J. agric. Sci., Camb. (1985), **104**, 263–270
With 2 text-figures
Printed in Great Britain

Effect of row arrangement on light interception and yield in sorghum–pigeonpea intercropping

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(*Received* 30 *May* 1984)

SUMMARY

Two experiments examined the effect of improving the distribution of the pigeonpea plants in sorghum–pigeonpea intercropping by having an alternate row arrangement of the two crops (SP) instead of the two sorghum: 1 pigeonpea row arrangement (SSP) that was studied earlier. One experiment was under conditions of good moisture supply (a deep Vertisol site in the high rainfall year of 1978) but the other experienced early moisture stress and had much lower end-of-season soil moisture storage (an Alfisol site in 1979). In 1978 the proportional sorghum yield was not affected by row arrangement (86 and 85% of the sole crop yield for the SSP and SP treatments respectively). Under the drier Alfisol conditions of 1979, the proportional sorghum yield was lower, probably because of the increased competitive ability of the drought resistant pigeonpea, and it was adversely affected by the alternate row arrangement (72% for SSP and 60% for SP).

Compared with the SSP arrangement, the SP arrangement increased the level of light interception by the intercropped pigeonpea immediately after the sorghum harvest from 30 to 48% in 1978 and from 44 to 60% in 1979; the total energy intercepted during the whole post-sorghum period was increased by 23 and 12% in the 2 years, respectively. However, these improvements in canopy cover were associated with only small increases in total dry matter of the intercropped pigeonpea at final harvest, from 69 to 74% of the sole crop in 1978 and from 60 to 65% in 1979. The increase in seed yield was even less than that in total dry matter in 1978 (from 90 to 93% of the sole crop) but similar in 1979 (71 to 76%); the value of this increase in 1979 was insufficient to offset the decrease in sorghum yield. None of the increases in total dry matter or seed yield of pigeonpea reached significance. It is concluded that with a good moisture supply alternate rows could be an alternative to the 2 sorghum: 1 pigeonpea arrangement, though it offers no additional yield advantage. With poorer moisture supply, alternate rows are not a worthwhile option because of the risk of reducing sorghum yield to an extent that cannot be offset by the small increase in pigeonpea yield.

INTRODUCTION

Studies on the growth and resource use of selected intercropping combinations were initiated at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in 1977 to help gain a better understanding of how intercropping is often able to achieve higher yields than sole crops. This understanding is essential if the improvement of intercropping systems is to be put on a sound scientific basis.

One of the combinations under study is sorghum (*Sorghum bicolor* (L.) Moench) intercropped with pigeonpea (*Cajanus cajan* (L.) Millsp.), typifying the situation where there is a large degree of temporal complementarity between component crops. This combination is very common in the drier parts of India where the farmer's objective is usually to maintain a good sorghum yield and to add a small 'bonus' yield of pigeonpea; this objective is achieved by sowing predominantly sorghum with only a very small proportion of pigeonpea. Both crops are sown at the same time at the beginning of the rainy season. Sorghum, the earlier maturing crop, is harvested at about the time when the rains end and the deeper rooting pigeonpea is left to complete its life cycle largely on the moisture left in the soil profile.

Two earlier papers (Natarajan & Willey, 1980*a*, *b*) reported a first investigation in 1977. It was found that with a spatial arrangement of 2 rows of sorghum : 1 row of pigeonpea, and with each component crop at its sole crop plant population density, the sorghum yield could be maintained virtually at a level equal to that of the sole crop (97%) and the proportional pigeonpea yield was substantially higher (70% of the sole crop) than in traditional systems. It was emphasized that significant further improvement in the system could be brought about only by increasing the pigeonpea contribution; measurements of resource use indicated that one way of achieving this might be by improving the pigeonpea canopy cover and light interception during the period after sorghum harvest. However, decreasing the within-row spacing of the intercropped pigeonpea to give plant population densities well above the sole crop optimum had little effect on yield. It was concluded that this lack of response was probably because the major limitation was that pigeonpea rows were too wide (135 cm) for the relatively small, poorly branched plants that remained after the period of sorghum competition. This paper describes two subsequent experiments that examined the possibility of increasing the light interception and yield of the intercropped pigeonpea by improving its plant distribution.

