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EFFECTS OF PIGEONPEA PLANT POPULATION AND ROW ARRANGEMENT IN SORGHUM/PIGEONPEA INTERCROPPING

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ABSTRACT

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A sorghum/pigeonpea intercropping experiment carried out for 3 years on a deep Vertisol in India examined the response to five pigeonpea populations in a 150 cm bed and furrow system at three row arrangements per bed: (a) 1 row sorghum : 1 row pigeonpea : 1 row sorghum at 45 cm between rows (SPS); (b) 1 row sorghum : 2 rows pigeonpea : 1 row sorghum at 30 cm between rows (SPPS); and (c) 1 row pigeonpea : 2 rows sorghum : 1 row pigeonpea at 30 cm between rows (PSSP). The distance between outer rows of adjacent beds was 60 cm. Pigeonpea seed yield in the intercropping system responded to plant populations above the sole crop optimum of 40 000 plants/ha but the response for the combined yield of both crops was less because of decreasing sorghum yield.

Maximum land equivalent ratio and gross monetary returns were at 70 000 plants/ha for the SPS arrangement and at 40 000 plants/ha for the SPPS and PSSP arrangements. The greater number of pigeonpea rows in SPPS and PSSP produced more pigeonpea yield but less sorghum yield; this resulted in a net benefit for the SPPS arrangement though not for the PSSP arrangement.

The sorghum intercrop reduced the total branch number in pigeonpea but had little effect on the number of pod-bearing branches. Intercropping also increased the harvest index of pigeonpea because the sorghum suppressed the early vegetative growth but was harvested before the reproductive phase.

INTRODUCTION

Sorghum/pigeonpea intercropping is one of the commonest cropping systems of the semi-arid areas of tropical India (Aiyer, 1949). In this system the sorghum is the more important component, being the staple food crop, and traditional management practices are aimed at maintaining a high yield of this crop. The pigeonpea is included to try to produce some "bonus" pulse yield, but only to the extent that it does not seriously reduce sorghum yield. These objectives are achieved either by sowing a seed mixture that is predominantly sorghum, or by sowing anything from six to twelve rows of sorghum for every row of pigeonpea. Although these practices maintain the sorghum yield, they produce very little bonus piegonpea.

Recent studies have indicated that these traditional systems can be much improved. Freyman and Venkateswarlu (1977) showed that a high sorghum population could help to ensure a high sorghum yield, and that this could then allow an increase in the sown proportion and yield of pigeonpea. In a later paper, Venkateswarlu et al. (1981) summarised a number of experiments from the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and recommended a row arrangement of 2 sorghum : 1 pigeonpea, with both crops at their approximate sole crop optimum populations (180 000 plants/ha for sorghum and 40 000 plants/ha for pigeonpea). Tarhalkar and Rao (1981) showed that sorghum yields could also be maintained in different "paired row" arrangements that allowed pigeonpea to be sown between pairs of sorghum rows. However these workers recommended a relatively low pigeonpea population (27 000 plants/ha) because they considered that higher populations reduced sorghum yields. In a more detailed study on the growth and resource use of a 2 sorghum : 1 pigeonpea row arrangement, Natarajan and Willey (1980a, b) suggested that pigeonpea yields were limited by poor light interception after sorghum harvest. An increased pigeonpea population produced some improvement in light interception and yield but it was considered that further response was restricted by the relatively wide distance (135 cm) between pigeonpea rows in the 2 : 1 pattern. It was therefore concluded that the pigeonpea population response needed to be studied at different row arrangements.

An improved sorghum/pigeonpea system has proved to be a particularly promising cropping component of the ICRISAT technology developed for deep Vertisols in assured rainfall areas. The major problems in these areas are poor drainage and difficulties in managing the very sticky soils, and these have resulted in a traditional system of leaving the land fallow during the rainy season. The ICRISAT technology is based on a graded broad bed and furrow system that improves drainage and soil workability (Kampen, 1980). Where sorghum/pigeonpea is the cropping system, both crops are sown together just before the onset of the rains. The sorghum utilises the rainy season and is harvested after about 95—100 days at approximately the end of the rains. The well established pigeonpea starts flowering shortly after sorghum harvest and continues growth for a further 80—100 days on the stored soil moisture, completing its crop cycle during the traditional post rainy season. In effect, therefore, this acts as a "double crop" system that utilises both the rainy and postrainy seasons.

