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Resource capture and tree-crop interaction in *Albizia procera*-based agroforestry system

(Bestandserfassung und Baum-Feldfrucht Wechselwirkungen in einem auf *Albizia procera* basierenden Agro-Forestry System)

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Abstract
A field experiment was conducted in a randomized block design at the National Research Centre for Agroforestry, Jhansi (UP) during two consecutive years (2000 – 01 and 2001 – 02). The experiment comprised eight treatments: T_1 – trees allowed to grow normally + crop, T_2 – pruning of trees up to 70% plant height + crop, T_3 – trees allowed to grow normally + soil barrier + crop, T_4 – pruning of trees up to 70% plant height + soil barrier + crop, T_5 – T_1 + irrigation as per requirement of crop, T_6 – pruning of trees up to 70% plant height + irrigation as treatment $_5$, T_7 – pure trees, and T_8 – pure crops (control). Blackgram (*Phaseolus mungo* Roxb.)/Mustard (*Brassica juncia* Coss.) crop sequence was included as an intercrop in the tree-crop system. Germination, plant height and branching of intercrops (blackgram and mustard) in the first row from the tree base was less compared to the second, third and fourth rows from tree base during both years. The competitive effect of trees on yield attributes and yield of blackgram and mustard was only observed in the first row of crop from tree base during the first year and this difference was wider during the second year. The light intercepted by under storey crops (blackgram and mustard) was more when the trees were pruned up to 70% plant height than when the trees were allowed to grow normally. However the value of light intercepted by crops was less in the tree-crop system than in the open field. The soil barrier was fully able to restrict the movement of root systems.

Keywords: *Albizia procera, blackgram, competition, complementarity, mustard, tree-crop interaction.*

Introduction

In agroforestry, tree and agricultural crops are combined together and they compete with each other for growth resources such as light, water and nutrients. The resource sharing by the

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components may result in complementary or competitive effects depending upon the nature of the species involved in the system, the manner in which they are grown and depending on the climatic factors, plants and trees may influence neighboring species, not only by the addition or removal of some factor, but also by affecting conditions such as temperature, light or wind movement or by altering the balance between beneficial and harmful organisms. Opportunities for substantial temporal complementarity exist for storable resources like water and nutrients in a system if major resources demand is at different times. On the other hand for un-storable resources like light spatial complementarity is the only phenomenon available.

In spite of increased combined productivity by both component in a system a negative effect of competition is envisaged which is usually significant in terms of gross production losses of the components of the system (Bellow & Nair, 2003; Scott et al., 2003; Ralhan et al., 1992). The main effects of tree – crop interactions are complementary (for example, increased productivity, soil fertility improvement, nutrient cycling, microclimatic improvement and sustainability) and competitive (yield reduction of crop components in various systems due to tree components). The overall (biomass) productivity of an agroforestry system is generally greater than that of an annual system although not necessarily greater than that of a forestry or grassland system. The basis for the potentially higher productivity could be due to the capture of more growth resources, e.g., light or water or due to improved soil fertility.

In an agroforestry system, biomass production from trees adequately compensates the crop reduction due to competition with tree. Land equivalent ratio of agroforestry land use is comparable or even better than mono-cropping systems indicating the suitability of this system (Pratap Narain et al., 1998). Agroforestry gives more income to the farmer per unit area of land than pure agriculture or forestry (Ralhan et al., 1992; Current et al., 1995; Hoekstra, 1990). In view of the above factors, an experiment was undertaken in an *Albizia procera*-based agro forestry system with the objectives of quantifying loss or gain in resource capture in the system and to understand and elucidate the effects of tree – crop interaction in the system on growth and yield of intercrops.

