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Growth and resource utilization of perennial pigeonpea (*Cajanus cajan* (L) Millsp.) at the tree-crop interface*

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Abstract. Perennial pigeonpea (*Cajanus cajan* (L) Millsp.) was grown as a multipurpose tree species in strips or blocks with annual crops (sorghum, sunflower and chickpea) on a shallow Vertisol from 1987 to 1989. The interaction between the perennial pigeonpea and annual crops was measured at the tree-crop interface (TCI) by comparing the plants at the interface (I) and in the middle of the block planting (N).

Perennial pigeonpea I plants had significantly more branches and bigger stems than N plants at the onset of the following rainy season. The greater number of flowers and grains of the I pigeonpea plants was partly due to a better lateral light level and partly due to a better access to water. On the other hand the negative effect on annual crops at the TCI extended to 1.5 m during the rainy season and to 2.5 m during the post-rainy season. Significant reduction in the growth of annual crops occurred at 30–40 days after sowing and was associated with the shading by the taller pigeonpea. Measurements of root profile of pigeonpea at the interface indicated that competition for moisture was the major cause for yield reduction of chickpea during the post-rainy season but an allelopathetic effect may also be involved. The results are compared with other TCI studies especially with *Leucaena leucocephala* in the semi arid crops and the possible mechanisms for moisture interaction at the TCI are discussed.

Introduction

Long duration genotypes of pigeonpea (*Cajanus cajan* (L) Millsp.) are traditionally grown in home gardens and field bunds to provide food, fodder and firewood but the use of pigeonpea as a perennial component in agroforestry systems is under-exploited. Susceptibility of pigeonpea to fusarium wilt, rhizoctonia stem rot and sterility mosaic diseases were often cited as the major constraints to developing perennial systems on a wide scale. The recent availability of genotypes with resistance to these diseases has stimulated research in developing agroforestry systems using the 'perennial' pigeonpea [2].

Several workers have postulated that the key to the development of compatible tree-crop combinations on agroforestry depends on an understanding of the interaction at the tree-crop interface [1, 4]. If the net effect at

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the tree-crop interface is advantageous or positive, planting arrangements which maximize the amount of interface would provide the greatest benefit. There is no particular advantage in modifying planting arrangements when the net effect of the tree-crop interface (TCI) is neutral. Finally, the interaction at the TCI may be negative as in the alley-cropping described for *Leucaena leucocephala* Lam and crop in semi-arid India [9] where it would be preferable to manage the tree and crops as separate stands.

Previous studies at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India have demonstrated that the interaction at the TCI of perennial pigeonpea and crops like sorghum and chickpea is neutral with perennial pigeonpea as the dominant species [2]. A comparison of 1:2 proportion of pigeonpea: crop as block planting (one interface) or as strip-planting (7 interfaces) produced the same dry matter and grain yield at the end of the two-year study. However block planting favoured the yield of the crop while strip planting promoted the yield of the pigeonpea.

In this paper the growth, morphology, and utilization of water and light of pigeonpea at the TCI are compared with the plants in the middle of the block planting.

Materials and methods

Site

The experimental site was a shallow Vertisol (Typic pellustert) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India (18°N 78°E, 545 m above sea level). Top soil has a depth of 40–45 cm with a variable murum layer below. Long term average rainfall is 610 mm during the rainy season with 148 mm occurring during the post-rainy season. In 1987, the total rainfall for the rainy season was 582 mm and 254 mm during the post-rainy season. In contrast 1988 was usually wet with 900 mm rainfall in the rainy-season but the post-rainy season was almost dry (7 mm in total).

Design and treatments

The experiment was designed to evaluate two planting arrangements: block and strip planting. In block planting, pigeonpea cv. ICP 8094 and annual crops were spatially separated with a single interacting surface (interface) between them. Strip planting consisted of four pigeonpea strips of 4.0 m alternated with annual crop strips of 8.0 m providing seven interfaces (Fig. 1). Spacing was common in both planting arrangements with pigeonpea at 1.0 m × 1.0 m and annual crops in 45 × 15 cm. There were three replicates