The broad bed in the ICRISAT system is 150 cm in width (furrow to furrow) and the row arrangement initially adopted was a single pigeonpea row down the middle of the bed with a sorghum row either side. The experiment reported here examined alternative arrangements and the possible need for higher pigeonpea populations. Although some aspects are particularly applicable to the broad bed and furrow system, the data provide useful general information on the pigeonpea population response in intercropping and its interaction with row arrangement.

MATERIALS AND METHODS

The experiment was conducted for 3 years (1978 -80) at ICRISAT Center, which lies about 25 km north-west of Hyderabad, India (17.5°N, 78.5°E and 545 m altitude). It was laid out on a new site each year following a previous uniform crop. All sites were on a deep Vertisol which is low in nitrogen and phosphorus but holds more than 200 mm of available water in a rooting depth of 150—180 cm. The average annual rainfall at ICRISAT Center is 760 mm, of which an average of 86% falls during the rainy season mid June to the end of September. Of the 3 years of the experiment, 1978 was very wet (908 mm in the growing period from mid June to January), 1979 was near average (710 mm), and 1980 was rather dry (599 mm).

Treatments

Intercropping row arrangements examined on the broad bed were:
(a) 1 sorghum : 1 pigeonpea : 1 sorghum with 45 cm between rows (SPS);
(b) 1 sorghum : 2 pigeonpea : 1 sorghum with 30 cm between rows (SPPS);
(c) 1 pigeonpea : 2 sorghum : 1 pigeonpea with 30 cm between rows (PSSP).
In all arrangements the distance between outer rows of adjacent beds (i.e. across the furrow) was 60 cm, so rows on the outside of the bed were more favourably situated than those on the inside. These treatments were laid out as main plots and were split for five pigeonpea plant populations (15 000, 40 000, 70 000, 100 000 and 130 000 plants/ha). Sole pigeonpea was included at two rows per bed (75 cm apart) and at the same five populations. Sorghum population was 167 000 plants/ha in all intercrop plots and in a single sole crop treatment of three rows per bed (45 cm apart). There were four replications each year.

Intercrop plots were four beds wide of which the middle two formed the harvest area. Sole plots were three beds wide of which the middle bed and one row from each outer bed formed the harvest area; this was equivalent to two full beds for the pigeonpea and a width of 255 cm for the sorghum. All plots were 9 m long. In 1980, yield components of pigeonpea were measured on a sample of ten random plants from each plot.

Crop culture

Crops were dry sown just before the onset of the rains using a bullock-drawn seeder; the first good shower (in the 3rd week of June each year) was taken as the effective sowing date. High seed rates were used and crops were thinned to the required plant populations 2—3 weeks later after emergence.

Cultivars were hybrid CSH-6 sorghum and ICP-1 pigeonpea. In the 3 years respectively, sorghum was harvested at 103, 107 and 102 days, and pigeonpea at 207, 200 and 185 days. A basal dressing of 18 kg N/ha and 46 kg P_2O_5/ha was applied to all plots and 3 weeks after emergence 52 kg N/ha was side banded to the sorghum about 5 cm below the soil surface. Weeds were controlled by two to three hand weedings; sole pigeonpea generally required one more weeding than other treatments. Sorghum did not require any plant protection but pigeonpea was sprayed twice with 0.35% Endosulphan, at flowering and early podding, to control pod borer.

RESULTS AND DISCUSSION

Sorghum yields

The reductions in sorghum yield due to intercropping (i.e. compared with sole cropping) were rather greater than reported in some earlier studies (Natarajan and Willey, 1980a, Venkateswarlu et al., 1981) but they were still relatively small (Fig. 1a). The mean reduction across all treatments was significant each year and it increased slightly with the increasingly drier years 10%, 13% and 16% for 1978, 1979 and 1980. Differences between row arrangements were small, though averaged over all pigeonpea populations the PSSP arrangements produced reductions in sorghum yield (14%, 15% and 19% for 3 years) that each year were significantly greater than those with SPS (8%, 9% and 14%). The major factor causing these greater reductions was probably the unfavourable situation of the sorghum rows on the inside of the bed. However, increased competition from the greater number of pigeonpea rows may also have contributed, judging from the lower sorghum yield from SPPS than SPS in 1979.