Materials and methods

The present study was undertaken at the National Research Centre for Agroforestry, Jhansi (UP) during two consecutive years (2000 – 01 and 2001 – 02). The experiment consisted of eight treatments: T_1 – tree allowed to grow normally + crop, T_2 – pruning of trees up to 70% plant height + crop, T_3 – T_1 + soil barrier (galvanised iron (GI) sheet installed to 1m depth at side between tree and crop) + crop, T_4 – pruning of trees up to 70% height + soil barrier + crop, T_5 – T_1 + irrigation as per requirement of crop, T_6 – T_2 + irrigation as per requirement of crop, T_7 – pure trees, and T_8 – pure crops. Blackgram (*Phaseolus mungo* Roxb.) and Mustard (*Brassica juncia* Coss.) crop sequence as an intercrop were planted. The experiment was conducted in randomized block design with three replications. The size of each plot was 288 m^2, which contained nine trees per plot with 8m x 4m planting distance.

The site of the experimental field was at 25° 27′ N latitude and 78° 35′ E longitude, 271 m above mean sea level in the semi-arid tract of the central plateau of India. Annual rainfall ranges from 700 – 1150 mm with a mean value of 958 mm. This region receives about 80% of its annual rainfall during the southwest monsoon. The mean annual temperature of the Jhansi is generally high with high degree of variation between maximum and minimum temperatures, sometimes the maximum temperature in the summer months of May and June touches 48°C which is the peak of summer season.

The soil of the experimental field was a mixture of black and red soil group of Bundelkhand regions covered under the order of Alfisol. Soil pH was measured by combined glass electrode pH meter (Jackson, 1958). Organic carbon was estimated according to Walkely and Black's rapid titration method (Jackson, 1958). Electrical conductivity was measured by the solubridge method advocated by Richards (1954). The initial soil pH, electrical conductivity (dsm^{-1}) and organic carbon per cent were 6.57, 0.08 and 0.51, respectively at 0–15 cm soil depth and 6.81, 0.06 and 0.34, respectively at 15–30 cm soil depth. The initial available N, P and K in the soil were 157.40, 8.58 and 132.20 kg ha^{-1} at 0–15 cm soil depth and 138.01, 5.24 and122.01 kg ha^{-1}at 15–30 cm soil depth, respectively.

For the planting of trees, marking was done at 8 m x 4 m spacing at the end of June, 45 cm^3 planting holes were prepared with the help of a post hole auger and refilled with soil + compost + insecticide mixture before the onset of the monsoon. After the onset of the monsoon (last week of July, 2000) three-month-old saplings of *Albizia procera* were planted in the prepared pit. After planting of the saplings, the root barrier GI sheet 0.6 mm thick was installed around the tree at 0.5 meter away from tree base and 1.0 meter in depth in selected treatments (tree allowed to grow normally + crop and pruning of tree up to 70% plant height + crop) to avoid below-ground competition between tree and crop.

Blackgram was sown on 6 and 20 of July 2001 and 2002, respectively and 12 kg seed ha^{-1} was used. The crop was sown at 30 cm apart and a basal dose of 20 kg N and 40 kg P ha^{-1} was applied. Before sowing of the crop, seeds were treated with fungicide (Thirum 1.5g + Bavistin 1.5g kg^{-1} of seed) and rhizobium culture at 5g kg^{-1} of seed to avoid any seed borne diseases and increase the nitrogen fixation. Thinning and weeding was done 20 days after sowing. Yellow mosaic virus spread was controlled by spraying of monocrotophos 36% SL at 500 ml ha^{-1} twice at 15 day intervals to control vector *Bemisia tabacc* (White fly). The harvesting of the crop was done manually on 3 and 9 October 2001 and 2002, respectively.

Mustard was sown on 8 November and 9 October during 2000 and 2001, respectively at 30 cm row spacing. Plant spacing of 10 cm was maintained by thinning of the crop 20 to 25 days after sowing. Before sowing of the crop, seed was treated with fungicide (Thirum) at 3 g kg^{-1} of seed. Fertilizer was applied at the rate of 60 kg N, 40 kg P and 40 kg K ha^{-1}. Half of the N doses (30 kg) along with full doses of P and K were applied at sowing and half N was top-dressed at the first irrigation of the crop. Seed rate of 5 kg ha^{-1} was used. Two-irrigations (first at flowering and second at siliquae formation stage) were given in those treatments in which irrigation was proposed as their requirement. In the rest of the treatments, one-irrigation was given to the crop at 30 days after sowing. Mustard was harvested on 8 March and 17 February during 2001 and 2002, respectively.

