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Response of cereals to nitrogen in sole cropping and intercropping with different legumes

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Abstract

The response of sole and intercropped cereal to nitrogen fertilization was compared in three contrasting cropping systems, sorghum/pigeonpea, maize/groundnut, and sorghum/cowpea. The cereal in these systems responded to nitrogen similarly as in sole cropping, although different legumes affected the cereal differently. There was no current season benefit from the legume, whether it matured earlier or later than the cereal, and for high yields the cereal in intercropping needs fertilizer application. Response to nitrogen varied with the amount and distribution of seasonal rainfall. With increased nitrogen fertilizer applied to the intercropped cereal, the legume yields were suppressed. The optimum dose for the intercropped cereal was similar to that for sole cropping but it was 50% less in a dry year particularly on a shallow Alfisol. The combined yields of both crops made intercropping more profitable than sole cropping. The relative advantage of intercropping was high in the sorghum/pigeonpea system (40 to 70%) because of the greater temporal difference between species, and moderate in the maize/groundnut (13 to 35%), and sorghum/cowpea (18 to 25%) systems. Although the relative advantage of intercropping (expressed as Land Equivalent Ratio (LER)) decreased with N, the economic value of the advantage was little affected within the optimum N range because absolute yields increased with fertilization.

Introduction

Intercropping is an age-old practice in the tropics, but only in recent years has it received attention of researchers. Several studies indicated that this practice offers considerable yield advantage over sole cropping because of its efficient utilization of plant growth resources (Ahmed and Rao, 1982; Natarajan and Willey, 1980; Reddy and Willey, 1981). Although several crops are involved in traditional cropping systems, cereal/legume combinations are by far the most predominant. Attempts to improve these traditional systems require agronomic studies covering all aspects, but, research has so far concentrated only on compatibility of different species, studies on plant density, spacing, genotypes *etc.*, with little emphasis on fertilizer inputs. Some issues of fertilization that should be examined include: 1. how to fertilize the component species in intercropping, particularly when the species respond differently to a particular nutrient; 2. whether intercropping is advantageous under high input technologies; and 3. whether legumes modify the nutrient responses of the associated cereal. Very few studies have actually considered the response of both components in determining the optimum dose fertilizer for an intercrop system (Feeraz Gominho and Mafra, 1979; Santa Cecilia *et al.*, 1982).

There has been some speculation, mostly based on laboratory experiments that legumes might benefit the associated cereals in intercropping by transfering part of the nitrogen fixed during the growing season (Rewari *et al.*, 1972; Ruschel *et al.*, 1979; Virtanen *et al.*, 1937; Wilson and Wyss, 1937). However, very few field studies have actually demonstrated the direct benefit of legumes to cereals in intercropping. Where positive effects were reported either an insufficient range of fertility situations were examined (De *et al.*, 1978; Singh, 1981), or the legume effect was confounded with plant population because the intercrops were planted in a replacement system (Remison, 1978; Eaglesham *et al.*, 1981). In fact, legumes intercropped with cereals showed consistently reduced nitrogen fixation indicating that they are of less benefit to the cereals (Nambiar *et al.*, 1983; Wahua and Miller, 1978). In some multilocational studies the response of maize intercropped with soybean to nitrogen fertilization was similar to that of sole-cropped maize (Ahmed and Gunasena, 1979; Ahmed and Rao, 1982). The maturity of the legume relative to that of the cereal may influence the competitive and/or beneficial effect of the legume, and consequently the cereal's response to fertilization. This paper describes a series of experiments conducted on cereal/legume intercrop systems at ICRISAT Center, Patancheru, India to examine the issues mentioned above.

Materials and methods

Three sets of experiments were conducted at ICRISAT Center in which the response of sorghum or maize to nitrogen fertilization was compared when it was grown as a sole crop, or intercropped with legumes of differing maturities such as a pigeonpea (later-maturing than the cereal), groundnut (similar maturity to the cereal) or cowpea (earlier-maturing than the cereal) (Table 1).

Sorghum/pigeonpea

The experiment was conducted on Vertisols for three successive years (1977 1979) and once on Alfisols in 1979. In 1977 it was laid out in a split-plot design with four replications. Sole crops of sorghum (180,000 plants ha^{-1}) and pigeonpea (40,000 plants ha^{-1}) and three different populations in intercropping (40:40, 80:80 and 120:120% of the respective sole crop optima) were allocated to main plots and four nitrogen levels (0, 40, 80 and 120 kg N ha^{-1}), applied only to sorghum, to subplots. In 1978 and 1979, only sorghum populations varied in intercropping against a constant optimum pigeonpea population (33:100, 67:100 and 100:100% of sole crop optima). The factorial combinations of the intercrop populations and sole sorghum with the N levels, plus the sole pigeonpea were examined in a randomised block design over three replications. Row spacing and planting geometry in intercropping are shown in Fig. 1. Required populations were maintained by adjusting spacing within rows. On Vertisols crops were sown

Table 1. Details of cereal legume intercrop experiments

Year	Cultivars		Sowing date[a]	Days to maturity		Soil nutrient status (ppm)	Rainfall (mm)	
	Cereal	Legume		Cereal	Legume	N P K	S[b]	P[b]
Sorghum pigeonpea								
1977 V	CSH 6	ICP 1	20 June	98	190	79 6.5 195	475	534
1978 V	CSH 6	ICP 1	20 June	100	180	62 7.0 144	863	906
1979 V	CSH 6	ICP 1	20 June	100	200	33 5.2 204	628	711
1979 A	CSH 6	ICP 1	30 June	90	184	48 10.8 130	570	653
Maize groundnut								
1978 A	SB 23	TMV 2	22 June	110	112	96 5.0 77	836	
1979 A	SB 23	TMV 2	29 June	122	114	98 10.4 75	600	
1980 A	SB 23	TMV 2	13 June	118	122	81 8.7 98	592	
Sorghum/cowpea								
1980 A	CSH 6	No. 779	18 June	107	76	100 60 75	592	
	CHS 6	EC 4216		107	53			

V – Vertisols, A Alfisols

[a] Day of dry seeding on Vertisols. The day of first heavy shower was considered as the effective date for initiation of germination.

