable cost. The gross return is the product of yield and the output price. The prices of the various yields are shown in Appendix III. The variable cost included the cost of seeds, fertilizer pesticides and labor charges, are shown in Appendix IV.

The net returns did not differ significantly between low and high fertility levels (Fig 12), but the net return means were significant for the different cropping systems (SE ± Rs 488) (Table 33).

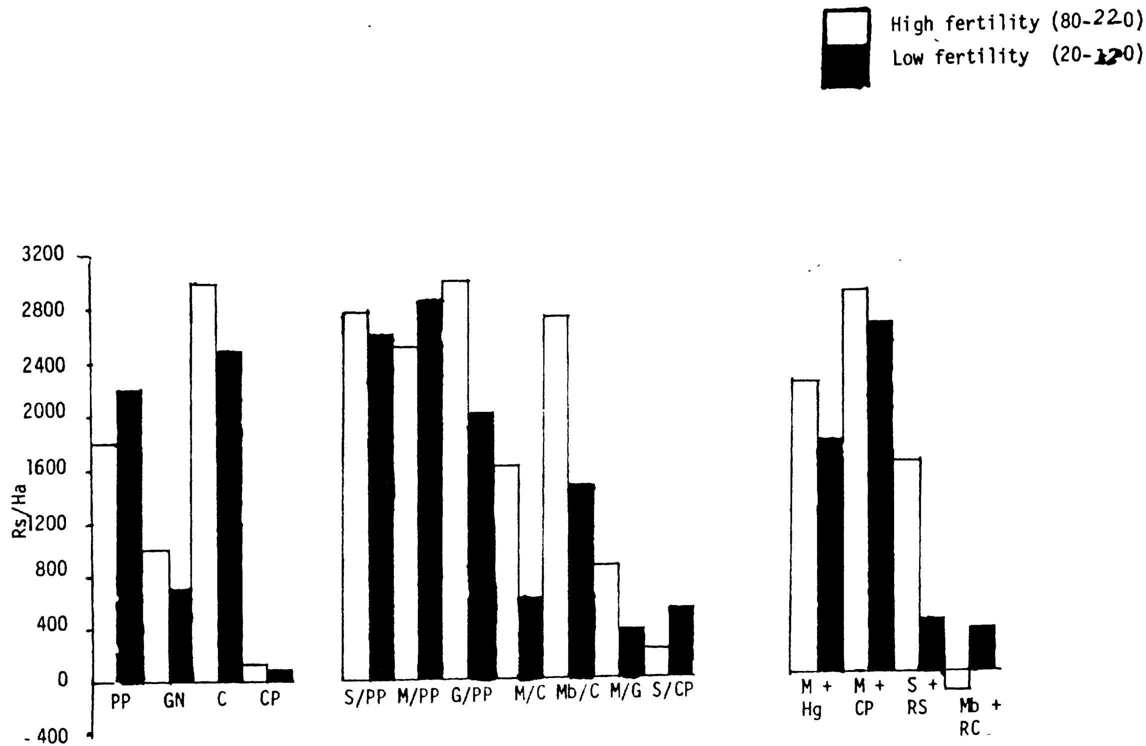
Table 3³. Net returns in Rupees/ha for the different cropping systems

Cropping systems	High fertility	Low fertility	Mean	SE of mean
Sorghum/pigeonpea	2758	2634	2696	
Millet/pigeonpea	2570	2864	2716	
Millet/groundnut	220	539	379	± 448 (897)
Groundnut/pigeonpea	3099	2057	2578	
Millet/Castor	1603	619	1111	
Mungbean/castor	2735	1446	2090	
Sorghum/cowpea	851	348	599	
Mungbean + relay castor	-170	324	76	
Millet + sequential horsegram	2277	1783	2030	
Millet + sequential cowpea	2891	2633	2762	
Sorghum + ratoon sorghum	1627	403	1015	
Sole pigeonpea	1810	2223	2017	
Sole groundnut	1087	692	890	
Sole cowpea	118	46	82	
Sole castor	3113	2485	2799	
Mean	1772	1406	1589	
SE of mean	154			

SE_1 for comparing different cropping systems at the same fertility level ± 634

SE_2 for comparing the 2 fertility levels at the same cropping systems ± 631

Fig. 12. Net monetary returns (Rs/ha) from the different cropping systems.