Light interception was measured with a Lux meter. The intensity of light was measured at different distances from tree base (0.5, 1.0, 2.0, 3.0, and 4.0 m) 5 cm above the canopy of the crop and at ground level at 10 am, 12 noon and 3 pm. The observations were taken at 15, 30, 60, 90 days after sowing and at harvest in mustard and in blackgram at 30, 60 days after sowing and at harvest in selected treatments (tree allowed to grow normally and pruning of tree up to 70% plant height). The light interception by the crop components was expressed in per cent according to Palaniappan (1985):

Light interception Ξ (Light intensity at top of the canopy of crop (Light intensity at ground level) (Light available to the crop × 100.

After one year of plantation, rooting pattern was studied in selected treatments. For root study, a coring technique was used with a core sampler of 5.0 cm diameter and 15 cm length. Coring was done at different distances from tree base (0.5, 1.0 and 2.0 m) and the core sampler was placed in a labeled plastic bucket and soaked in water over night. After soaking in water the soil was removed carefully from the core and washed with clean water. After complete washing, the muddy water was filtered with a 0.87 mm sieve and the whole root system was sorted out from the water and kept in Petri dishes for washing again with distilled water. The roots were separated into live and dead categories based on color and tensile strength – live roots were placed on soaking paper for five minutes to minimize the water content and measure the total root length by the root image analysis system (Sky root imaging systems). After measuring the root length, samples were dried in an oven at 70°C until constant weight was noted. After drying, samples were weighed to calculate the root length density and specific root length. The following formula was used to calculate root length density and specific root length:

$$\text{Root length density} = \text{root length (cm)} \div \text{soil volume (cm}^3)$$
$$\text{Specific root length} = \text{root length (m)} \div \text{dry weight of root (g)}$$

The statistical analysis of various data collected during the time of experimentation was done on the pattern of randomized block design by applying the technique of 'analysis of variance' as advocated by Fisher (1968).

The significance of the treatment effect was tested with the help of variance ratio (F value). The value of SE m $\pm$ and least significant difference (LSD) were worked out by the following formula for judging the significance of difference between two treatment means.

$$\text{SE m}\pm = \sqrt{\ } \text{Error mean sum of square (EMSS)} \div \text{Replications (r)}$$
$$\text{LSD} = \text{SE m} \pm \times \sqrt{\ } 2 \times \text{t value at 5\% of level.}$$

Results

Effect of intercrops (blackgram and mustard) on growth of trees

The growth performance of *Albizia procera* in tree-crop system did not vary significantly as compared to pure trees during both the years. However, crown diameter of the trees were significantly higher in pure trees (1.42 m) compared to that of the tree-crop system during 2001. In general, the growth performance of trees was obviously better in those treatments in which trees were growing normally and associated crops (mustard) received irrigation as per their requirement during both the years (Table I). The growth performance of pure trees was

Table I. Growth performance of *Albizia procera* after one and two years of plantation.

	Height (m)		Collar diameter (cm)		Crown diameter (m)	
Treatment	2001	2002	2001	2002	2001	2002
Trees allow to grow normally + crop	1.26	2.68	3.34	7.16	1.02	3.28
Pruning of trees up to 70% plant height + crop	1.08	2.26	2.92	5.87	0.71	2.65
Trees allow to grow normally + soil barrier + crop	1.24	2.39	3.39	6.36	1.21	2.71
Pruning of trees up to 70% height + soil barrier + crop	1.29	2.24	3.70	5.98	0.75	2.52
Trees allow to grow normally + crop + irrigation as per requirement of crop	1.45	2.43	3.69	6.63	1.26	3.09
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	1.46	2.63	4.20	6.86	0.79	3.29
Pure trees (control)	1.54	2.78	3.84	7.09	1.42	3.09
LSD(0.05)	NS	NS	NS	NS	0.47	NS

Table IIa. Effect of trees on germination, plant height and branching of intercrop (blackgram).