[b] S – sorghum growing period.
P = pigeonpea growing period.

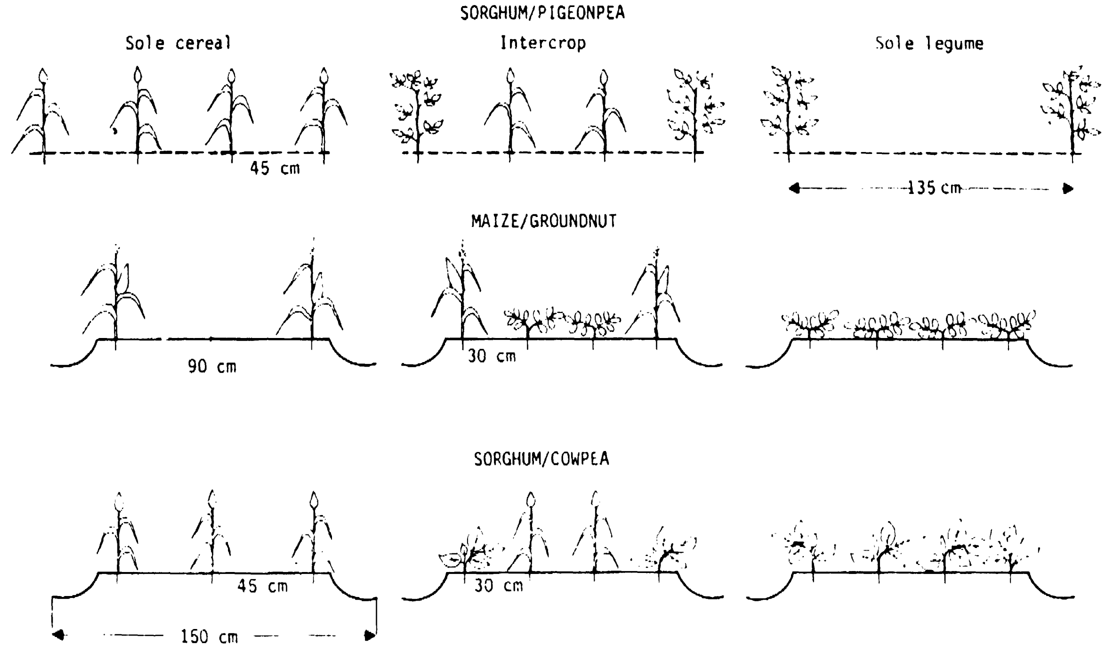

Fig. 1. Row arrangements of crops in sole and intercropping.

in dry soil just ahead of the rains; on Alfisols they were sown after the onset of the rains. During the final land preparation, 20 kg P ha^{-1} was uniformly broadcast and incorporated. Nitrogen was applied only to sorghum, first at 20 kg N ha^{-1} (as ammonium sulphate) immediately after thinning (*i.e.*, at 2-week stage), and the balance as urea, 2-weeks later. During the growing period the crops were hand-weeded twice and were protected against shoot fly (*Atherigona soccata*) on sorghum by one or two 0.2% endrin sprays and pod borer (*Heliothis armigera*) on pigeonpea by one or two sprays of 0.35% endosulphan (Thiodan®) 35 EC. Plot sizes varied across years from 31.5 to 48.6 m^2, the harvest area had six rows of 5 m in 1977, 8 m in 1978 and 7 m in 1979 (*i.e.*, 13.5 m^2 in 1977, 21.6 m^2 in 1977, and 18.9 m^2 in 1979).

Maize/groundnut

The experiment on maize/groundnut was conducted for three rainy seasons from 1978 to 1980 on Alfisols in a randomised-block layout with four replicates. The study had nine treatments, maize with or without groundnut at four nitrogen levels (0, 50, 100, and 150 kg N ha^{-1}) and a sole groundnut. The area was cultivated into 150 cm broadbed and furrows for the convenience of planting with a bullock-drawn planter. Each broadbed consisted of a 90 cm bed and a 60 cm furrow. The spatial arrangement of crops in sole and intercropping is shown in Figure 1. Sole maize was thinned to a population of 60,000, and sole groundnut to 267,000 plants ha^{-1}. The intercrop was maintained at 100% of sole maize and 50% of sole groundnut populations. The plot size was 4.5 m wide (3 broadbeds) and 37 m long. A uniform dose of 20 kg P plus 25 kg zinc sulphate ha^{-1} was incorporated during the final land preparation. Nitrogen was applied only to maize in two equal splits at 15 and 30 days after sowing. Weeds were controlled by two hand weedings. Maize generally did not require any protection but groundnut required two sprays of 0.20% dimethoate (Rogor®) 40 EC during its early growth stages to control thrips, and one or two sprays of 35% endosulphan (Thiodan®) 35 EC to control *Heliothis armigera* at later stages. Groundnut was also affected by leaf spot (*Phaeoisariapsis personata*) and one or two sprays of chlorothaonil (Daconil®, 1.8 kg ha^{-1}) were given depending on the disease intensity. An area of 3 (2 beds) × 7 m was harvested from each plot for final yield estimation.