KEY: PP - Pigeonpea; GN - Groundnut; C - Castor; CP - Cowpea; S/PP - Sorghum/pigeonpea intercrop
M/PP - Millet/pigeonpea intercrop; G/PP - Groundnut/pigeonpea intercrop; M/C - Millet/castor intercrop
Mb/C - Mungbean/castor intercrop; M/G - Millet/groundnut intercrop; S/CP- Sorghum/cowpea intercrop
M+Hg - Millet + sequential horsegram; M+CP - Millet + sequential cowpea; S+Rs - Sorghum + ratoon sorghum;
Mb+RC - Mungbean + relay castor.

Mungbean + relay castor under high fertility treatments had a negative net return, as both yields were very low and could not cover the cost of inputs.

SE of comparing between cropping systems at the same fertility level + Rs 634; SE of comparing two fertility levels at the same or different cropping systems 631.

Cowpea under both fertility levels had also a very low net returns due to poor yield.

The interaction effects were not significant.

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DISCUSSION AND CONCLUSION

DISCUSSION AND CONCLUSIONS

5.1 Light interception

Fast growing crops like millet and cowpea were able to intercept more light, and they more or less dominated the other crops in the intercrop. Thus during the first light measurement (35 days after emergence), sole cowpea was intercepting the maximum amount of light, followed by sole millet and sorghum/cowpea intercrop.

After the harvest of one of the component crops in the intercrop, light interception dropped down significantly. Except in pigeonpea based cropping systems, the light interception in the other cropping systems continued to decline. This is because most of the crops had started to mature. However, in case of pigeonpea, after the harvest of sorghum, millet and groundnut, competition was reduced and pigeonpea canopy increased and by flowering time, it was able to intercept as much as 90% of incoming radiation. The light interception in sole pigeonpea was higher under low fertility than under high fertility. This according to Steiner (1982) is because nitrogen fertilizer reduces rhizobium action and has a retarding effect on growth.

Peak values of light interception were obtained mostly from sole crops. In fact, Natarajan and Willey (1980a, b) demonstrated that 90% peak light interception of sorghum/pigeonpea intercrop was nearly identical to sole sorghum. In this experiment, all intercrops under low fertility intercepted more light than the sole crops, but under high fertility, sole crop like millet were able to intercept as much as the intercrops.

The intercropping systems having long duration crops were able to intercept more light and for a longer time. In fact, their light interception curves are bimodal. For example, millet/pigeonpea (Fig 10). The first peak occurring at 50% after emergence involved millet while a second peak at 125 days involved pigeonpea. This light interception trend is evident in both fertility levels. The situation is quite different when short duration crops are involved. Their light interception curve was unimodal, e.g. sorghum/cowpea intercrop (Fig 6). This shows that the long duration crops are more efficient in utilizing the solar radiation over a long period of time (solar radiation cannot be stored). This effects were clearly evident in the LER and also in net returns.

The amount of light intercepted was affected by several factors:

1. The crop stand determined the amount light intercepted. For example, the millet in millet/castor intercrop had a poor germination and the crop stand was also poor, and as a consequence the amount of light intercepted was very low.

2. There was considerable moisture stress around the 65th day after emergence when light interception declined drastically. The plants wilted and hence were not able to intercept more light.

3. The fertility level as expected affected the light interception. Under low fertility, the crop growth was poor, hence the light interception was quite low and under high fertility with a better crop growth, the amount of light intercepted was more. This was different in case of sole pigeonpea, which intercepted more light under low fertility than under high fertility.

4. Incidence of diseases and pests in some crops also reduced the amount of light intercepted. This happened in the case of cowpea which was affected by stem fly (*Melanogromyza* spp.) and also in groundnut, affected by leafspot.

5.2 Yield

The yield of different crops was significantly affected by the fertility level. Throughout the whole experiment, the yield of different crops under high fertility was almost twice that under low fertility, regardless of whether the crop is intercropped or sole.

Intercropping did not seem to reduce the yield significantly and the yields for sole crops were not very much different from the yields under intercropping for each crop. This agrees with Rao (1980) who reported that it is possible to grow intercrops at sole crop populations without affecting the yield severely.

The yields of the double cropping systems were quite high except for relay castor. The sequential cowpea yielded much more than the kharif cowpea. This shows that there is a possibility of extending the cropping season beyond the monsoon season.