MATERIALS AND METHODS

The two experiments were conducted at International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India. The 1978 experiment was sited on a medium deep Vertisol (black soil) with an available-water-holding capacity of approximately 200 mm in the top 150 cm. The rainfall during the growing period (June–December) was 1089 mm. The 1979 experimental site was a medium deep Alfisol (red soil) with an available-moisture-holding capacity of about 90 mm. Rainfall during the growing period was 711 mm but during a drought spell early in the season a 20 mm irrigation was applied to allow timely thinning and top dressing with nitrogen fertilizer.

Distribution of the pigeonpea plants in intercropping was improved by having an alternate row arrangement of the two crops (SP) compared with the standard 2 rows sorghum : 1 row pigeonpea arrangement (SSP) of the earlier study. In the 1978 experiment two plant population densities of sorghum (90000 and 180000 plants/ha) were also included and the interaction between this factor and row arrangement was confounded between two sub-blocks to allow accurate comparison of the other effects within the sub-blocks (R. Mead, personal communication). Sole crop treatments were included in each of the sub-blocks and there were two full replicates. However, there were no significant differences in grain yield between sorghum densities so the row arrangement effects are presented here as means over the sorghum densities, effectively making four replicates. The 1979 experiment was laid out in three randomized blocks and sorghum plant population density was 180000 plants/ha. Pigeonpea plant population density was 40000 plants/ha in both experiments. For each crop the same plant population density was maintained in intercropping as in sole cropping by reducing the within-row spacing. All treatments were sown in 45 cm rows.

Sorghum (variety CSH 6) and pigeonpea (variety ICP 1) were sown together in the last week of June; they were harvested, respectively, 98 and 169 days after emergence in 1978, and 95 and 163 days after emergence in 1979. In both years a basal dose of 20 kg/ha of P and 18 kg/ha of N was applied to all the plots before sowing. A top dressing of 62 kg/ha of N was applied to the sorghum rows 3 weeks after the emergence of sorgum seedlings in both sole and intercrop treatments.

In 1978, plant sampling for growth analysis was carried out at weekly intervals in sorghum and at fortnightly intervals in pigeonpea starting from 22 days after emergence. In 1979, sampling was done at 10-day intervals until the sorghum harvest and at fortnightly intervals afterwards. Harvest areas per plot were 3 m^2 for growth samples and 40–50 m^2 for final yields. Only the above-ground parts of the plants were harvested.

Light interception was measured with tube solarimeters 67·5 cm long (Szeicz, Monteith & Dos Santos, 1964) placed at ground level in pairs across three adjacent rows (135 cm). For each treatment in 1978, one pair of solarimeters was placed in each of two positions within the same plot; in 1979 one pair was placed in each of two replicates. For the SSP treatment each pair covered the required 2 : 1 row arrangement; for the SP treatment one pair covered $1\frac{1}{2}$ rows of sorghum and $1\frac{1}{2}$ rows of pigeonpea to give the required 1 : 1 ratio. Readings were averaged across both pairs and the light interception patterns in Fig. 1 are therefore derived from four solarimeters per treatment. The solarimeters were integrated (using Times Electronics Ltd integrators) for a full 24 h period every 3 or 4 days. The percentage light interception was calculated by comparison with a control solarimeter placed above the crop; absolute energy values were calculated by reference to a Kipps–Zonen solarimeter at the nearby meteorological site.

