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Sorghum–pigeonpea intercropping and the effects of plant population density

2. Resource use

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SUMMARY

The use of growth resources is examined in an intercropping combination of early sorghum (82 days) and later-maturing pigeonpea (173 days) in a row arrangement of 2 sorghum:1 pigeonpea.

Prior to sorghum harvest, light interception by the intercrop combination was almost as high as sole sorghum. After sorghum harvest, light interception by the remaining pigeonpea was very poor and it is suggested that pigeonpea yield could be increased with higher plant population density and better plant distribution. Soil water measurements indicated that this would increase the amount of water being transpired through the crop but would not increase the total evapotranspiration demand. Higher nutrient concentrations in the intercrop pigeonpea compared with sole pigeonpea during this post-sorghum period suggested that yield of intercrop pigeonpea was not limited by nutrient stress, though the total uptake of nutrients by both crops was much greater from intercropping than sole cropping.

INTRODUCTION

Part 1 of this series (Natarajan & Willey, 1980) emphasized the need for detailed studies on intercropping to provide a sound scientific basis for yield improvement. Growth and yield data were reported for an intercropping experiment on sorghum (*Sorghum bicolor* (L.) Moench) – pigeonpea (*Cajanus cajan* (L.) Mill.) in which plant population density was varied at a constant 2 sorghum:1 pigeonpea row arrangement. It was shown that this combination could satisfy the farmers' primary objective of producing a 'full' yield of sorghum (i.e., as much as a sole crop) while giving 'additional' yields of pigeonpea of up to 73% of a sole pigeonpea yield.

The most commonly suggested reason for higher yields in intercropping compared with sole cropping is that the component crops make 'complementary' use of resources and therefore achieve better overall resource use when growing together. This paper examines resource use in the experiment presented earlier and considers ways in which the yield advantages of this intercropping combination might be further improved.

MATERIAL AND METHODS

Experimental details were given in Part 1 (Natarajan & Willey, 1980). Measurements on resource use were carried out over all three replicates but only on certain treatments. For light interception and water use these were: S_2, sole sorghum (optimum density 180000 plants/ha); P_2, sole pigeonpea (optimum density 50000 plants/ha); S_1P_1, intercrop (90000 plants/ha sorghum + 25000 plants/ha pigeonpea); S_2P_2, intercrop (180000 plants/ha sorghum + 50000 plants/ha pigeonpea); S_3P_3, intercrop (320000 plants/ha sorghum + 100000 plants/ha pigeonpea). For nutrient uptake, only the sole and S_2P_2 treatments were examined.

Light interception was measured with tube solarimeters sensitive to all solar radiation wavelengths (Szeicz, Monteith & Dos Santos, 1964), and with a recording surface 67·5 cm long. Crop rows were in an approximately N–S direction and row width was 45 cm. Two solarimeters per plot were placed at ground level across the rows to cover exactly three rows in each sole crop plot and the full 2 sorghum:1 pigeonpea row pattern in the intercrops. One replicate per day was recorded by

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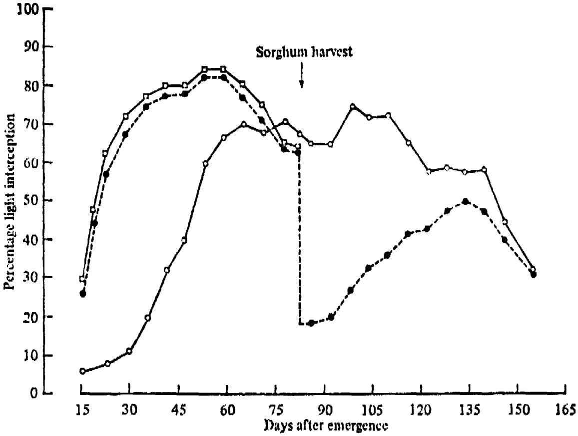

Fig. 1. Light interception by sole crops (—) and intercrop (---) of sorghum (□) and pigeonpea (○). In intercrop each crop is at the same plant population density as its sole crop (i.e. S_2P_2 treatment).

attaching each solarimeter to an individual integrator (Times Electronics Ltd.) for a full 24 h period. Different replicates were recorded on consecutive days to give a 3-day average for each treatment. Percentage interception was calculated by comparison with a 'control' solarimeter placed above the crop and integrated every day. Absolute incident energy was assumed to be that recorded at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) meteorological site with a Kipps–Zonen solarimeter.

Soil moisture was monitored every 15 days using gravimetric determination in the top 22·5 cm and a neutron probe for lower measurements at 15-cm intervals to a depth of 127·5 cm. Access tubes were sited between the crop rows, and for each replicate these totalled four for each intercrop plot and two for each sole crop plot.