5.3 Land Equivalent Ratio (LER)

This is an indication of the yield advantage obtained by intercropping as compared to sole cropping (Mead and Willey, 1979). Most of the intercropping systems have higher yield advantage at both fertility levels although the yield advantage was constantly high under low fertility than under high fertility (Fig 11). This agrees with results obtained by Reddy et al (1982) & Steiner (1982). Steiner gives two reasons why LERs are low under high fertility, particularly for legume/non-legume intercrops.

1. Legume yields decrease sharply because of the shading of the dominant non-legume crop.

2. Nitrogenous fertilizers have a negative influence on symbiotic nitrogen fixation.

Another reason is that initial yield increase due to nitrogen fertilizer of cereals intercropped with legumes are much less than the increases in sole cropped cereals because yields of intercropped cereals are already higher at 0-N than those of sole crops (Steiner, 1982). Sorghum/pigeonpea and mungbean/castor gave a mean yield advantage of 77%. This high yield advantage was due to high yield of pigeonpea in the sorghum/pigeonpea intercrop. In case of mungbean/castor intercrop, mungbean grew and matured before castor was able to give any competition and the castor grew without any competition from the mungbean. Thus both crops grew almost as sole crops and hence the high yield advantage.

In fact, the intercropping systems that involved long duration crops were the ones that had the highest net returns at both fertility levels. Thus, sorghum/pigeonpea intercrop had a net return of Rs 2696/ha, as compared to sorghum/cowpea which had only a net return of Rs 599/ha. One of the contributing factors is that the intercropping having long duration crops intercepted light for a long time (Fig 10) and also was able to utilize the residual moisture and this resulted in relatively high yields.

Millet/groundnut intercrop did not give any yield advantage, and this is contrary to published data (Rao, 1980; Reddy and Willey, 1981). The millet contribution was very low because of very poor crop stand already mentioned in section 5.5. The same problem affected the millet/castor intercrop.

5.4 Net returns

The net returns were comparatively higher under high fertility than under low fertility, but the difference was not statistically significant. Among high fertility treatments, groundnut/pigeonpea intercrop and sole castor gave the highest net returns (more than Rs 3000/ha). Under low fertility treatments, millet/pigeonpea, millet+ sequential cowpea gave the highest returns (Rs 2500/ha).

Among the intercrop systems, the system which had high yield advantage (LER) also gave high net returns. Thus, sorghum/pigeonpea, millet/pigeonpea, groundnut/pigeonpea, mungbean/castor, all having a yield advantage of more than 50% had mean net income of more than Rs 2500 (Fig 11 and 12). Millet/groundnut and millet/castor both of which had low yield advantage, also had low net income.

The relay cropping of castor in mungbean gave a negative net income under high fertility. This is mainly because the relay castor had very low yield. The plants were very short compared to the kharif crop and also, their racemes were very small.

The response to high fertilizer application was not very high and as a consequence the cost of fertilizer reduced the net income significantly. Also, while planting the relay castor, there was much damage to the mungbean and this might have resulted in the low mungbean yields.

The sequential cropping gave good net returns. This is because both the kharif millet had a good yield and also the sequential cowpea and horsegram had good yields. Although the sequential crops grew with only 102 mm of rainfall, it had good distribution and the crops grew without any competition unlike the intercrops. This shows that in good rainfall distribution years it might be possible to grow a second crop successfully and get as much net returns as in intercrops.

Except for sole castor and sole pigeonpea, the sole crop net returns were very low. This indicates why intercropping is still a better cropping system compared to sole cropping.

5.5 Operational scale evaluation

One of the objectives of this experiment was to find out the feasibility of different cropping systems on an operational scale. Most of the observations made regarding this objective were qualitative rather than quantitative hence no statistical analysis could be carried out. The observations and conclusions are listed below:

1. It was possible to find out the practicability and feasibility of carrying sowing of all the crops using the bullock drawn implements with the farmers use. The use of the large plots facilitated this observation.

2. Some cropping systems that have proved feasible under small scale experiments were found not to be as advantageous as already reported. For example, in case of millet/groundnut intercrop, yield advantage of 60% have been reported (Rao, 1980). However, when put under operational evaluation there was no yield advantage mainly because of poor millet stand. It was difficult to maintain sowing depths when millet and groundnut were planted as an intercrop, and the millet was sown as deep as the groundnut resulting in poor germination.