Increasing the pigeonpea population caused observable reductions in sorghum grain yield in all years, and these effects were significant in the last two years. Averaged over all years and all row arrangements, sorghum yield was 7% less than the sole crop at the lowest pigeonpea population and 17% less at the highest population. For these sorghum yields, there was no interaction between pigeonpea population and row arrangement.

Sorghum stover yield (Fig. 1b) declined with the increasingly drier season from 1978 to 1980 and this was reflected in a marked increase in the mean harvest index for each year (38%, 43% and 53%). The decrease in stover yield due to intercropping was similar to that for grain yield for the first two years (7% in 1978, 12% in 1979) but it was greater under the drier conditions of 1980 (24%). But apart from these trends the effects on sorghum stover closely paralleled those on grain: thus the biggest reductions due to intercropping occurred in the PSSP row arrangement and at high pigeonpea populations.

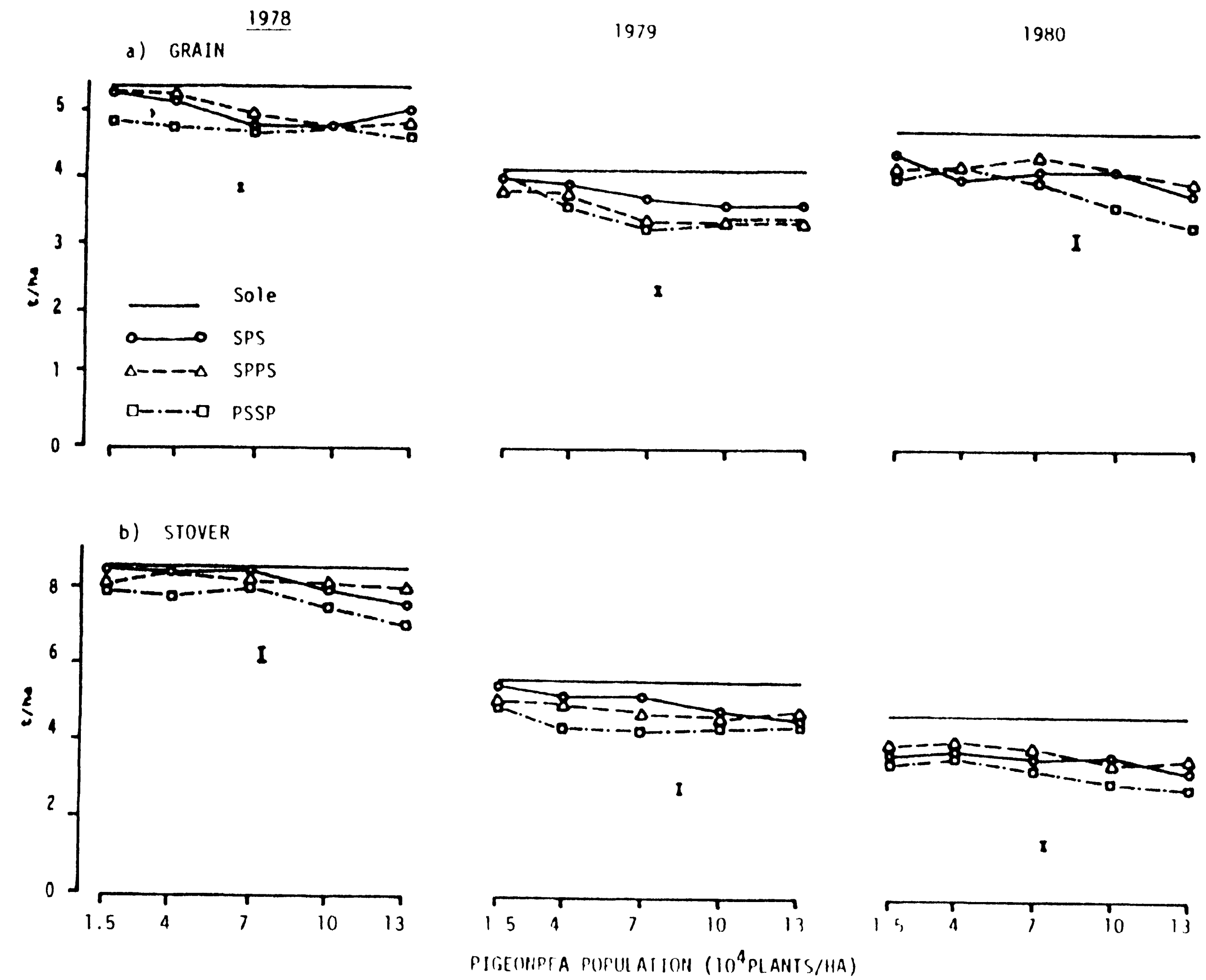

Fig. 1. Sorghum grain and stover yields as affected by pigeonpea plant population and row arrangement.

Pigeonpea yields

Seed yield of pigeonpea decreased with the increasingly drier year but vegetative growth was not affected (Fig. 2). Thus, unlike the sorghum, harvest index decreased in the drier year. This probably occurred because for the pigeonpea crop a major effect of a relatively dry rainy season on these deep soils is a reduced amount of stored soil moisture and an earlier onset of end-of-season stress. Thus this late stress could have reduced the later reproductive yield even though the earlier vegetative growth was unaffected.

The sole pigeonpea response to plant population differed markedly between stalk yield and seed yield (Fig. 2). The stalk yield showed a consistent response up to the highest population in each year, but for seed yield there was no consistent evidence of a requirement of any more than 40 000 plants/ha. The decline in yield above 40 000 plants/ha in 1980 may have been due to an intensification of the moisture stress effect suggested above and it produced a significant year × pigeonpea population interaction. No other year × treatment effect approached significance.

