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Leucaena – Linseed competition in an alley-cropping system in central India

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Abstract: Relative influence of above- and below-ground competition on the growth and productivity of *Linum usitatissimum* (L.) was studied in a *Leucaena leucocephala* (Lam) De Wit based alley cropping system at a sub-humid site in central India. To examine the relative impact of above- and below-ground competition three competition situations were created: Crop + *Leucaena* shrub neighbour, Crop + *L.* hedge neighbour and sole crop in 4 m and 8 m alley-sizes. Sunlight at ground, soil organic C and total N in soil were measured in all the competition treatments at different distances from shrub and hedge neighbours. Sunlight did not differ in crop + hedge treatment compared to that in sole crop plot, whereas, it was reduced by 36 to 82%, across the alley sizes, in crop + shrub treatment compared to that in sole crop plot. Moreover, reduction in sunlight was greater in 4 m alley. Soil organic C was high but total N was low in crop + hedge neighbour and crop + shrub neighbour treatments compared to that in sole crop plot. Growth rate in *Leucaena* shrub, across the alley – sizes, ranged from 5.6 to 11.8 g m^{-2} day^{-1}. Above-ground biomass and grain yield of the crop were reduced by 9 to 37% and 17 to 26%, respectively in crop + hedge treatment and 64 to 98% and 89 to 96%, respectively in crop + shrub treatment compared to that of sole crop. Comparing the two competition treatments (crop + hedge and crop + shrub neighbour) it was observed that above-ground biomass was reduced to the maximum by 55-60%, growth rate by 42-55% and crop yield by 71-72% due to above-ground competition. Below-ground competition was 3.6 times greater in 4 m compared to that in 8 m alley. Intensity of competition ranged, across the alley – sizes, from 0.10 to 0.37 in crop + hedge and from 0.64 to 0.77 in crop + shrub neighbour competition treatment. Intensity of competition was greater in 4 m alley.

Resumen: Se estudió la influencia relativa de la competencia aérea y subterránea sobre el crecimiento y la productividad de *Linum usitatissimum* L. en un sistema de cultivo en callejones basado en *Leucaena leucocephala* (Lam) De Wit en una localidad subhúmeda de la India central. Para examinar el impacto relativo de la competencia aérea y subterránea se crearon tres situaciones de competencia: cultivo + arbusto vecino de *Leucaena*, cultivo + seto vecino de *L.*, y cultivo solo, en callejones de 4 y 8 m de tamaño. Se hicieron mediciones de la luz solar al nivel de suelo, el C orgánico en suelo y el N total en suelo para todos los tratamientos de competencia a diferentes distancias de los vecinos arbusto y seto. La luz solar no difirió entre el tratamiento cultivo + seto y la parcela de cultivo solo, mientras que esta variable se redujo entre 36 y 82% para ambos tamaños de callejones en el tratamiento cultivo + arbusto en comparación con la parcela de cultivo solo. Además, la reducción de luz solar fue mayor en el callejón de 4 m. El C orgánico del suelo fue alto pero el N total fue bajo en los tratamientos cultivo + seto vecino y cultivo + arbusto vecino en comparación con la parcela de cultivo solo. La tasa de crecimiento en presencia de arbustos de *Leucaena* para todos los tamaños de callejón varió de 5.6 a 11.8 m^{-2} $día^{-1}$. La biomasa aérea y la cosecha de grano del cultivo se redujeron 9-

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37%, y 17-26%, respectivamente, en el tratamiento cultivo + seto, y 64-98% y 89-96%, respectivamente, en el tratamiento de cultivo + arbusto, en comparación con las del cultivo solo. Al comparar los dos tratamientos de competencia (cultivo + vecino arbusto y cultivo + vecino seto) se observó que la biomasa aérea tuvo una reducción máxima de 55-60%, la tasa de crecimiento de 42-55%, y la cosecha del cultivo en 71-72% debido a la competencia aérea. La competencia subterránea fue 3.6 veces más grande en los callejones de 4 m que en los de 8 m. La intensidad de la competencia fluctuó, para ambas clases de tamaño de callejón, de 0.10 a 0.37 en el tratamiento de competencia de cultivo + seto vecino, y de 0.64 a 0.77 en el tratamiento de arbusto vecino. La intensidad de la competencia fue mayor en el callejón de 4 m.