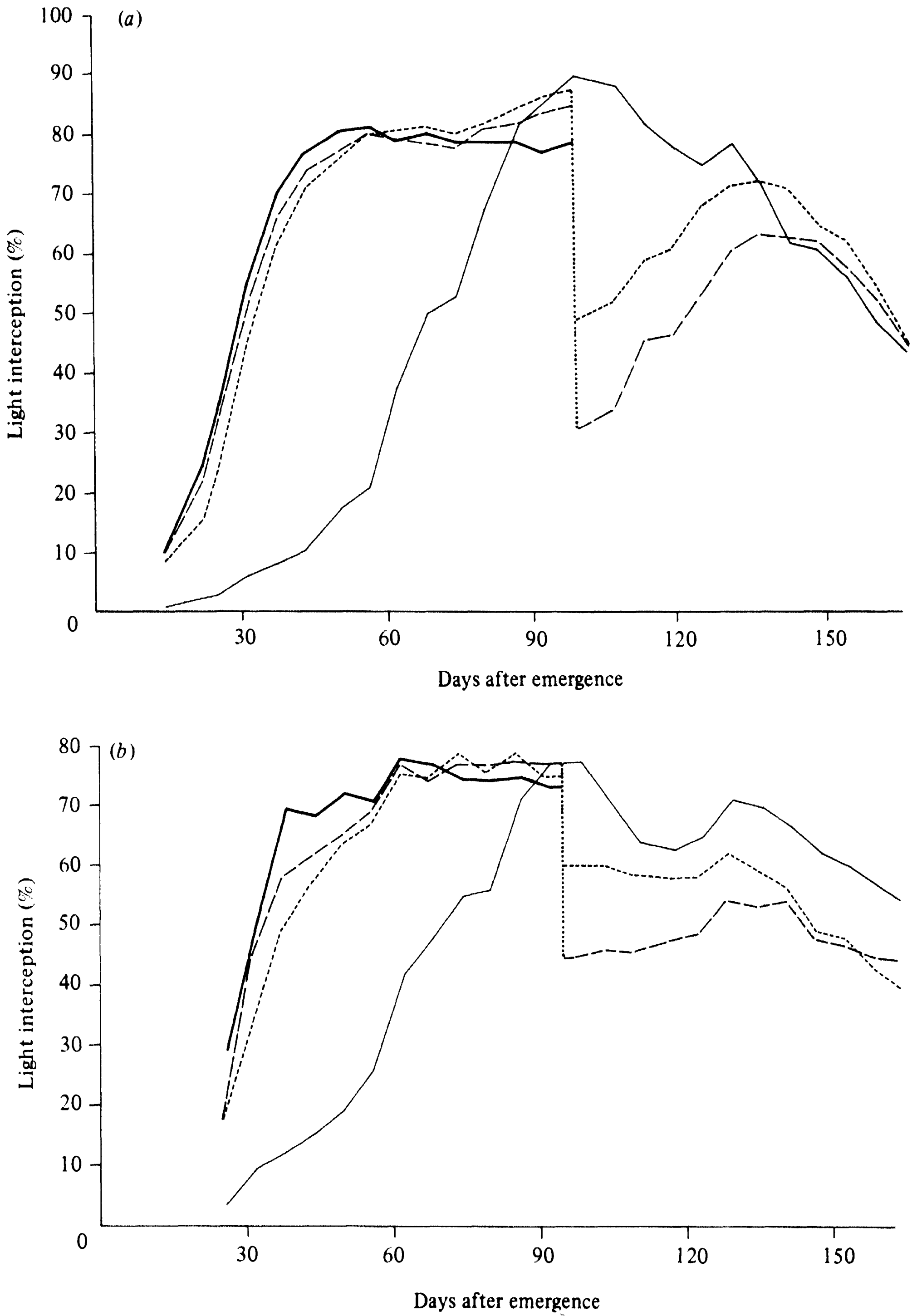

Fig. 1. Light interception by sole crops of sorghum (——) and pigeonpea (——), and intercrops in SSP (– –) and SP (- - -) row patterns on (*a*) a Vertisol in 1978 and (*b*) an Alfisol in 1979.