Nitrogen, phosphorus and potassium contents were determined on a whole plant basis from the dry-matter samples referred to in Natarajan & Willey (1980). For sorghum, all the five dry-matter samples taken at 2-week intervals were analysed; for pigeonpea, only alternate samples were analysed to give five samples at 4-week intervals.

RESULTS AND DISCUSSION

Light interception

The sole crops and S_2P_2 intercrop are compared initially (Fig. 1) because in these treatments the plant population density of each crop was the same in intercropping and sole cropping. Interception increased very rapidly in sole sorghum, and at only 30 days after emergence it was already intercepting more than 70% of the incident light. Peak interception of 84% was recorded at about 55–60 days, and thereafter it declined to 65% at harvest. Interception increased much more slowly in sole pigeonpea. At 30 days after emergence it was intercepting only about 10% of the incident light. At 60–65 days it reached a near-maximum value of about 70%, which was more or less maintained until about 110 days; after that it declined to about 30% at final harvest.

Prior to sorghum harvest it was not possible to measure light interception of the individual crops. During this period, combined interception of the S_2P_2 intercrop was only a little less than the sole sorghum interception. This was surprisingly efficient because there was very little pigeonpea growth at this time (see Natarajan & Willey, 1980) and the sorghum component, although at the full sole crop plant population density, was being

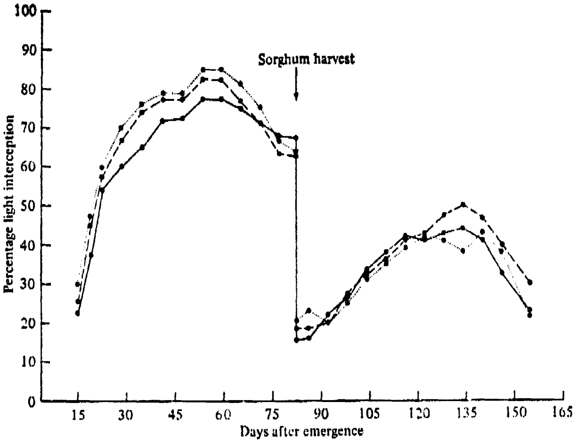

Fig. 2. The effect of increasing the plant population density of both crops on the light interception by the combined intercrop. ——, S_1P_1; ---–, S_2P_2; ·····, S_3P_3.

grown in only two rows out of every three. Immediately after sorghum harvest, interception by the remaining intercrop pigeonpea was only 19%, and the maximum interception that it eventually attained was only about 50% after approximately 135 days.

Summarizing this interception in absolute terms, by the time of sorghum harvest the combined interception of the S_2P_2 intercrop was 778 MJ/m² compared with 812 for the sole sorghum and 469 for the sole pigeonpea. By the time of pigeonpea harvest, the intercrop had intercepted 1347 MJ/m² compared with 1243 for the sole pigeonpea.

Prior to sorghum harvest, combined interception by the different intercrop treatments showed a small but consistent response to increase in plant population density, especially between S_1P_1 and S_2P_2 (Fig. 2). After sorghum harvest there was no observable response, despite the small yield responses reported in the earlier paper.

The efficiency of conversion of light energy was examined for each treatment by calculating the slope of the linear regression of accumulated dry matter against accumulated light energy (Fig. 3). Sole sorghum was much more efficient than sole pigeonpea, presumably reflecting the respective C_4 and C_3 photosynthetic pathways of these crops. Prior to sorghum harvest, all three intercrop treatments showed efficiencies more typical of sorghum than of pigeonpea, no doubt because sorghum was very much the major component. The intercrop treatments also showed an increase in efficiency with increase in plant population density, the overall difference between S_1P_1 and S_3P_3 being significant ($P < 0{\cdot}05$). Both the S_2P_2 and S_3P_3 treatments showed higher efficiency than the sole sorghum, and although these differences were not significant they reflect the consistent patterns of light interception (Figs 1, 2) and dry-matter accumulation (see Natarajan & Willey, 1980). Thus these intercrops did not intercept any more light than the sole sorghum (in fact S_2P_2 intercepted less), but they produced just as much sorghum and some additional pigeonpea.

After sorghum harvest the remaining pigeonpea in all three intercrop treatments showed an efficiency of conversion of dry matter very similar to the sole pigeonpea (Fig. 3). The intercrop pigeonpea put a much greater proportion of dry matter into reproductive growth compared with sole pigeonpea but clearly this did not change the overall efficiency with which pigeonpea was able to convert light energy into total dry matter.

