INTERCROPPING RESEARCH AT CPATSA

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CONTENTS

1 - INTRODUCTION

This report was based on the cooperative work of the author with his Brazilian counterpart scientists at CPATSA. The Center's staff and the specific experiments in which they participated were:

L.B. Morgado	Scientist	Most of the experiments
J.M.P. Lima Filho	Scientist	A maize/cowpea physiology experiment
S.G. de Albuquerque	Scientist	Experiments on cactus
J. Cavalcanti	Scientist	Experiments on sole castor
J.C. Ferreira	Scientist	Weed control by herbicides
E.A. Menezes	Scientist	Limited participation in population studies
A.M. Siqueira	Trainee	- - - - -
A.A. Freire de Sá	Technical Assistant	All experiments except those on cactus and sole castor
F.A. Bernardino	Technical Assistant	Experiments on cactus
X.M. Peixoto	Technical Assistant	Experiments on sole castor

I arrived in Petrolina on 2 May 1982, by which time rains had already stopped. It was a dry year and the few intercropping experiments planted in that year, except the one provided with supplemental water, had failed.

Intercropping - the system of growing two or more crops simultaneously - is practised throughout the northeast Brazil. It is less common in the high rainfall coastal area ('mata') where plantation crops such as sugarcane and cocoa are the principal crops. In much of the semi arid ('agreste') and arid ('sertão') Northeast intercropping with 2 to 4 crops is the basic cropping system. The crops involved are maize, beans, cowpea, fava beans, cotton (perenial and annual), cassava, castor, tobacco, cactus and rice (only in the sub-humid parts of Maranhão and Piauí states).

However, intercropping research was relatively new, perhaps gained momentum only with the set up of various EMBRAPA research centers in mid seventies. Research in this area is highly justified for the simple reason that it directly benefits the small and medium farmers who constitute bulk of the Northeast population and who invariably practise intercropping.

Based on the previous work carried out at CPATSA and various state enterprises, the needs and priorities for intercropping research in northeast Brazil were identified[1]. The work at CPATSA was organised under five projects four of which were proposed and approved after my arrival in 1982. They were:

1- Crop physiological studies in intercropping
2- Studies on plant population and spatial arrangements in intercropping
3- Intercrop responses to water, nutrients and their interactions
4- Evaluation of yield stability in intercropping
5- Intercropping studies in 'sertão' of Pernambuco (existing project mostly with genotype studies).

Research on 'key' combinations was supposed to cover all the above aspects. But in the first instance more emphasis was given to cereal/cowpea systems because of their importance. Others that received attention were systems with castor and cactus which have not received much attention earlier. No specific studies were planned on cotton as two studies were already under way at CPATSA and some information was available on this crop. However, a comprehensive review was prepared on systems based on cotton and cassava giving present results and perspectives for future research[2].

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[1]See Rao <u>et al</u>. (1982) under publications.

[2]See Rao & Morgado (1983a) under publications.

The climate and soils vary greatly in northeast Brazil giving rise to diverse agroclimatic regions. Results of any particular location can not be generalized for the entire region. In this context multi-location experiments covering a range of representative sites are very important. Petrolina ($9^o09'$ S, $40^o22'$ W) with 400 mm of annual rainfall represents the arid climate. Not only the present dryland agriculture around this region is limited but the potential also remains low because of low and highly variable rainfall. If CPATSA has to fulfill its mandate, that is to develop systems for the semi arid northeast Brazil, it is essential that it works cooperatively with the state enterprises which have research stations in various agroclimatic environments. Therefore, we emphasized that our experiments should be conducted at a number of locations in cooperation with other centers. But due to shortage of funds and lack of well established links with others, we could not extend our studies beyond Petrolina except with one experiment. However, our efforts to develop a cooperative program has come off well. For this purpose we organised two meetings, the first one during 10-11 November, 1982 at Petrolina to discuss the need for cooperative work in intercropping and establish links with state research units, and the second one during 24-28 October, 1983 at Teresina (Piauí state) to update the available information and identify gaps for future research. As a result of these the number of projects under the coordination of CPATSA have now increased considerably.

This report summarises the work done during the postrainy season of 1982 and the rainy and postrainy seasons of 1983. Besides giving the experimental results, suggestions are given for future research.

2 - STUDIES ON CEREAL/LEGUME INTERCROPPING SYSTEMS

'Sertão' is characterised by highly variable rainfall in terms of amount over seasons (400 - 750 mm/year) as well as in the onset and distribution within a given season. The poor and light textured latosols that predominate in this region have low water holding capacity and further compound the problem of drought and increase the risk of crop failure. Cowpea and maize together constitute the principal food crops of the region. The short cycle and drought tolerante cowpea is fairly well adapted to the local conditions and yields at least 300 to 500 kg/ha. Its importance to this region can be understood from the fact that much of the cowpea produced in the Northeast (about 91% of national production) is from 'sertão'. Maize being a somewhat later maturing and moisture sensitive crop fails frequently but it continues to be grown because it is the preferred cereal of the local people. Although these crops, individually or together, are intercropped with crops such as perennial cotton, cactus and cassava, intercropping of maize/cowpea itself is by far the most common 2 - crop system encountered in the 'sertão'. In a survey conducted by CPATSA (Centro de Pesquisa Agropecuária do Trópico Semi-Árido) in the Ouricuri region, it was observed that about 90% of the farms grew maize and cowpeas in various cropping systems and that maize/ cowpea intercrop accounted for 28% of intercropping (Miranda, 1983).

A set of experiments were conducted on cereal/legume intercropping at CPATSA Center, Petrolina in 1983 cropping season. The cereal could be the traditional maize or the alternatives such as sorghum or pearlmillet.

2.1- Effect of Plant Population and Row Arrangement on Maize/Cowpea

The objectives of this experiment were: (i) to find out the optimum population for maize and cowpea in intercropping, (ii) to determine the optimum row proportion of maize/cowpea intercrop for maximum land productivity and (iii) to understand the growth, development and resource use of a maize/cowpea intercrop in relation to the respective sole crops.

Materials & Methods: The study had six intercrop treatments, comprising the factorial combinations of two maize populations (25 000 and 50 000 plants/ha) and three cowpea populations (25 000, 50 000 and 75 000 plants/ha) in the most commonly used row arrangement of 1 maize : 2 cowpea, two treatments with the above two maize populations against a constant cowpea population of 50 000 plants/ha and the two sole crops at 50 000 plants/ha. The ten treatments were randomized in each of four replications. Rows were planted at a uniform spacing of 60 cm which gave a row width of 1.2 m for maize in alternate row arrangement and 1.8 m in alternate double row system. The plot was 4.8 m x 15 m for sole crops and 1:1 arrangement while it was 6 m x 15 m for 1:2. The idea of using such a big plot was to make periodical harvests for estimating leaf area and dry matter. We also intended to measure light interception and water and nutrient use but due to lack of sufficient staff and inability to acquair the necessary equipment forced us to postpone the resource use measurements to a later date.

The experiment was planted on 20 December 1982 on a light latosol in the Bebedouro Experimental Farm. Two supplemental irrigations were given on 7 & 15 January 1983 to facilitate gap filling and thinning respectively. These irrigations helped the maize seedlings survive the early drought, but no water was given thereafter. The area was fertilised basally with 50 kg P_2O_5/ha and maize was top dressed after thinning with 60 kg N/ha in two equal splits. The experiment was weeded thrice; cowpea required five sprays of Nuvacron while maize required one spay each of Ambush and Folimat. Rainfall during the experiment was 400 mm. Sadly, a rain of 63 mm on 14 March 1983 was accompanied by heavy winds and caused lodging in maize. Since the crop was in cob development at that time lodging was severe and it had to be

Table 2.1.1. Effect of plant population on maize/cowpea intercropping. 1983.

System	Cowpea Grain	Cowpea Hauls	Maize Total dry matter	Land Equivalent Ratio[1] Cowpea	Land Equivalent Ratio[1] Maize	Land Equivalent Ratio[1] Total
	(kg/ha)					
1 Maize : 1 Cowpea						
M_{25} C_{50}	280	691	3390	0.31	0.60	0.91
M_{50} C_{50}	117	574	5489	0.22	0.97	1.19
1 Maize : 2 Cowpea						
M_{25} C_{25}	278	816	2895	0.35	0.51	0.86
M_{25} C_{50}	403	1146	3121	0.50	0.55	1.05
M_{25} C_{75}	443	1250	2467	0.54	0.44	0.99
M_{50} C_{25}	247	720	3549	0.31	0.63	0.94
M_{50} C_{50}	188	538	4053	0.23	0.72	0.95
M_{50} C_{75}	269	694	3776	0.31	0.67	0.98
Sole Crops						
Maize	-	-	5664	—	1.00	1.00
Cowpea	1291	1830	—	1.00	—	1.00
SEI	68	124	562	—	—	—
'F' Tests						
Sole vs Intercrop	**	**	**			
M_{25} vs M_{50} in 1:2	*	*	*			
M_{25} vs M_{50} in 1:1	-	-	*			

[1]Calculated on the basis of dry matter yields.

*Significant at 5%, **Significant at 1%

harvested prematurely at 82 days. Cowpea matured in 80 days.

Results & Discussion: In the absence of maize yields and resource use data (Table 2.1.1.), only the main agronomic effects are considered. Both the crops grew well in sole cropping, cowpea produced 1291 kg/ha and maize 5.6 t/ha of dry matter. Cowpea was severely suppressed in intercropping by the excellent growth of maize, as a result of which it yielded only 10 to 34% of the sole crop. The competitive effect of maize was high in alternate rows and it increased with increase in population from 25 to 50 thousand plants/ha. Thus, cowpea yields in 1:2 arrangement averaged 235 kg/ha against 50 000 plants/ha compared to 375 kg/ha with 25 000 plants/ha, and in alternate rows, they were 117 and 280 kg/ha for the two maize populations respectively. Increasing the cowpea population improved its performance but higher than the sole crop optimum did not bring any additional advantage. The haulms yield was affected similarly as grain yield in intercropping.

Although the overall sole vs intercrop comparison was significant for maize yields, comparison of sole with each intercrop treatment was important because of significant differences due to maize populations. Intercrop yield in alternate rows was similar to that of sole crop when population across the two systems was same, but when the population was reduced to half of the sole crop density, yield decreased by 40%. In 1:2 arrangement, half the sole crop density averaged 50% of sole maize yield over different cowpea populations, but doubling the population to the level of sole crop density did not result in similar yield as the sole crop. It gave only 67% of sole crop yield which was because of closer within row spacing and consequently greater intraplant competition in 1:2 arrangement. Cowpea was competitive to maize, particularly in low maize population where an increase from 25 000 to 75 000 plants/ha had caused a 15% decrease in maize yield.

Land equivalent ratios[1] calculated on the basis of total dry matter did not indicate any substantial advantage for intercropping over the sole crops. The best advantage of 19% was observed in alternate rows with 'full' population of both the components. And whatever little advantage (5%) noted in 1:2 system was with half the population of maize plus 'full' population of cowpea. Thus, two clear situations were evident. Where maize is the principal component and expected to yield high (say 4 to 5 t/ha), the best strategy for intercropping is to plant full population of maize so that it gives its potential yield and allows some yield of cowpea which will be a bonus or additional yield. The arrangements that would accomodate 'full' population of maize are the alternate rows or both crops planted in the same row (as is common in parts of Minas Gerais). But on the contrary, where cowpea is more important, as is the case in the Northeast, full population of cowpea with a moderate population (about half the sole crop optimum) of maize seemed to be the appropriate combination. (More details on maize population can be had from another study described later). Then the suitable row arrangement would be 1 maize : 2 cowpea if the rows are at a closer spacing (50 to 60 cm) or alternate rows when rows are at a somewhat wider spacing (0.75 m to 1.0 m).

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[1]Land equivalent ratio is defined as sum of the land areas required for the sole crops to produce the same yields as from one ha of intercropping. It is calculated as follows:

$$\text{LER} = \frac{\text{yield of crop A in intercrop}}{\text{yield of crop A in sole}} + \frac{\text{yield of crop B in intercrop}}{\text{yield of crop B in sole}}$$

A LER greater than 1.0 indicates that the intercrop is advantageous over growing both sole crops together.

2.2- Effect of Plant Population and Row Arrangement in a Sorghum/ Cowpea Intercropping

Farmers in northeast Brazil continue to grow maize for home consumption despite the fact that it is highly sensitive to stress and occurrence of drought is a common phenomenon in this region. Some attempts have been made by state research organizations, particularly that of Pernambuco, to substitute maize with sorghum in the traditional cropping systems. These results have shown that sorghum is not only more productive but also more stable than maize (IPA, 1981; Rao & Morgado, 1983). However, no information is available on how sorghum compares with maize, optimum population, and row arrangement for intercropping in the very dry areas such as Petrolina, so the following experiment was conducted to get some information on the above.