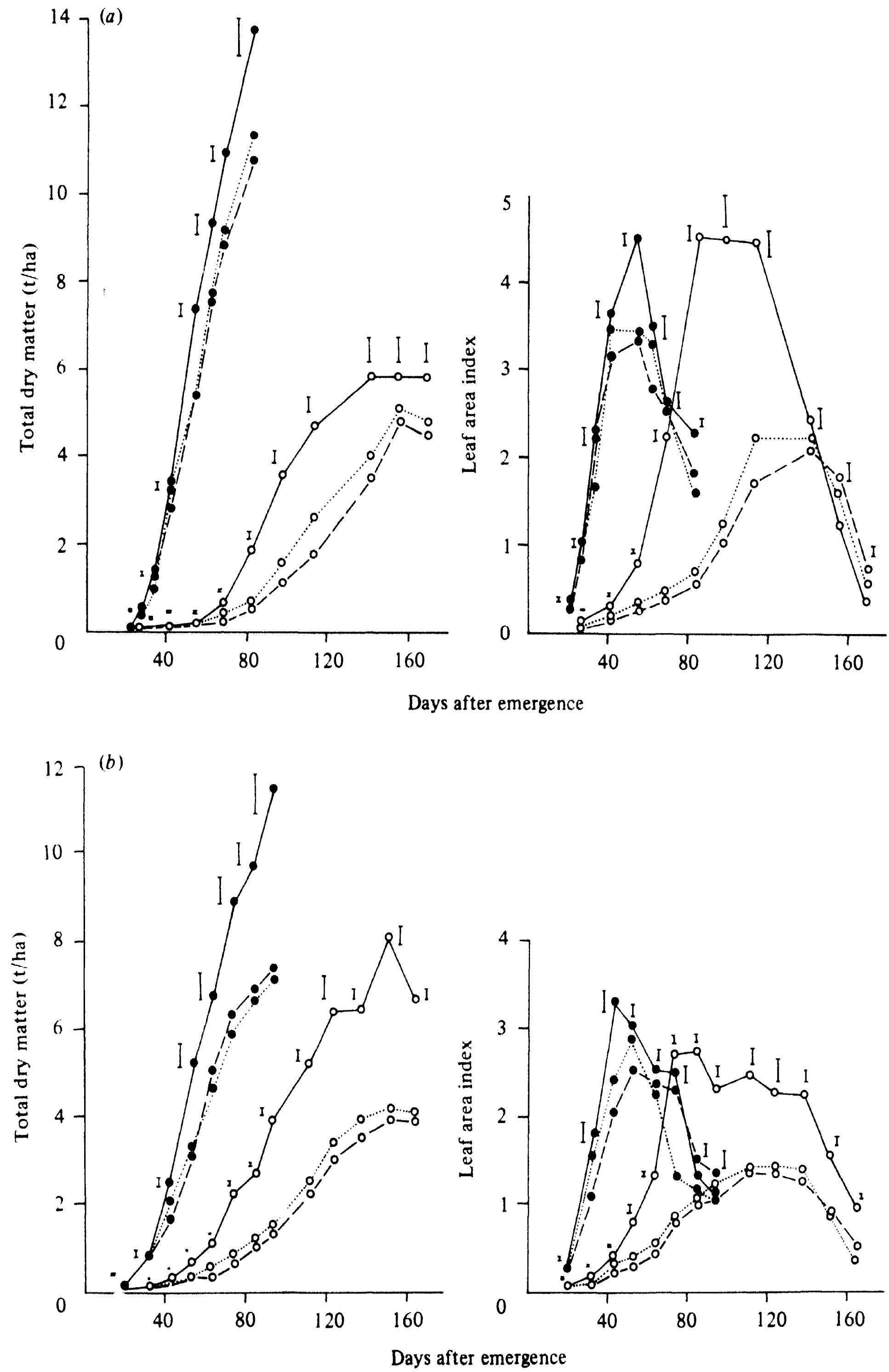

Fig. 2. Dry-matter accumulation and leaf area index in sole crops (——), and intercrops in SSP (– –) and SP (...) row patterns, of sorghum (●) and pigeonpea (○) on (*a*) a Vertisol in 1978 and (*b*) an Alfisol in 1979. Standard errors of individual means are represented by bars separately for sorghum and pigeonpea.

Table 1. *Effect of row patterns on the grain yields of intercrops and land equivalent ratios (LER)**

	Sorghum		Pigeonpea			
	Grain yield (t/ha)	LER	Grain yield (t/ha)	HI (%)	LER	Total LER
1978 (Vertisol site)						
Sole crop	4·91	—	1·30	20·3	—	—
SSP	4·23	0·86	1·16	26·2	0·90	1·76
SP	4·15	0·85	1·21	25·5	0·93	1·78
S.E.	0·164	0·034	0·090	0·6	0·07	—
1979 (Alfisol site)						
Sole crop	5·02	—	1·90	25·3	—	—
SSP	3·60	0·72	1·35	29·8	0·71	1·43
SP	3·01	0·60	1·44	29·6	0·76	1·36
S.E.	0·307	—	0·056	0·8	—	—

HI, grain yield as a proportion of the total above-ground dry matter.

* LER is defined as the relative land area under sole crops that is required to produce the yields achieved in intercropping (Willey, 1979).

RESULTS AND DISCUSSION

The two experiments were conducted under very different conditions of moisture availability. In 1978 the good moisture-holding capacity of the Vertisol and the heavy rainfall combined to provide a good moisture supply throughout the whole cropping period. In 1979 the lower moisture-holding capacity of the Alfisol and the lower rainfall, especially in the early part of the season, resulted in some moisture stress, as is common on this soil type.