Treatment	Germinated plants running m^{-1} at 15 DAS				Plant height (cm)				Number of branches $plant^{-1}$			
	Row number from tree base											
	1	2	3	4	1	2	3	4	1	2	3	4
						2001						
Trees allow to grow normally + crop	10.17	11.67	13.83	15.33	30.33	33.67	37.00	42.33	4.00	5.50	5.00	6.00
Pruning of trees up to 70% plant height + crop	13.30	14.50	16.83	17.83	33.08	35.42	36.58	35.33	4.50	5.17	5.83	5.50
Trees allow to grow normally + soil barrier + crop	11.67	12.33	14.50	17.00	31.33	34.08	36.67	33.58	5.33	5.17	4.50	5.00
Pruning of trees up to 70% height + soil barrier + crop	14.83	14.83	16.33	18.83	31.58	31.17	34.00	38.00	5.67	6.50	6.17	6.83
Trees allow to grow normally + crop + irrigation as per requirement of crop	13.67	16.50	18.33	18.33	35.17	34.92	37.92	40.42	4.83	5.67	5.83	6.67
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	13.00	16.50	19.17	20.33	38.92	40.42	39.92	48.50	6.33	7.33	6.67	7.50
LSD (0.05)	2.55	2.23	2.30	1.92	5.04	4.44	NS	6.39	1.01	1.39	1.19	1.25
Pure crop		16.78 (16.80)				43.10 (48.72)				7.21 (8.00)		
				2002								
Trees allow to grow normally + crop	4.33	6.17	6.83	9.00	37.60	40.27	40.27	40.99	3.58	4.52	4.89	5.13
Pruning of trees up to 70% plant height + crop	8.83	12.00	11.33	10.50	43.38	42.83	45.94	44.49	5.02	6.11	5.63	5.25
Trees allow to grow normally + soil barrier + crop	6.33	8.50	9.17	7.33	41.55	41.27	39.69	39.77	5.08	5.88	5.55	5.94
Pruning of trees up to 70% height + soil barrier + crop	9.67	12.17	11.83	12.67	34.08	40.66	40.69	40.44	6.17	6.50	6.50	7.33
Trees allow to grow normally + crop + irrigation as per requirement of crop	6.17	10.50	8.83	7.83	33.75	38.77	39.44	41.16	4.52	5.33	5.38	5.02
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	6.33	12.67	11.67	13.17	35.22	35.38	36.72	38.77	5.83	6.92	6.83	6.83
LSD (0.05)	2.04	2.61	2.96	NS	NS	NS	NS	NS	NS	NS	NS	1.35
Pure crop		10.25 *				44.96 *				6.36 *		

Figures in parenthesis are the value of growth, yield and yield attributing characters, in which one irrigation was given to the crop at pod formation stage.
* During 2002, no moisture deficit was observed, because during September, the crop received 116.5 mm rain.

better than that of the tree-crop system during the first year. But during the second year, the growth of trees in the tree-crop system was similar to that of pure trees.

Effect of trees on growth, yield attributes and yield of intercrop (blackgram)

In general, germination in the first row from the tree base was less compared to second, third and fourth rows from tree base after one year of tree plantation. However, in pruning, the germination was significantly higher than trees allowed to grow normally. Overall, germination in the pure crop was higher when compared to the tree-crop system (Table IIa).

One year after planting, the competitive effect of trees on growth of crop was observed only up to the second row and this effect was more pronounced during the second year (Table IIa). The plant height of the crop was significantly higher in the first and second rows from tree base under pruning + irrigation of crop as per their requirement as compared to other treatments. The plant height of the crop was almost similar in the third and fourth rows. In some cases plant height was better in the third row and in some cases better in the fourth row, which indicated that the trees did effect the crop up to the second row from tree base after one or two years of planting.

A similar effect was also observed on the branching of the crop, whereas the number of branches plant $^{-1}$ was less in the first row from tree base compared to the second row (Table IIa). Among different treatments, the branching of the crop under pruned trees was higher during both the years as compared to other treatments. Soil barrier had a significant effect on the branching of the crop after a year of planting either with pruned trees or trees allowed to grow normally.