Materials & Methods: Factorial combinations of three populations of sorghum and three of cowpea were examined in each of two row arrangements, 1 sorghum : 2 cowpea and 1 sorghum : 3 cowpea. The cowpea populations in both arrangements were 20 000, 40 000 and 60 000 plants/ha while that of sorghum were 30 000, 60 000 and 90 000 plants/ha in 1:2 and 22 500, 45 000 and 67 500 plants/ha in 1:3. There were four additional treatments, a standard maize/ cowpea intercrop and the three sole crops of maize (50 000 plants/ ha), sorghum (150 000 plants/ha) and cowpea (40 000 plants/ha). The 22 treatments were tried in a randomised block design with three replications. The plot size was 5 m x 8 m having ten rows at 50 cm apart. Six rows (2 cereal plus 4 cowpea in 1:2 and 1 sorghum plus 5 cowpea in 1:3) of 6 m length were harvested for yield. Planting was done on 20 January 1983 using 3 to 4 seeds per hill, but thinned three weeks later to the required stand. Fifty kg of P_2O_5/ha was band placed at planting and sorghum and maize were top dressed with 40 kg N/ha in two equal splits. The crops were weeded and sprayed as and when needed. Cowpea was harvested 63 days after planting and sorghum after 123 days. Maize failed to

Table 2.2.1

Effect of plant population and row arrangement in sorghum/cowpea intercropping, Petrolina 1982. (Kg/ha)

Arrangement	Sorghum	Cowpea	LER	Arrangement	Sorghum	Cowpea	LER
1 Sorghum: 2 Cowpea				1 Sorghum: 3 Cowpea			
S 30000 C 20000	384	59		S 22500 C 20000	302	43	
S 30000 C 40000	291	114		S 22500 C 40000	433	137	
S 30000 C 60000	205	137		S 22500 C 60000	844	118	
S 60000 C 20000	331	47		S 45000 C 20000	509	56	
S 60000 C 40000	481	101		S 45000 C 40000	963	109	
S 60000 C 60000	302	85		S 45000 C 60000	297	100	
S 90000 C 20000	280	49		S 67500 C 20000	305	35	
S 90000 C 40000	42	60		S 67500 C 40000	888	103	
S 90000 C 60000	916	137		S 67500 C 60000	300	97	
1 Maize: 2 Cowpea		92					
Sole Crops							
Sorghum	30						
Maize	-	-					
Cowpea		205					

produce any yield.

Results & Discussion: Although the crops established and grew well in the beginning, they did not give reasonable yields because of severe moisture stress (Table 2.1.1). As a sole crop, the early maturing cowpea gave only 205 kg/ha and it produced much lower yields in intercropping varying from 35 to 137 kg/ha. Sorghum yields were highly variable across the intercrop treatments (42 to 963 kg/ha), and in sole cropping it produced only 30 kg/ha. Under these circumstances one can not draw any useful conclusions. However, the results did give some guidelines for future studies.

The population used for sole sorghum i.e. 150 000 plants/ha appeared to be very high for the limited rainfall conditions at Petrolina. Probably, the available moisture here can not support more than 75 to 90 thousand plants/ha. Sorghum was wide apart in 1 sorghum : 3 cowpea and considering the limited moisture and poor growth of the cereal, only the 1:1 and 1:2 arrangements seem to be worth examining. Maize definitly is a risky crop for the Northeast and it should be discouraged wherever rainfall is less than 500 mm for the cropping period. While sorghum gave some grain and stover, maize failed to produce any thing. Cowpea was very much affected by sorghum in intercropping and increasing the population of sorghum still increased its competitiveness. Therefore, if one requires to preserve a high proportion of cowpea yield in intercroppign, sorghum must be planted at a low population.

2.3- Intercropping of Pearlmillet with Cowpea

Pearlmillet (<u>Pennisetum americanum</u>) is a short cycle cereal grown throughout the semi arid tropics of India and Africa. It completes its cycle in 70 to 90 days and is well adapted to low moisture conditions. It provides nutritive human food and can be used to feed animals. Since rainfall in 'sertão' is low and variable it can be a good alternative to the presently

Table 2.3.1

Effect of millet and cowpea population on yields and LER in millet/cowpea intercropping. Petrolina, 1983.

Millet population (1000 plantes/ha)	Cowpea population (1000 plantes/ha)											
	(sole millet) 0	20	40	60	Mean	20	40	60	Mean	20	40	60
	Millet yield (kg/ha)					Cowpea yield (kg/ha)				Land Equivalent Ratio		
50 (16,7)	627	342	333	192	374	148	178	233	186	0.79	0.85	0.72
100 (33,3)	744	492	267	271	444	86	117	144	116	0.85	0.62	0.69
200 (66,6)	494	539	529	350	478	64	104	79	82	0.87	0.95	0.64
Sole cowpea	-	-	-	-	-	446	367	361	391	1.00	-	-
Mean	621	458	376	271		186	192	204				
SE		78					29				0.14	
LSD (0.05)		228					84				-	

LERs were calculated using the highest yields of 744 kg/ha of millet and 446 kg/ha of cowpea in sole cropping.

grown cereal, maize, which is highly sensitive to moisture stress. Millet was tested in Petrolina under irrigation in 1977 (Silva et al. 1981) but was never examined under rainfed condition. So the following experiment was conducted to i) explore the potential of millet under rainfed conditions ii) find out the scope of intercropping it with the traditionally grown legume of the region, cowpea and iii) to find out the optimum population in sole and intercropping.

Materials & Methods: The experiment had three populations of millet in sole cropping (50 000, 100 000 and 200 000 plants/ha), three populations of sole cowpea (20 000, 40 000 and 60 000 plants/ha) and the nine factorial combinations of the above in intercropping. The intercrop was planted in an arrangement of 1 millet : 2 cowpea using only 1/3 populations of sole millet corresponding to the spatial arrangement. Thus, the intercrop millet populations were 16 667, 33 333 and 66 666 plants/ha. The trial was conducted in a randomised block design with three replications. Plot size was 5 m x 8 m containing ten rows at a uniform row spacing of 50 cm. The harvest area was six rows from 3 m x 6 m.

Both crops were planted simultaneously on 24 January 1983. The soil under the experiment was a shallow sandy reddish yellow podzol with low water holding capacity (about 60 mm) and low nutrient status. Rainfall during the period of crop growth was 280 mm. The area was fertilized with 50 kg P_2O_5/ha basally and later millet was fertilized with 40 kg N/ha in sole cropping. The intercropped millet received 1/3 that of the sole crop. Cowpea was given four sprays of Nuvacron (20 mℓ/20 ℓ of water). The genotypes were millet: Synthetic 1, which matured in 80 days and cowpea: Pitiuba matured in 60 days.

Results & Discussion: Millet and cowpea grain yields along with the land equivalent ratios for intercropping treatments are given in Table 2.3.1-. Sole millet gave the maximum yield of 744 kg/ha at 100 000 plants/ha. The low population of 50 000 plants/ha gave only slightly lower yield than the above, but higher than 100 000 plants/ha caused a decrease in yield. In the case of sole cowpea, the lowest population of 20 000 plants/ha gave the maximum yield (446 kg/ha) and higher populations than this had a negative effect on yield. These results indicate that high populations would be detrimental to yield under limited moisture conditions.

Intercropped millet responded to population up to the highest level tested (66 667 plants/ha) at each of the cowpea populations. At the first level of population (16 667 plants/ha) it yielded about 55% of the corresponding sole crop which decreased to 31% of the sole crop with increase in cowpea population to 60 000 plants/ha. At the second level, intercropped millet produced 66% of the sole crop at 20 000 plants/ha of cowpea but it gave only 36% of the sole crop at 60 000 plants/ha of cowpea. At the highest population, intercrop yield was lower than that of the sole crop only at the highest cowpea population. Millet was more competitive to cowpea and caused considerable reduction in cowpea yields. The competitive effect of millet was higher particularly at higher populations. The combined yields of the two crops, expressed in the form of land equivalent ratios, were lower than 1.0 indicating no advantage for intercropping over sole crops. The available moisture was sufficient to support only 20 000 plants/ha of cowpea. But all the intercrop treatments had the additional population of millet over and above that of cowpea which might have increased competition for water and resulted in lower yields than in sole crops.

Given the poor moisture conditions of the experiment, the performance of sole millet and sole cowpea was creditable. The millet yield of 744 kg/ha was particularly valuable considering that maize in the adjoining experiments failed completely and sorghum gave poor yields. These results confirm the usefulness of millet for the arid climate of 'sertão'. However, under these conditions the popular practice of intercropping does not seem to be advantageous over sole cropping. Further tests are required before firm conclusions can be drawn. The genotype used in the study developed a leaf blight probably associated with Drechslera sp.. More genotypes of millet have to be evaluated for assessing the full potential of millet and to identify less disease susceptable cultivars before it can be recommended. The 50 cm row spacing used in the present trial seemed to be too close for field operations, and 1:2 arrangement would be difficult to adapt to improved land management systems. It is worth examining the alternate row arrangement at 75 cm row spacing.

2.4- Effect of Continuous Variable Moisture and Population on Maize/Cowpea Intercropping

Research to improve the traditional practice of maize/cowpea intercropping has been limited and whatever that has happened was outside the main 'sertão'. However, Rao and Morgado (1983) summarised the results of 34 experiments conducted in the northeast and found that maize/cowpea intercrop would give 41% higher yields over the sole crops. Similar yield advantage was noted for this combination in other semi arid regions (Enyi 1973; Remison, 1980). Another advantage of intercropping is that it provides insurance against the vagaries of weather. But the relationship between intercropping advantage and water has not been very clear. Rao and Morgado (1983) did not observe any discernible relationship between LER advantage and rainfall. Studies conducted at ICRISAT on similar other combinations such as millet/groundnut indicated that the relative advantage of intercropping increased with some degree of stress but decreased thereafter. However, the intercrops were still advantageous over sole crops under severe stress (ICRISAT, 1981). On the contrary, Fisher (1977) and Stewart (1982) working in Kenya observed that maize/beans intercropping does not offer any advantage over sole cropping under limited moisture. Within the Northeast, Mafra et al. (1979) and Lira et al. (1978) found that intercrops of maize/beans were advantageous only in good rainfall years. These contradicting results raised doubts whether intercropping offers any genuine advantage over sole crops especially in drought prone areas.

Generally 40 000 to 50 000 plants/ha have been found to be optimum for sole crops of maize and cowpea (Espinoza et al. 1980, Dale and Shaw, 1965 Braga Paiva & Albuquerque, 1970) while in intercropping alternate rows or 1 maize : 2 cowpea with half the optimum of sole maize and full population of cowpea have given the maximum advantage (Rao and Morgado, 1983). However, these populations can not be generalised to all situations, considering the strong plant population x moisture interactions and highly variable seasonal moisture in 'sertão'. To cite an example, studies of Stewart (1982) and Espinoza et al. (1980) showed that under poor moisture conditions 20 000 plants/ha is sufficient for sole maize. Very little quantitative information is available on the effects of population x water in intercropping and this can be obtained only through studies with controlled water application. In this context the following experiment was taken up to study i) the effect of different levels of water application on intercropping advantage of maize/cowpea and ii) to determine the optimum populations for maize and cowpea in sole and intercropping at different moisture regimes.

Materials & Methods: The experiment was conducted in the nonrainy period during May to September 1983 at the Bebedouro Experimental Farm of CPATSA Center. The soil was a light textured latosol of medium depth but with poor nutrient status (Table 2.4.1). The treatments consisted of three populations of 20 000, 40 000 and 60 000 plants/ha for sole maize and sole cowpea (M_1, M_2 & M_3 for maize and C_1, C_2 & C_3 for cowpea respectively) and three intercropping treatments with 10 000, 20 000 and 40 000 plants/ha of maize against a constant cowpea population of 40 000 plants/ha (m_1C_2, m_2C_2 & m_3C_2 respectively). A high population of cowpea was used in intercropping because it is the important component. These nine treatments were randomised in each of four replications, two

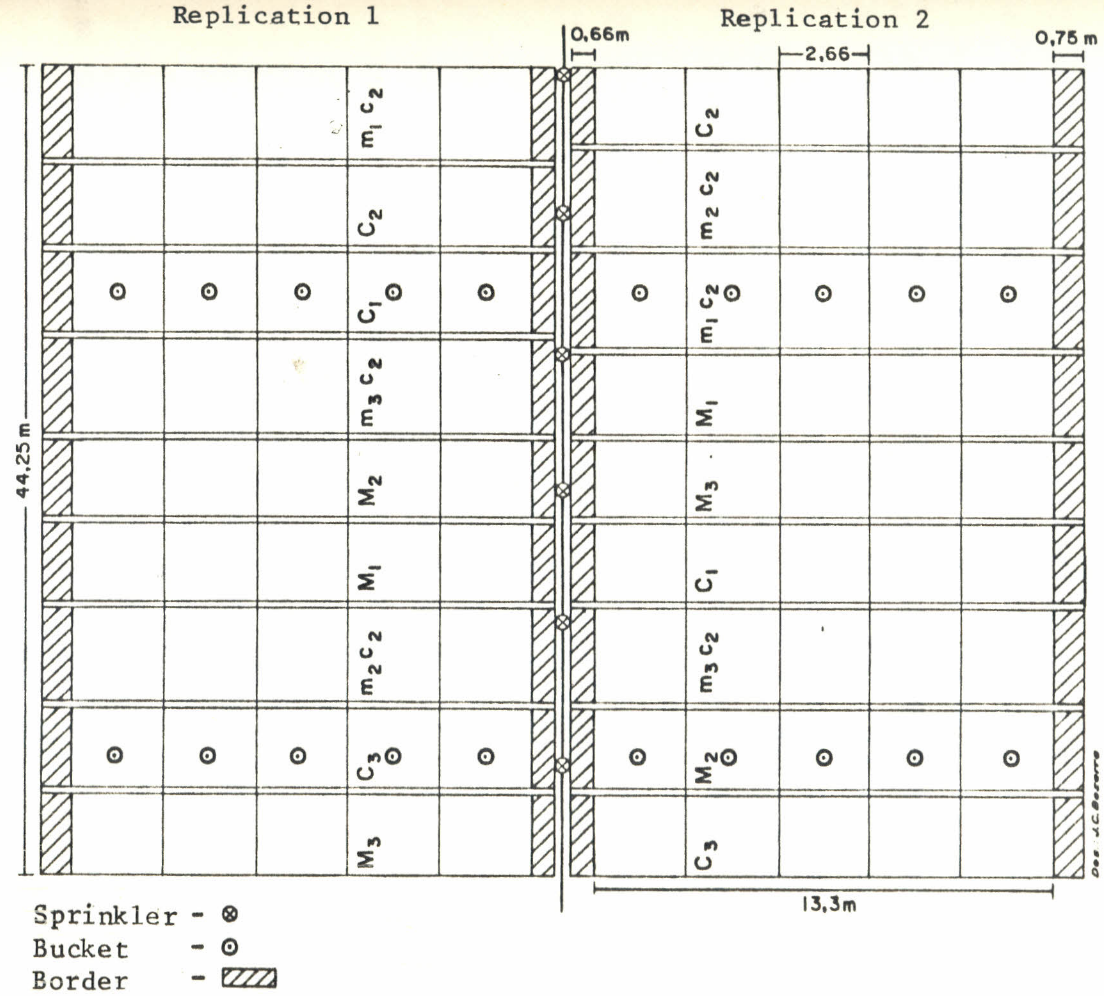


Fig. 2.4.1.- Field layout of two replications and the line-source sprinkler system.