Sorghum/cowpea

One experiment was conducted in 1980 on Alfisols on 150 cm broadbed and furrows. There were 14 treatments; sorghum sole and intercropped with grain and fodder cowpea, all at four levels of nitrogen (0, 40, 80 and 120 kg ha^{-1}), and sole treatments of grain and fodder cowpeas. These were examined in three replications of a randomised-block design. The plot was 4.5 m wide and 26 m long. The sowing pattern of crops in sole and intercropping is shown in Fig. 1. The sorghum population in both systems was maintained at 167,000 plants ha^{-1}. Cowpea was not thinned within rows. The spatial advantage given to intercropped cowpea by sowing it outside the bed (through the extra space of the furrow) was thought to improve its growth and benefit the cereal more than when it was sown in the center of the bed. The experimental site was fertilized with a uniform dose of 18 kg P ha^{-1} before sowing. Sorghum was fertilized later with the specified levels of nitrogen in two equal splits, once at thinning (2 weeks after planting) and again at the 4-week stage. Cowpea required one spray of 0.2% dimethoate in the early stages and only grain cowpea required another spray of endosulphon 35 EC to control pod borer in the later stages. Grain or dry-matter yields were estimated by harvesting two sub-sample areas of 3 m × 8 m (2 beds) from each plot.

Analyses of data

In addition to normal analysis of variance, regressions were fitted between yield and applied nitrogen, and optimum rates of nitrogen estimated. The productivity of intercrops was assessed by Land Equivalent Ratios (LERs). This is calculated as the sum of the respective sole crop land areas required to produce the same yields as the component crops in one ha of intercropping (Willey, 1979). LERs at different N levels were calculated using the sole crop yields at the corresponding N level.

The component crops in an intercrop system may respond differently to any particular input *e.g.*, the cereal in cereal/legume systems responds positively to nitrogen whereas the legume may not respond. The optimum dose for any one component in intercropping can not be determined independently of the response of the other component because of interaction between species. Hence the optimum doses for the intercrops in the present study were calculated considerng the responses of both the crops together as follows:

Let the responses of component crops A and B to an input x be: $Y_A = a_1 + b_1x + c_1x^2$ and $Y_B = a_2 + b_2x + c_2x^2$ respectively. Given the price of x, A and B as P, V_A and V_B respectively, the profit function can be written as:-

$$\pi = V_AY_A + V_BY_B - P_x$$

The input requirement for maximum profit can be obtained from

$$\frac{d\pi}{dx} = V_A\frac{d(Y_A)}{dx} + V_B\frac{d(Y_B)}{dx} - P = 0$$

$$x = \frac{P - (V_Ab_1 + V_Bb_2)}{2(V_Ac_1 + V_Bc_2)}$$

Given that the response of one component is quadratic the response of the other can either be quadratic, positively linear or negatively linear. The optimum dose for an intercropping system can be estimated when the response of at least one of the component is of curvilinear form.

Results

Sorghum/pigeonpea

Neither the effects of population nor population × nitrogen were significant in any of the years, so only the effect of nitrogen fertilization on the sole and intercropped sorghum at 'full' sorghum population is examined here.

In 1977, both the sole and the intercropped sorghum gave a significant response to nitrogen applied up to 80 kg N ha^{-1} (Fig. 2). Further increase in nitrogen did not produce any worthwhile additional yield in either system. The response pattern in both systems was similar, but the intercropped sorghum yields were significantly reduced where 80 and 120 kg N ha^{-1} were applied. Intercropped pigeonpea produced about 60% of the sole crop yield when sorghum received no nitrogen, and the yield remained virtually the same even when nitrogen