Resumo: A influência relativa na competição aérea e subterrânea no crescimento e produtividade do *Linum usitatissimum* L. foi estudada num sistema baseado numa associação em áleas com *Leucaena leucocephala* (Lam) De Wit numa estação sub-húmida na Índia cental. Para examinar o impacto relativo da competição na camada aérea e na subterrânea foram criadas três situações de competição: Cultura + moitas de Leucaena na vizinhança, Cultura + sebe de Leucaena na vizinhança e cultura extrema em áleas com a largura de 4m e 8m. A radiação luminosa ao nível do solo, o carbono orgânico e o N total no solo foram medidos em todos os tratamentos para estudo da competição a diferentes distâncias da vizinhança das moitas e sebes. A luz solar não diferiu no tratamento cultura + sebe quando comparado com a parcela de cultura extreme, enquanto que ficou reduzida entre os 36 e os 82%, através da dimensão das diferentes áleas, no tratamento cultura + moitas quando comparado com a cultura simples. Além disso, a redução na radiação solar foi maior nas áleas de 4m. O C orgânico foi mais elevado mas o N total foi mais baixo no tratamento cultura com tufos de Leucaena na vizinhança quando comparado com a cultura extreme. A taxa de crescimento da Leucaena ao longo das fiadas das áleas oscilou entre os 5, 6 a 11, 8g.m^{-2}.dia. A biomassa aérea e o rendimento em grão da cultura decresceram cerca de 9% a 37% e 17% a 26%, para o tratamento cultura + sebe, respectivamente, tendo atingido valores de decréscimo entre os 64% a 98% e os 98 a 96% para o tratamento cultura + moitas de Leucaena, respectivamente, quando comparados com a cultura extreme. Comparando os dois tratamentos de competição (cultura + sebes e cultura + vizinhança de Leucaena) observou-se que a biomassa aérea teve uma redução máxima de 55-60%, a taxa de crescimento entre 42-55% e o rendimento da cultura entre 71-72% devido à competição na parte aérea. A competição na parte subterrânea foi 3,6 vezes maior nas áleas de 4m em comparação com as de 8m. A intensidade da competição variou, ao longo das dimensões das áleas entre 0,10 a 0,37 para o modelo cultura +sebes e enter 0,64 e 0,77 para o tratamento cultura + moitas de Leucaena na vizinhança. A intensidade da competição foi mais elevada nas áleas de 4m.

Key words: Alley-cropping, belowground competition, *Leucaena* shrub, linseed.

Introduction

In agroforestry, crop yields decline under trees due to competition (-ve interaction) between tree and crop components for above-ground (light) and below-ground (soil water, nutrients) growth resources (Huxley *et al.* 1989; Ong *et al.* 1991; Pandey *et al.* 1999). Trees generally utilize the growth resources proportionately greater and make them growth limiting. Competition starts between the tree and crop component for the growth limiting resources (Wedin & Tilman 1993). Differences in establishment timing of competing species lead to asymmetries in their size and in resource capture (Miller 1987; Weiner 1990). Once difference in resource acquisition rate between tree and crop components are established, it is maintained or magnified during competition because of a positive feed back between growth and resource capture (Wedin & Tilman 1993). Competition for light seems more asymmetric than competition for nutrients (Weiner 1990). Abilities to compete for light and nutrients are positively correlated because greater size and growth rate of tree allows it to preempt both above- and below-ground resources (Grime 1973).

Some studies have separated effects of above- and below-ground competition on growth and productivity of crops in alley-cropping system (Singh *et al.* 1989; Willey & Reddy 1981). However, there is a great lack of information on relative effect of above- and below-ground competition on the growth and productivity of crops in tree or shrub based intercropping. This study was designed to examine (i) relative impact of above – and below-ground competition on the growth and productivity of *Linum usitatissimum* (L.) in *Leucaena leucocephala* (Lam) De Wit shrub/*L. usitatissimum* intercropping. (ii) processes through which shrub neighbour modify growth resources and affect the crop.