each were located on either side of a sprinkler line (Fig. 2.4.1). Different levels of water application was created across the plots by a closely spaced (6 m apart) sprinkler line which produces a water application pattern that is uniform along the line but is variable across the line, applying maximum near the line and decreases with distance away from the line with little or no water at about 14 m (Hanks *et al*. 1976). The experiment was laid out such that the sprinkler line lies parallel to the prevailing wind (East-West) to minimise the effect of wind on water application, and for the same reason irrigations were given in the evening when wind velocity was minimum. The crop rows were perpendicular to the sprincker line. The plot size was 14.5 m length and 3.75 m width in the case of sole crops (5 rows) and the same lenth but 5.25 m width in the case of intercropping (7 rows). Leaving a border of 0.66 m on either ends, it was devided into five subplots of 2.66 m which gave whole number of plants for all populations used in the study. At each irrigation small bucket collectors were placed at the center of the subplot to measure the quantity of water applied. The water measured at the center was treated as the water applied to that subplot. The sprinklers were operated at about 3 bars pressure and in most occasions they wetted a radius of 13 to 14 m. For convenience of measuring, the buckets were positioned in the plots of low canopy sole cowpea and they were raised with the height of the crop using stones. Water applied through uniform irrigations was also measured by keeping buckets at random over the experimental area.

Sowing was done on 23-24 May using 3 to 4 seeds per hill. Both the crops were planted in 75 cm rows and the intercrop was in alternate rows at 75 cm. A basal dose of 50 kg P_2O_5/ha was applied. An uniform irrigation of 30 mm was applied on 25 May. Another uniform irrigation was given on first June and soon the crops were thinned to the required stand. Forty kg of nitrogen/ha were applied to sole maize in two splits, one half after thinning and the other half one month later followed by an uniform irrigation. A total of 87 mm was given by the three uniform irrigations. Further irrigations (7 in number) were given by the line source system, applying at each time about 40 to 45 mm in the first subplot (Fig. 2). The total water applied, including the 87 mm of uniform irrigations and 18 mm of rain during the experiment, was 391, 356, 281, 196 and 124 mm for the maize cycle and 295, 273, 213, 149 and 112 mm for the cycle of cowpea respectively in the five subplots from the sprinkler line. The pan evaporation was 542 mm during cowpea growth and 910 mm for the maize period. The crops were weeded and protected against pests as and when necessary. Cowpea was sprayed twice, once with Nuvacron against jassids and aphids and another time with Ambush to control borers. Maize required three sprays of Ambush to control stem borers. Cowpea was harvested on 3 August, 70 days after planting, whereas maize was harvested on 15 September, 113 days after planting.

Grain and stover yields were estimated from each subplot by harvesting two central rows of 2.66 m length in sole crops and four rows (2 maize and 2 cowpea) in intercropping. But, however, only the grain yield is considered here to illustrate the adaptation of line source system for an intercropping study and the effects of water and populations. Fertility variation affected the treatment effects in one replication, so in the final analysis the results of only three replications were considered. Since the moisture levels were not randomized, a formal analysis of variance can not be done. But to provide some basis for comparison of the effects of treatments, the results were analysed as for the strip-plot design which is the nearest one to the layout where strips of populations and cropping systems were running in one direction across the strips of moisture levels in another direction. (~~Table 1~~ Fig. 2.4.1). In such of these designs with systematic arrangement, the best approach would be to fit appropriate regressions between yield and the concerned factor and analyse the trends of the effects. So regressions were fitted between total water applied and yields at each population of different systems. Land equivalent ratios were calculated

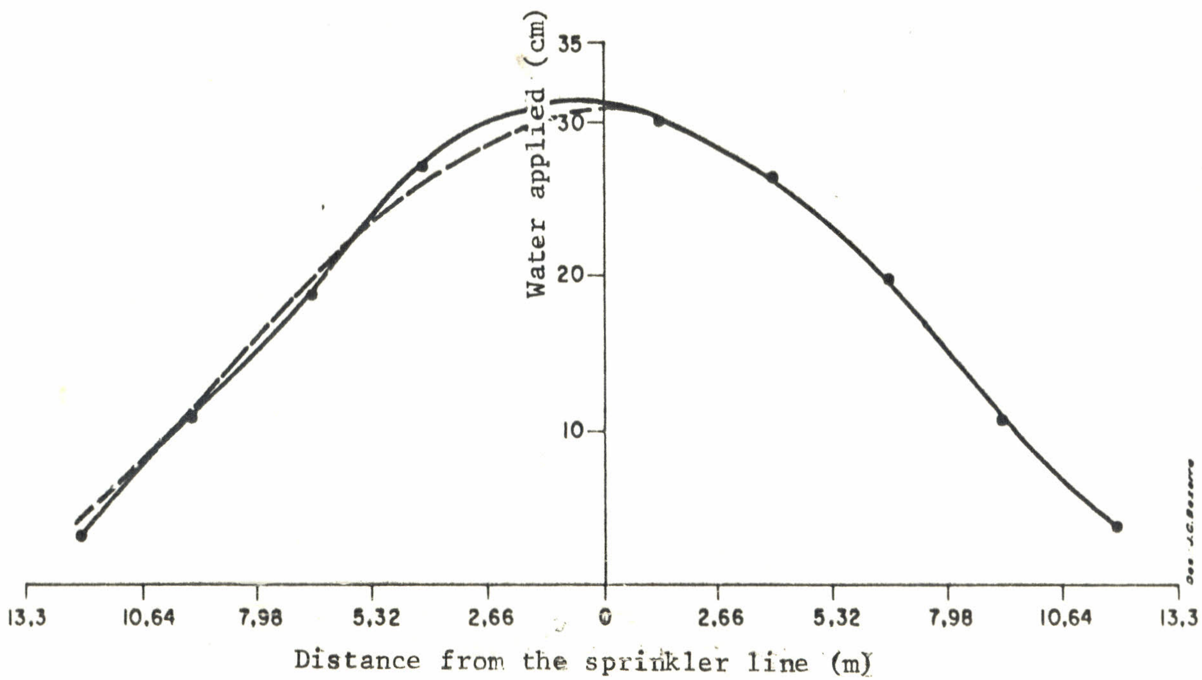


Fig. 2.4.2.- Differential quantities of total water applied through line-source on both sides of the line.

Table 2.4.1 Characterization of soil under the maize/cowpea intercropping studies, 1982.

Texture			Bulk density	Moisture at		Organic matter	Available nutrients		
Sand	Silt (%)	Clay	-(g/cc)-	1/3 bar (%)	15 bar	%	P (ppm)	K me/100g	NO_3 ppm
86	3	11	1.54	7.41	3.76	0.41	12	0.18	39
88	2	10	1.52	6.95	3.22	0.46	14	0.19	39

Table 2.4.2 Analysis of variance for maize and cowpea yields.

Source	Degrees of freedom	Maize yield		Cowpea yield	
		Mean Squares	F	Mean Squares	F
Replication	2	3,040,123.87	2.01	47,166.14	< 1
Sole vs Intercrop Systems	1	13,042,401.36	8.60*	2,327,419.22	34.5**
Populations within sole	2	52,258.40	< 1	11,310.86	< 1
Populations within intercrop	2	346,214.86	< 1	139,870.69	2.07
Error (a)	10	1,510,745.25		67,511.30	
Moisture	4	10,736,363.63	37.76**	53,162.69	3.42
Error (b)	8	284,287.27		15,559.27	
Population in sole x moisture	8	702,004.01	2.03	14,873.64	< 1
Population in intercrop x moisture	8	200,353.2	< 1	1,792.44	< 1
System x moisture	4	431,451.93	1.25	42,188.57	2.45
Error (c)	40	344,420.71		17,018.01	
Total	89				

* Significant at 5%. ** Significant at 1%

using the computed yields from these regressions.

Results & Discussion: The variable quantities of water applied through the line source system is shown in Fig. 2.4.2. The applied water remained fairly uniform on either side except on two occasions when wind affected the distribution pattern, once applying more water on northern side and on another occasion more on southern side. As a result of the above differences in opposite directions, the total water applied was similar on both sides and deviation from the expected (indicated by broken line in Fig. 2.4.2) was small. In view of this, the results were averaged over three replications.

Maize and cowpea yields in sole and intercropping systems along with the fitted regressions are shown in Fig. 2.4.3. and Table 2.4.3. The intercrop maize yields were significantly lower than those of sole maize (Table 2.4.2). They varied from 44% to 83% of the sole crop at different maize populations. This was because population in intercropping was only 50% of that of sole crop at the first two levels and 66% at the highest level. Besides this, cowpea might have given some competition to maize in intercropping. Maize yields increased with increase in the available moisture. It also responded to population but the response was determined by the available moisture. Similary, the population x moisture interaction was also dependent on the cropping system. At 20 000 plants/ha, sole maize reached its peak yields at 356 mm and dropped a little at the highest moisture. On the contrary, yield at 40 and 60 thousand plants/ha increased linearly with water suggesting that the available water was not sufficient for these high populations to reach their potential yields. However, intercrop maize yields increased linearly at all the three populations. In other words maize associated with cowpea required more water than the corresponding sole crop treatments.

The interaction of water x population in sole cropping was significant at 10% probability. Response to population was

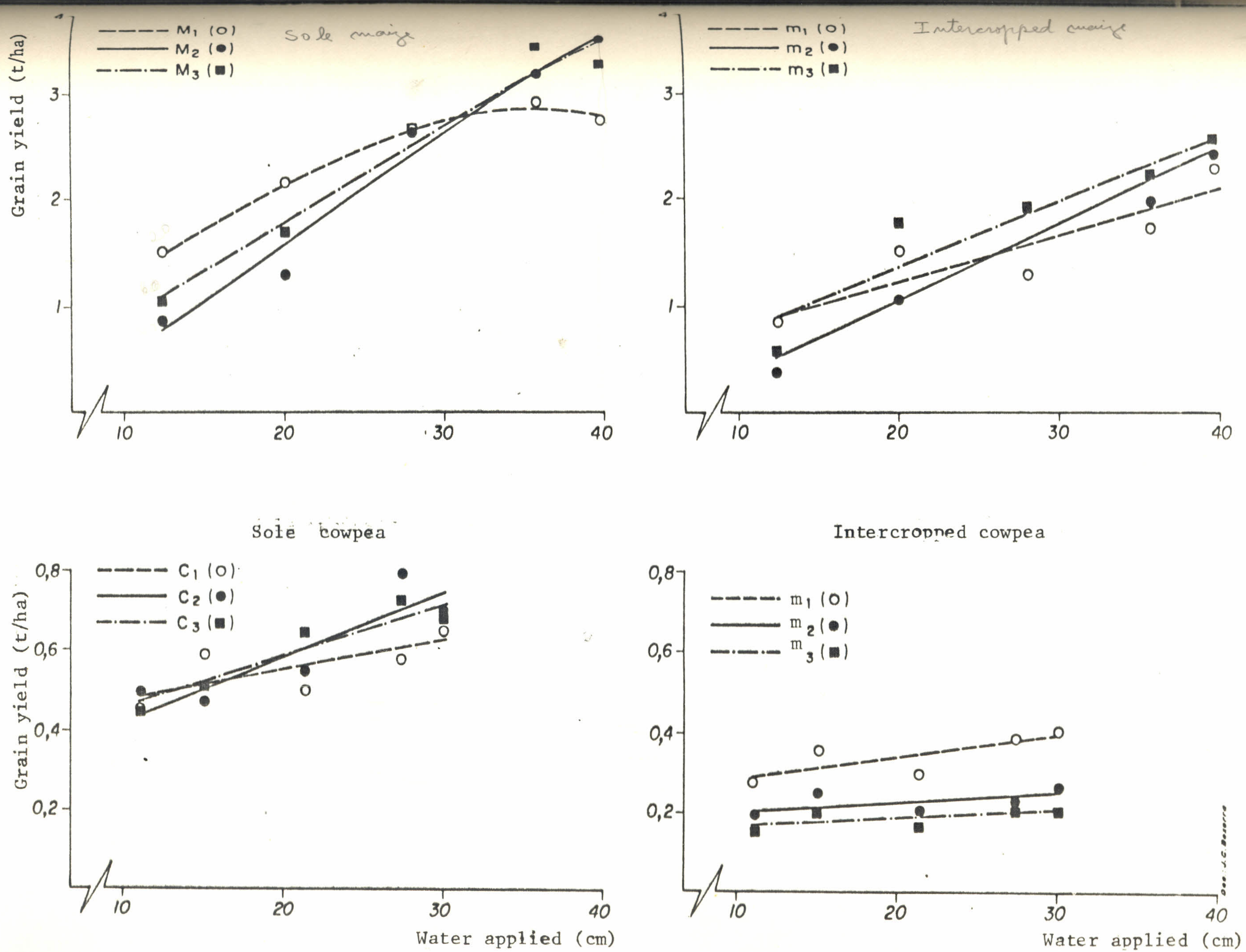


Fig. 2.4.3.- Grain yields of maize and cowpea in sole and intercropping.

significant up to 40 000 plants/ha at the first two moisture levels. At the third level (281 mm) all the three populations gave similar yields, but at the two lower levels 20 000 plants/ha gave the highest yields. Obviously, under limited moisture high populations suffered from stress effects more than the low populations. The population x water interaction was not significant in intercropping but the effects to a certain extent were similar to those observed in sole cropping. The advantage of high populations (20 000 and 40 000 plants/ha) was noticed up to 281 mm below which the low population of maize (10 000 plants/ha) was found to give higher yields.