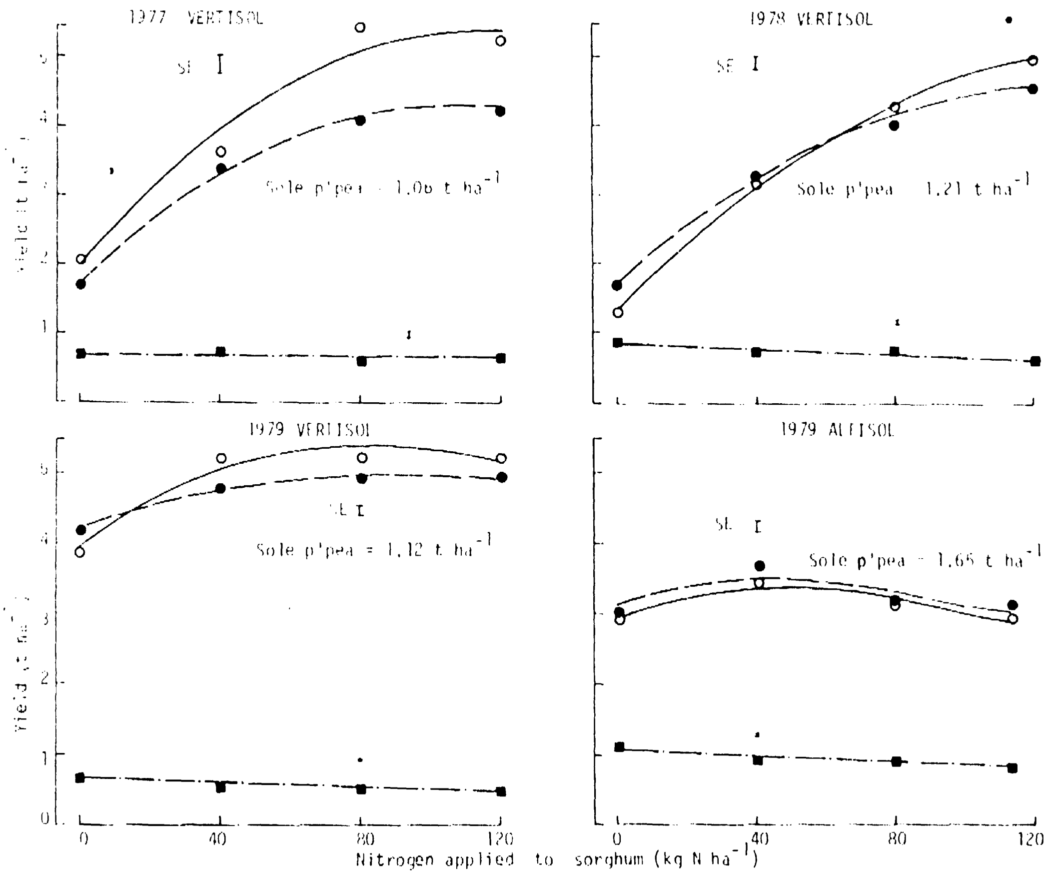

Fig. 2. Effect of nitrogen fertilization on sole *vs.* intercropped sorghum with pigeonpea (O O sole sorghum, ● ● intercropped sorghum and ■ . ■ intercropped pigeonpea).

applied to sorghum was increased from 40 to 120 kg N ha^{-1}. In 1978, the intercropped sorghum yield was not very different from that of the sole crop. A response to N was observed up to 120 kg N ha^{-1} in both systems during this year, but pigeonpea yield decreased significantly from 70% of its sole crop yield at 0 N, to 52% at 120 kg N ha^{-1}. Results in 1979 were somewhat different from those of the previous years in that the response to N was limited only to 40 kg ha^{-1} on both soil types, though the yields were higher on Vertisols than on Alfisols. In fact, applications of more than 40 kg N ha^{-1} decreased yield on Alfisols. Intercropped pigeonpea yield dropped gradually with increasing fertility, more so on Alfisols than on Vertisols.

In 1977, intercropped sorghum averaged 75 to 82% of the sole crop yield except at 40 kg N ha^{-1} where it gave 93% of the sole crop (Fig. 3). The pigeonpea yield varied from 65 to 59% of the sole crop. The component LERs totalled 1.46 at 0 N ha^{-1} indicating that the intercrop system was 46% more productive than the sole crop systems. The relative advantage tended to decrease with nitrogen application to sorghum. In 1978 the intercropped sorghum yielded more than 90% of the sole crop where nitrogen was applied but its yield at 0 N ha^{-1} was 31% higher than that of the sole crop. This was because sole sorghum without N was more affected by shoot fly and grew poorly compared with intercropped sorghum. The high sorghum LER coupled with that of pigeonpea LER (0.7) resulted in a total LER of 2.0 at 0 N ha^{-1}. But a drop in the component LERs, particularly that of pigeonpea with nitrogen application, caused a decrease in the total LER from 2.0 to 1.6 at