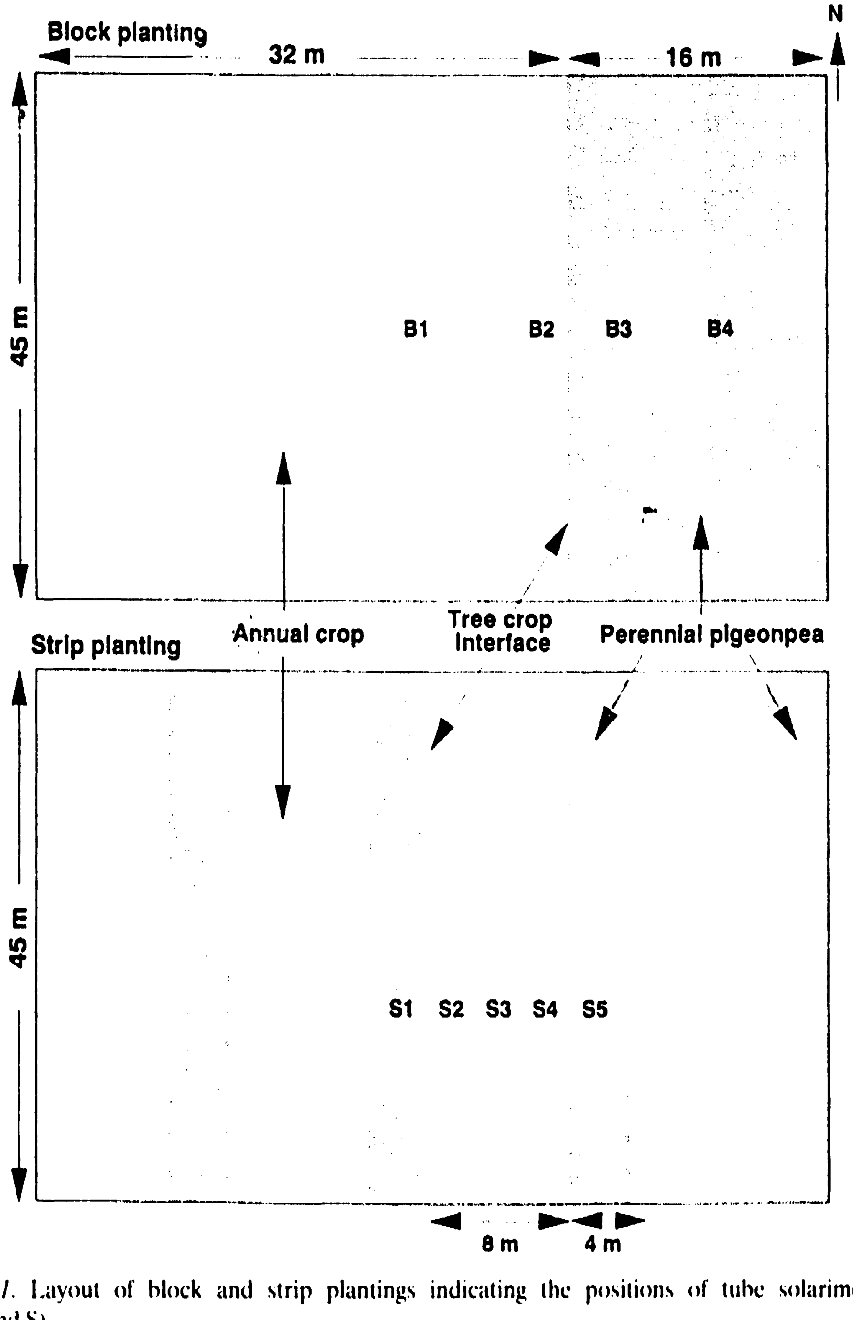

Fig. 1. Layout of block and strip plantings indicating the positions of tube solarimeters (B and S).

and each replicate measured 48 × 45 m of which a third of the area was under pigeonpea and the remainder under annual crops. Details of sowing dates, crops and harvesting dates are given in Table 1.

Any difference in productivity between the planting configurations would be due to the difference in the proportion of plants in the interface and the change in growth and yield of plants with distance from the interface. In the

Table 1. Dates of major events during experimental period, 1987–1989.

Dates	Events
10 Jun 1987	Sowing of pigeonpea (ICP 8094), sorghum, *Sorghum bicolor* (L) Moench cv. CSH 9
24 Sep 1987	Harvest of sorghum
21 Oct 1987	Sowing of chickpea, *Cicer arietinum* L. cv. Annigeri
15 Feb 1988	Harvesting of chickpea
11 Mar 1988	Harvesting and pruning of pigeonpea
15 Jun 1988	Sowing of sunflower *Helianthus annus* cv. Morden
22 Sep 1988	Harvesting of sunflower
18 Oct 1988	Sowing of chickpea cv. ICCC 42, emergence on 3 Nov.
09 Jan 1989	Harvesting and pruning of pigeonpea
04 Feb 1989	Harvesting of chickpea

strip cropping system, 40% of pigeonpea plants were in the interface whereas the corresponding figure for sole block cropping was 5.7%. Furthermore, in strips, the maximum distance of a pigeonpea plant from the interface row was 1.0 m whereas it was 8.0 m in sole blocks. Therefore, growth observations were made at the interface, 3rd, 6th and 9th rows in the block, and at the interface and inner rows in the strip.

The whole area was fertilized with 100 kg ha^{-1} of diammonium phosphate, broadcast and incorporated at the beginning of each season. Sorghum and sunflower were top-dressed with 42 kg ha^{-1} three weeks after sowing.

Measurements

Plant height, stem diameter at 20 cm from ground level and number of branches were measured at fortnightly intervals from 22 weeks after sowing (WAS) onwards with ten plants per treatment in each replication.

Growth analysis of annual crops began in the post-rainy season in November 1987 with chickpea. Plants were harvested for growth analysis from 24 days after sowing (DAS) at fornightly intervals until maturity. At each harvest all above-ground materials were collected from two one-meter row lengths of each treatment at 0.5, 2.5 and 4.5 m distance from the interface. In 1988, an additional harvest was made at 1.5 m in both treatments. At maturity, four 8.0 m row lengths were harvested to estimate final grain and dry matter yield.

Pigeonpea was harvested at grain maturity in March 1988 and January 1989 by cutting the branches at 1.0 m above ground and the materials were separated into grain, stems and leaves for dry matter determination at 80 °C.

Light interception was measured between interface — 1st row and 8th–9th row in block planting of pigeonpea and in the middle of sole annual crop at positions illustrated in Fig. 1. Light interception was estimated with tube solarimeters (Delta-T, U.K) placed at ground level across three rows of annual crop and between two rows of pigeonpea in an east-west direction in all replications. One neutron probe access tube was installed at the interface B_2, B_3 and S_1, S_2 in each plot between rows to a depth of 1.2 m. Water content in the upper 30 cm of the profile was determined gravimetrically and below 30 cm, at 15 cm increments, with a neutron probe. The probe was calibrated against gravimetric measurements from a sample soil core adjacent to the access tubes installed in the border rows of the crop.

Root distribution and density were measured in five interface plants in strip planting towards pod maturity (January 1989) in the second year. Trenches were dug with a power digger to expose a soil profile of 2.0 m deep and 2.0 m long from the base of the pigeonpea plant. This surface was smoothened and washed with a hose fitted to a hydrant. An approximate pattern of root distribution was obtained by placing a grid of 10 cm squares against the exposed soil face and counting the number of root ends in each square [3]. Soil cores for root extraction were taken with a soil auger of 10 cm diameter at 10, 30, 50, 75, 125 and 175 cm from the base of the plant in the horizontal axis and at 7.5, 22.5, 37.5, 50, 80, 120, 160 and 200 cm in the vertical axis. Thus, there were 42 soil cores for each plant. Roots were extracted by washing the core samples in a Gillison's hydropneumatic root washer, blotting off excess moisture and separating manually any remaining debris. Root length was estimated with a modified Delta-T area meter, and the root density was expressed as cm root cm^{-3} of soil.