Cowpea yields also increased with moisture, but unlike in the case of maize the rate of response was less, probably due to its low water requirement. It gave about 450 kg/ha with 112 mm of water and increase in yield for an additional 200 mm of water was only 250 to 300 kg/ha. Compared to this, maize gave an increase of 600 to 1800 kg depending on the population. Unlike in the case of maize, where the fitted regressions between yield and the applied water explained 76% to 99% variation in yield, the regressions in the case of cowpea could explain only 53% to 90% variation, that too only in sole crop (Table 2.4.3). There was no significant relationship between yield and water in intercropping implying that besides moisture other factors (such as competition from maize) might have affected the yield heavily in this system. Response of cowpea to population was also not marked. The populations of 40 and 60 thousand plants/ha gave only slightly higher yields over 20 000 plants/ha up to 213 mm of water, but the differences between the three populations narrowed at less than the above water level. Thus, cowpea was less responsive to the inputs of water and populations. Intercropping affected cowpea yields significantly and the drop was more with higher populations of maize. Its yield in association with 20 000 and 40 000 plants/ha of maize were only half that obtained with 10 000 plants/ha of maize.

Table 2.4.3.- Fitted regressions for maize and cowpea yields against the applied water.

Sole maize

M_1	$y = -221 + 16.72x - 0.0229\,x^2$	$r^2 = 0.99$
M_2	$y = -549.86 + 10.65x$	$r^2 = 0.98$
M_3	$y = -47.4 + 9.21x$	$r^2 = 0.96$

Intercrop

M_1	$y = 383 + 4.24x$	$r^2 = 0.76$
M_2	$y = -384 + 7.15x$	$r^2 = 0.94$
M_3	$y = 119 + 6.2x$	$r^2 = 0.86$

Sole cowpea

C_1	$y = 405 + 0.71x$	$r^2 = 0.53$
C_2	$y = 261 + 1.64x$	$r^2 = 0.77$
C_3	$y = 307 + 1.39x$	$r^2 = 0.90$

Both maize and cowpea gave fairly good yields (1515 kg/ha at M_1 population and 456 kg/ha at C_1 population respectively) even at the lowest quantify of water applied i.e. 124 mm and 112 mm of water respectively. This raised doubts whether the crops were benefitting from water table. The CPATSA Experimental Farm is situated in the middle of the Bebedouro irrigation project where water table has been generally high. In the experimental area there was no free water table within 1 1/2 m but the profile had moisture below 60 cm depth at the time of sowing. Periodic observations did not indicate the presence of water table within the root zone but it might still be possible that the crops, particularly cowpea, benefitted from sub soil moisture. This gains strength from the fact that while the regressions of maize yields against available water had negative intercepts, those of cowpea had positive intercepts. Therefore, the results of the study have to be considered in the light of this limitation.

Land equivalent ratios (LER): LER's of individual components and totals of different intercrop treatments are given in Fig. 2.4.4. These were calculated at each moisture level using the highest sole crop yields, that is the yields of M_2 and C_2 in 1 to 3 moisture levels and those of M_1 and C_1 in the remaining moisture levels. At m_1 population, the proportional yields of maize and cowpea were similar in good moisture, but with decrease in moisture, cowpea became more competitive and increased its proportional yield over that of maize. The total LER's exceeded 1.0 at all moisture levels and the best of 20% advantage was noted in the range of 200 to 280 mm of applied water. At lower than 200 mm of water the advantage dropped to 10%. At m_2 population, maize was competitive to cowpea up to 280 mm of water producing 67% of the sole crop yields. Cowpea was again dominant at the other extreme of moisture. Total LER's at this population did not exceed 1.0 at any of the water levels indicating no advantage for intercropping over sole crops. In fact, it was disadvantageous in low moisture regimes. At m_3 level, maize was much more dominant to

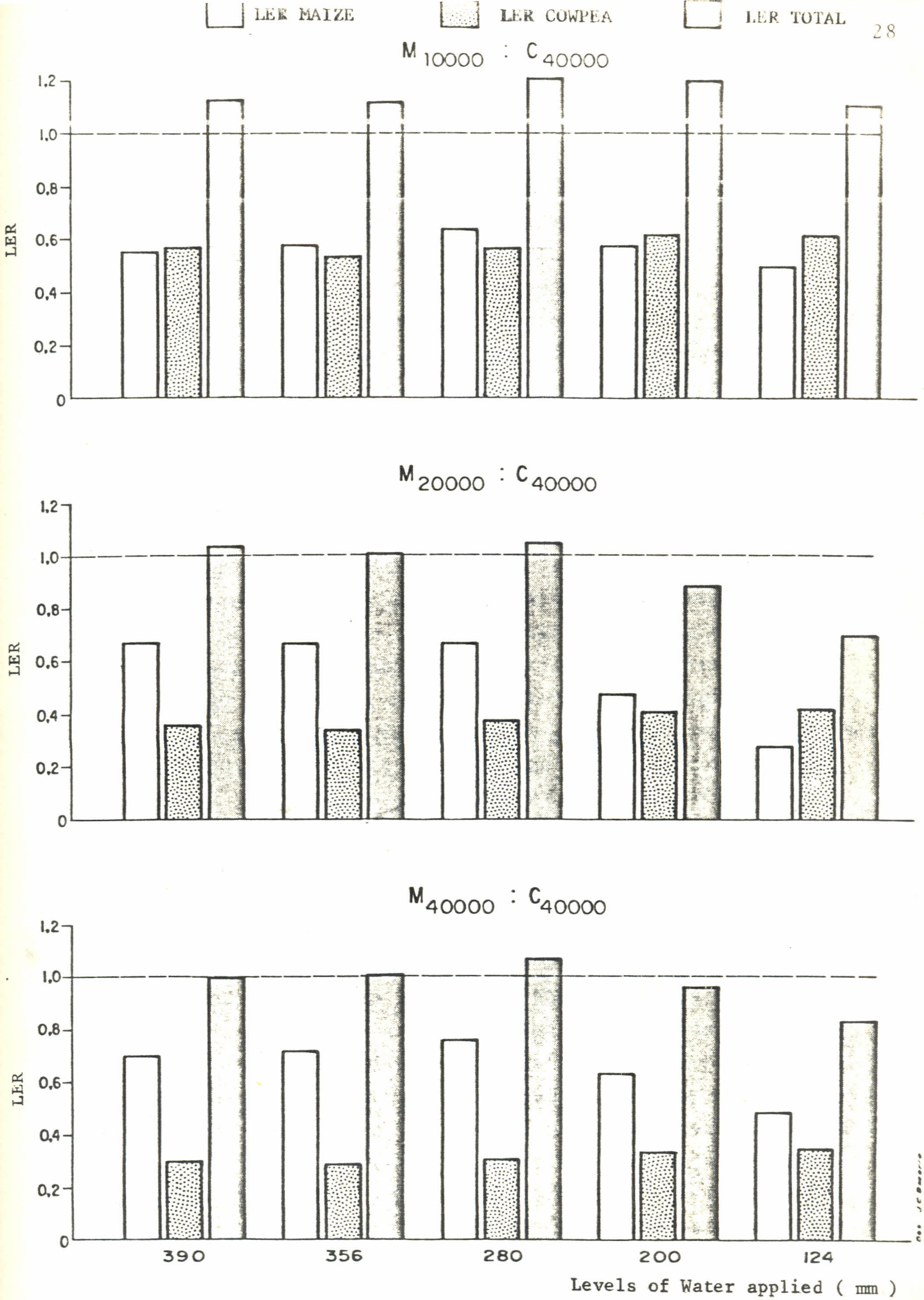


Fig. 2.4.4.- Land equivalent ratios of maize/cowpea intercropping at different densities of maize and levels of water.

cowpea throughout the moisture levels, although yields decreased from 70% to 49% of the corresponding sole crop with a decrease in moisture from 390 to 124 mm. Intercropping again did not present any advantage over sole cropping. The advantage of having low populations in low moisture regimes would be evident much more clearly if LER's were to be calculated using the sole crop yields of the generally recommended 40 000 plants/ha. While intercropping with high maize populations (m_2 and m_3) did not show any advantage over sole crops, the same with low maize population (m_1) gave 30% and 47% higher yields at 196 mm and 124 mm of applied water respectively.

The advantage of intercropping was thus confined to only the combinations of cowpea with low population of maize and 200 mm and above of applied water. Subsistence farmers interested in both the components can opt for this system as it represents an efficient land use practice. Although intercropping did not show worthwhile advantage when maize population was increased from 10 000 to 20 000 plants/ha, absolute yields were higher with high population in better moisture conditions. However, most experiments that reported 20% to 30% yield advantage for this combination have used 20 to 25 thousand plants/ha of maize and 40 to 50 thousand plants/ha of cowpea (Rao and Morgado, 1983; Mafra et al. 1979; Faris et al. 1983). The strategy in rainfed agriculture should be such that the selected system exploits fully the better water resources in a good year and yet does not run into the risk of total loss in a poor year. Since the type of season ahead can not be predicted in advance and hence the appropriate system, the ideal approach seems to be to plant high populations initially and thin later to the required stand as the season progresses. If the season appears to be normal with 300 mm or more of effective rainfall 20 000 plants/ha of maize can be maintained, but if the available water is likely to fall short of this quantity the maize stand is thinned to 10 000 plants/ha. If the rainfall is doubtful to provide at least 200 mm of available water maize may be completely removed leaving only the drought tolerant cowpea to mature. Such a flexibility in the system enables it to make efficient use of the available resources in any given season with little risk.

Water was applied in this experiment in small quantities and at regular intervals, so a high percent (say 90%) of it must have been utilized by the crop. This may not be the case with rainfall in real world situation. Rainfall is highly variable within and over seasons in the semi arid tropics which coupled with shallow soils make only 50% to 60% of the seasonal rainfall to be effective for crop growth. On this basis, the results of the present experiment suggest that intercropping may not give worthwhile advantages over sole cropping if the rainfall is less than 350 mm. A majority of experiments conducted at CPATSA in the last 3 to 4 years on maize/cowpea and moco cotton/cowpea did not show any advantage for intercropping when rainfall was 300 to 400 mm per year. However, further experimentation is required to confirm these results and to identify alternate crops and crop combinations that may have potential for this region.

Farmers interested in total returns would be better off by growing sole maize because of its higher yield potential. Returns from cowpea did not match those of maize due to low yields, and they would be comparable only if cowpea is valued four times that of maize. Of course,the potential of cowpea might have been underestimated in this study because of low temperature during May to August. Although intercrop returns were higher than those from sole cowpea, they were lower than those of sole maize. Intercropping will be remunerative to sole maize provided cowpea is three times more costlier than maize. At present cowpea costs only 1.8 times that of maize.

2.5- Weed Control by Herbicides in Cereal/Legume Intercropping Systems

Weeds cause severe yield losses in the semi-arid tropics. Small farmers in the Northeast generally control weeds manually using a hand implement called 'enxada' (a spade with long handle). Herbicide use is limited to only cash crops in the 'mata' zone. Labour is not often sufficient to cope with the weeds and it is a common sight to observe crops heavily infested with weeds. Herbicides are definitly beyond the reach of subsistence farmers, but those who operate more than 10 ha holding may have to depend on them for timely and efficient weed control, because the limited family labour may not be sufficient and hired labour is scarce during periods of peak agricultural activity. But selection of suitable herbicides for intercropping systems is not an easy task particularly for those with diverse crops such as cereal/legume systems. A preliminary experiment was conducted to evaluate the efficacy of some promising herbicides on maize/cowpea and sorghum/cowpea systems.