The competitive effect of trees on pod formation in the crop was more obvious in the first row and this row had 4.06 to 9.44% less pods as compared to the second row of crop from tree base during 2001 and this difference was higher during 2002. Among all the treatments, irrigation given to the crop at pod formation stage significantly contributed more pods plant $^{-1}$ either with pruning of trees or trees allowed to grow normally than other treatments (Table IIb). The number of pods plant $^{-1}$ under the tree-crop system was less compared to that of pure cropping.

The trees did not affect the seed formation in the crop either nearby the tree base (first row from tree base) or away from the tree base (second, third and fourth rows from tree base). However seeds pod $^{-1}$ were comparatively higher in pruning of trees irrespective of soil barrier and irrigation, but differences were not significant during both the years (Table IIb). In the tree-crop system, seeds pod $^{-1}$ were almost similar to that of the pure crop during both years.

In the tree-crop system, the grain yield running meter $^{-1}$ in the first row from tree base was 2.47 – 9.32% less than the yield obtained in the second row. Likewise the yield from the second row was 5.06 – 11.05% less than the yield of the third row from the tree base irrespective of treatments (Table IIb). However, the treatments effect was not significant during the first year. During the second year, the significant effect of treatments was observed in the first, third and fourth rows from tree base. The grain yield of pure crop was almost similar to that of the tree-crop system. Among different treatments, the grain yield (q ha $^{-1}$) was maximum in pruning of trees + irrigation given to the crop as per their requirement during both the years. The pure crop yield was 6.58 and 20.71% higher during 2001and 2002, respectively when compared to the tree-crop system (Table III). The grain yield of the crop was 4.50% higher in pruned trees than trees allowed to grow normally (Table III). Installing a soil barrier around the trees, contributed 3.10% higher grain yield of crop either in pruning of trees or trees allowed to grow normally. Similar results were obtained during the

Table IIb. Effect of trees on yield and yield attributes of intercrop (blackgram).

Treatment	Pods plant $^{-1}$				Seeds pod $^{-1}$				Grain yield (g m $^{-1}$)			
	Row number from tree base											
	1	2	3	4	1	2	3	4	1	2	3	4
	2001											
Trees allow to grow normally + crop	19.83	20.67	26.67	30.17	6.78	6.70	6.88	6.75	17.50	19.30	20.33	21.50
Pruning of trees up to 70% plant height + crop	19.17	21.17	24.83	29.17	6.77	6.90	6.44	6.77	18.17	19.20	21.33	25.17
Trees allow to grow normally + soil barrier + crop	23.83	24.83	31.33	33.17	6.53	6.43	6.47	7.09	18.50	20.80	22.83	24.00
Pruning of trees up to 70% height + soil barrier + crop	28.17	30.17	36.17	38.67	6.66	6.60	6.67	6.50	18.83	19.50	20.67	23.67
Trees allow to grow normally + crop + irrigation as per requirement of crop	28.50	31.00	31.67	34.50	6.76	6.87	6.53	6.28	19.67	20.17	20.83	29.17
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	34.83	36.67	43.17	48.67	6.88	6.63	6.93	6.98	20.33	21.33	23.83	26.50
LSD (0.05)	3.45	4.57	5.26	7.13	NS	NS	NS	0.39	NS	NS	NS	NS
Pure crop	44.70 (48.90)				6.85 (7.10)				22.10 (30.06)			
	2002											
Trees allow to grow normally + crop	18.36	18.83	20.81	20.88	6.39	5.69	5.88	6.22	16.46	18.84	19.90	25.34
Pruning of trees up to 70% plant height + crop	23.00	23.86	31.44	32.00	6.22	6.13	6.24	6.61	31.74	32.53	33.44	33.83
Trees allow to grow normally + soil barrier + crop	22.92	25.61	27.40	29.80	6.39	6.33	6.55	6.13	25.60	28.85	30.09	31.32
Pruning of trees up to 70% height + soil barrier + crop	31.57	32.00	40.43	43.50	6.44	6.58	5.83	6.44	34.95	42.77	43.49	45.04
Trees allow to grow normally + crop + irrigation as per requirement of crop	24.44	25.69	27.22	33.00	5.86	6.38	6.14	6.47	22.75	28.12	30.39	31.21
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	27.74	30.08	32.85	35.50	6.00	6.44	6.41	6.92	27.69	34.95	36.54	37.27
LSD (0.05)	6.55	NS	NS	8.03	NS	NS	NS	NS	6.27	NS	11.05	7.46
Pure crop	27.19 *				6.71 *				32.23 *			