Materials and methods

Study site

An alley-cropping system was established at the Research Farm of Indira Gandhi Agricultural University, Raipur (21^{O} 4′N lat. and 81^{O} 31′E long), Chhattisgarh, India. The altitude was 293 m above mean sea level. The climate is sub-humid monsoonic, with marked seasonality. Rainy season prevails from mid-June to September, winter from November to February and summer from March to mid-June. October constitutes the transition month between rainy and winter seasons. Average rainfall for the year is 1384 mm of which 88% occurs during the rainy season. Soil is vertisols, black in colour, clay-loam in texture and moderate in nutrients.

Experimental design

Twelve parallel rows of hedge of *L. leucocephala*, each twenty meter long, were raised in an agricultural field in east-west direction in July 1994. Six successive hedgerows were planted with *L. leucocephala* seedlings, raised in a nursery, at 8 m distance and remaining six at 4 m distance. Thus, there were 5 alleys of each 4 m and 8 m size. Within a row, distance of the seedlings was 50 cm. All the hedgerows were pruned to 1 m from ground thrice in a year i.e., August, November and May as a standard practice of alley-cropping. Intensive, 20 cm deep ploughing was done frequently in the alleys, generally from 30 cm distance from the hedgerow for better tilth.

To measure the above-ground and below-ground competition, half portion of two successive hedge were left unprunned randomly either in east or west side from beginning of July 1997. Unprunned hedge grew to a shrub in November 1997. A plot without hedgerows was arranged in either side of each alley in the same east-west direction as was the hedgerows. Each plot was 10 m long but its width corresponded to the width of corresponding alley. *Linum usitatissimum* was sown in November 1997 in each alley including adjacent plots at an inter-row distance of 25 cm. Plant to plant distance was 5 to 6 cm. Thus, there were three competition treatments, i.e. sole crop (having no neighbour), crop with *L.* hedge (neighbour having only root system), and crop with *L.* shrub (neighbour having both root and shoot system). Watering was not done in the alley including adjacent plots, as residual soil moisture of rainy season in vertisols is adequate for the crop growth. Water requirement of Linseed is reported low (Singh 1984). Fertilizer, ($N^2P^2O^5$, K^2O) was applied as basal dose at the rate of 60:30:30 kg ha^{-1} in each alley and adjacent plot at the time of the crop sowing. The hedge (crop + hedge competition treatment) was pruned and fine branchlets were removed frequently from rainy season to stabilize death and decomposition of hedge's root, if any, resulted from pruning and branch removal and to ensure full availability of light to crop in the alley. The study was repeated for one more year during the crop growing seasons in 1998.

Sampling and analysis of vegetation and soil in laboratory

Three alleys, each having shrub neighbour crop, hedge neighbour + crop and an adjacent sole crop plot were selected randomly for sampling. Thus, there were 3 replicates for the competition treatments. Line transects were laid horizontally, across the competition treatments, in each alley at 50 cm, 1 m and 2 m distance from the hedge and shrub neighbour from both alley sides in 4 m alley. Similarly, line transects were laid in each alley, across the competition treatments, from both the sides at 50 cm, 1 m, 2 m, 3 m and 4 m distance from the hedge and shrub neighbour in 8 m alley. A quadrat 50 x 50 cm was placed at three random places along the transects in each treatment in each alley size, and number of tillers was counted. The crop was harvested close to the ground in the quadrat for estimation of above-ground biomass. Below-ground biomass was determined by taking randomly a monolith (15 x 15 cm), to a depth of 15 cm in each harvested plot. Monoliths were washed with a fine jet of water to remove adhered soils, using successsively 2.0 and 0.5 mm mesh screens. Plant materials were dried to 80^{O}C to constant weight and weighed. Values of each parameter at corresponding distance from both sides of each alley, including corresponding sole crop plot, were averaged. Sampling for tiller numbers, above-ground biomass and below-ground biomass of *L. usitatissimum* was done twice, at the time of tillering and peak biomass of the crop (before flowering) of the crop. However, grain yield was measured at the time of crop maturity. Above-ground biomass of shrub was estimated on per m^2 basis as density (D) of shrub x weight of a shrub. Density of shrub was calculated as:

$$D = \frac{\text{area } (100 \times 100 \text{ cm})}{\text{row to row (cm)} \times \text{shrub to shrub (cm) distance}}$$