Results

Shoot growth of pigeonpea

The effect of distance from interface on growth of pigeonpea is presented in Table 2. Because the growth of pigeonpea was similar at the interface rows (I) of blocks and strips, the values were combined. Similarly the values for the middle of the strip and third row of the block treatment were combined. The ninth row (N) in the block treatment was the least productive in the first year but by the second year there was no significant difference between the third, sixth and ninth rows in terms of grain yield. In the first year, the N plants were taller than the I plants because the chickpea plants were short (30 cm) and did not compete strongly against the I pigeonpea whereas there was considerable mutual shading in the N row. At the end of the second year, differences between the I and N plants had widened in grain yield from 1.48 to 3.46 times and in stem diameter from 1.16 to 1.43 times.

Differences in the height and stem diameter between I and N plants were evident but not statistically significant from 22 to 52 WAS (Fig. 2a and 2b). Significant differences in both parameters commenced at the onset of the

Table 2. Growth and yield of perennial pigeonpea with increasing distance from the interface. ICRISAT Center.

Parameter	Distance from interface (m)				SE
	0	3	6	9	
First year					
Maximum height (cm)	232	250	—	254	± 8.7
Maximum stem diameter (mm)	29	26	—	25	± 0.8
Grain yield per plant (g)	59	53	—	40	± 6.8
Second year					
Maximum height (cm)	324	315	294	294	± 9.9
Maximum stem diameter (mm)	56	39	37	39	± 3.2
Grain yield per plant (g)	515	137	125	149	± 7.8

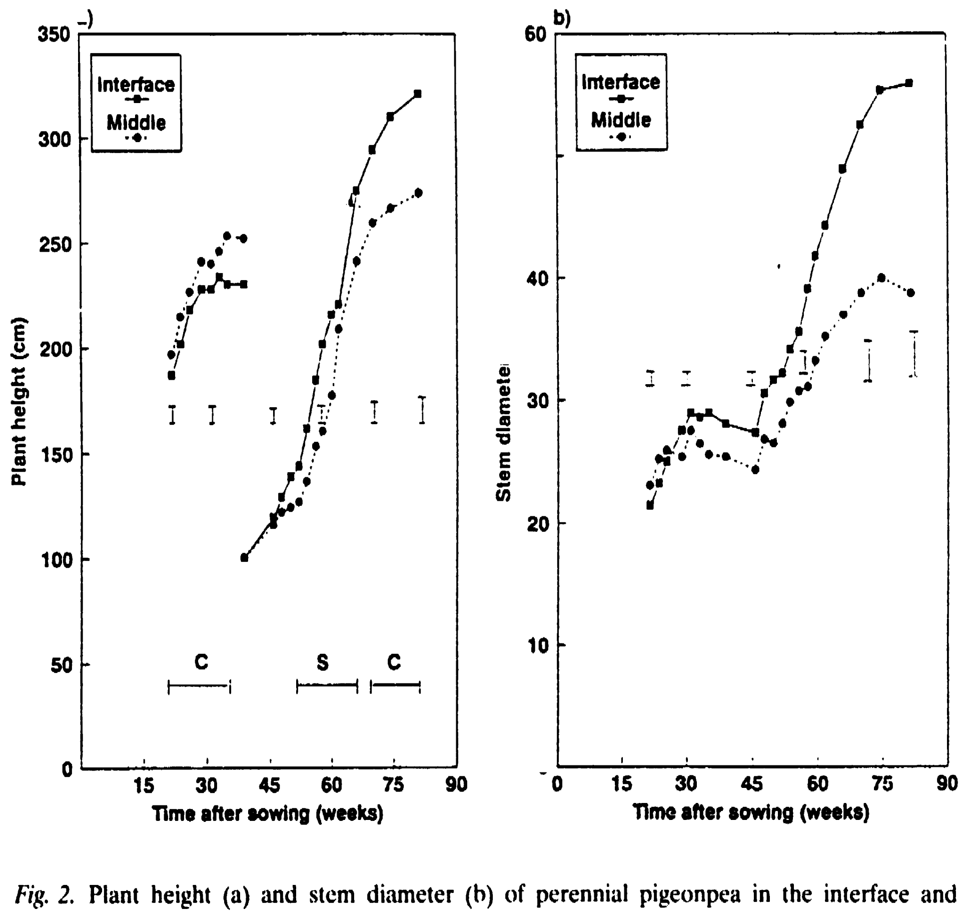

Fig. 2. Plant height (a) and stem diameter (b) of perennial pigeonpea in the interface and middle of the stand during two cycles of growth. Horizontal bars indicate growth period of chickpea (c) or sunflower (s). Vertical bars are standard errors.

rainly season in 1988. Increase in height and diameter of I plants continued from 75 to 80 WAS whereas N plants showed a decline in growth from 65 WAS onwards.

The number of primary branches reached a maximum at about 26 WAS and remained unchanged in the I plants (Fig. 3). There was dieback of branches in the N plants resulting in a decrease in primary branch number and consequently a significant difference between treatments was evident at 29 and 33 WAS. Number of flowering branches in both treatments increased curvi-linearly and after 31 WAS, the I plants had significantly more flowering branches than N plants. The coefficient of variation for all growth parameters was less than ten except the number of flowering branches which had a very high coefficient of variation initially, but declined to less than 15% after 30 WAS.