3. Another cropping system that was not feasible was relay cropping. It was found that while doing the relay sowing, most of the mungbean plants were destroyed, either by being uprooted or the pods shattered.

Ratooning although it proved to be economically remunerative had a lot of problems while cutting the stubbles. The plants were getting uprooted and more time than necessary was used to complete the ratooning.

Contrary to some published work that it is not possible to mechanize intercropping, it was found that for most intercrops it was possible to sow all the intercrops without much problem.

CONCLUSIONS

1. It is more economical to grow intercrops than sole crops. Among the intercrops, sorghum/pigeonpea, millet/pigeonpea, mungbean/castor, groundnut/pigeonpea intercrops are more advantageous in both yield advantage and net returns. All these intercrops include a long duration crop so there is temporal complementarity (Rao and Willey, 1980) and also includes the advantageous effects of a legume.

2. It is possible to have sequential cropping systems involving short duration crops. This, however, would depend mainly on the rainfall distribution after the harvest of the first crop could be reduced then the cropping system might even prove to be more beneficial.

3. It was found that relay cropping is not a feasible or remunerative cropping system, due to the problems of planting of the relay crop without damaging the first crop.

4. The net returns from ratoon cropping sorghum are not high, but still it is a feasible cropping system, which can be used to extend the cropping season beyond the rainy season.

5. In most of the cropping systems being evaluated the yield and net income was more under high fertility than under low fertility.

However, the net benefit ratio and the value/cost ratio of fertilizer used was high under low fertility than high fertility, and if monetary resources are limited, then it would be more economical not to apply high fertilizer rates.

6. Various people had reported that it is not possible to mechanize intercropping. However, from this study, it was found that it is possible to do all the planting with bullock-drawn tropicultor. The only planting which is not really feasible is relay cropping due to damage of the first crop. The use of relatively large plots, made this assessment possible.

7. The advantages of using research watershed fields in the red soil could not be clearly pointed out in this experiment because no data on runoff or drainage problems were taken. The only advantage that was found in this experiment is that it is easier to guide the bullocks along the furrows and hence plant in more straight rows.

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SUMMARY

The experiment entitled "Evaluation of different cropping systems for Alfisols at different fertility levels on an operational scale" was carried out at ICRISAT Research Centre during the Kharif and Rabi seasons 1982/83. A total of fifteen cropping systems were evaluated. These included seven intercropping systems, one relay cropping system, two sequential cropping systems, one ratoon cropping and four sole cropping systems. Two fertilizer levels were used, a high level of *(80-22-0)* and low fertility level of *(20-12-0)*.

The salient features that were observed from this experiment were :

i) That light interception was generally higher under high fertility treatments than under low fertility treatments; and that intercropping increased light interception significantly as compared to the sole crops.

ii) That the yield of individual crops under high fertility treatments was almost twice the yield under low fertility treatments. This relationship was not observed in case of monetary net benefits, because this was more dependent on the individual prices.

iii) The Land Equivalent Ratios (LER) for intercropping having any longer duration crops e.g. sorghum/pigeonpea intercrop was higher than for intercrops having short-duration crops, reflecting the better utilization of light and soil moisture.

(iv) The LER was higher under low fertility than under high fertility.

(v) Intercropping systems having long duration crops had more net returns than those having short duration crops. For example, groundnut/pigeonpea intercrop had a mean net return of Rs 2,578/ha as compared to a mean of Rs 599/ha for sorghum/cowpea intercrop. Sequential cropping followed long duration intercropping systems. Sole cropping of long duration crops also gave good net returns e.g. sole castor gave as much as Rs 2,799/ha.

As a concluding remark, intercropping systems were more profitable than the other cropping systems and in these, intercropping of long duration crops were the most advantageous both in terms of LER and net returns.

Relay cropping although would increase the cropping intensity, is limited by the problems of planting the second crop without damaging the second. Sequential cropping gave good yield and good net returns but the time spent on land preparation after the harvest of the first crop can be critical particularly in a low rainfall year and hence this system have to be handled with caution. That leaves intercropping as the most feasible and profitable of the all the cropping systems that were being evaluated.