All shrubs in each row were cut at the time of crop harvesting at 1 m from ground and biomass of their leaves and stems were estimated separately. Growth rate (biomass accumulation rate) of above-ground biomass was calculated as:

$$r = \frac{w_2 - w_1}{t_2 - t_1}$$

where, w^2 was final biomass at time t^2 and w^1 was initial biomass at time t^1.

Harvest index (HI) was calculated as: grain yield divided by total biomass (grain yield + straw yield). Intensity of competition was calculated following Wilson & Tilman (1991) as:

$$CI = \frac{rNN - rSN}{rNN}$$

where, CI is competition intensity, rNN is growth rate in crop without shrub neighbour and rSN is growth rate in crop in presence of shrub neighbour.

New growth in the hedgerows was pruned periodically at 8 days intervals to measure biomass production in *Leucaena* shrub neighbour during the crop growing period. Hedgerows were pruned at the time of crop sowing to make the new growth zero. Total shoot biomass production was calculated as:

$$\sum_{i=1}^{n} \Delta LB + \Delta SB$$

where, LB is leaf biomass and SB is stem biomass.

Light intensity was measured at each sampling distance at 15 day intervals after germination of the crop at 1 hr intervals from 9 A.M. to 2 P.M. by a digital lux meter (Lutron LX – 101).

Soil was sampled at 4 random places in each harvested plot at 0 to 15 cm depth. Distance wise composite samples were prepared by mixing samples from harvested plots along the transects of corresponding distance from both sides of the plot in each competition treatment. Composite samples were analysed for organic-C by Walkley and Black rapid titration method and total N by micro-kjeldahl digestion method.

Statistical analysis of data

Data were subjected to a factorial multivariate analysis of variance (MANOVA) to test for differences owing to treatment and distance. Number of alleys, (treated as blocks) including all the three competition treatments, served as replicates. Differences between means were tested using least significance difference (LSD) test. Analysis was done separately for each alley-size. Correlation coefficient test was performed to know the relation between two parameters. Step-wise multiple regression analysis was applied to see relative effect of light, organic C and total N on the growth and productivity of the crop. Growth and productivity of the crop did not differ significantly due to year, therefore, mean values for 1997 and 1998 were used for the statistical analysis. All the statistical analysis were performed using SPSS/PC + (1986).

Results

Aboveground and below-ground growth resources

Sunlight to ground varied among the competition treatments in both the alley-sizes ($P<0.0001$). However, variation in sunlight due to distance ($P<0.0001$), and competition treatment x distance interaction was significant ($P<0.0001$) in 8 m alley. Sunlight was reduced by 82% in 4 m and 36% in 8 m alley, under the shrub compared to that in sole

crop plot (Table 1). Sun light under the hedge, both in 4 m and 8 m alleys, did not differ from that in sole crop plot. Sunlight, in crop + shrub neighbour treatment, in 8 m alley, was correlated to distance (r = 0.937, P<0.01).

Soil organic-C and total N differed due to the competition treatment (P<0.0001) and the distance (P<0.0001) and competition treatment X distance interaction (P<0.0001) in both the alley-sizes. Soil organic C in crop + shrub neighbour treatment, being at par to that in crop + hedge neighbour, was 19% higher in 4 m and 11% higher in 8 m alley compared to that in sole crop plot (Table 1). Soil organic C was inversely related to the distance in crop + hedge neighbour and crop + shrub neighbour treatment in 4 m (P<0.05) and 8 m (P<0.01) alley-sizes. Total N followed the pattern of organic C in both the competition treatments and alley sizes. C/N ratio in both the alley sizes varied due to the competition treatment (P<0.001), distance (P<0.01) and their interaction. Contrary to organic C and total N in the soil, C/N ratio declined in crop + hedge and crop + shrub neighbour treatments compared to sole crop plot (Table 1).