Growth of annual crops

Analysis of total dry matter production (TDM) of annual crops at various distances from the interface showed that chickpea at 0.5 m was severely affected from 40 days after sowing of chickpea whereas crop at 2.5 m away

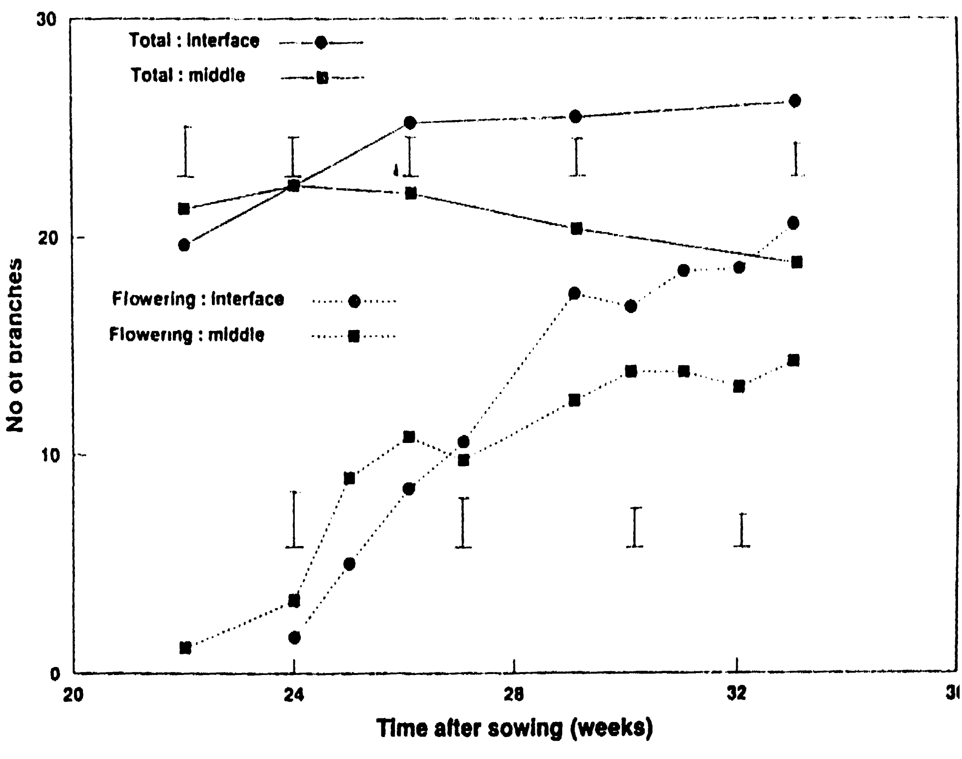

Fig. 3. Number of total and flowering branches in the interface and middle of the stand during the first cycle of growth.

was only influenced after 80 DAS (Fig. 4a). At maturity chickpea growth at 0.5 m was reduced to 21% compared to the chickpea at 4.5 m. In the following rainy season sunflower growth at 0.5 m was also greatly reduced (to 48%) but there was no difference in growth at 1.5 m and 2.5 m distance away from the interface (Fig. 4b). Shading by the dense canopy of the I pigeonpea may account for the reduction in sunflower growth and the effect was observed as early as 40 DAS. The most drastic reduction in annual crop was evident in the post-rainy season when chickpea growth was reduced to 8% of sole crop at 0.5 m and extending to 2.5 m away from the interface. (Fig. 4b).

Root growth and moisture utilization

Lateral roots of pigeonpea had extended into the annual crop area in the strip planting treatment and into the fallow area of the block treatment. Since there was no difference in root distribution of pigeonpea between cropped and fallow areas, it was assumed that the roots of chickpea, harvested about a month earlier, did not have a significant influence on the root counts.

Root ends were seen in the entire 2.0 × 2.0 m soil profile (Fig. 5). However, the major concentration of roots, denoted by more than 10 root ends 100 cm^{-2}, was to a depth of 1.3 m and a distance of 1.0 m away from the base of the plant. Roots of more than 2.0 mm diameter were mostly confined to the upper 0.5 m and to a distance of 1.2 m laterally. Nevertheless, occasionally roots of more than 5.0 mm diameter penetrated deeper than 1.5 m (data not presented).

Root density was highest in the upper 15 cm soil layer and decreased with increasing depth (Fig. 6). The surface soil layer contained more than 1.0 cm of root $^{-3}$ of soil up to a horizontal distance of 1.25 m, beyond which there was a sharp decline in root density. Similarly, the decline in root density with increasing depth from 7.5 cm to 22.5 cm was very marked. Almost 36% of total root density in the 2.0 × 2.0 m area investigated was in the upper most 15 cm of soil.

Moisture depletion by perennial pigeonpea in the interface was studied in the post-rainy seasons of 1987 and 1988. Although the drying cycle commenced in late-November in the first year (1987) and in early-October in the second year (1988), the plants were almost at the same phenological stage of onset of flowering in both years. Moisture depletion was monitored over a period of six weeks in both years. This period extended from the onset of flowering to early pod filling stage.

Moisture depletion in the first year was highest at a depth of 30 cm and 45 cm of the interface plant and was relatively less in the deeper layers (Fig. 7a and 7b). In the second year however, depletion was generally high in all the layers and it was obvious that the access tubes were not sufficiently deep for an accurate measurement of the total water uptake by pigeonpea. Never-