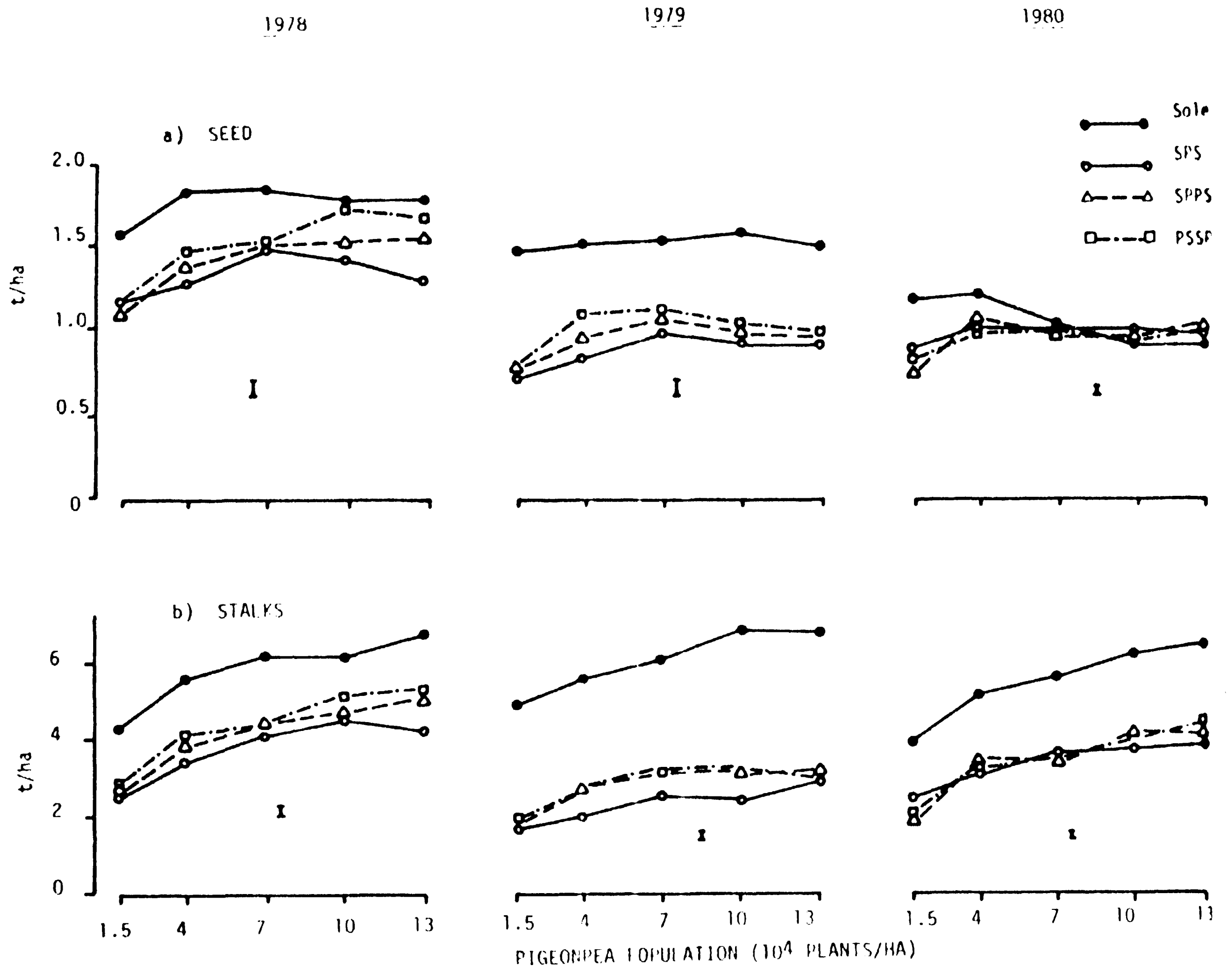

Fig. 2. Pigeonpea seed and stalk yields as affected by pigeonpea plant population and row arrangement.

In intercropping, pigeonpea seed yields were quite high and were mostly well above 50% of the sole crop. In 1978 and 1979, yields were lowest in the SPS row arrangement but they were increased both by introducing an additional pigeonpea row (SPPS) and by changing the pigeonpea rows to the more favoured position on the outside of the bed (PSSP). In the dry year of 1980 there was no difference in pigeonpea yields between these row arrangements. Population responses were rather variable but in the first two years there was good evidence of a pigeonpea seed yield response in intercropping up to 70 000 plants/ha, rather higher than the sole crop. Stalk yield response in intercropping was similar to the sole crop and yields increased up to the highest population used.

Yield components of pigeonpeas

The yield components of pigeonpeas were not significantly affected by row arrangement so intercropping effects are presented as means of the three row arrangement treatments (Fig. 3).