Figures in parenthesis are the value of growth, yield and yield attributing characters, in which one irrigation was given to the crop at pod formation stage.
* During 2002, no moisture deficit was observed, because during September, the crop received 116.5 mm rain.

Table III. Grain yield of blackgram.

Treatment	Grain yield (q ha $^{-1}$) 2001	2002
Trees allow to grow normally + crop	7.00	5.15
Pruning of trees up to 70% plant height + crop	7.33	7.55
Trees allow to grow normally + soil barrier + crop	7.17	6.10
Pruning of trees up to 70% height + soil barrier + crop	7.40	7.90
Trees allow to grow normally + crop + irrigation as per requirement of crop	7.63	6.55
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	7.80	8.10
LSD(0.05)	NS	NS
Pure crop	7.90 (8.30)	8.69

Figure in parenthesis are the value of growth, yield and yield attributing characters, in which one irrigation was given to the crop at pod formation stage.
* During 2002, no moisture deficit was observed, because during September, the crop received 116.5 mm rain.

second year but differences in yield between the treatments was 24.30%, which was higher than the first year.

Effect of trees on growth, yield attributes and yield of intercrop (mustard)

Germinated plants per running meter did not vary significantly between the treatments during the first year (2000–01).Similar results were also obtained during the second year (Table IVa). However, in the third and fourth rows, the differences were significant. The plant population near to the tree base (first row) indicated that four months of tree plantation (planted during July 2000) did not exert any adverse effect on the germination of the crop either in the first or second row and so on. During the second year too, the effect of the trees was not obvious on the germination of the crop.

The maximum plant height was recorded in pruning of trees irrespective of irrigation and soil barrier as compared to trees allowed to grow normally (Table IVa). Irrigation as per requirement of crop significantly contributed to the growth of the crop as compared to the crop which received only one irrigation at flowering stage. In general the growth of the crop was less in the first row in most of the treatments during both the years.

Similar results were also obtained in case branching and competitive effect of trees with crop which increased simultaneously with increase in growth of trees. The adverse effect of trees was only observed up to the second row of crop from tree base. Among different treatments, pruning of trees + irrigation given as per requirement of crop recorded maximum branches during both the years over other treatments (Table IVa).

Similar results were also obtained in siliquae plant $^{-1}$ and seeds siliqua $^{-1}$ (Table IVb). However, trees allowed to grow normally + irrigation as per requirement of crop and pruning of trees + irrigation as per requirement of the crop had higher siliquae plant $^{-1}$ and seeds siliqua $^{-1}$ as compared to rest of the treatments during both the years (Table IVb). Pure crop had higher siliquae plant $^{-1}$ and seeds siliqua $^{-1}$ either in irrigation given as per requirement of crop or giving only irrigation at flowering stage as compared to tree-crop system (Table IVb).

Table IVa. Effect of trees on germination, plant height and branching of intercrop (mustard).