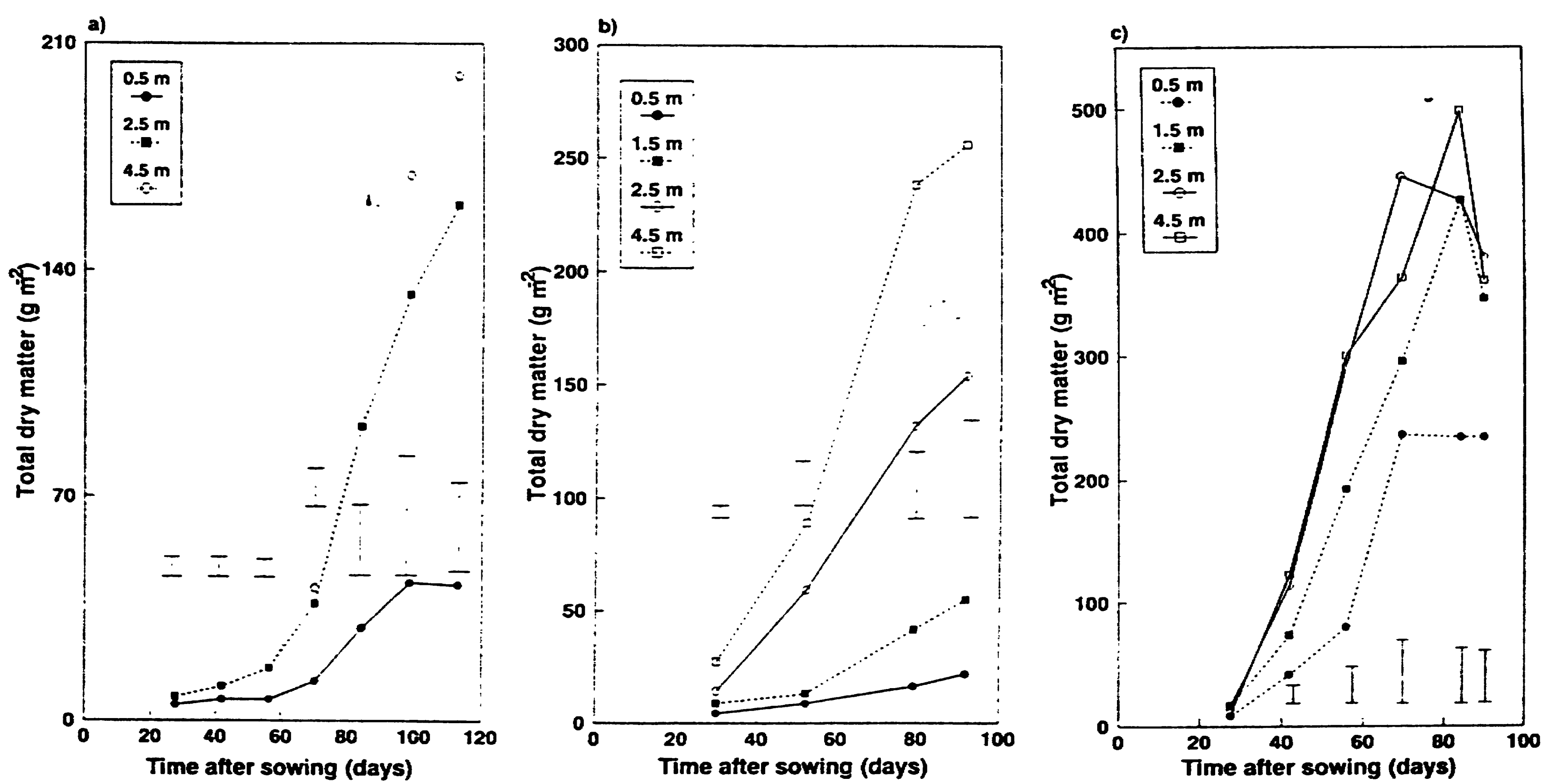

Fig. 4. Growth of annual crops at various distances from the pigeonpea interface during the post-rainy season (chickpea a. first year b. second year) and rainy season (c. sunflower).

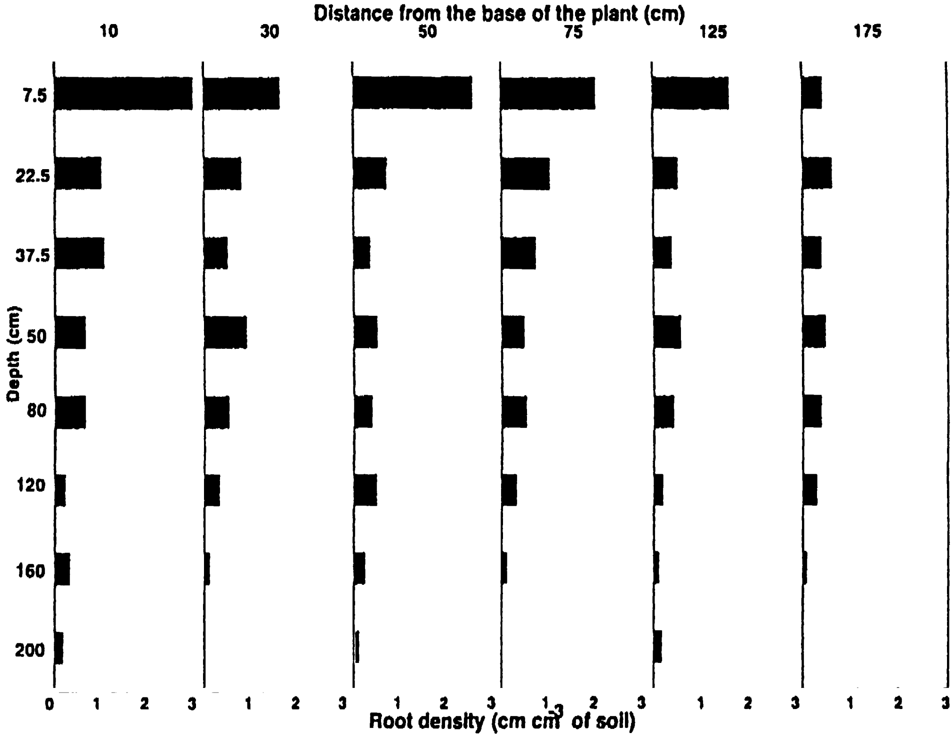

Fig. 5. Root distribution of perennial pigeonpea in the interface towards the end of second cycle.

theless the total quantity of moisture depleted (from 0–1.0 m) during the flowering to pod filling period in the second year was at least twice as much as the moisture removed in the first year during the same growth period.