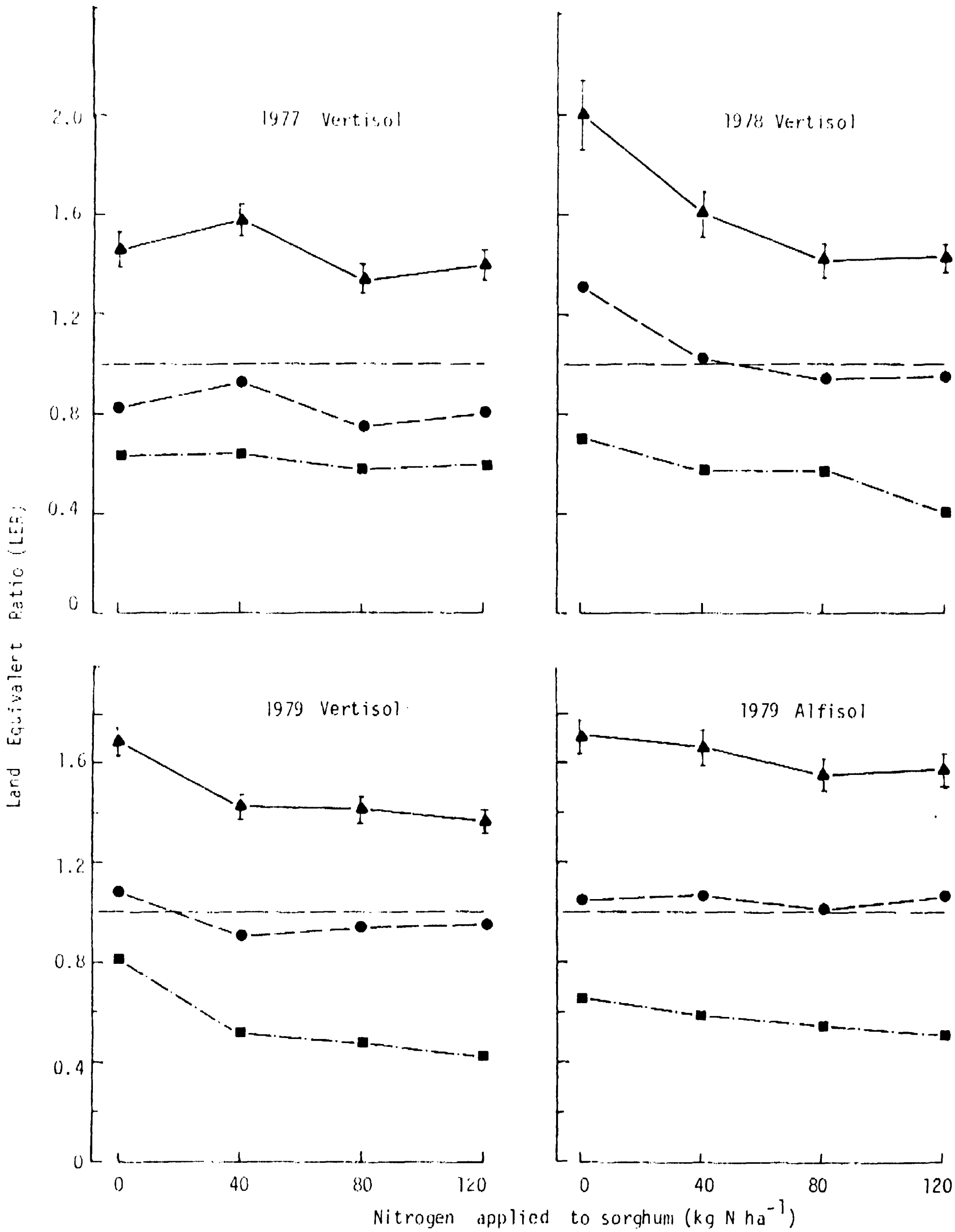

Fig. 3. Effect of nitrogen fertilization on Land Equivalent Ratios in sorghum/pigeonpea intercropping (● —● sorghum LER, ■ . ■ pigeonpea LER and ▲ — ▲ total LER).

40 kg N ha⁻¹ and finally to 1.44 at 120 kg N ha⁻¹. On Vertisols in 1979 intercropped sorghum gave almost 100% of sole crop yield at 0 N ha⁻¹ and more than 90% of the sole crop when it was fertilized with nitrogen. The intercropped pigeonpea yield also declined in this year from 61% of the sole crop yield at 0 N ha⁻¹ to 42% at 120 kg N ha⁻¹ as a result of which the LER advantage decreased from 69% at 0 N ha⁻¹ to 37% at 120 kg N ha⁻¹. On Alfisols in the same year intercropped sorghum yielded as much as the sole crop at each level of nitrogen application, but there was a drop in total LERs with nitrogen fertilization primarily because of a decrease in pigeonpea LER.