Growth in the shrub neighbour

Shoot biomass (stem + leaves) of *Leucaena* shrub neighbour ranged from 672 to 1419 g m^2 across the alley – sizes. Growth rate (biomass accumulation rate) of *L.* shrub ranged from 5.6 to 11.8 m^{-2} day^{-1} (Table 2).

Effect of competition on the crop

Grain yield of crop varied due to the competition treatments (P<0.0001), distances (P<0.0001) and their interaction (P<0.0001) in 4 m and 8 m alley-sizes. Grain yield, across the distance, was reduced maximum (96% in 4 m and 89% in 8 m alley sizes) in crop + shrub neighbour treatment and minimum (25% in 4 m and 17% in 8 m alley sizes) in crop + hedge neighbour treatment compared to that in sole crop plot (Table 3). Harvest index of the crop varied among the competition treatments (P<0.0001) and distances (P<0.001) in both the alley-sizes. Harvest index was reduced in crop + shrub neighbour by 76% in 4 m alley and 68% in 8 m alley compared to that in sole crop plot (Table 3). Grain yield was correlated to harvest index (P<0.01) in both the competition treatments (crop+hedge and crop + shrub neighbour) in both the alley-sizes.

Above-ground biomass of the crop varied among the competition treatments (P<0.0001) and distances (P<0.0001) in both the alley – sizes. Effect of treatment and distance interaction on the above-ground biomass was also significant (P<0.0001) in 8 m alley-size. Above-ground biomass was reduced 80% in crop + shrub neighbour and 37% in crop + hedge neighbour treatment compared to that in sole crop plot in 4 m alley. Similarly, above-ground biomass in 8 m alley-size was also reduced maximum 64% in crop + shrub neighbour and minimum 9% in crop + hedge neighbour treatment compared to that in sole crop plot (Table 3). Above-ground biomass was correlated to distance in crop + hedge neighbour and crop + shrub neighbour competition treatments in 4 m (P<0.05 to P<0.01) and 8 m (P<0.01) alley-sizes. Growth rate (biomass accumulation rate) of the crop was affected due to competition treatment (P<0.0001) and distance (P<0.0001) in both the alley-sizes. Effect of competition treatment and distance interaction on growth rate was also significant (P<0.001) in 8 m alley. Growth rate in crop + hedge neighbour treatment was reduced by 37% in 4 m and 9% in 8 m alley-sizes (Table 4). This reduction in crop + shrub neighbour treatment was 79% in 4 m alley and 64% in 8 m alley

Table 2. Growth and biomass production of *Leucaena* shrub (Data are mean across the shrub rows and years ±1 SE).

Alley-size (m)	November		Biomass production (Nov. 1997 to March 1997)			Growth rate (g m^{-2} day^{-1})
	Height (m)	Canopy diameter (m)	Leaf biomass (g m^{-2})	Stem biomass (g m^{-2})	Total above ground biomass (g m^{-2})	
4	3.45 ± 0.18	2.40 ± 0.09	288 ± 19	1130 ± 54	1419 ± 72	11.83 ± 0.60
8	3.83 ± 0.17	2.53 ± 0.03	130 ± 6	542 ± 26	672 ± 0	5.60 ± 0.27
Mean ± 1 SE	3.70 ± 0.18	2.47 ± 0.07	209 ± 13	836 ± 41	1046 ± 48	8.70 ± 0.44

compared to that in sole crop plot. Density of the crop varied significantly among the competition treatments (P<0.0001), distances (P<0.0001) and their interaction (P<0.0001) in 4 m and 8 m alley-sizes. Density was reduced maximum in crop + shrub neighbour by 82% in 4 m alley and 57% in 8 m alley compared to that in sole crop plot. Reduction in density in crop + hedge neighbour tratment was minimum 36% in 4 m alley-size and 16% in 8 m alley-size (Table 3). Density was correlated (P<0.05 to P<0.01) to distance in both the competition treatments in both the alley-sizes.