Shading and light interception

At the time of emergence of the sunflower crop in July 1988, there was minimal shading (9.4 ± 1%) at the TCI by the perennial pigeonpea in its second years (data not shown). Throughout the season there was no apparent difference in the shading at the TCI between the block and strip treatments i.e. in positions B_2, S_2 or S_4 in Fig. 1. From September to October, when the sunflower crop was removed, and before the emergence of the post-rainy chickpea, shading at the TCI ranged from 50 to 53 ± 4% (Fig. 8). Therefore perennial pigeonpea shading at the TCI was largely confined to 1.0 m distance from the last row being consistent with the growth data during the season.

The seasonal trend in the fractional light interception (f) of sole perennial pigeonpea (B_4), annual crops (B_1) and strip stands are illustrated in Fig. 9.

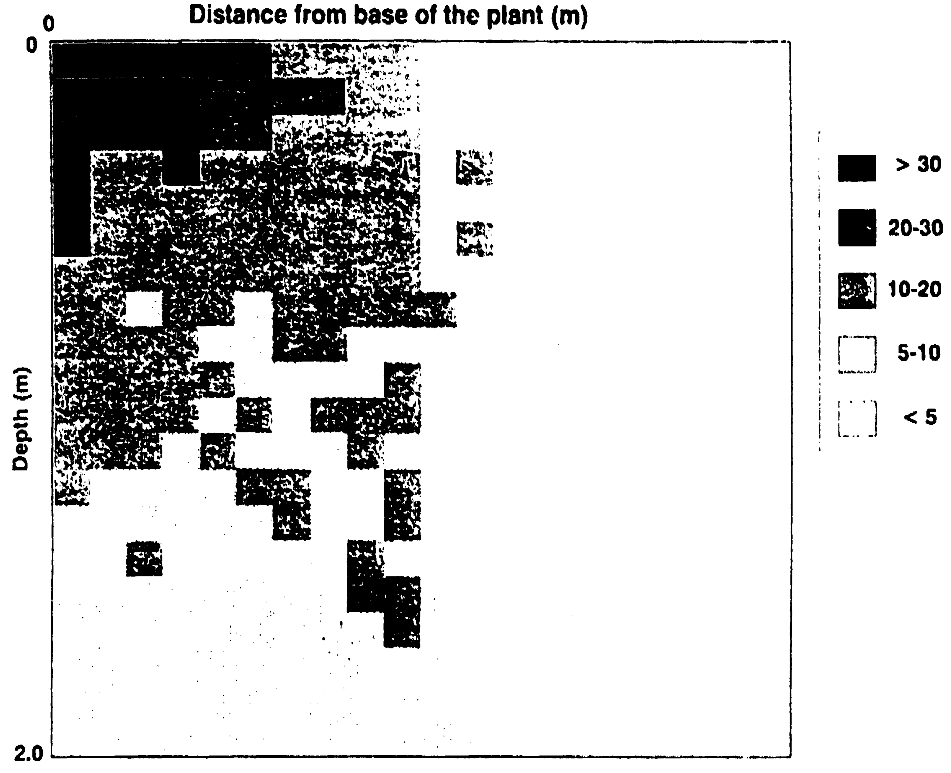

Fig. 6. Root density of perennial pigeonpea in the interface towards the end of second cycle.

The total interception of the strip treatment is the average f measured at positions S_1 to S_5. In early July, interception by sole perennial pigeonpea already reached 45% whereas interception by sole sunflower was only 10% and that of strip treatment was 35%. By early August all crops had intercepted 90% of the radiation but heavy rains later in the month resulted in complete mortality of the sunflower crop which was removed in September. Growth of perennial pigeonpea was not adversely affected by the heavy rain and light interception was maintained at about 80% until leaf senescence in December, falling to 50% by mid January. In contrast, growth of chickpea was slow and f was consistently lower than that of perennial pigeonpea. Interception by strip treatment was intermediate between f of sole perennial pigeonpea and annual crops from August to January. During the dry season regrowth of pigeonpea was slow and reached only a maximum f of 30% in May.

Light interception by the annual crop in the middle of the perennial pigeonpea strips (S_3) was similar to that of sole crop (B_1) in the rainy season but in the post-rainy season f at S_3 was 13% greater than in sole chickpea at maturity. These results are not consistent with the growth data which showed that the dry matter was less at S_3 than at B_1. During the post-rainy season the reduction in chickpea yield at the TCI extended well beyond (2.5 m) the shade (< 1 m) of the perennial pigeonpea, suggesting that the yield reduction