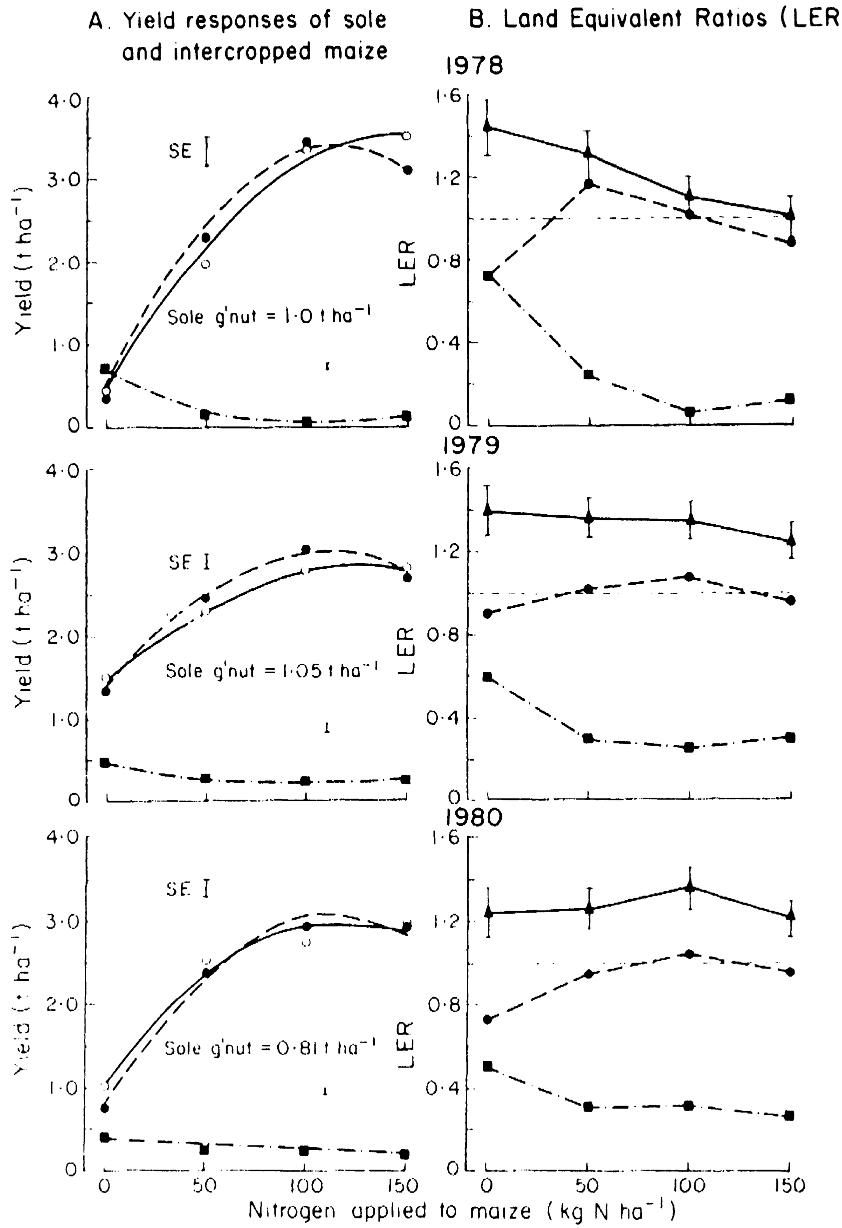

Fig. 4.. Effect of nitrogen fertilization on sole and intercropped maize with groundnut A. Yield responses of sole *vs.* intercropped maize. B. Land Equivalent Ratios (O —O sole maize, ● ● intercropped maize ■ . ■ intercropped groundnut ▲ ▲ Total LER).

Maize/groundnut

Maize yields without the addition of nitrogen fertilizer were generally very poor, and the response to fertilizer was remarkable in all years up to 100 kg N ha⁻¹ in sole as well as intercropping (Fig. 4). Further increase in nitrogen application did not cause much change in the maize response. Intercropped maize produced slightly less yield than the sole crop at 0 N but yielded slightly more than the sole crop at the two intermediate levels. Obviously, apart from showing no beneficial effect the legume was competiting with maize when no fertilizer was applied to the cereal. This pattern was consistent in all three years; however, the cropping system × N interaction was not significant, and maize response to nitrogen in both systems can be regarded as similar. Sole groundnut produced good growth in all years but that was not reflected in its pod yield partly because of the incidence of leaf spots to which the cv TMV 2 the cultivar used is highly susceptible. Intercropped groundnut yields decreased with N application to maize, and the drop for the first 50 kg N ha^{-1} was significant at the 5% level of probability.

The intercropped maize yield in 1978 was only 72% of its sole crop yield at 0 N ha^{-1} but that allowed groundnut to produce 73% of its sole crop yield giving an advantage of 45% for intercropping at that fertility. With N fertilization, maize grew vigorously yielding as much as the sole crop, but it suppressed groundnut so heavily that the advantage of intercropping went down to 31% at 50 N ha^{-1} and 10% at 100 kg N ha^{-1}. There was no advantage at 150 kg N as the intercropped maize yielded slightly less than that in sole cropping at this fertility. This pattern continued in the folowing year also except that groundnut was less affected by maize because there was less rainfall, and poorer maize growth than in the previous year. As a result, the relative advantage of intercropping was higher than in the previous year where nitrogen was applied to maize. However, there was no consistent trend in the LER advantage in 1980.

Sorghum/cowpea

Sole sorghum responded to N up to 120 kg N ha^{-1}, but in a typically diminishing pattern beyond 40 kg N ha^{-1} (Fig. 5). Intercropped sorghum responded similarly to N indicating that the legume had no effect on the response pattern of the associated cereal. However, cowpea harvested for grain or fodder was competitive to sorghum and significantly reduced its yield. Grain cowpea tended to be more competitive than fodder type, though the difference between the two was not significant. Sorghum affected both cowpea types similarly, allowing only about 50% of their sole crop yield. The increased competition of cowpea on sorghum could be attributed to better growth of cowpea due to the spatial advantage given to it at sowing. The sorghum/grain cowpea system was 19% more productive than the sole crops whereas the sorghum/fodder cowpea was slightly more productive at 22% over their respective sole crops. There was no definite trend in LER advantage in relation to fertility as cowpea yields were little affected by the application of different N levels to sorghum.

Discussion

The intercropped cereal, irrespective of the legume associated with it, responded to N similarly as in sole cropping suggesting that the legumes did not greatly modify the N requirement of the cereal.

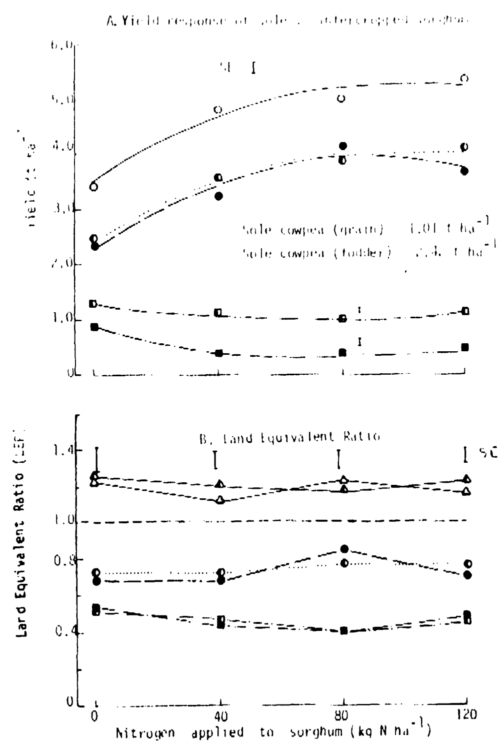

Fig. 5. Effect of nitrogen fertilization on sole and intercropped sorghum with grain or fodder cowpea. A. Yield responses of sole vs. intercropped sorghum and B. Land Equivalent Ratios (○—○ sole sorghum, ●— ● sorghum intercropped with grain cowpea, ◐····◐ sorghum intercropped with fodder cowpea, ■ . ■ grain cowpea, ◧-. ◧ fodder cowpea, ▲——▲ total LER of sorghum/grain cowpea, and ∆— ∆ total LER of sorghum/fodder cowpea).