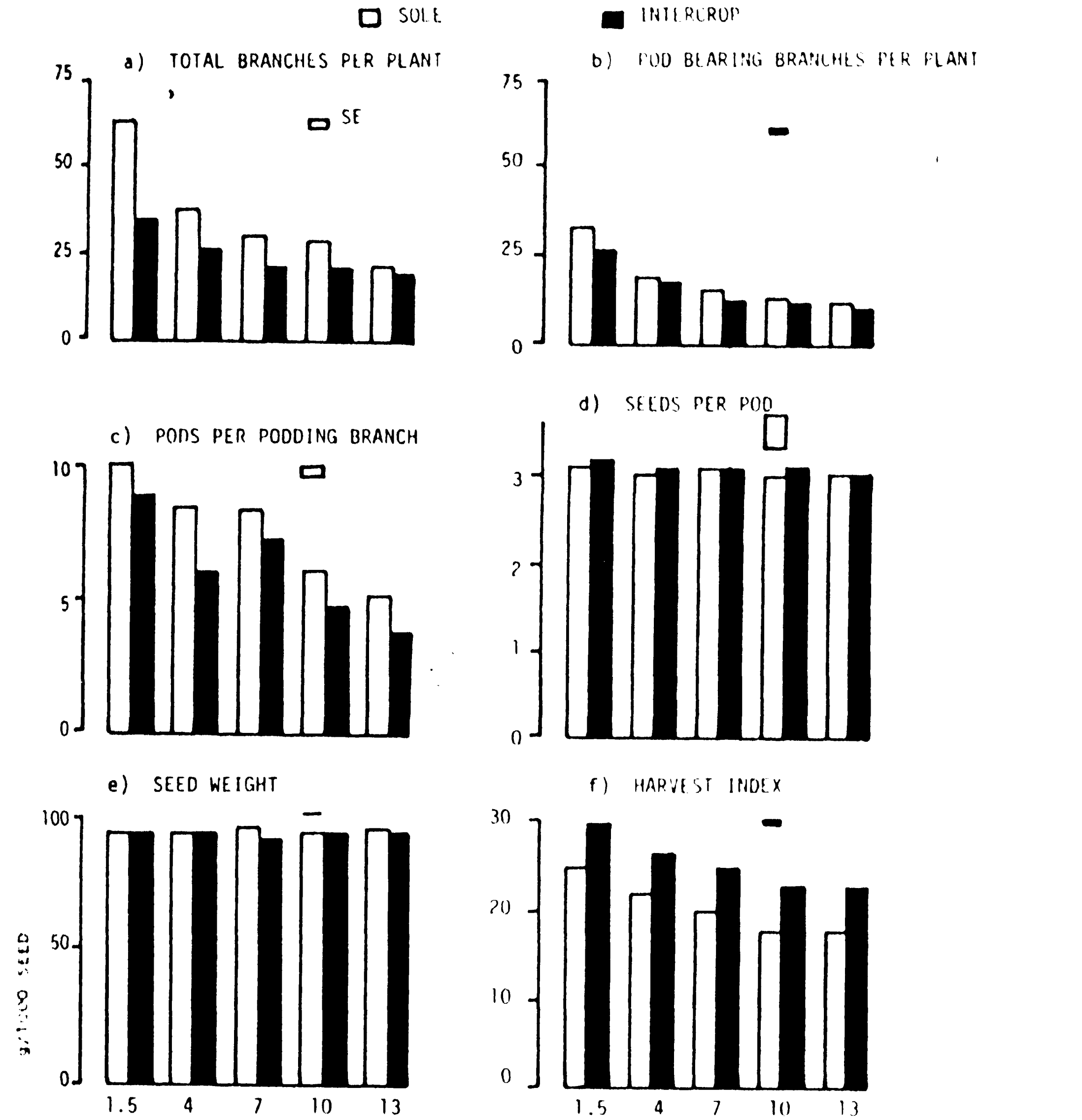

Fig. 3. Pigeonpea yield components in sole cropping and in intercropping with sorghum as affected by pigeonpea plant population (1980).

Total branches per plant were markedly reduced by increase in population, and also by the competitive effect of a sorghum intercrop. But a rather higher proportion of these branches bore pods in the intercrop (56–75% across different populations) compared with the sole crop (48–57%). Thus the pod bearing branches per plant were only slightly less in intercropping and the reduction was significant only at the lowest population. These effects suggest that a sorghum intercrop mainly suppresses the early branches that do not normally bear pods. Of the remaining components, the number of pods per pod bearing branch was clearly the major one determining yield; it decreased with increase in population and with the addition of a sorghum intercrop. Neither seeds per pod nor seed weight were significantly affected.

A particularly interesting effect was a significant increase in harvest index in intercropping at [illegible] populations. This has also been observed in a previous study (Natarajan and Willey, 1980a). It can be attributed to the fact that the sorghum intercrop suppresses mainly the early vegetative growth of the pigeonpea and that the pigeonpea recovery growth and seed yield accumulation occur after sorghum harvest.

Combined performance of both crops

The combined yields of the two crops are presented in Fig. 4 as a land equivalent ratio (LER), i.e. the proportional land area that would be required as sole crops to produce the yields achieved in intercropping. For each year, the LERs were calculated on the basis of the maximum sole pigeonpea yield and the sole sorghum yield; they are presented as means over the three years.