Treatment	Germinated plants running m^{-1} at 15 DAS^{-1} s^{-1}				Plant height				Number of branches^{-1}			
	Row number from tree base											
	1	2	3	4	1	2	3	4	1	2	3	4
	2000–01											
Trees allow to grow normally + crop	8.00	8.33	8.33	8.83	180.50	182.50	198.33	191.00	15.83	17.67	16.67	16.17
Pruning of trees up to 70% plant height + crop	6.50	7.33	7.17	8.00	191.71	211.00	205.00	209.00	17.00	18.33	18.50	19.00
Trees allow to grow normally + soil barrier + crop	7.83	7.00	8.00	6.67	191.50	192.33	194.17	182.33	17.67	18.67	18.17	17.00
Pruning of trees up to 70% height + soil barrier + crop	7.67	8.17	8.00	7.95	192.00	193.00	195.33	194.00	16.00	17.17	18.83	18.83
Trees allow to grow normally + crop + irrigation as per requirement of crop	9.67	6.83	8.33	7.50	198.17	211.50	211.67	216.00	17.00	18.27	18.33	19.17
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	8.33	8.83	8.83	7.17	201.17	193.33	216.00	219.67	18.00	22.67	26.77	20.67
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pure crop (One irrigation at flowering)		6.57				176.32				19.23		
Pure crop (Irrigation as per requirement of crop)		7.91				184.41				25.08		
	2001–02											
Trees allow to grow normally + crop	7.33	7.00	7.67	7.83	190.00	196.83	193.17	198.67	17.83	21.17	22.50	23.17
Pruning of trees up to 70% plant height + crop	7.83	7.17	7.83	8.67	191.33	197.83	200.50	201.83	19.83	22.17	24.33	24.83
Trees allow to grow normally + soil barrier + crop	7.17	7.17	8.50	8.50	184.67	188.50	184.50	194.83	17.33	20.50	21.33	21.33
Pruning of trees up to 70% height + soil barrier + crop	8.50	7.83	9.00	8.67	196.83	190.33	197.00	211.83	19.83	25.27	26.33	26.67
Trees allow to grow normally + crop + irrigation as per requirement of crop	7.33	7.83	9.83	8.67	192.83	196.33	204.00	211.00	21.50	25.67	30.33	31.17
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	7.83	8.17	9.17	9.17	201.67	207.55	208.83	211.83	22.83	25.83	29.17	33.83
LSD (0.05)	NS	NS	1.39	0.72	NS	NS	NS	NS	NS	NS	NS	6.18
Pure crop (One irrigation at flowering)		7.24				184.12				26.42		
Pure crop (Irrigation as per requirement of crop)		8.33				200.33				32.24		

Table IVb. Effect of trees on yield and yield attributes of intercrop (mustard).

	Siliquae plant $^{-1}$				Seeds siliqua $^{-1}$				Grain yield (g m $^{-1}$)			
	Row number from tree base											
	1	2	3	4	1	2	3	4	1	2	3	4
Treatment	2000 – 01											
Trees allow to grow normally + crop	278.50	328.67	263.33	267.83	14.37	13.58	14.70	13.66	36.23	37.27	38.11	40.23
Pruning of trees up to 70% plant height + crop	286.33	343.17	279.17	294.00	14.33	13.37	14.25	13.37	38.93	39.61	40.43	44.23
Trees allow to grow normally + soil barrier + crop	234.00	360.00	279.83	304.83	13.56	14.04	13.96	14.16	39.00	35.01	38.21	38.16
Pruning of trees up to 70% height + soil barrier + crop	281.67	335.50	290.50	262.17	11.46	14.50	12.70	14.16	41.70	37.88	39.51	41.72
Trees allow to grow normally + crop + irrigation as per requirement of crop	306.33	357.17	349.50	305.83	15.00	14.58	15.12	14.29	45.07	44.42	45.36	52.53
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	304.67	373.17	348.33	307.17	15.25	14.75	15.47	15.13	47.29	47.03	48.33	59.69
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Pure crop (one irrigation at flowering)	398.33				14.01				46.71			
Pure crop (irrigation as per requirement of crop)	458.20				15.72				60.16			
	2001 – 02											
Trees allow to grow normally + crop	299.88	313.40	347.25	355.21	13.33	13.33	14.67	14.67	49.37	51.57	54.66	56.89
Pruning of trees up to 70% plant height + crop	388.38	388.72	408.02	406.04	14.00	14.00	15.38	15.20	53.31	57.12	58.69	59.68
Trees allow to grow normally + soil barrier + crop	343.89	350.83	377.50	381.47	13.28	13.87	14.20	14.65	50.69	52.88	54.74	57.13
Pruning of trees up to 70% height + soil barrier + crop	422.20	425.21	439.10	488.33	13.97	14.46	14.67	15.94	53.85	57.37	59.40	61.88
Trees allow to grow normally + crop + irrigation as per requirement of crop	432.57	440.50	450.20	472.13	14.24	15.05	15.83	16.43	65.52	67.95	68.10	68.45
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	439.87	477.13	503.33	538.23	15.30	15.37	16.30	17.10	70.50	73.20	74.75	75.90
LSD (0.05)	44.38	36.83	43.67	71.27	NS	NS	NS	NS	6.03	4.41	6.50	6.48
Pure crop (One irrigation at flowering)	489.02				14.57				63.14			
Pure crop (Irrigation as per requirement of crop)	539.25				17.39				79.70			