Materials & Methods: Three herbicides were examined each at two levels in maize/cowpea and sorghum/cowpea systems. These twelve treatments together with two weed free checks, one each for the two cropping systems, were evaluated in two replications of a randomised block design. Details of the herbicide treatments are as follows:

Herbicide	Doses used (ℓ/ha)		Type of application
Dual (Metolachlor)	2,5,	5,0	pre-emergence
Herbadox (Pendimenthalin)	2.0,	4.0	pre-emergence
Basagran (Bentazon)	1.5,	3.0	post-emergence

The crops were planted on 2 May 1983 on 75 cm ridges. Each plot was 5.25 m x 6.0 m with seven rows and in intercropping the row arrangement was 1 cereal : 1 cowpea. The pre-emergence herbicides were applied on 4 May 1983 while the post-emergence one was applied on 24 May after the weeds appeared. The area was fertilized with 50 kg P_2O_5/ha basally and the cereals were top dressed later with 40 kg N/ha in two split doses. There was a

TABLE 5.2.1 Effect of weed control by herbicides in maize/cowpea and sorghum/cowpea intercropping.

Herbicide	Maize-Cowpea Intercropping: Yield (kg/ha)		Yield as % check		LER[1]	Sorghum[2]-Cowpea	
	Maize	cowpea	Maize	Cowpea		Cowpea (kg/ha)	% Check
Dual (2.5 ℓ)	3910	285	110	90	1.11	288	90
Dual (5.0 ℓ)	2660	320	75	100	0.89	192	60
Herbadox (2.0 ℓ)	2503	377	71	119	0.92	634	198
Herbadox (4.0 ℓ)	1870	356	53	112	0.77	455	142
Basagran (1.5 ℓ)	2243	342	63	108	0.83	320	100
Basagran (3.0 ℓ)	2874	224	81	71	0.83	185	58
Weed free check	3543	317	100	100	1.07	320	100

[1] LERs were calculated using the yields obtained for sole maize (4877 kg/ha) and cowpea (922 kg/ha) in a neighbouring experiment conducted in the same period using the same cultivars.

[2] Sorghum stand was not uniform and was damaged by birds severely.

heavy and uniform infestation of weeds in the experimentation area. The crops were irrigated (15 irrigations) and protected against pests as and when needed. The weed free checks were weeded thrice to keep off the weeds. Cowpea (Pitiuba) completed its cycle in 76 days, and maize (Centralmex) matured in 128 days. Sorghum did not establish well and was also heavily damaged by birds. Yields were estimated from a harvest area of 3.0 m x 4.68 m.

Results & Discussion: The herbicide Dual controlled weeds reasonably well. Cowpea exhibited mild phytotoxicity in the form of wrinkled leaves in the beginning, but it soon recovered and grew normally. However, 2.5 ℓ/ha seemed to bring about good weed control and it should be preferred over 5 ℓ/ha as a safe level to both the crops. Both crops produced almost similar yields as that of weed free check and the combined yields showed a 11% advantage for intercropping over sole crops. At 5.0 ℓ/ha maize yield was affected resulting in a total LER of only 0.89. Herbadox did not cause any injury to the crops but was less effective against weeds. Hence maize yields were 30% to 47% less compared to the check. Cowpea yields were normal because of less competition from maize. Basagran caused leaf burning in cowpea and was not as effective as Dual against weeds. Maize showed 20% to 37% decrease in yield compared to the check and the combined yields were only 0.83 at both levels of application. In the absence of sorghum yields, the usefulness of these herbicides for sorghum/cowpea system can not be indicated. However, the study did show the prospects of identifying some herbicides for cereal/legume intercrop systems. Future studies should involve more chemicals and should preferably be evaluated in rainfed situation because available moisture (i.e. rainfall) can vastly modify the effectiveness of some herbicides.

2.6- Suggestions for Future Research

(i) The rainy season in much of the 'sertão' is limited to only 2 1/2 to 3 months. But maize and sorghum genotypes currently in use require a minimum of 120 days and experience stress at critical grain filling stage. Therefore, efforts must be made to identify short duration genotypes, probably that complete their cycle in about 90 to 100 days. CPATSA should establish good cooperative links with the Maize & Sorghum Center and should screen a large number of promising genotypes of these crops in the above maturity range.

(ii) The limited rainfall and poor soils of 'sertão' can not support high populations. The present studies indicated that the optimum for sole maize would be 40 000 plants/ha while the optimum of solemillet or sole sorghum would be around 100 000 plants/ha. In intercropping maize requires less than 20 000 plants/ha while millet and sorghum need around 50 000 to 60 000 plants/ha. Further studies are required to define the optimum populations in relation to the available seasonal moisture. The row spacing of 50 cm appeared to be narrow. A wider spacing of 75 cm to 100 cm may be practical, and such a spacing avoids early competition for moisture and facilitates planting of intercrops on ridge and furrow systems. However, at such wider spacings row arrangement options are limited to alternate rows or at the maximum 1 cereal : 2 legumes.

(iii) All our experiments were conducted on a flat land. Recent studies at CPATSA have shown that some broad ridge and furrow systems can improve 'insitu' moisture conservation. The intercrop systems can be adapted easily to these land management systems without sacrifycing much on populations. Future intercrop comparisons should preferably be done on the most promising land management sytems.

(iv) Visual observations indicated that intercropping of cowpea/ maize reduces disease incidence on cowpea, but no quantitative information is available on this. Recommendations based on well protected experiments at research stations may not bring out the expected results on farmer's fields who generally operate under moderate or no protection. Studies should soon be initiated to examine how intercropping affects pests and dieseases compared to the sole crops. These studies are limited in the Northeast partly due to the lack of sufficient staff in this area.

3 - INTERCROP RESPONSES TO NUTRIENTS, WATER AND THEIR INTERACTIONS

Fertilizer studies are important to understand i) how intercrops respond to nutrients ii) at what fertility level the farmer is likely to get maximum intercropping advantage iii) what modifications are required to the sole crop based recommendations for intercrop systems, particularly when one of the component is a legume. Moreover, nutrient responses can not be treated independent of responses to water because of strong interactions between these two factors. Since water is the most limiting factor and is highly variable in the Northeast, a single blanket recommendation can not be made for all situations. Very few studies were conducted at CPATSA on fertilisation of dryland crops, hence the following two studies were initiated.

3.1- Response to Nitrogen Fertilisation of Sole vs Intercropped Sorghum

The objectives of the study were to (i) examine whether legumes would modify the response of an intercropped sorghum to nitrogen compared to that of sole sorghum (ii) evaluate the current season and residual effects of an intercropped legume and (iii) evaluate the relative advantage of intercropping at different levels of fertility.

Materials & Methods: There were four nitrogen levels (0, 40, 80 and 120 kg N/ha) to sorghum in sole cropping and intercropping with cowpea. These eight together with two other treatments - a sole crop of cowpea and a fallow - were randomised in each of three replications. Sole sorghum was planted at a density of 150 000 plants/ha in 50 cm rows while in intercropping it was planted at half the density of sole crop. Accordingly, intercropped sorghum received only half the doses of nitrogen applied to sole crop. Cowpea was planted in both systems at 40 000 plants/ha at 50 cm

Table 3.1.1

Effect of nitrogen fertilization on sorghum and cowpea yields in sole and intercopping

System kg N/ha	Sorghum Grain	Sorghum straw	Total dry matter (kg/ha)	Cowpea Grain	LER[1]
Sole Sorghum					
0	251	3580	3831		
40	129	3785	3914		
80	217	3539	3756		
120	234	4197	4431		
Sole Cowpea				417	
Intercrop					
0	669	2099	2768	228	1.27
40	236	2139	2375	154	0.98
80	779	2057	2836	215	1.28
120	249	1893	2142	158	0.86
SE$\pm$	203	238		28	

1 LER of sorghum is based on total drymatter.

rows. The intercrop row arrangement was 1 sorghum : 2 cowpea at a uniform 50 cm. Large plots of 5 m x 29 m were used so that the response of another cereal to nitrogen can be studied in the subsequent season in each plot at three levels. These responses would enable to permite the residual effect of sole vs intercropped cowpea.

Crops were planted on 19 January 1983. The area was fertilised basally with 50 kg P_2O_5/ha and different levels of nitrogen were applied only to sorghum in two equal splits after thinning of the crops. Rainfall during the crop growth was 335 mm. Cowpea required six sprays of Nuvacron while sorghum required the same number of sprays with Ambush. Drift from cowpea sprays caused phytotoxicity on intercropped sorghum. Sorghum (cv. IPA 1011) matured in 139 days while cowpea was harvested in 79 days. Cowpea yield was estimated from 21 m^2, but because of high variability in sorghum, it was estimated from 81 m^2.

This experiment was planned to be conducted at two other locations, one in Rio Grande do Norte (Mossorõ) using sorghum/ cowpea and another in Alagoas using maize/beans. But it could not be planted in Alagoas as there was no sufficient rainfall. It was planted at Mossorõ but the crops did not come up well and had to be irrigated frequently.

Results & Discussion: Cowpea gave a reasonable yield in sole cropping at 417 kg/ha (Table 3.1.1). But it averaged in intercropping 188 kg/ha representing only 45% of the sole crop yield. The competitive effect of sorghum increased with nitrogen fertilisation and consequently the cowpea yield decreased from 228 kg at nil nitrogen to 158 kg at 120 kg N/ha. Sorghum grew well up to boot leaf stage but thereafter suffered from severe moisture stress resulting in highly variable yields across different treatments. On the basis of total dry matter, there was no effect of nitrogen in sole cropping but the highest level seemed to have a detrimental effect in intercropping. Inspite of having only 50% of sole crop population, intercropped sorghum averaged 64% of the dry matter of sole crop. However intercrop gave higher grain yield than the sole crop which suggests that sole crop at 150 000 plants/ha experienced greater competiton for moisture than the intercrop. In future studies sorghum populations must be reduced to 90 000 or 100 000 plants/ha in sole cropping. The combined yield of both crops exceeded a LER 1.0 only with nil nitrogen and at 80 kg N/ha. In view of the variable results, no useful conclusions can be drawn.

The experiment was sited on a newly cleared area, and cowpea was not inoculated. It showed nitrogen deficiency symptoms for a long time in the early stage and observations revealed that nodulation was very poor. Our attempts to get rhizobium inoculum were not sucessful primarily because no institute in the Northeast has a microbiologist working on legumes. Under these circumstances one can not expect any beneficied effect of legume to the associated cereal or subsequent crops. Therefore, it was decided that this trial should be repeated next year inoculating cowpea with appropriate rhizobium. The variability in sorghum was primarly due to soil heterogenity. The general practice of conducting experiments immediately after clearing the land should be avoided. At least one cover crop should be raised before utilising the new land for experiments. The other changes that need to be made in the trial are i) plant the intercrop in alternate rows on appropriate ridge and furrow system ii) reduce nitrogen levels to 0, 30, 60 and 90 kg N/ha.

3.2- Response of Maize/Cowpea to Nutrients, water and their Interactions

The objectives of the study were i) to compare the response to nutrients of maize/cowpea intercrop with those of the respective sole crops and ii) to evaluate the interaction of nutrients and water on sole crops of maize and cowpea and their intercrop.

Materials & Methods: Two experiments were conducted, the first one during August - December 1982 and the second one during May - September 1983 with controlled water application. In the first experiment, combinations of two levels each of nitrogen and phosphate were examined at three moisture regimes in sole and intercrops. Nitrogen was applied only for maize. The treatments were:

Water regimes

I_1 Irrigation at 7 day interval
I_1 Irrigation at 14 day interval
I_2 Irrigation at 21 day interval

Nutrient levels		
Sole Maize	Sole Cowpea	Intercrop
N_0P_0	N_0P_0	N_0P_0
N_0P_{40}	N_0P_{40}	N_0P_{40}
$N_{60}P_0$	N_0P_{40}	$N_{60}P_0$
$N_{60}P_{40}$		$N_{60}P_{40}$

The trial was conducted in a split plot design with three replications. Irrigations were in main plots and the nutrient levels in subplots. Crops were planted on 120 cm beds with two rows per bed. Each plot was 6 m x 9 m having ten rows from which six rows of seven meters were harvested for yield (25.2 m^2).

Crop details were as follows: Cowpea - cultivar Pitiuba, planted at 90 000 plants/ha in sole and intercrop, harvested at 75 days. Maize - cultivar Centralmex, planted at 50 000 plants/ha in sole but half of that density in intercrop, harvested at 123 days. Therefore, intercropped maize was fertilized at half of the levels used in sole. In addition to the two uniform irrigations given to all treatments for establishment of crops, I_1 received 468 mm of water (440 mm in 12 irrigations + 28 mm rain). While I_2 & I_3 about 178 mm (150 mm in five irrigations + 28 mm rain). Due to some practical problems I_2 & I_3 could not be maintained at sheduled intervals and finally they were treated as one treatment.

The treatments were modified in the second year: three irrigation intervals were there for both systems but only nitrogen levels (0, 40 and 80 kg N/ha) were included for maize in sole and

Table 3.2.1

Effect of fertilisation and two levels of water application on maize/cowpea intercropping, Petrolina 1982.