For the sole crops, these different growing conditions had little effect on the general patterns of growth. In both years sorghum reached its peak light interception at about 50–60 days after emergence of the seedlings (DAE) while the much slower growing pigeonpea did not peak until about 90–100 DAE, around the time of sorghum harvest (Fig. 1); this pattern was very similar to that reported from the earlier experiment (Natarajan & Willey 1980*b*). But growing conditions did produce some differences in yields. The wetter conditions in the 1st year resulted in more vegetative growth of sorghum as can be seen from the rather higher peak values of light interception (Fig. 1*a*), the appreciably higher leaf area index, and the higher total dry matter (Fig. 2*a*). Harvest index (grain yield expressed as a proportion of the total above-ground dry matter) of sorghum was higher in the 2nd year, however, presumably because the drier conditions restricted vegetative growth, and seed yields were identical across the 2 years (Table 1). Pigeonpea also made more vegetative growth in the 1st year, as seen by higher peak values of light interception and the much higher leaf area index. But total dry matter (Fig. 2), harvest index and seed yield were higher in the 2nd year (Table 1). Pigeonpea is especially noted as a very drought-resistant crop and its higher yields in this 2nd year illustrate its better adaptation to lighter soils and drier conditions.

In 1978 the light interception of the standard SSP intercrop lagged behind that of the sole sorghum initially, despite the intercrop's higher total plant population density (Fig. 1*a*). This lag was obviously because in the intercrop the poor interception in the pigeonpea rows was not fully compensated by higher interception in the sorghum rows. Because of an increasing pigeonpea contribution, however, the intercrop interception caught up with and then exceeded that of the sole sorghum from about 50–60 DAE up to the sorghum harvest. Totalled over the full sorghum growing period the absolute amount of energy intercepted by the intercrop (891 MJ/m^2) was very similar to that intercepted by the sole sorghum (889 MJ/m^2). Immediately after sorghum harvest, light interception by the remaining pigeonpea was only 30% but it subsequently increased to a peak of just over 63% at about 130–140 DAE.

Reflecting its greater number of pigeonpea rows, light interception in the SP intercrop lagged behind the SSP intercrop in the early growth stages but exceeded it in the later period before sorghum harvest; total energy intercepted during the sorghum growing period (870 MJ/m^2) was very similar to the SSP intercrop and sole sorghum treatments. Immediately after sorghum harvest, light interception by the pigeonpea was 48%, which rose to a peak of just over 70% at about 130–140 DAE. Thus both the initial and the peak values of interception during this post-sorghum period were higher than those recorded in the SSP treatment. Total energy intercepted during this post-sorghum period was 23% higher in the SP intercrop (793 MJ/m^2) than in the SSP treatment (645 MJ/m^2). In this 1st year, therefore, the better distribution of pigeonpea plants in the SP treatment did achieve the objective of improving light interception by the intercropped pigeonpea in the period after sorghum harvest.

In 1979, light interception in the early growth stages followed a similar pattern to 1978, with the SP intercrop intercepting less than the SSP intercrop, which in turn intercepted less than the sole sorghum. During the later stages of sorghum growth the light interception by the intercrops only slightly exceeded that by the sole sorghum and their total interception during the whole sorghum period (831 MJ/m^2 for SSP, and 806 MJ/m^2 for SP) was a little less than that of the sole sorghum (896 MJ/m^2). Light interception by the pigeonpea in the SSP intercrop immediately following sorghum harvest was 44%, higher than in 1978, but during subsequent growth this increased only slightly to about 55% at 130–140 DAE. As in 1978, the SP intercrop gave higher interception than the SSP intercrop immediately after sorghum harvest (60%) but there was no subsequent increase in this value. The total energy intercepted during the post-sorghum period was only 12% greater for the SP intercrop (680 MJ/m^2) than for the SSP treatment (606 MJ/m^2). This smaller increase compared with 1978 may have been because in this 2nd year the standard SSP intercrop was already intercepting a rather higher proportion of light at sorghum harvest and thus there was less scope for further increase. A further factor may have been the slightly earlier senescence of the pigeonpea in this 2nd year, which left less time for the higher interception of the SP intercrop to express its full effect.