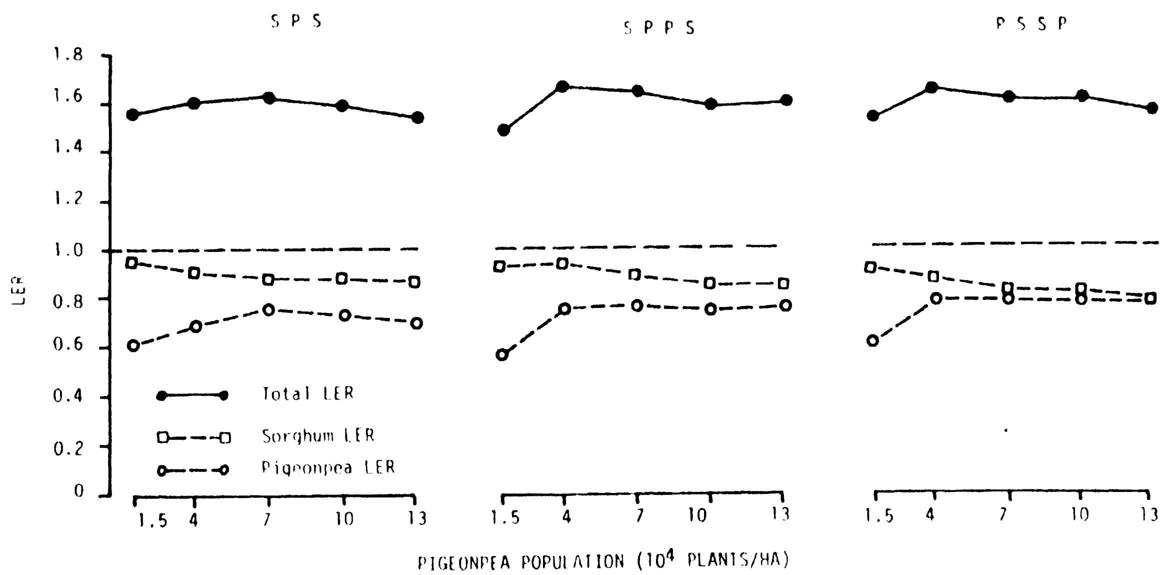

Fig. 4. Land equivalent ratios (LER) as affected by pigeonpea plant population and row arrangement (means of 3 years).

From 15 000 to 70 000 plants/ha in the SPS row arrangement, the increase in pigeonpea yield more than offset the decrease in sorghum yield so total LER increased up to a peak value of 1.64. This indicates that, at least with this particular row arrangement and on deep Vertisols, there can be an overall intercropping response to pigeonpea populations higher than the 27 000—40 000 plants/ha previously proposed (Tarhalkar and Rao, 1981 Venkateswarlu et al., 1981). However, the response above 40 000 plants/ha was very small and it did entail a small sacrifice in sorghum yield. In the other two row arrangements, this response in total LER only occurred up to the 40 000 plants/ha; at higher populations the total LER declined because the decrease in sorghum yield was not associated with any increase in pigeonpea yield. Thus the dispersion of the pigeonpea into two rows per bed (whether inside or outside rows) seemed to obviate the need for a pigeonpea population of more than 40 000 plants/ha. The increased pigeonpea yield achieved by having two pigeonpea rows produced a slight increase in LER for the SPPS treatment (peak value 1.69), but not for the PSSP treatment because of poorer sorghum yield.

Combining the yields of the two crops as a gross monetary value presents a similar picture. The SPS treatment gave its maximum value of Rs.9481/ha (at the time of writing, 9 Indian rupees (Rs.) was approximately equal to US$1.00) at 70 000 plants/ha, the PSSP gave a similar maximum value of Rs.9494/ha at 40 000 plants/ha, and the SPPS was slightly higher at Rs.9714/ha, also at 40 000 plants/ha. The monetary values varied little across the different treatments, the full range being only Rs.8800—9714/ha. To a large extent this can be attributed to the compensation that occurred between the crops, a yield decrease in one crop being often at least partly counterbalanced by a yield increase in the other crop. As far as total yield or returns is concerned therefore, there seems to be considerable flexibility in choice of sown proportions or spatial arrangements for this particular crop combination.