Above-ground biomass/below-ground biomass (AB/BB) ratio of the crop differed due to competition treatments (P<0.0001) and distances (P<0.05 – P<0.001) in both the alley-sizes. Effect of competition treatment and distance interaction on the AB/BB ratio was also significant (P<0.05) in 8 m alley. AB/BB ratio declined (P<0.05) by 28% in crop + hedge neighbour and by 48% in crop + shrub neighbour treatment compared to that in sole crop plot in 4 m alley. AB/BB ratio declined by 28% in crop + shrub neighbour compared to that in sole crop plot in 8 m alley (Table 4). AB/BB ratio was correlated to distance (P<0.05 to P<0.01) in crop + hedge neighbour and crop + shrub neighbour treatments in both 4 m and 8 m alley-sizes. Below-ground biomass of the crop was correlated to its above-ground biomass in both the crop + hedge neighbour and crop + shrub neighbour treatments in 4 m and 8 m alley-sizes (P<0.05 to P<0.01). Neighbour root/crop root ratio differed significantly due to competition treatments (P<0.001), and competition treatment x distance interaction (P<0.0001) in both the alley-sizes (Table 4).

Competition intensity

Intensity of competition differed among competition treatments (P<0.0001) in 4 m and 8 m alley-sizes. Effect of treatment and distance interaction on the intensity of competition was significant (P<0.0001) in 8 m alley. Intensity of competition in crop + shrub neighbour treatment was 2 times greater in 4 m and 6.4 times greater in 8 m alley-size compared to that in crop + hedge neighbour treatment. Intesnity of competition in crop + shrub neighbour treatment was 20% greater in 4 m alley compared to that in 8 m alley (Table 4).

Discussion

Estimate of sunlight revealed that light to ground in the crop + hedge neighbour competition treatment did not differ to that in sole crop plot. This indicated that reduction in growth of the crop due to hedge neighbour was primarily owing to below-ground competition. However, decline in growth rate and yield of the crop in crop + *Leucaena* shrub treatment compared to that of sole crop plot suggested that both above and below-ground competition occurred under canopy of the shrub.

When growth rate and yield of the crop in crop + shrub competition treatment were compared with growth rate and yield of the crop in crop + hedge competition treatment, it was observed that reduction in growth rate and yield of the crop was greatest (42 to 55% and 71 to 72%, respectively across the alley-sizes) due to above-ground competition and least (9 to 37% and 17 to 25%, respectively across the alley-sizes) due to below-ground competition. Greater effect of above-ground competition is evident also from results of step-wise multiple regressions which indicated that light explained maximum 84 to 86% of the variability in growth rate and 74 to 83% of the variability in grain yield across the alley-sizes. However, total nitrogen and organic C in soil explained only 0.9 to 1.7% and 0.7 to 14% of the variability, respectively in growth rate, and 6 to 10% and 6 to 20%, respectively of the variability in grain yield of the crop. Ong *et al.* (1992) in a similar experiment reported that reduction in maize yield in *Leucaena* – maize intercropping was 46 to 55% on plots with overstorey of *Leucaena* tree and 18 to 20% on plots with pruned hedgerows. Tilander *et al.* (1995) found that when trees were coppiced in the alley farming system, competition from tree was generally not strong enough to result in significant row differences in sorghum yield in both 5 m and 8 m alleys. Karim *et al.* (1991) and Kang *et al.* (1981) found above-ground competition for light greater than below-ground competition for soil-water and nutrients in *Leucaena*-maize intercropping. We compared two competition treatments because effects of above-ground and below-ground competition are additive. Greater reduction in density and yield of the crop in alley with *Leucaena* shrub compared to that in alley with *L.*

hedge neighbour indicated that effect of above and below-ground competition could have been additive. Our assumption that effect of above-ground and below-ground competition may be additive, is also based on the fact that difference in transpiration rates of hedge row pruned at 50 cm and understorey trees of *Leucaena* is neigligible (Ong *et al.* 1992). They reported that this negligible difference was due to young, activity transpiring leaves of pruned hedge compared to proportionately greater older leaves and reproductive structures in *Leucaena* tree. Positive interactions between above- and below ground competition, such that their combined effects are greater than the sum of their separate effects, were reported in replacement series type pot experiments by Donald (1958). Lower effect of below-ground competition on the crop may be due to low amount of root of *Leucaena* in upper layer (0-15 cm) of soil which is apparent from low neighbour root/crop root ratio.