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Appendix I. Meteorological data at ICRISAT Centre
June 1982 to January 1983

Stan. week	Rain-fall mm	Evapo-ration mm	Maximum temp. °C	Minimum temp. °C	R. Hu 0717	R. Hu 1417	Sunshine hrs.
25	24.2	46.9	31.8	23.1	87.9	59.7	5.3
26	29.1	58.5	33.4	23.4	78.0	56.7	6.7
27	9.2	61.5	34.2	23.6	75.9	41.6	8.2
28	27.3	41.6	30.3	22.1	88.9	64.6	6.4
29	18.9	46.7	29.9	22.4	86.9	62.1	4.7
30	5.0	46.1	30.2	22.5	88.1	62.4	4.0
31	74.4	46.1	30.4	22.3	89.1	62.1	7.5
32	24.9	37.8	30.0	22.8	87.6	62.3	3.9
33	14.4	36.6	28.8	22.4	88.4	67.1	1.5
34	3.4	39.6	29.9	22.4	84.6	58.1	2.4
35	0.8	43.8	31.5	22.3	79.9	50.6	8.0
36	59.1	40.4	30.5	21.8	89.6	58.1	5.5
37	40.7	24.4	28.2	22.0	96.1	73.0	3.5
38	35.4	33.2	30.7	22.3	92.4	61.6	5.7
39	44.9	27.6	28.6	21.3	94.0	72.4	5.1
40	0.0	38.6	31.5	19.7	86.9	38.3	9.9
41	0.0	41.9	32.2	18.9	86.3	36.6	9.9
42	44.5	30.4	28.9	19.8	90.3	59.6	6.5
43	14.3	25.2	29.0	21.4	92.9	62.6	6.5
44	2.4	32.7	29.2	19.0	86.4	52.0	9.2
45	9.4	28.5	28.2	20.8	94.6	63.1	6.2
46	0.0	32.6	29.8	16.7	88.3	44.1	9.7
47	0.0	31.0	27.7	15.0	92.3	44.9	8.7
48	0.0	28.7	27.9	15.0	93.3	43.6	7.8
49	00.0	32.3	28.4	14.1	90.3	40.7	9.7
50	0.0	32.3	28.4	14.1	94.3	40.7	8.4

Stan. week	Rain-fall mm	Evapo-ration mm	Maximum temp °C	Minimum temp °C	R. Hu 0717	R. Hu 1417	Sunshine hrs
51	0.0	34.3	28.5	13.1	94.4	42.1	10.0
52	0.0	36.4	28.5	13.7	91.6	35.1	9.6
1	0.0	33.9	27.8	10.5	83.6	83.6	10.3
2	0.0	34.8	29.8	12.3	84.9	84.9	10.1
3	0.0	39.2	28.5	13.8	90.6	90.6	10.1
4	0.0						

Appendix II. Number of days to emergence

Treatment	1st crop	2nd crop
Sorghum/pigeonpe	5	7
Millet/pigeonpea	5	7
Millet/groundnut	8	9
Pigeonpea/groundnut	8	7
Millet/castor	7	9
Mungbean/castor	4	8
Sorghum/cowpea	5	3
Mungbean + relay castor	4	10
Millet + sequential horsegram	4	4
Millet + sequential cowpea	4	3
Sole sorghum	5	
Sole pigeonpea	7	
Sole groundnut	7	
Sole cowpea	3	
Sole castor	8	

Appendix III. Plant population at harvest

Crop	Sole cropping	Intercropping
1. Sorghum	138,000	120,216
2. Millet	218,000	141,000
(Groundnut)	-	79,000
3. Castor	113,000	97,000
4. Pigeonpea	60,510	52,777
5. Groundnut	261,600	241,966
6. Cowpea	440,000	286,500
7. Mungbean	508,500	254,330
8. Ratoon sorghum	99,395	-
9. Relay castor	101,666	-
10. Sequential cowpea	390,500	-
11. Sequential horsegram	401,500	-

Appendix IV. Average grain or pod yields of different crops in kg/ha

Cropping system	High fertility 80-50-0		Low fertility	
	Yield of Crop 1	Yield of Crop 2	Yield of Crop 1	Yield of Crop 2
Sorghum/pigeonpea	1554	630	626	681
Millet/pigeonpea	1225	549	715	651
Millet/groundnut	478	400	256	420
Pigeonpea/groundnut	708	329	375	521
Millet/castor	781	767	354	392
Mungbean/castor	219	1197	203	646
Sorghum/cowpea	1618	320	833	177
Mungbean + relay castor	235	404	206	314
Millet + sequential horsegram	1773	1012	792	717
Millet + sequential cowpea	1707	806	1172	657
Sorghum + ratoon sorghum	1866	510	767	323
Sole pigeonpea	1035	-	644	-
Sole groundnut	667	-	564	-
Sole cowpea	506	-	326	-
Sole castor	1457	-	1096	