Water use

Total water use was similar for the three intercrop plant population densities, so only the mean of these three treatments is considered. Total

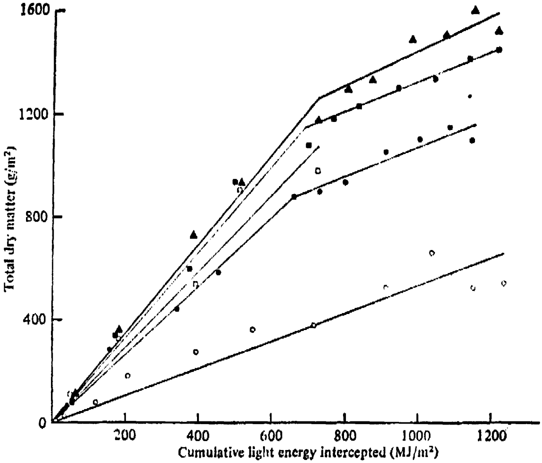

Fig. 3. Total dry matter accumulated by sole crops and intercrops of sorghum and pigeonpea compared with cumulative light energy intercepted. S_1P_1 (●); S_2P_2 (■); S_3P_3 (▲); P_2 (○); S_2 (□).

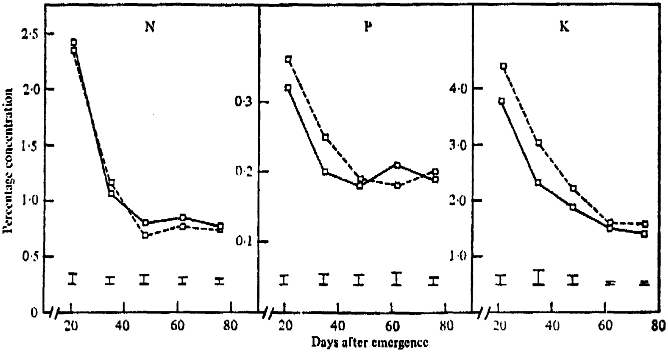

Fig. 4. Concentration of N, P and K in total dry matter (%) in sole sorghum (—) and intercrop sorghum (---) at the same plant population density (S_2P_2). I, S.E. of the individual mean.

water use was also little affected by cropping system. During the sorghum growing period, total water use by sole sorghum, sole pigeonpea and intercropping was 434, 430 and 417 mm, respectively. After sorghum harvest, it was 154 and 168 mm for sole and intercrop pigeonpea, giving

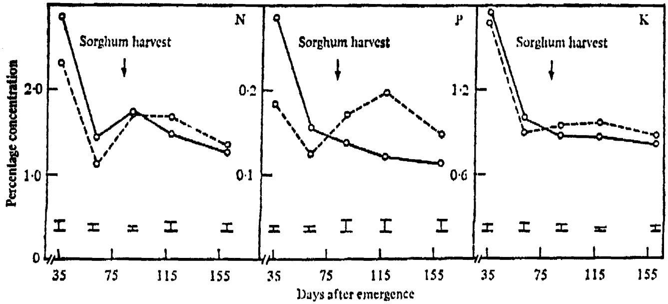

Fig. 5. Concentration of N, P and K in total dry matter (%) in sole pigeonpea (—) and intercrop pigeonpea (- - -) at the same plant population density (S_2P_2). I, s.e. of the individual mean.

virtually identical seasonal totals of 584 and 585 mm for these two treatments.

Estimates of the proportion of total water use actually transpired through the crop were made on the basis of the amount of incident energy intercepted by the crop. For the period after sorghum harvest, this was 78% (120 mm) and 60% (101 mm) for the sole and intercrop pigeonpea, respectively. Thus, as expected, the sparse canopy of the intercrop pigeonpea resulted in less water being transpired through the crop. As seen above, however, the total demand on the soil profile was similar, presumably because the sparse intercrop canopy also allowed greater evaporation from the soil surface.

Nutrient uptake

On a whole plant basis, the N concentrations of sole and intercropped sorghum showed no significant differences at any of the five sampling times (Fig. 4). In contrast, the P and K concentrations in the earlier samples were higher in the intercrop (and occasionally significant), suggesting that at this stage the sorghum was more competitive for these nutrients. By the time of sorghum harvest, there was no consistent difference in P concentration; however, there was still a slightly higher K concentration, which was significant. Since the total dry matter of sole and intercrop sorghum was very similar, these patterns of nutrient concentration closely reflect total uptake.