However, different legumes caused different degrees of yield reduction in the cereal. The slow-growing and later-maturing pigeonpea was least competitive with sorghum. Although it was sown as an intercrop at 100% of its sole crop density, it suppressed sorghum on an average by only 10%. Similar results were observed in earlier studies (Natarajan and Willey, 1980; Rao and Willey, 1980). Lack of benefit or competition from pigeonpea was because it produced very little growth during the sorghum growing period. But there was no benefit even from groundnut to maize, or from cowpea to sorghum, despite the fact that these legumes matured at the same time or earlier than the cereal. Any beneficial effect from a legume should have been evident where 0 N ha^{-1} was applied to the cereal. In fact, the legume reduced the cereal yield in both maize/groundnut and sorghum/cowpea at 0 N. The spatial advantage for promoting growth and N_2-fixation given to cowpea in the sorghum/cowpea system was counter-productive in the sense that the cowpea became competitive rather than beneficial to sorghum. No legume benefit was noticed even when more time was allowed for the decomposition of root residues by harvesting cowpea early for fodder. The cereal may have seriously reduced the nitrogen fixation of legumes (Nambiar *et al.*, 1983; Wahua and Miller, 1978). These results suggest that the cereals under most field situations do not derive any beneficial effect from legumes during the current season, particularly when they are grown at full population and with N fertilization. Therefore, to obtain good yields they should receive fertilizers in both inter and sole cropping.

The response of sorghum to nitrogen and the optimum level at which it can be fertilized are mainly dependant on the seasonal rainfall. In a normal season such as 1977 it was economical to fertilize sole sorghum to 102 kg N ha^{-1} (Table 2). In the following year, when rainfall was high and well distributed, the economic optimum was high at 125 kg N ha^{-1}. Though the rainfall in 1979 was only slightly less than normal, there was drought stress due to prolonged dry spell at the beginning of the season, which restricted the nitrogen require-

Table 2. Best fit regressions for grain yields of crops and optimum doses of nitrogen in different systems

Cropping systems	Year	R^2			Optimum dose (kg ± SE)	
		Sole sorghum	Int. sorghum	Int. pigeonpea	Sole sorghum	Int. sorghum
Sorghum/pigeonpea	1977	0.966[b]	0.997[b]	0.59[a]	102 ± 26	90 ± 5
	1978	0.999[b]	0.997[b]	0.908[a]	125 ± 9	99 ± 9
	1979 (V)	0.936[b]	0.987[b]	0.975[a]	69 ± 8	34 ± 8
	1979 (A)	0.972[c]	0.782[c]	0.973[a]	16 ± 2	10 ± 5
Maize/groundnut		Sole maize	Int. maize	Int. groundnut	Sole maize	Int. maize
	1978	0.989[b]	0.995[b]	0.971[d]	136 ± 24	108 ± 30
	1979	0.999[b]	0.993[b]	0.994[d]	100 ± 4	84 ± 6
	1980	0.962[b]	0.992[b]	0.740[a]	104 ± 17	93 ± 6
Sorghum/cowpea		Sole sorghum	Int. sorg. with grain cowpea	Int. grain cowpea	Sole sorghum	Int. sorghum with grain cowpea
	1980	0.958[b]	0.986[b]	0.984[b]	88 ± 18	80 ± 17
		Sole sorghum	Int. sorg. with fodder cowpea	Int. fodder cowpea	Sole sorghum	Int. sorghum with fodder cowpea
	1980	0.958[b]	0.986[b]	0.838[d]	88 ± 18	90 ± 16

V = Vertisol; A = Alfisol; [a]$Y = a - bx$; [b]$Y = a + bx - cx^2$; [c]$Y = a - bx + c\sqrt{x}$; [d]$Y = a - bx + cx^2$.
Prices used for calculating optimum dose per kg were:
Nitrogen — Rs. 4.50; Sorghum — Rs. 0.80; Maize — Rs. 1.00; Pigeonpea — Rs. 2.40; Groundnut — Rs. 2.50; Cowpea — (grain) — Rs. 1.50; and cowpea (dry fodder) — Rs. 0.50

ment of sole sorghum to only 67 kg N ha^{-1} in Vertisols and 16 kg N ha^{-1} in the low water-holding Alfisols. Another reason for this limited response could be that much of the nitrate form of nitrogen accumulated at sowing in the profile (0–30 cm) during the dry period, 33 kg on Vertisols and 22 kg on Alfisols was available to the crop in this year compared to that in a good rainfall year (1978) when most of the nitrate form might be leached out of the root zone. This also explains the high base yields (4 t ha^{-1} on Vertisols and 3 t ha^{-1} on Alfisols of sole sorghum, and 1.6 t ha^{-1} of sole maize) without nitrogen application in 1979, and their greater response to applied nitrogen in 1978. Generally, maize responded to higher doses of nitrogen than sorghum indicating its higher N requirement.

Although the pattern of intercropped cereal response was more or less similar to that of the sole crop, the efficiency of nitrogen utilization was less in intercrops, probably because of competition from the legumes, and their sharing of some nitrogen. The difference between a sole and intercropped cereal was less when the associated legume was pigeonpea or groundnut, but the cereal yield was significantly reduced by intercropping with cowpea. However, the cereal was generally much more competitive to the high value legume component, the severity being more with increasing nitrogen application to it. Hence the optimum rates of nitrogen for intercropping calculated on the basis of the combined responses of both crops were 10 to 50% lower than that required for sole cropping.