In 1978, the leaf area development and total dry-matter production of sorghum was reduced by intercropping rather more than in the earlier study (Natarajan & Willey, 1980*a*). But there was no difference between the two intercrop treatments and the grain yield of sorghum was equivalent to 86% of the sole crop for the SSP intercrop and 85% for the SP intercrop. Typical of this crop combination, pigeonpea growth was depressed by competition from the sorghum but less than in the earlier study. In the SSP treatment, total dry matter of the pigeonpea was equivalent to 35% of the sole crop by the time of the sorghum harvest. Compensatory growth after sorghum harvest increased the dry-matter yield of pigeonpea to 69% of the sole crop in the final large plot harvest and, because of a significant increase in harvest index, pigeonpea in this intercrop produced seed yield equivalent to 90% of that of sole pigeonpea (Table 1). It was explained in the earlier paper (Natarajan & Willey, 1980*a*) that this increase in harvest index occurs because sorghum competition suppresses mainly the early vegetative growth and compensation occurs during reproductive growth. Comparing the two row arrangements, the SP treatment produced small but consistent increases in the leaf area index and total dry matter of the pigeonpea, which was in accordance with expectation from the increased light interception. But there was only a very small increase in final seed yield (from 90 to 93%) which was not significant (Table 1). Summarizing the overall performance of the two intercrops, their land equivalent ratios (LERs, defined in Table 1), were very similar at 1·76 for the SSP treatment (0·86 sorghum and 0·90 pigeonpea) and 1·78 for the SP treatment (0·85 sorghum and 0·93 pigeonpea).

In 1979, there was a greater depression of sorghum yield in intercropping, the SSP treatment achieving only 72% of the sole crop. This greater decrease in cereal yield on the light soil type has been recorded in several experiments conducted at the ICRISAT Center and can be attributed largely to the increased competitive ability of the pigeonpea which is particularly well suited to this soil type. However, the yield decrease was rather more than expected; in another experiment conducted for 2 years on an Alfisol with combinations of six cereal genotypes and four pigeonpea genotypes, the maximum decrease in cereal yield was only 20% (Rao & Willey, 1983). In the present experiment the early drought probably pushed the balance of competition further more in favour of the drought-resistant pigeonpea. In the SP intercrop the decrease in sorghum yield was even greater and it achieved a yield of only 60% of the sole crop. The less favourable distribution of sorghum plants in this SP treatment probably reduced the amount of resources that the sorghum could explore, which in turn may also have made the sorghum less able to compete with the pigeonpea.

By the time of the sorgum harvest the pigeonpea in the SSP treatment had produced total dry matter equivalent to 34% of the sole crop yield which was very similar to the result obtained in 1978. In the final, large plot harvest the total dry matter of pigeonpea was 60% of the sole crop; this was rather less than in 1978, presumably because the poorer moisture-holding capacity of the lighter soil allowed less compensatory growth in the post-sorghum period. Harvest index of the pigeonpea in SSP treatment was again higher than that of the sole crop and its final seed yield was equal to 71% of that of the sole crop. The greater number of pigeonpea rows in the SP treatment again resulted in small but consistent increases in leaf area index and total dry matter of the pigeonpea, as would be expected from the greater light interception. There was also a small increase in seed yield (to 76 % of the sole crop) but again this was not significant. Looking at the overall performance of intercropping in this 2nd year, the SSP treatment gave an LER of 1·43 (0·72 sorghum and 0·71 pigeonpea). For the SP treatment, the slightly increased pigeonpea yield (0·76) was more than offset by the lower sorghum yield (0·60), so total LER was lower at 1·37.

These LER values in 1979 were a good deal lower than those in 1978, which at first sight suggests that this sorghum–pigeonpea intercropping combination has greater yield advantages to offer on the heavier soil. But a practical assessment of the advantages of this intercropping system must take into account the very different sole crop systems that are possible on these two soil types. On the light Alfisol, because there is insufficient moisture to grow a second crop after a sole sorghum crop, the intercropping system can be regarded as making some sacrifice in the main sorghum crop in order to provide additional yield of pigeonpea. Compared with sole sorghum, therefore, (or indeed compared with a system of some sole sorghum and some sole pigeonpea, which is strictly speaking what the LER advantage indicates) the 1979 experiment indicated genuine extra yield advantages of 37–43 %. These advantages are if anything a little less than those found in other experiments on this soil type (Freyman & Venkateswarlu, 1977; Rao & Willey, 1983).