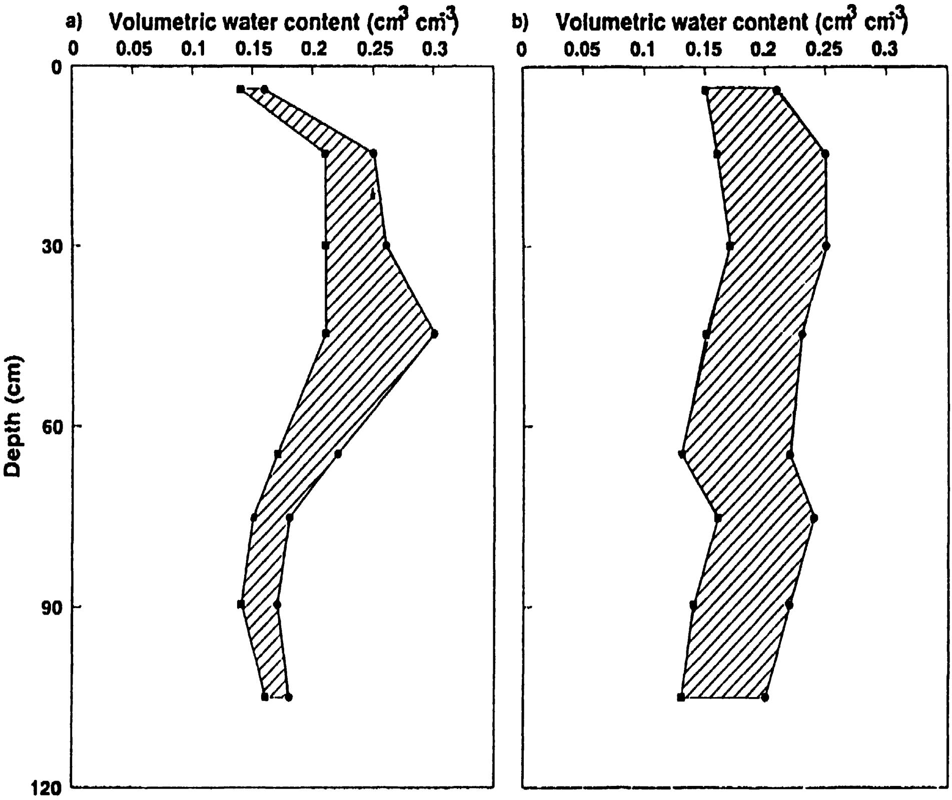

Fig. 7. Moisture depletion by perennial pigeonpea in the interface from flowering to early pod filling in 1987 to 1988 (a) and 1988 to 1989 (b). Shaded area indicates amount of water depleted.

was due to competition for moisture by the lateral roots of pigeonpea (Fig. 5).

Discussion

The present study showed that the growth of perennial pigeonpea is similar to that of tree [8] in that early growth is slow compared to annual crops but after the first year, it becomes more competitive than annual crops. Therefore, perennial pigeonpea plants at the TCI had significantly more branches and bigger stems than plants in the middle of the stands at the onset of the following rainy season i.e. at 52 WAS. However, significant differences in the number of flowering branches at the I and N plants occurred earlier at 26 WAS. Measurements of solar radiation indicated that intense shading (80–90%) had occurred at floral initiation of perennial pigeonpea and lower branches of N plants did not produce any flowers. Artificial shading of annual pigeonpea has shown that abortion of flowers occurs at low irradiance

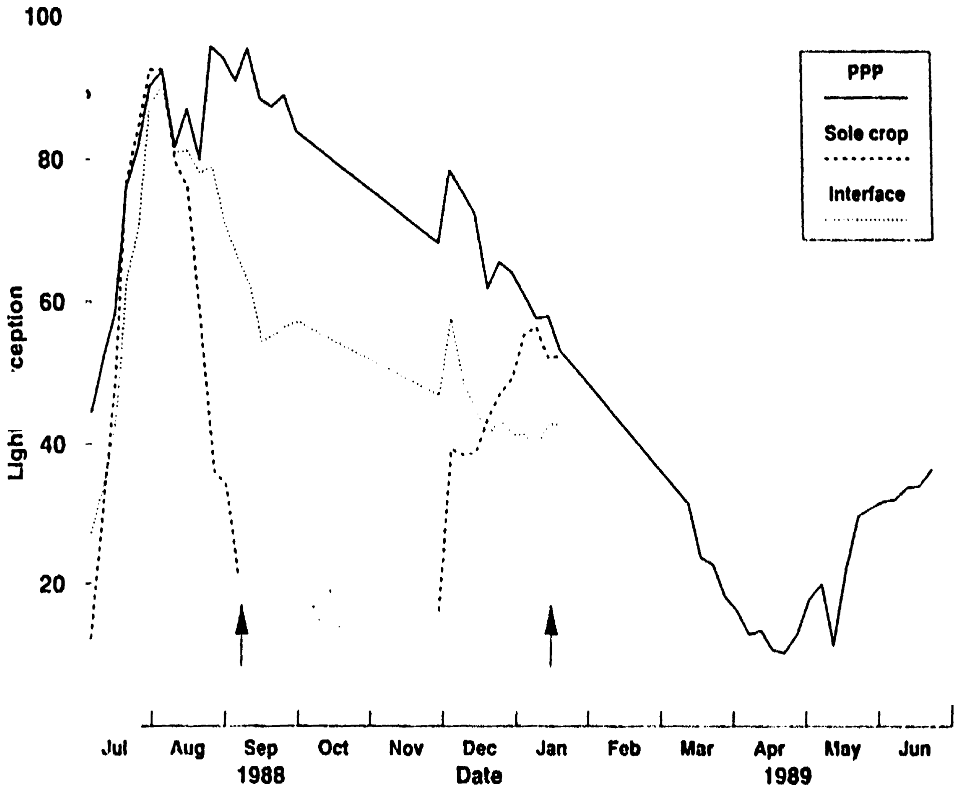

Fig. 8. Light interception of perennial pigeonpea, sole crops and at interface from July 1988 to January 1989. Arrows indicates harvest of crops.

suggesting that assimilate supply may be limiting [10]. In contrast, pigeonpea plants at the TCI were exposed to full light on one side when the rainy season annual crops were harvested at 13 WAS in the first year and at 65 WAS in the second year.

The benefit of the interface effect on the perennial pigeonpea growth appeared to be confined to the first row only, probably because the plants were already fairly widely spaced at 1 m apart, and partly because of the intense shading by the outermost perennial pigeonpea row. Although it was not possible to separate the benefit at the interface due to below ground interactions, the extensive lateral root distribution suggests that access to water and nutrients was significantly greater at the TCI. The neutron moisture techniques used in this study was unsatisfactory for quantifying the water uptake at the TCI because access tubes could not be installed to adequate depth and there was insufficient number of tubes across the TCI. Thus it is not possible to make firm conclusions about the water uptake by the pigeonpea plants. A more appropriate approach is the sap-flow technique described by Ong et al. [7] which is relatively simple to use and furthermore is non-destructive.