Since rainfall in the semi-arid tropics is erratic and undependable one cannot generalize the optimum N dose for all seasons. Therefore, a strategy that can be adopted, is to apply a minimum level of nitrogen (say 10 to 20 kg N ha^{-1}) at the beginning of the season and depending on the weekly course of rains decide on the additional quantity required.

All the three intercrop systems gave worthwhile yield advantages over sole crops, whose magnitude was related to the temporal difference between the component crops of the systems. Thus, the advantage was high in sorghum/pigeonpea, and between the other two systems was more stable in sorghum/cowpea than in maize/groundnut. However, the relative yield advantage decreased with nitrogen fertilization (Figs. 3 to 5). Averaged over three years, it decreased from 1.7 at 0 N to 1.4 at 120 kg N ha^{-1} in sorghum/pigeonpea on Vertisols and from 1.35 at 0 N to 1.13 at 150 kg N ha^{-1} in maize/groundnut. These trends may apparently support the hypothesis that intercropping is more relevant for poorer environments, but the monetary advantage (*i.e.* value of combined intercrop yield X

$$\frac{\text{LER-1}}{\text{LER}}\text{, Willey, 1979)}$$

which remained little affected by N within the optimum range does not suggest that intercropping has to be replaced by sole cropping when N fertilizer is used. The monetary advantage was estimated to be Rs. 1555, 1555, 1375 and 1285 at 0, 40, 80, and 120 kg N ha^{-1} respectively in sorghum/pigeonpea and Rs. 574, 670, 679 and 317 at 0, 50, 100 and 150 kg N ha^{-1} in maize/groundnut respectively. In sorghum/cowpea there was no definite trend as with the LER itself. The present results confirm the earlier studies in maize/soybean that the cereal/legume combinations should be fertilized judiciously to fully exploit the species complementarity.

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References

Ahmed S and Gunasena H P M 1979 N utilization and economics of some intercropped systems in tropical countries. Trop. Agric. (Trinidad) 56, 115–123.

Ahmed S and Rao M R 1982 Performance of maize-soybean intercrop combination in the tropics: Results of a multilocation study. Field Crops Res. 5, 147–161.

De R, Gupta R S, Singh S P, Pal M, Singh S N, Sharma R N and Kaushik S K 1978 Interplanting maize, sorghum and pearl millet with short-duration grain legumes. Indian J. Agric. Sci. 48, 132–137.

Eaglesham A R J, Ayanaba A, Ranga Rao V and Eskew D L 1981 Improving the nitrogen nutrition of maize by intercropping with cowpea. Soil Biol. Biochem. 13, 169–171.

Feeraz Gominho M S and Mafra R C 1979 Uma metodologia de analise agroeconomica para culturas consorciadas em expermientos de adubação Pesq. agropec. Pernamb. Recife 3, 161–182.

Nambiar P T C, Rao M R, Reddy M S, Floyd C N, Dart P J and Willey R W 1983 Effect of intercropping on nodulation and N-fixation by groundnut. Expl. Agric. 19, 79–86.

Natarajan M and Willey R W 1980 Sorghum-pigeonpea intercropping and the effects of plant population density. I. Growth and yield. J. Agric. Sci. Cambridge, 95, 59–65.

Rao M R and Willey R W 1980 Evaluation of yield stability in intercropping: studies on sorghum/pigeonpea. Expl. Agric. 16, 105–117.

Reddy M S and Willey R W 1981 Growth and resource use studies in an intercrop of pearl millet/groundnut. Field Crops Res. 4, 13–24.

Remison S U 1978 Neighbour effects between maize and cowpea at various levels of N and P. Expl. Agric. 14, 205–212.

Rewari R B, Sen A and Pandy S L 1972 Excretion of nitrogen from the roots of guarbean, *Cyamopsis psoralioides*. J. Indian Soc. Soil Sci. 5, 237–245.

Ruschel A P, Salati E and Vose P B 1979 Nitrogen enrichment of soil and plant by *Rhizobium phaseoli Phaseolus vulgaris* symbiosis. Plant and Soil 51, 425–429.

Santa Cecilia F C, Ramalho M A P and Garcia J C 1982 Abubação nitrogenada e fosfatada na consorciação milho-feizao. Pesq. Agropec. bras., Brasilia 17, 1285–1291.

Singh S P 1981 Studies on spatial arrangement in sorghum legume intercropping system. J. Agric. Sci. Cambridge 97, 655–661.

Virtanen A I, Von Hausen S and Laine T 1937 Investigation on the root nodule bacteria of leguminous plants. XX Excretion of nitrogen in associated cultures of legumes and nonlegumes. J. Agric. Sci. 27, 610.

Wahua T A T and Miller D A 1978 Effects of intercropping on soybean N fixation and plant compilation on associated sorghum and soybeans. Agron J. 70, 292–295.

Willey R W 1979 Intercropping — its importance and research needs. I. Competition and yield advantages. II. Agronomy and research approaches. Field Crop Abstr. 32, 1–10, 73–85.

Wilson P W and Wyss O 1937 Mixed cropping and the excretion of nitrogen by leguminous plants. Soil Sci. Soc. Am. Proc. 2, 289–297.