On the Vertisols, however, there can be enough residual moisture to grow a second crop after a sole sorghum. This means that a practical evaluation of sorghum–pigeonpea intercropping on the Vertisols usually has to involve some comparison with sequential 'double-crop' systems. Such a comparison has been discussed elsewhere for deep Vertisols (Reddy & Willey, 1982), where it was concluded that total productivity was little different for cereal–pigeonpea intercropping systems or sequential systems. However, it was also found that the intercropping systems were on average both a little more profitable and gave more stable yields than the sequential systems because they avoided the costs and risks of establishing a second crop at a time when upper soil layers are drying out at the end of the rains. Furthermore, ICRISAT studies have observed that farmers on Vertisols have a distinct preference for the intercropping system because it avoids having to sow a second crop during a period when there is high labour demand for harvesting and threshing the first crop. Thus there are clearly a number of practical points in favour of the sorghum–pigeonpea system for the Vertisols also.

CONCLUSION

In both years changing the intercropping row arrangement from 2 sorghum : 1 pigeonpea (SSP) to alternate rows of each crop (SP), increased the light interception by the pigeonpea immediately after sorghum harvest and the total energy intercepted thereafter. Thus the better distribution of pigeonpea plants in the SP arrangement did improve the subquent canopy cover of the pigeonpea. The increase in total dry-matter yield of the pigeonpea in the alternate row arrangement was less than expected from the improvement in light interception, however. This suggests a lower efficiency of conversion of the intercepted light energy into dry matter by the pigeonpea after harvest of the sorghum in the SP than in the SSP arrangement, and indeed the measured efficiency during the post-sorghum period was only 488 mg/MJ for the SP intercrop compared with 539 mg/MJ for the SSP intercrop, a decrease of 10 %. But these figures are not very meaningful for the pigeonpea crop during the later stages of growth because of the very large amount of leaf fall that occurs, and which could not be taken into account during the present experiment. It was probably this leaf fall that caused the total dry matter to decline before maturity (Fig. 2).

The increase in the seed yield of pigeonpea due to the better distribution of plants in the SP intercrop was slightly less than the corresponding increase in total dry-matter yield in 1978 but similar to the total dry-matter increase in 1979. However, in both the years increase in the seed yield was small and not significant.

Intercrop sorghum yields were not affected by row arrangement in 1978, so in that year there was little to choose between the intercrop treatments either in terms of the individual crops or in terms of the total LER. In 1979, however, the small increase in pigeonpea yield in the SP treatment (from 71 to 76 %) was associated with a larger relative decrease in sorghum yield (71 to 60 %). Even allowing for the much higher unit price of pigeonpea (usually 3–4 times that of sorghum) this increase in pigeonpea yield would not have paid for the loss in yield of sorghum. Thus the conclusion from the present experiments is that the alternate row arrangement does not offer advantages over the 2 sorghum : 1 pigeonpea row arrangement tried earlier. At best, alternate rows might be another option for producing similar proportions and yields of the two crops under conditions of good, assured moisture supply, but under drier conditions, alternate rows may result in a sacrifice of sorghum yield that is not sufficiently offset by an increase in pigeonpea yield.

We thank Mr A. A. H. Khan for help in the light measurements and Mr B. N. Reddy for the assistance in collecting the growth and yield data. The help by Mr B. Uday Kumar in preparing the diagrams and Mr Y. M. Prasada Lingam in typing the manuscript is also acknowledged.

REFERENCES

FREYMAN, S. & VENKATESWARLU, J. (1977). Intercropping on rainfed red soils of the Deccan Plateau, India. *Canadian Journal of Plant Science* **57**, 697–705.

NATARAJAN, M. & WILLEY, R. W. (1980*a*). Sorghum–pigeonpea intercropping and the effects of plant population density. 1. Growth and yield. *Journal of Agricultural Science, Cambridge* **95**, 51–58.

NATARAJAN, M. & WILLEY, R. W. (1980*b*). Sorghum–pigeonpea intercropping and the effects of plant population density. 2. Resource use. *Journal of Agricultural Science, Cambridge* **95**, 59–65.

RAO, M. R. & WILLEY, R. W. (1983). Effects of genotype in cereal/pigeonpea intercropping on the Alfisols of the semi-arid tropics of India. *Experimental Agriculture* **19**, 67–78.

REDDY, M. S. & WILLEY, R. W. (1982). Improved cropping systems for the deep Vertisols of the Indian semi-arid tropics. *Experimental Agriculture* **18**, 277–287.

SZEICZ, G., MONTEITH, J. C. & DOS SANTOS, J. M. (1964). Tube solarimeter to measure radiation among plants. *Journal of Applied Ecology* **1**, 169–174.

WILLEY, R. W. (1979). Intercropping – its importance and research needs. 1. Competition and yield advantages. *Field Crop Abstracts* **32**, 1–10.