Fertiliser/ Systm	Irrigation level 1			Irrigation level 2		
	Maize	Cowpea	LER	Maize	Cowpea	LER
Sole Maize			(kg/ha)			
N_o P_o	1253			264		
N_o P_{40}	1534			163		
N_{60} P_o	1128			250		
N_{60} P_{40}	1521			132		
Sole Cowpea						
P_o		1649			1427	
P_{40}		2006			1014	
Intercrops						
N_o P_o	1017	799	1.29	167	689	1.11
N_o P_{40}	847	778	0.94	118	580	1.29
N_{60} P_o	1382	687	1.64	100	622	0.84
N_{60} P_{40}	927	861	1.04	90	597	1.27

intercropping. The 21 treatments were tried in three replications of a randomised block design. The crops were planted on 75 cm ridges and intercrop was established in alternate rows. Cultivars were same as before, and the only change was that maize was planted at 40 000 plants/ha in sole cropping and at half that density in intercropping. Different quantities of water applied in the three irrigation treatments were 300, 200 & 130 mm respectively during the maize cycle but 260, 170 and 100 mm for the cowpea cycle. These amounts were in addition to four common irrigations used for establishment of crops and 20 mm of rain after cowpea was harvested. Cowpea was harvested in 80 days and maize in 125 days.

Results & Discussion: Maize did not grow well in the first year and inspite of frequent irrigations it gave only 1.1 to 1.5 t/ha in sole cropping (Table 3.2.1). Where limited water was applied, it produced very low yields. This could be partly due to the hot dry weather conditions that prevailed during August to December. Response to fertilization was limited; only phosphorus gave about 28% higher yield in sole cropping, but intercrop showed no response to either of the nutrients.

Cowpea also responded to phosphorus only in sole cropping (22%) and with 7 - day irrigations. The results were highly variable particularly in the second and third levels of irrigation, with some plots failing to produce any worthwhile yield. The area was under fallow for two seasons before it was used for this experiment. There must have been a high build up of NO_3 - nitrogen in the profile during the fallow period. Nitrate nitrogen forms only a small fraction of total nitrogen but is all readily available to crop growth and is important under upland conditions. This could be one of the reasons for lack of response to nitrogen although the soil was very low in total nitrogen status.

The combined yields (i.e. LER) exceeded 1.0 in some cases indicating an advantage for intercropping. But there was no definite trend in LER advantages with regard to fertilization or

TABLE 32.2 Effect of different levels of irrigation and nitrogen on sole crops of maize and cowpea and thei[r] intercropping, 1983.

Nitrogen (kg/ha)	Irrigation 1				Irrigation 2				Irrigation 3			
	Sole Maize	Intercrop			Sole Maize	Intercrop			Sole Maize	Intercrop		
		Maize (kg/ha)	Cowpea	LER		Maize (kg/ha)	Cowpea	LER		Maize (kg/ha)	Cowpea	LER
0	3355	1895	663	1.25	3176	571	540	0.75	558	952	552	2.35
40	3676	1752	531	1.02	2014	1752	709	1.62	1314	1700	542	1.93
80	6080	2680	592	1.05	5442	2900	651	1.22	3248	2014	462	1.16
Sole Cowpea	-		970	1.00			945	1.00			853	1.00
Variable water applied (mm)		300				200				130		

Summary of Statistical Analysis

Factor	Maize 'F'test	Maize SE	Maize LSD(0.05)	Cowpea 'F'test	Cowpea SE	Cowpea LSD(0.05)
Nitrogen (N)	**	337	971	NS	50	-
Irrigation (I)	**	337	971	NS	50	-
Cropping system (C)	**	275	789	**	-	205
N x I	NS	585	-	NS	86	-
N x C	NS	478	-	-	-	-
I x C	NS	479	-	NS	-	-
N x I x C	NS	826	-			

LSD
DMS

water.

Maize grew very well in the second year and produced excellent yields at high moisture and high nitrogen (Table 3.2.2). But soil heterogenity was still a major problem which resulted in a high coefficient of variation (> 50%) in maize yields. It was also suspected that the crops might have benefitted from water table in this experiment. Nitrogen increased maize yields in sole and intercropping at all the three moisture levels but the response was more in low moisture regime. Response to water was equally striking. Sole maize averaged 1.7 t/ha at the lowest moisture, an additional 70 mm of water increased yield to 3.5 t/ha, and with a further application of 100 mm of water it averaged 4.4 t/ha. However, similar responses were not observed with cowpea. At the lowest moisture (I_3), sole cowpea gave 853 kg/ha, 70 mm of additional water improved the yields to 945 kg/ha but more water did not bring in much change in yields.

Both crops produced lower yields in intercropping than their respective sole crops. In the first two water levels maize averaged 48% of the corresponding sole crop and in the third level it averaged 99% (due to unusually low yield of sole maize at no nitrogen). But cowpea averaged 60% of the respective sole crops in all the three regimes. With good water supply intercropping was advantageous only when no nitrogen was applied. But in moderate water supply and in limited water, intercropping was advantageous at all levels of nitrogen, although the degree of advantage decreased with increase in nitrogen fertility. These results do give some strength to the popular belief that intercropping would be less important in high input situations. Together with the results of section 2.4, it can be said that intercropping may not have any special advantage over sole crops in unlimited water and very little water supply but it is most beneficial in conditions of moderate water supply. However, more tests are needed to confirm the present results with good control on water application.

3.3- Suggestions for Future Studies

1. Fertiliser and water response studies should be conducted on uniform sites having no water table. One or two cover crops must be grown before taking up experiments on newly cleared areas. Inoculation is a must for getting the potential benefits of legumes, particularly when they are grown for the first time on new areas.
2. Response to nitrogen was very inconsistent which could be partly due to build up of nitrate nitrogen during non-cropping period. NO_3 - nitrogen must be determined in the beginning of the experiments. A small study may be initiated to understand the fate of nitrate nitrogen by sampling periodically under fallow and cropped areas.
3. Future studies should emphasise more on phosphate fertilisation and its residual effects, fertiliser responses in other crop combinations and crop residue management.

4 - STUDIES ON CASTOR

Next to cotton, castor is an important cash crop of northeast Brazil. The deep root system and tolerance to drought make this crop better adapted to the drought prone Northeast than some of the annuals. It is grown principally in the states of Bahia, Pernambuco and Ceará where more than 50% the area is intercropped with annuals such as cowpea and beans with or without maize as a third crop. Inspite of its importance, research has been very limited and whatever little that has been done is not published. Some work in Bahia state indicated that a spacing of 2.0 m x 1.5 m would give hither yields than the commonly used 2.0 m x 2.5 m spacing (Cavalcanti, 1981).

In view of the dearth of information on castor, two experiments were initiated, one to study the optimum spacing and population in sole castor and another to determine optimum population in intercropping with sorghum or cowpea. Both the experiments used a tall biennial castor (cultivar - Amarela de Irecê). The first one was initiated in 1982 by Mr. Josias Cavalcanti before I came to Petrolina but I took its responsibility in 1983 when he left for higher studies.

4.1- Effect of Plant Population and Spatial Arrangement on Tall Castor

The objectives of this experiment were i) to find out the optimum population and spatial arrangement for sole castor ii) to explore the usefulness of paired row system of planting in comparison with normal rows from the point of intercropping and iii) to evaluate the potential of ratooning castor for second year in comparison with a plant crop.

Materials & Methods: Four populations of castor (1 000, 2 000, 3 000 and 4 000 plants/ha) in factorial combination with three spatial arrangements were examined in a randomised block design. The arrangements were i) equidistant or square planting ii) rectangular planting and iii) paired row system. The spacing for different populations were as follows:

Population (plants/ha)	Spatial arrangements Square	Rectangular (m)	Paired rows	Plot size (m^2)	Harvest area (m^2)
1 000	3.16 x 3.16	5.48 x 1.82	8.77x2.19x1.82	159.7	39.9
2 000	2.23 x 2.23	3.87 x 1.29	6.19x1.55x1.29	79.5	19.9
3 000	1.82 x 1.82	3.16 x 1.05	5.06x1.26x1.05	53.0	13.3
4 000	1.58 x 1.58	2.73 x 0.91	4.38x1.1 x0.91	39.9	9.9

Each plot had 16 plants of which the middle four were harvested for yield. The harvest area differed among treatments because of different spacings but yields were computed on hactare basis before they were analysed statistically.

The experiment was sited on a sandy reddish yellow podzol situated in the lower part of a watershed low in phosphorus and nitrogen but rich in potassium. The trial was planted on 6 January 1982 using 4 seeds/hill. It was thinned to one plant/hill later. The area was fertilized basally with 50 kg P_2O_5/ha and the crop was top dressed later with 40 kg N/ha in two equal splits. It was weeded depending on the necessity. 'Mamona caterpiller' (Citheronio laocoon) appeared at a number of stages but it was destroyed by hand. Rainfall during the experiment was 235 mm. The spikes were harvested and threshed separately for primary and secondary branches as and when they were mature. A total of 12 harvests were made during 26 May - 8 August 1982.

The crop was pruned at about 1 m height just before rains and allowed to continue in the second year (1983). The severe drought conditions from April to January caused mortality of plants which

Table 4.1.1

Effect of plant population and spacing on the sole crop of a biennial castor, Petrolina, 1982 - 83

Treatment	Spikes			yield(kg/ha)			Mortality	Mortality(4.3.83)			Yield of ratoon in 2nd year	Yield 1 year*
	Pri.	Sec.	Total	Pri.	Sec.	Total	30-12-82	Border	Net Plot	Whole Plot	1983	1983
				← 1982 →								
	← (no.) →			← (kg/ha) →			← (%) →				← (kg/ha) →	
Population (Plants/ha)												
1000	4.2	18.0	22.2	179	141	320	22	18	55	29	230	67
2000	4.0	20.8	24.8	195	198	393	32	36	47	39	283	54
3000	3.6	17.1	20.7	187	193	380	33	46	66	51	256	90
4000	3.4	9.7	13.1	171	99	270	33	51	61	53	250	47
SE±	0.2	1.2	-	6	7	30	-	-	-	-	38	-
Planting System												
Square	3.9	16.2	20.1	190	140	330	26	38	44	40	260	91
Rectangular	3.5	17.9	21.4	169	210	379	32	42	60	46	256	75
Paired rows	4.0	15.1	19.1	190	123	313	31	35	69	43	249	37
SE±	0.1	1.0	-	5	18	26	-	-	-	-	33	-

* Experiment planted in 1983.

was further aggravated by the occurrence of stem rot. Counts on dead plants were taken on 30 December 1982 and on 4 March 1983. No fertilizer was given to the ratoon crop but it required two weedings and one spray of Ambush when there was a severe attack of 'manimagro' (Stiphra robusta) and 'mamona caterpiller'. Nine harvests were made in this year during 20 April and 4 August.

The experiment was repeated in 1983 on a new area. It was planted on 15 January 1983 in the dry soil and the first rain of 33 mm on 18 January triggered the germination. The treatments were same as in 1982, the only difference was in plot size where each plot had four rows of 20 to 22 m length. The crop was fertilized with 50 kg P_2O_5/ha before planting and was top dressed later with only the first half dose of 40 kg N/ha (i.e. 20 kg/ha). The total rainfall during the year was 350 mm. The crop gave only three harvests from 8 June to 19 July, 1983.

Results & Discussion: Grain yields, spikes and stand mortality are given in Table 4.1.1. Castor gave a reasonable yield of 340 kg/ha in the first year of 1982 experiment. The first four harvests were totally from primary spikes while the last six harvests were from secondary spikes. Both primary and secondary spikes gave some yield in the fifth and sixth harvests. Yield was significantly affected by plant population. The lowest population (1 000 plants/ha) gave 320 kg/ha and doubling the population (2 000 plants/ha) has brought about 22% increase in yield. However, further increases in population reduced yield and the highest population of 4 000 plants/ha produced only 69% of the maximum obtained with 2 000 plants/ha. Different spatial arrangements did not affect yield. Thus, plant population was more important for castor than the spatial arrangement and one could realise the potential yield by planting about 2 000 plants/ha. In other words castor can be planted without any effect on yield at row spacings varying from 2 to 5 m. Such a flexibility in spacing improves scope for intercropping without being much affected.

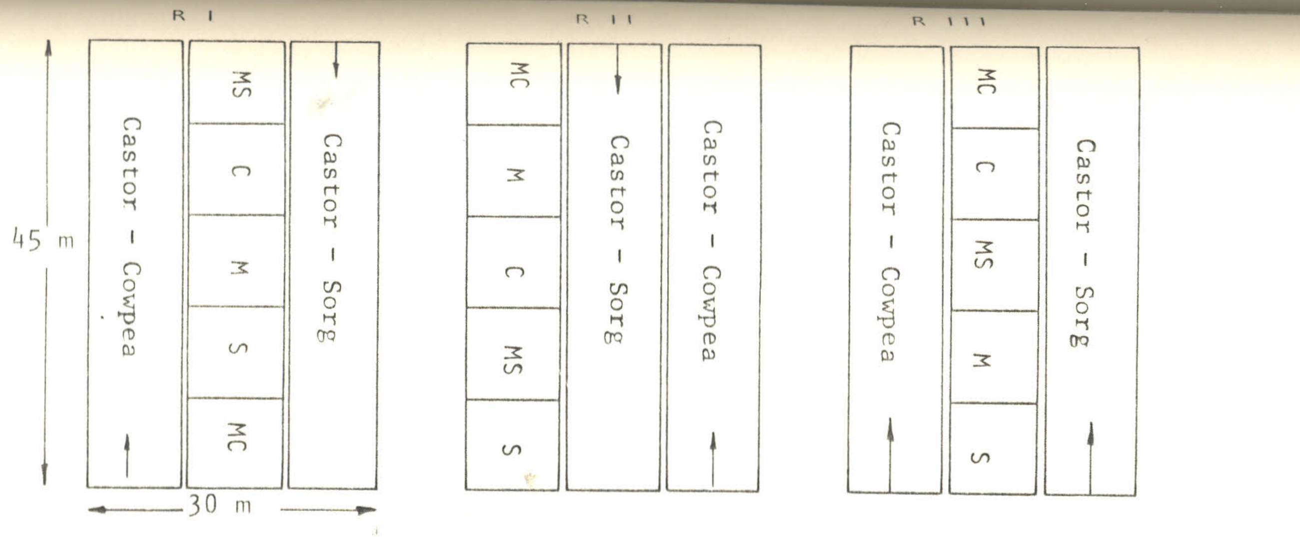
Plant population affected the primary and secondary spikes. With increase in population the spikes decreased significantly and at the highest population the contribution of the secondary spikes to yield was only 1/3 as compared to 1/2 at other populations. Different spatial arrangements did not affect the total spikes but they did influence numbers of primaries and secondaries. The square and paired row plantings had more primaries and less secondaries compared to the rectangular system.