Finally a note of caution is necessary on the use of these measures of combined yield in the present situation. Most of the LER values were at least 1.5, which in most circumstances can be interpreted as a 50% yield advantage for the intercropping system. But strictly speaking it is a 50% yield advantage compared with dividing the same area into some of each sole crop (Willey, 1979). The validity of this comparison breaks down on these deep Vertisols because in many years the sole sorghum can be followed by another crop. Thus a more stringent evaluation of these particular intercropping systems must recognise the possibility of alternative "double crop" systems (Reddy and Willey, 1982). The same argument applies to the use of combined monetary values; all intercrops far exceeded the value of any combination of sole sorghum (Rs.6509/ha) and sole pigeonpea (Rs.5055/ha), but such a combination would again undervalue the possible returns from two successive sole crops. Other ICRISAT studies (Reddy and Willey, 1982) have compared both sorghum/pigeonpea and maize/pigeonpea intercropping with a range of double crop systems. Combined yields were comparable and the intercropping systems were usually at least as profitable because they avoided some of the cost of establishing the second crop. These intercropping systems also have the considerable advantage that in farming practice they avoid the problems associated with trying to sow a second crop at the end of the rains when upper soil layers may be dry and when there is a critical labour peak for harvesting and threshing rainy season crops (Ryan et al., 1981).

CONCLUSIONS

In intercropping, pigeonpea seed yield responded to plant populations above the sole crop optimum of 40 000 plants/ha but the response of the combined intercrop yield was rather less because of decreasing sorghum yield. For the SPS treatment, peak LER and gross monetary values were at 70 000 plants/ha, though the response above 40 000 plants/ha was small (an extra return of Rs.175 for an additional seed outlay of about Rs.45); a reasonable recommendation for this row arrangement is probably about 50—60 000 plants/ha. For the treatments with two pigeonpea rows per bed the optimum pigeonpea population for the combined intercrop yield proved to be the same as the sole crop optimum. Compared with the SPS arrangements, these treatments gave a rather higher proportion of pigeonpea at the expense of some loss in sorghum, but these changes were probably too small to be important in practice. Combined yields were higher in the SPPS arrangement than in the SPS, and the increase in gross monetary return of Rs.233 (or about Rs.260 if the seed cost of a higher pigeonpea population for SPS is included) was probably just sufficient to be worthwhile if the four row system can be managed as easily and cheaply as the three row system. The PSSP arrangement was poorer than the SPPS arrangement because of lower sorghum yield and it offered no advantages over the SPS arrangement.

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EFFECT OF POPULATION DESIGN AND PLANTING PATTERN ON YIELD RESPONSE OF GRAIN SORGHUM

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ABSTRACT

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A range of grain sorghum cultivars were grown under irrigation of various population densities and planting pattern in three seasons. Yield responses are interpreted by a method allowing extrapolation to a wider environmental range.

High populations (4 and 8 × 10^5 plant per ha) were always superior or equal to the standard population (2 × 10^5 plants per ha) generally used under irrigation. Whilst cultivar responses varied, no yield depressions were recorded at high population. Application of these results to other irrigated environments may be made with some confidence.

This superiority of high population varied with season, and was related to variability of pre-anthesis growth. Seasonal conditions favouring rapid pre-anthesis growth resulted in a yield plateau at low populations (<2 × 10^5 per ha) (asymptotic response). In contrast, environments causing slow pre-anthesis growth (e.g. cool spring conditions) led to an increasing yield over the entire population range (hyperbolic response).

Most of the yield differences were associated with differences in grain number, and hence with pre-anthesis environmental conditions. Maximum yield appeared to be the result of rapid canopy closure, whether achieved by high rated of growth of individual plants (asymptotic responses), or by high populations, when rates of growth of individual plants slow down (increasing hyperbolic response). These results contrast with responses to increasing population recorded for most species, where clear optimal ranges can be defined (parabolic responses).

INTRODUCTION

Under intensive cropping systems with adequate levels of soil moisture and nutrients, and freedom from disease, there is a need to determine relationships between yield, and plant populations and arrangements.

The response of grain yield to increasing plant population is likely to be unique for each genotype in its environment (Donald, 1963; Willey and Heath, 1969). Hence, the evaluation of general principles behind seasonal responses is necessary. A detailed understanding of cultivar differences leading to improved yield levels under these intensively competitive condi-