The sole and intercrop pigeonpea showed a very distinct, and similar, pattern for all three nutrients (Fig. 5). In the two earliest samples the concentration of all nutrients was lower in the intercrop, especially for P and N for which the effects were significant. Approximately at the time of sorghum harvest, this pattern was reversed and concentrations became higher in the intercrop, especially for P; these differences were maintained until pigeonpea harvest. It is possible that in the post-sorghum growing period, these higher nutrients concentrations in the intercrop were partly related to the higher proportion of dry matter going into reproductive growth (see Natarajan & Willey, 1980). But no changes in dry-matter partition occurred to explain lower concentrations in the earlier samples. Thus these results suggest that during the sorghum growing period the pigeonpea was the poorer competitor for nutrients; after sorghum harvest, however, the intercrop pigeonpea probably suffered less nutrient stress than the sole pigeonpea.

Dalal (1974) examined nutrient uptake in maize–pigeonpea intercropping and found that the sole maize took up a greater quantity of nutrients than intercropping. But Dalal's intercropping situation was a 'replacement' one in which the total plant population density was equivalent only to either sole crop optimum. Calculations of nutrient uptake in the present experiment emphasized the greater nutrient demands that may be made at higher plant population densities, especially when the cereal crop is producing a 'full' yield (Fig. 6). Compared with sole sorghum, the 'additional' pigeonpea intercrop resulted in the uptake of 13% more K by the time of sorghum harvest; by pigeonpea harvest, the uptake was 58% more N, 31% more P and 32% more K. Some of the N could obviously have originated from fixation, but the P and K figures indicate additional removal of nutrients from the soil.

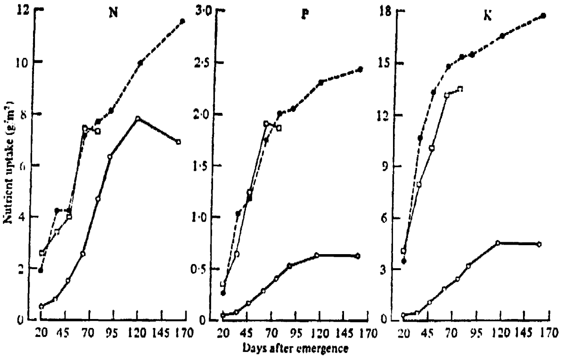

Fig. 6. Total uptake of N, P and K in sole crops (○, P_2; □, S_2) and an intercrop (●, S_2P_2) with each component crop at the same plant population density as its sole crop.

CONCLUSIONS

It was emphasized in Part 1 (Natarajan & Willey, 1980) that the primary objective of maintaining a 'full' sorghum yield was achieved if the plant population density of the intercrop sorghum was equivalent to the sole crop optimum. Thus in this situation even the relatively small amount of 'additional' pigeonpea during the period of sorghum growth represented a greater efficiency of resource use by intercropping than could be achieved by sorghum alone. In terms of light use, this increased efficiency seemed to occur because the sorghum was able to produce the equivalent of a full sole crop yield while growing in only two out of every three rows, a spatial arrangement in which it undoubtedly intercepted less light. This effect has been quite frequently reported in cereal crops in India where rows have been 'paired' to make room for various intercrops (All India Coordinated Research Project for Dryland Agriculture, 1973; Rao, Rego & Willey, 1977; Shelke & Krishnamoorthy, 1978; Singh, 1979). Considering the below-ground resources during this period of sorghum growth, intercropping had no observable effect on the amount of water lost from the profile but it did result in a 13% greater uptake of K.

Assuming a full sorghum yield, the objective then becomes to maximize the intercrop pigeonpea yield, which is mainly dependent on the efficiency of resource use after sorghum harvest. Interception of light by the intercrop pigeonpea was poor during this period, indicating that yield might be improved by having a better canopy cover. The soil moisture measurements indicated that this would not result in any greater total demand for water from the soil profile but would only channel a greater proportion through the crop. On the other hand, a higher intercrop pigeonpea yield would make greater demands on nutrients, and in the intercropping treatments tried in this experiment the total uptake was already substantially more than sole sorghum. However, the consistently higher concentration of nutrients in the intercrop pigeonpea compared with the sole pigeonpea suggests that, at least under the conditions of this experiment, further improvement of intercrop pigeonpea yield would not be limited by nutrient stress.

A rather surprising feature of the results was that increased plant population density of the intercrop pigeonpea did not increase light interception after sorghum harvest. One factor may have been that, in the treatments in which light interception could be measured, increase in pigeonpea density was confounded with increase in sorghum density. A further factor may have been that pigeonpea density was increased by reducing within-row spacing when the main cause of inefficiency was the inability of the sparsely branched intercrop to cover across the rows. It is suggested, therefore, that better light interception may be dependent on not just an increased plant population density but also an improved plant distribution.

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