As indicated earlier, there was stand mortality during the dry period. About 30% plants died by the first observation made on 30 December. The death was generally more in high populations and harvest area than in low populations and border. The mortality increased after pruning up to 50% in high populations. This suggests that competition for water might be the major cause for death, although some plants died due to stem rot. However, the survived plants grew well and produced about 255 kg/ha in the second year. Yields in this year were estimated on whole plot basis because more than 50% of the plants died in the net plot, which were about 75% of the yields of the first year. As in the first year, there was no effect of spacing and only population had showed some influence on yield. The maximum yield was observed again at 2 000 plants/ha.

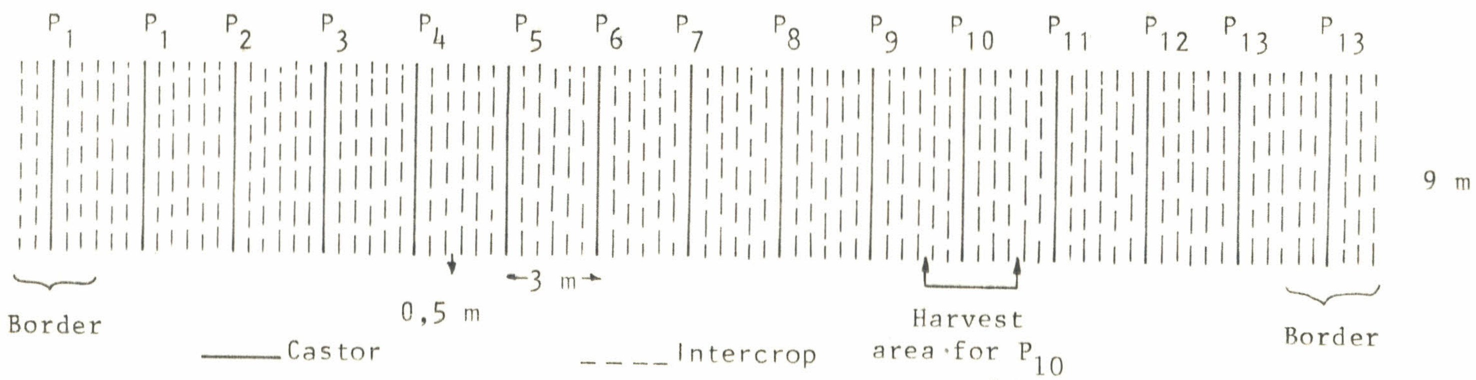
The plant crop in 1983 gave very poor yields (less than 100 kg/ha) and several plots did not produce any yield. Although the crop established well, it did not make good growth because of severe moisture stress. The experiment was sited on an elevated area which was shallow and held little water compared to that in 1982 experiment. Although rainfall was more in 1982, the available moisture was less which could not sustain the long cycle castor. However, the ratoon crop flowered early, and with only 50% of the initial stand suffered less due to moisture stress than the plant crop.

4.2- Effect of Plant Population on Castor Intercropped with Sorghum or Cowpea

The objectives of the study were i) to explore the potential



A mainplot of Castor intercropped with Sorg. or Cowpea



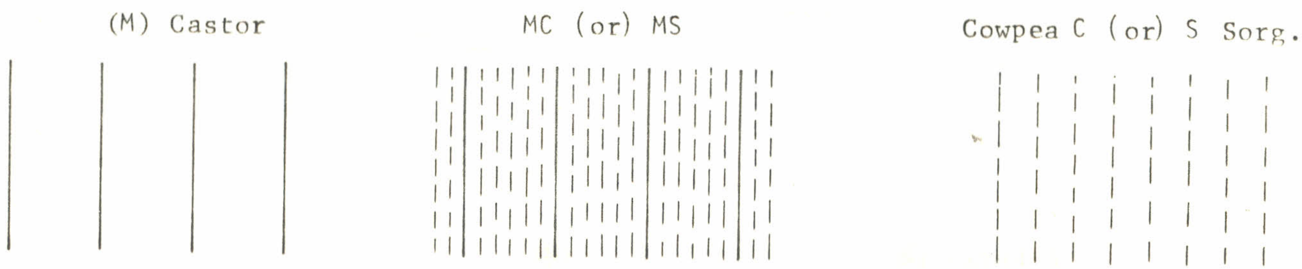


Fig.4.21 Experimental layout and a mainplot showing the systematic arrangement of different populations of Castor in intercropping.

of intercropping castor with sorghum or cowpea, ii) to determine the optimum plant population for castor intercropped with a competitive cereal or low canopy legume and iii) to find out the viability of ratooning castor for a second year.

Materials & Methods: The study evaluated 13 populations of castor ranging from 650 to 5786 plants/ha in intercropping with either sorghum or cowpea. The experiment had three replications and each was devided into three main plots allocated randomly to i) castor/sorghum ii) castor/cowpea and iii) five additional treatments (Fig. 4.2.1.). Castor populations in the first two main plots were arranged in a systematic order increasing from one end of the plot to the other at a 20% constant change. Considering that sole crop optimum is around 2 000 plants/ha, the populations used in the study represent a range of one third to three times the sole crop optimum. In intercropping, sorghum was planted at 150 000 plants/ha and cowpea at 40 000 plants/ha. The additional treatments in the other main plot included a) sole castor at 2 000 plants/ha, b) sole sorghum at 150 000 plants/ha, c) sole cowpea at 40 000 plants/ha, d) castor/sorghum and e) castor/cowpea. Castor at different populations was to be intercropped only in the first year whereas the extra treatments (d) and (e) were meant to be intercropped in the second year also to explore the viability of this practice. The additional treatments were randomised and in the other two main plots, the direction in which the castor population has to be increased was randomised (indicated by an arrow in Fig. 4.2.1). The intercrop was planted at a row arrangement of 1 castor: 5 sorghum or cowpea in 50 cm rows, and for each population there was only one row of castor except at the ends where an additional row was planted for the extreme populations as border. The harvest area for each population consisted of 1 row of castor and five rows of intercrop (two rows on one side and three on the other). One meter head border was left to harvest only 7 m long rows for intercrops, but in the case of castor the row length varied in different populations to harvest whole number of plants.

The experiment was planted on 21 January 1983. The area was fertilized with 50 kg P_2O_5/ha before planting, and after thinning sorghum and castor were top dressed with 20 kg N/ha. The crops were kept free from weeds and insects by periodical weeding and sprayings. Cowpea matured in 80 days from planting while sorghum completed its cycle in 128 days. Rainfall during the experiment was 324 mm.

Results & Discussion: Yields of the intercrops are given in Table 4.2.1. Castor failed to produce any yield in both sole and intercropping. Cowpea grew normally and produced a reasonable yield varying from 234 to 433 kg/ha. Its yield in intercropping varried from 433 to 327 kg/ha, the decrease accompanied with increase in the population of castor. Sorghum established and grew well up to flowering but from then on suffered due to severe moisture stress. Many plants did not produce ears and as a result its yield was highly variable. It produced good dry matter yield (3 to 4 t/ha) which was less variable than the grain yield and indicated that castor was least competitive to sorghum. Castor grew normally untill sorghum reached the knee high-stage but later it was smothered completely due to competition for both light and water. There didn't appear to be competition for light in intercropping with cowpea but even then it failed due to moisture stress. The sole castor reached flowering but did not produce yield. The experiment was sited on the upper part of a sloping area and the soil was also very shallow. About 50% of the total rainfall was received in one month (February) and most part of the cropping period remained dry resulting in the failure of sorghum and castor. These results raise serious doubts about the possibility of intercropping castor with tall competitive crops such as sorghum or maize.

4.3- Conclusions & Suggestions for Future Research

i) Castor is highly flexible to plant population and spacing in sole cropping. About 2 000 plants/ha is an optimum

Table 4.2.1

Effect of plant population of castor on castor/sorghum and castor/cowpea intercropping systems, Petrolina, 1982.

Treatments	Castor/sorghum			Castor/cowpea	
	Sorghum				
Plant population of castor in intercrop(pl/ha)	Grain	Straw	Castor[1]	Cowpea	Castor[1]
	Kg/ha				
650	917	4071		412	
780	600	3314		417	
936	1128	3866		411	
1123	453	3452		433	
1347	321	3176		404	
1616	234	3314		401	
1939	58	3245		354	
2326	364	3383		372	
2791	560	3521		415	
3349	385	3521		379	
4018	617	3867		362	
4822	777	3728		327	
5786	540	4142		336	
Additional Treatments					
Sole Castor					
Sole of intercrops	774	4100		234	
Cator/sorghum (or) cowpea	408	2969		453	

1 Castor failed to produce any yield.

density which can be planted at rows varying from 2 to 5 m without any affect on yield.

ii) Castor can be maintained for two years economically. The ratoon crop, being an already established one, flowers early and avoids moisture stress. There can be some loss of stand due to mortality which needs to be replanted.

iii) Castor is very sensitive to competition and it can not be intercropped with competitive cereals especially in dry areas.

iv) Future studies on intercropping of castor should be confined to only with short cycle crops such as cowpea, millet, guar etc. The proportion of intercrops has to be necessarily low in the arid 'sertão'. Spatial arrangements that would minimise competition between castor and the intercrops have to be identified. Since moisture is the most limiting factor in the arid areas, efforts should be made to identify suitable land management systems for 'insitu' moisture conservation.

5 - SCOPE FOR INTERCROPPING OF CACTUS

Cactus is intercropped with short season crops such as maize, cowpea, fava or long cycle crops such as cassava or annual and perennial cottons. Although the importance of this practice was noted much earlier (Gomes, 1973, Duque, 1980), very few studies have actually quantified the advantage of intercropping cactus. Several studies conducted by SUDENE (1971) revealed that moco and cactus complemented well in alternate row intercropping and on average was 36% more profitable than sole cotton. This advantage compared very well to the intercropping of moco with annual crops. In fact a combination of 3 crops-maize, cactus and moco-was more advantageous than intercropping of only moco and cactus (IPA, 1981). This three crop system has the advantage that it meets the subsistence, cash and fooder needs of the farm. There was no sole crop of cactus in all the previous experiments making it difficult to assess the effect of moco or maize on cactus.

Hitherto maize is the only cereal intercropped with cactus, although it is known to be sensitive to moisture stress and is risky. Sorghum and pearlmillet tolerate drought better than maize and may be better adapted to the conditions of 'sertão'. Only one study had evaluated the effect of sorghum on cactus in the valley of Ipojuca at São Bento do Una-PE (IPA, 1981). A proportion of 2/3 sorghum (200 000 plants/ha) and 1/3 cactus (5 000 plants/ha) in 2 sorghum: 1 cactus over two years gave 83% of sole sorghum but severely suppressed the growth of cactus resulting in only 23% of the yield of the sole crop. Therefore, there was no advantage of intercropping in terms of land productivity. Increasing the proportion of cactus to 2/3 (10 000 plants/ha) and lowering that of sorghum to 1/3 (100 000 plants/ha) improved the growth of cactus but still did not give much advantage because of a drop in the yield of sorghum. The population of cactus was too low to withstand the competition of sorghum in the first proportion while the spatial arrangement might not be an ideal one in the second. Earlier studies in sole cropping had shown that populations less than 10 000 plants/ha affect cactus and that for obtaining potential yields one must have 10 000 to 15 000 plants/ha (Lima et al, 1974). These studies also pointed out that at any given population row spacings of 1 to 2 m or paired row planting (with 3 to 3.5 m between pairs of rows and 1 to 0.5 m within pairs) did not affect yield. The wide row spacing may improve the performance of intercrops and facilitate field operations. Obviously, more studies are required involving a range of plant populations and spatial arrangements to identify the optimum population and spacing for intercropping.

5.1- Intercropping of Cactus with Annual Crops

The present study was taken up with the following objectives: i) to evaluate the advantage of intercropping cactus with sorghum or cowpea ii) to determine the response of cactus to plant population in sole and intercropping and iii) to find out the ideal spatial arrangement for intercropping of cactus.

Materials & Methods: The experiment was conducted in the Dryland Farm of CPATSA, at Petrolina in Pernambuco. It consisted of 16 treatments, 15 of which were factorial combinations of five spacings of cactus and three cropping systems-sole crop, and cactus intercropped with sorghum or cowpea. The spacings used were 1 m x 1 m (the traditional narrow row), 2.0 m x 0.5 m, 2.0 m x 0.67 m and 2 m x 1.0 m (wider rows) and 3.0 m x 1.0 m x 0.5 m (paired rows) with populations varying from 5 000 plants/ha (2 m x 1 m) to 10 000 plants/ha (1 m x 1 m). Intercrop rows between rows of cactus were, one in the case of 1 m spacing, three in 2 m spacing and five in the interpair spaces of the paired row arrangement. The sixteenth treatment was devived (divided) into three sub-plots, each of which was planted to a sole sorghum, sole cowpea and a sorghum/cowpea intercrop in 1:2 arrangement. The trial was laid-out in a randomised block design with three replications. The plot size was 120 m^2 with dimensions of 10 m x 12 m.