Appendix V. Cost of inputs

1. Seeds .

	s/kg	Kg/ha
Sorghum	8.70	10
Pearl millet	6.40	4
Pigeonpea	4.00	10
Groundnut	4.00	100
Cowpea	4.00	20
Mungbean	4.00	20
Castor	7.00	20
Horsegram	2.50	20

2. Fertilizer

1. Diammonium phosphate	Rs.3744 per metric ton
2. Gromor	Rs.3744 ,,
3. Urea	Rs.2444 ,,

3. Pesticides

1. Rogor 35 EC	Rs.63.99/litre
2. Thiodan	Rs.64.93/litre
3. Metasystox	Rs.88.07/litre

Appendix VI. Market prices of the output in Rs/quintal

Crop	Rs/Quintal
Sorghum	97.000
Pearl millet	119.00
Cowpea	233.00
Mungbean	306.00
Groundnut	339.00
Castor	341.00
Pigeonpea	400.00
Sequential cowpea	300.00
Sequential horsegram	170.00
Relay castor	300.00
Ratoon sorghum	130.00
Sorghum fodder	20.00
Millet fodder	10.00
Pigeonpea fire wood	10.00

Appendix VII. Variable cost for high fertility treatments in Rs/hectare

Cropping Systems	Seed cost Rs/ha	Fertilizer cost Rs/ha	Pesticide cost Rs/ha	Labour cost Rs/ha	Total variable cost Rs/ha
1. Sorghum/pigeonpea	127	825	97	762	1811
2. Millet/pigeonpea	113	825	97	704	1739
3. Millet/groundnut	426	825	145	522	1918
4. Pigeonpea/groundnut	440	580	245	584	1849
5. Millet/castor	166	1069	97	923	2235
6. Mungbean/castor	220	825	97	876	2018
7. Sorghum/cowpea	167	825	97	697	1787
8. Mungbean + relay castor	220	1124	-	758	2103
9. Millet + sequential horsegram	76	1124	-	789	1989
10. Millet + sequential cowpea	106	1124	-	765	1994
11. Sorghum + ratoon sorghum	87	580	44	852	1564
12. Sole pigeonpea	40	580	97	533	1251
13. Sole groundnut	400	580	145	380	1507
14. Sole cowpea	80	580	97	436	1195
15. Sole castor	140	825	97	793	1855

Appendix VIII. Variable cost for low fertility treatments in Rs/hectare

Cropping system	Seed cost Rs/ha	Fertilizer cost Rs/ha	Pesticide cost Rs/ha	Labour cost Rs/ha	Total variable cost Rs/ha
Sorghum/pigeonpea	127	280	97	631	1137
Millet/pigeonpea	113	280	97	638	1128
Millet/Groundnut	426	280	145	513	1364
Groundnut/pigeonpea	440	280	243	505	1469
Millet/castor	166	280	97	768	1312
Mungbean/castor	220	280	97	779	1377
Sorghum/cowpea	167	280	97	573	1117
Mungbean + relay castor	220	280	-	748	1248
Millet + sequential horsegram	76	280	-	649	1005
Millet + sequential cowpea	106	280	-	685	1071
Sorghum + ratoon sorghum	87	280	44	682	1093
Sole pigeonpea	40	280	97	482	899
Sole groundnut	400	280	145	393	1218
Sole cowpea	80	280	97	421	879
Sole castor	140	280	97	735	1252

V I T A

I, Joseph Kangara Kimemia was born on 23rd August 1956 in Kihingo Village, Kiambu District, Kenya. I was educated at Biberiani Primary School, Ngenia High School, Njoro High School, and the University of Nairobi where I graduated in B.Sc. Agriculture in 1980. I worked for the Ministry of Agriculture at National Dryland Research Station - Katumani till 1981, when I proceeded to India to do my Master Degree at Andhra Pradesh Agriculture University under FAO Scholarship.
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