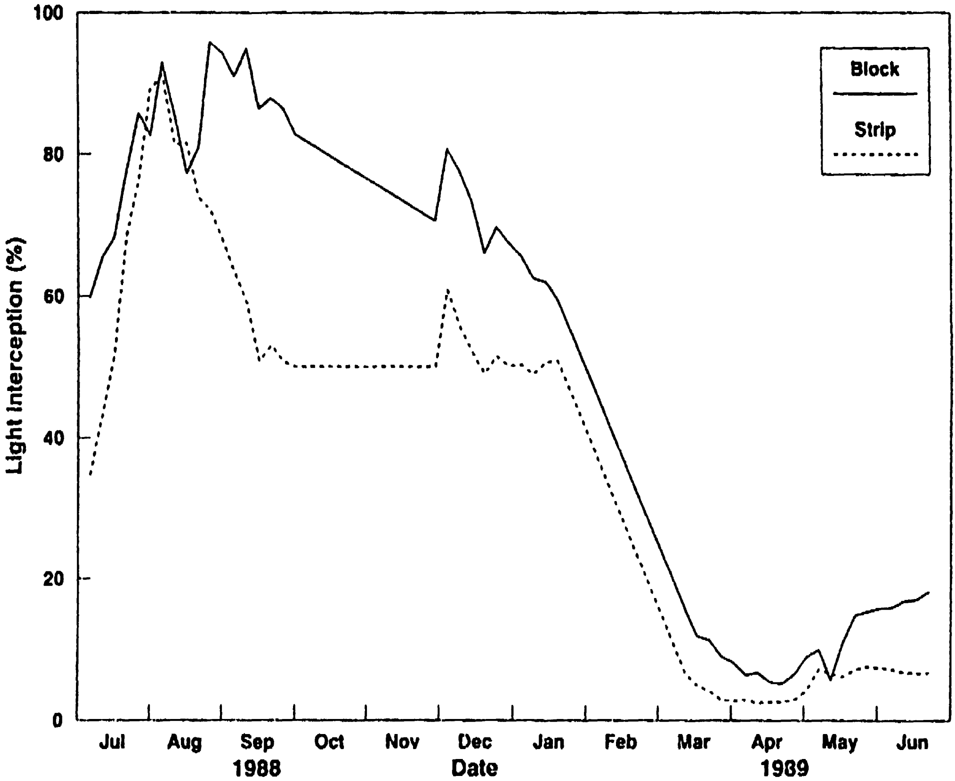

Fig. 9. Comparison of light interception of block and strip plantings.

The negative effect of the TCI on the growth and yield of annual crops was greatest during the post-rainy season. For example, during the rainy season the reduction in growth of sunflower extended to 1.5 m compared to 2.5 m during the post-rainy season. In both seasons the negative effect on crops became apparent at 30–40 days after the sowing of the annual crops. During the rainy season the negative effect was probably caused by shading by the taller pigeonpea since rainfall was close to the evaporative demand but shading extended to 1 m into the sunflower stand. In both post-rainy seasons the reduction in the chickpea growth extended beyond the distance of the lateral roots of the perennial pigeonpea (1.75 m). However it is possible that some roots of perennial pigeonpea might have decomposed when root sampling was made. Since shading by pigeonpea extended to 2.5 m of chickpea stand, competition for moisture most probably was a major cause for the negative effect on chickpea growth. Results from an unrelated experiment in an adjacent field strongly indicate that other factors might also be involved. The unpublished evidence showed that annual pigeonpea has a strongly negative residual effect on a post-rainy chickpea and this 'allelopathic' effect cannot be removed by application of carbofuron. Firm evidence of the competition for moisture between trees and annual crops have been reported in alley cropping systems based on *Leucaena leucocephala* using root barriers [9]. Such techniques would be useful to examine this kind of below ground interactions.

In the study of Singh et al. [9] the growth and yield of annual crops (sorghum, cowpea and castor bean) during the rainy season in an Alfisol were reduced to a distance of 3 m from a single row of *L. leucocephala*. In another *L. leucocephala* study of the TCI on Alfisols Rao et al. [8] reported that the yield of sunflower was reduced to a distance of 3.6 m from a paired-row of *L. leucocephala*. In comparison, in the present study the negative effect of perennial pigeonpea on the growth of sunflower was confined to a distance of 1.5 m. Although these observations suggest that perennial pigeonpea is less competitive than *L. leucocephala*, the influence of rainfall, soil types and density of trees cannot be distinguished in the above reports. Recently attempts have been made at ICRISAT Center to compare the interface effects of both tree species on maize but serious psyllid (*Heteropsylla cubana*) on *L. leucocephala* var. K 8 has confounded interpretation of the results obtained. Nevertheless, the unpublished data confirmed that maize yield was less reduced (6%) by perennial pigeonpea than by *L. leucocephala* (28%).

The present study shows that the TCI is the basic unit for tree-crop interaction as proposed by Huxley [4]. While the interface effect was extended well into the annual crops in the present study the benefit to the tree was restricted to the outermost row consistent with other observations [5]. In their detailed study of TCI in a semi-arid site in Kenya with a bimodal rainfall regime, Huxley et al. [5] also reported changes in soil moisture at various distances from the trees and they suggested that the drier soil profile near the trees were due to a combination of uptake by roots of trees and the interception of rain by the tree canopy. In an analysis of the microclimatic interactions in agroforestry systems, Monteith et al. [6] suggested that interception of water by the tree component in an alley cropping system may divert enough water (20% of incident rainfall) from the annual component to reduce its production. Thus, trees like *Faidherbia albida* (formerly *Acacia albida*), which sheds its leaves during the onset of the rainy season and is used in traditional agroforestry systems in the semi-arid tropics, avoid the negative interactions for water both at the canopy level (by less rainfall interception) and at the subterranean level (by roots). Similarly, the slow initial growth rate of perennial pigeonpea is an important trait for intercropping with annual crop [2]. Therefore, Ong et al. [7] argued that the use of a tree species or management regime which encourages slow regrowth is desirable for a positive response at the tree-crop interface. In the present study perennial pigeonpea was cut once (in March) during the dry season for fodder but a further cut is possible before the sowing of the rainy season annual crops [2]. Recently, studies showed that perennial pigeonpea is less competitive to annual crops when cutting is done just before sowing of the annual crop.

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