The experimental area was a latosol having profile depth varying from 30 cm to 60 cm. The land was cleared off the 'caatinga' by burning. The area was not cultivated but hills were marked directly by pick axes according to the spacings. Cactus was planted on 16 and 17 December, 1983 using one racket per each hill. Although the period was rather unconventional for planting cactus in that the temperature were very high (38 to 40^{o}C), more than 80% of the rackets established. The limited gaps were filled in immediately after the first shower. Sorghum and cowpea were planted on 25 January 1983 following a 29 mm rain on 24 January. The annual crops were fertilized with 50 kg P_2O_5/ha through single superphosphate all at planting. The genotypes used were sorghum: IPA 1011 and cowpea: Pitiuba. Sorghum was planted in a continuous row and cowpea in hills using 3-4 seeds per hill, but both these were thinned out 3 weeks later to 133 000 plants/ha in the case of sorghum and 40 000 plants/ha in the case of cowpea. Following heavy showers on 9 & 10 Feb. and 28 March, water stagnated in a few patches but it soon was baled out. The crops grew well, sorghum particularly did not suffer from any pests or diseases. But cowpea was infested with jassids and required four sprays of Nuvacron (20 cc/20 L water). However, it was infested around flowering with a virus disease which affected the yield. Sorghum was sprayed only once with carvin. It was harvested 112 days after planting while cowpea was harvested finally after 105 days. The harvest area varied across the plots, around 30-32 m^2 for the sole crops and the sorghum/cowpea intercrop and 64 to 80 m^2 for intercrop treatments of cactus. Besides grain yields, sorghum stover was also considered after correcting for the moisture content. Cowpea lost much of the leaves at the time of harvest, so its haulms were not weighed.

In order to quantify the growth of cactus in sole and intercropping, measurements on plant height, canopy spread, number of rackets, area of the rackets, and thickness of the rackets were taken on 8 September 1983. Considering that the rackets are approximately elliptic, their area was estimated as for the formula of an ellipse (22/7 x a x b where a and b are half the length and width of an ellipse). The total rainfall during the rainy season was 464 mm of which 370 mm was received during the growth of the intercrops.

Results & Discussion: Yields of the intercrops and the growth characters of cactus are presented in Table 5.1.1. For the rainfall conditions that prevailed during the year, sole sorghum gave a good yield at 2708 kg/ha. Sorghum yield in intercropping varied from 1712 to 2765 kg/ha but the differences among different spacings of cactus were not significant suggesting that the observed variation was mainly due to soil heterogenity. The intercropped sorghum (2337 kg/ha) represented a high proportion of the sole crop yield (86%) and the comparison of sole vs intercrop was not significant. In other words cactus did not exercise much competition to sorghum. The fodder yield of sorghum followed similar pattern as the grain yield, the sole crop produced 4261 kg/ha and the intercrop averaged 96% of the sole crop.

Inspite of good vegetative growth, cowpea produced poor grain yield at 380 kg/ha in sole cropping. The virus disease that appeared at flowering affected pod set and resulted in poor yield. Intercropped cowpea varied from 300 to 393 kg/ha, and neither the differences among various spacings of cactus nor the comparison of intercrop vs sole crop were significant. Similar to the case with sorghum, cactus did not affect the growth of even the low canopy cowpea.

Growth measurements on cactus were taken on 8 September, five months after the intercrops were harvested. Cactus might have compensated in the intervening period from harvest of intercrops to the time of observations but because of the dry period it would be little and the effect of intercrops could still be noted. Different spacings and/or populations did not influence significantly the growth of cactus in sole as well as intercropping. Only the rackets produced in paired rows of the sole crop appeared to be thinner than those in other spacings but such a distinction was not evident in intercropping. Intercropping significantly affected the growth of cactus, in respect of height and spread of the plant and other racket characteristics. There was no

Table 5.1.1

Effect of plant spacing and intercropping on the growth of palma and yields of the intercrops.

Treatment (spacing between & within rows).	Intercrop yields			Plant height of palma			Size of rackets		
	Sorghum		Cowpea	Sorghum	Cowpea	Sole	Sorghum	Cowpea	Sole
	Grain	Stover							
	(kg/ha)			(cm)			(cm^2)		
1 m x 1 m	2239	4000	348	35(29)[a]	40(42)	53(53)	162(4.9)[b]	160(7.2)	214(17.2)
2 m x 1 m	2300	4187	393	32(32)	38(42)	55(59)	171(5.7)	156(6.4)	208(17.4)
2 m x 0.67 m	2765	5162	372	39(34)	37(35)	50(60)	175(5.9)	165(6.2)	224(14.8)
2 m x 0.5 m	1712	3281	322	36(30)	37(35)	54(57)	203(5.6)	187(5.6)	197(15.6)
3 m x 1 m x 0.5 m	2667	3996	300	30(26)	38(39)	47(45)	170(6.0)	150(6.1)	200(12.3)
Sole sorghum	2708	4261	-	-	-	-	-	-	-
Sole cowpea	-	-	380	-	-	-	-	-	-
Sorghum/cowpea	1823	2329	66	-	-	-	-	-	-
Intercrop				-	-	-	-	-	-
SE ±	272	1079	45	4(6)	4(6)	-	-	18.4(1.2)	-
CV (%)	20.4	25.4	25.0	17.3(24.7)	17.3(24.7)		-	17.5(23.6)	-

Height and racket size of palma were as measured on 8 September, 1983.

a: Lateral spread of plants (cm)

b: Thickness of the rackets (mm)

significant difference between the two intercrops for various measured characters but lower values for cactus associated with sorghum (all characters except area of rackets) compared to that with cowpea suggests that sorghum was more competitive than cowpea. Sorghum being a tall cereal was competitive to cactus for all resources-water, nutrients and light. But competition from cowpea, a low canopy legume, would be only in respect of water and nutrients other than nitrogen. Cactus intercropped with sorghum attained only 65% of the size of the sole crop (measured in terms of height and lateral spread) while that intercropped with cowpea reached 73% of the sole crop. The intercropped cactus had significantly fewer, thinner and smaller rackets compared to that of sole crop. The detrimental effect of intercropping was particularly noted in the case of number of rackets and their thickness (or turgidity). As a result, the intercropped cactus possessed only 49% of the rackets with only 38% as thick as those on the sole crop.

In the absence of yield from cactus one can not correctly assess the advantage of intercropping with these annual crops. The rackets being the ultimate economic product, we considered the characteristics of rackets as indicators of yield and computed the land productivity as is generally done with grain yields as follows:

$$\text{Land equivalent ratio} = \frac{\text{yield of sorghum (or) cowpea in intercrop}}{\text{yield of sorghum (or) cowpea in sole}} + \frac{\text{total volume of rackets in intercropping}}{\text{total volume of rackets in sole cactus}}$$

The volume of rackets was calculated by no. of rackets x area of the rackets x thickness of the rackets x plant number.

On this basis, the intercrop did not present any advantage over sole cropping. However, calculation done on the basis of leaf area showed a 24% advantage for intercropping with sorghum and 33% for intercropping with cowpea. In fact this may be more valid for the reason that thickness of rackets simply represents turgidity and may not necessarily be proportional to the dry matter. However, these results have to be considered as preliminary and it is possible that cactus with time may compensate and improve the overall advantage of intercropping.

At current value, cowpea just met the costs of seed, fertilizer and sprayings but sorghum gave a net return of Cr$ 70 000/ha. Both the intercrops produced considerable quantity of fodder which has better nutritive value than cactus itself. These returns from the intercrops are all the more important considering that cactus will not be harvested until the third year.

The intercrops will be grown in the subsequent years as long as cactus permits, but the proportion of the intercrops may have to be reduced depending on the spread of the crop. The wide row and paired row systems may be particularly useful in the later years.

5.2- Effect of shade of 'Algaroba' (*Prosopis juliflora*) on Cactus

Although there is no experimental evidence as such, some observations indicate that shading of cactus by 'algaroba' is beneficial. Alves (1976) did not observe any significant effect of shade on the productivity of cactus. But Alves & Barbosa (1979) based on their observations in non experimental conditions affirmed later that shade prolonged the productive period of cactus from 10 to 20 years. Whether shading improves the yield of cactus or not, the intercropped 'algaroba' would provide nutritive pods (15 kg/tree), wood and nector for apiary (Azevedo, 1961).

In the absence of quantitative information, an experimental was undertaken to (i) assess the beneficial effect of intercropping cactus with 'algaroba' and ii) determine the optimum spacing for algaroba to realise maximum advantage. The treatments included i) sole cactus ii) cactus with algaroba at 5 m x 5 m iii) algaroba at 7 m x 7 m, iv) algaroba at 10 m x 10 m and v) algaroba at 12.5 m 12.5 m. These five treatments were replicated thrice in a randomised block design. Cactus was planted in the middle of December 1982 at a spacing of 2 m x 0.5 m (i.e. 10 000 plants/ha). Seedlings of 'algaroba' were transplanted at the required spacings in February 1983. Both the species have established well but at present no data are available because of the perennial nature of the crops.

6 - EVALUATION OF YIELD STABILITY IN INTERCROPPING

Less risk or improved stability is often said to be one of the major reasons why small farmers practise intercropping. But only few studies have actually quantified the degree to which intercrops can be more stable over sole crops. This is partly due to the lack of sufficient data covering a range of environments to draw proper inferences and lack of appropriate methods to quantity risk. Rao and Willey (1980) while examining the stability of sorghum/pigeonpea suggested that calculating the probability of failure of differenc systems for any determined level of income expresses the risk very clearly. On this basis, they found that sorghum/pigeonpea fails to give an income of Rs 1 000/ha only once in thirty six years compared to the failures of once in every five, eight and thirteen years, respectively, by sole pigeonpea, sole sorghum or a combination of both the sole crops. Also Francis and Sanders (1978) in maize/beans and Baker (1980) in sorghum/groundnut observed greater stability for intercrops compared to the sole crops.

As indicated earlier, for assessing the stability of intercrops information over a range of sites is required. Genotypes, populations and management etc across sites should necessarily be uniform. But no specific studies have ever been planned in the Northeast to gather data for evaluating stability of systems. In view of this we followed two approaches, i) to make use of the published results from various state organisations and ii) to initiate a multilocation experiment at selected sites involving all possible alternative systems.

We collected results of 51 experiments on maize/beans and 34 on maize/cowpea systems from various sources and summarised the results from the point of agronomic and stability aspects[3]. The

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[3]For details see Rao & Morgado (1983b) under publications.

salient results of this work were as follows:

i) Maize/beans intercrop was about 32% more productive and maize/cowpea about 41% compared to their respective sole crops.

ii) The arrangements of 1 maize: 2 beans and 1 maize: 3 beans were equally productive for maize/beans intercrop while for maize/cowpea alternate rows or 1 maize: 2 cowpea could be adapted. The optimum populations were: maize-half the sole crop optimum in both systems (20 000 to 25 000 plants/ha), beans-3/4 sole crop density (150 000 to 200 000 plants/ha), and cowpea-full population of the sole crop (40 000 to 50 000 plants/ha).

iii) There were very few genotype trials and the available information did not help much to define the genotype requirements in both these systems.

iv) There was no significant relationship between intercropping advantage and rainfall or fertilization indicating that the benefits of intercropping were not just limited to poorer environments.

v) The probability of failures to obtain specified levels of income or yields were less with intercrops compared to sole crops in both combinations.

vi) Sorghum was more productive and consistent than maize suggesting that it can be a good substitute for maize in the traditional systems of the Northeast.

In order to collect more valid and purposeful data over a considerable length of time, an experiment involving all possible intercrops along with their respective sole crops was initiated at CPATSA. We intended to conduct this experiment at a number of state research centers but due to shortage of funds it was confined to only CPATSA. The treatments were:

Sole Crops	2- Crop Systems	3- Crop Systems
1- Maize	8- Maize/Cowpea	14- Castor/Sorghum/Cowpea
2- Sorghum	9- Sorghum/Cowpea	15- Moco/Sorghum/Cowpea
3- Cowpea	10- Castor/Cowpea	16- Annual cotton/Sorghum/Cowpea
4- Castor	11- Moco/Cowpea	17- Cassava/Sorgo/Cowpea
5- Perennial cotton	12- Annual cotton/Cowpea	
6- Annual cotton	13- Cassava/Cowpea	
7- Cassava		

The above systems were evaluated in two replications at two fertility levels, i) no fertilizer and ii) 20 N-50 P_2O_5 - 0 K_2O. Due to pressure on work and dearth of sufficient people it was planted late after finishing all other experiments. Moreover, the soil was also very shallow and stony. As a result the crops did not come up well and only cowpea gave reasonably good yield as in the neighbouring experiments (about 400 kg/ha). The cereals did not produce anything. Castor and cassava grew well but could not survive the dry period. Both the types of cotton gave very little yield. This experiment has to be reestablished in the coming season. The 3-crop systems, except with moco, can be eliminated because sorghum appeared to be very competitive to castor, annual cotton and cassava. To collect meaningful data for stability analysis, this experiment must be conducted at a couple of representative sites where these systems are common.

7 - PUBLICATIONS

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