Greater reduction in growth rate and yield in4 m alley may be attributed to its smaller width size. Canopy of shrub neighbour extended 2.4 m from both sides in the alley (Table 2) and as a result intercepted greater sunlight. Below-ground competition in 4 m alley increased by 3.6 times compared to that in 8 m alley most likely due to extension of roots of shrub from both sides in smaller volume of soil. But, it could not dominate over the effect of above-ground competition. Extension of root of shrub neighbour up to 2 m in the plot was observed both in 4 m and 8 m alley-size. Greater reduction in density and yield due to above-ground competition even in small alley-size, further substantiated our conclusion that light was major limiting factor under the canopy of *Leucaena* shrub.

Low AB/BB ratio and harvest index of the crop in crop + shrub neighbour, compared to that in crop + hedge neighbour treatment indicated greater impact of above-ground competition on the crop. Greater importance of above-ground competition is further evident from inverse relation of AB/BB ratio and harvest index with distance, and positive relation between sunlight and distance. Reduction in AB/BB ratio (Grunow *et al.* 1980) and harvest index (Ong 1993) due to shade, is well documented.

Well developed canopy at the time of crop sowing and 6 to 10 times higher growth rate (net accumulation rate of biomass) in *Leucaena* shrub over the crop, seem to have allowed it to utilize proportionately greater mineral nitrogen. This disproportionately greater utilization of available nitrogen could have caused below-ground competition for it between the shrub neighbour and the crop. High amount of organic C and total N in the soil and low C/N ratio under the shrub neighbour indicated greater availability of mineral nitrogen. Greater mineralization rate is reported to occur under the tree shade due to relatively higher soil moisture in the soil (Belsky 1994). Soil moisture was found 110% greater under *Acacia nilotica* tree shade during the winter season in the study region (C.B. Pandey, Unpublished). Low population of the crop and higher neighbour root/crop root ratio nearer to the shrub neighbour could have facilitated greater utilization of nitrogen (mineral N) by the shrub neighbour. Amount of total nitrogen in the soil under the shrub neighbour was expected to decline. However, it increased perhaps due to long term build up of organic carbon via dead roots and root nodules of the shrub which did not allow the system to reflect reduction in total nitrogen. Chulan & Waid (1981) found 94% transfer of net nodule nitrogen to soil in a tropical legume crop. Well developed canopy of the shrub intercepted sunlight asymmetrically greater which caused above-ground competition for the light. Uptake of water and nutrients are reported to be related directly to above-ground demand i.e. the size of the leaf canopy and the above-ground sink strength for nutrients (Van Noordwijk *et al.* 1996). We expected that *Leucaena* shrub being a nitrogen fixer might not be competing for nitrogen. Contrary to this, below-ground competition occurred perhaps for nitrogen due to substantially higher shoot growth rate (greater above-ground demand) in it. Cruz (1997) observed low level of nodulation but strong growth in *L. leucocephala* shrub under high N and soil-water condition (N uptake by the above-ground biomass more than 1000 kg ha^{-1} yr^{-1}) in a *L. leucocephala* shrub-*Dichanthum aristatum* stand in French Antilles. He argued that *Leucaena* legume shrub was more competitive for soil N rather than a N supplier. Karim *et al.* (1991) also observed below-ground competition for nitrogen in a *Leucaena*-maize intercropping. Plants of nutrient-rich habitats are reported capable of rapidly consuming any surplus in available nutrients in pot experiments (Crick & Grime 1987; Granato & Raper 1989).

Conclusions

Our study concludes that *Leucaena* shrub grew quickly and developed its canopy and as a result built a big sink of nutrients above-ground which allowed proportionately greater consumption of nitrogen. This disproportionate utilization led to below-ground competition between the shrub and the crop for the nitrogen. Canopy of the shrub neighbour intercepted light asymmetrically greater and as a result developed above-ground competition for light. Effect of above-ground competition on the growth and productivity of the crop under the shrub was greater than the below-ground competition.

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