The grain yield running meter $^{-1}$ in the first, second, third and fourth rows from tree base was more or less similar to each other during the first year. But during the second year, the grain yield in the first row was less than in the second, third and fourth rows in all the treatments (Table IVb). The competitive effect of trees in various treatments on grain yield running meter $^{-1}$ was not significant during first year, but the differences in grain yield were significant during second year. The grain yield in pruned trees was higher than under trees allowed to grow normally. Soil barrier did not have any influence on grain yield a year after the trees were planted. Irrigation of the crops as per their requirement increased the grain yield running meter $^{-1}$ by 18.53 and 16.16% during 2000–01 and 2001–02 respectively than the crop which received one-irrigation at flowering stage. Overall, the grain yield of crop in the tree-crop system was similar to that of pure crop either in crop which received only irrigation at flowering or as per requirement of crop during first year. But during the second year, the grain yield running meter $^{-1}$was less as compared to that of pure crop. Similar results were also obtained in the case of grain yield quintal per hectare (Table V).

Light interception

Light interception in blackgram at 0.5, 1.0, 2.0, 3.0 and 4.0 m away from the tree base varied significantly in trees allowed to grow normally and pruning of trees up to 70% plant height. Light intercepted by crop under tree-crop system at 0.5 m away from tree base was 21.15–23.56% less in pruned trees and 37.52–42.60% less in trees allowed to grow normally as compared to pure crop (Table VIa). The light interception in crop gradually increased with increasing distances from tree base in both the treatments. The results and trend of light interception in mustard crop were similar to blackgram. However the quantum of light intercepted by the mustard was different from Blackgram (Table VIb).

Root length density and specific root length

Root length density (root length (cm)/soil volume (cm^3)) and specific root length (root length (m)/dry weight of root (g)) after one and two years of planting showed that soil barrier was fully able to restrict the movement of root. But in case of other treatments (trees allowed to grow normally and pruning of trees up to 70% plant height) the horizontal movement of roots

Table V. Grain yield of mustard.

	Grain yield (q ha $^{-1}$)	
Treatment	2000–01	2001–02
Trees allow to grow normally + crop	8.85	11.14
Pruning of trees up to 70% plant height + crop	10.36	11.95
Trees allow to grow normally + soil barrier + crop	9.64	13.72
Pruning of trees up to 70% height + soil barrier + crop	10.61	14.59
Trees allow to grow normally + crop + irrigation as per requirement of crop	11.17	16.28
Pruning of trees up to 70% plant height + crop + irrigation as per requirement of the crop	11.28	16.93
LSD(0.05)	NS	3.89
Pure crop (One irrigation at flowering)	10.89	15.29
Pure crop (Irrigation as per requirement of crop)	12.11	17.23

Table VIa. Light intercepted (%) by the intercrop (blackgram) at different distances from the tree base in *Albizia procera* based agroforestry system in selected treatment.

	Pruning of trees up to 70% plant height					Trees allow to grow normally					
Duration	0.5 m	1.0 m	2.0 m	3.0 m	4.0 m	0.5 m	1.0 m	2.0 m	3.0 m	4.0 m	Pure crop
2001											
30 DAS	23.09	23.63	27.70	28.38	28.77	17.34	18.33	27.29	27.65	28.41	30.21
60 DAS	35.15	36.40	40.24	41.40	41.75	28.14	29.36	39.57	40.19	41.34	45.04
At harvest	34.17	35.12	38.71	39.44	40.34	25.35	26.32	38.20	38.85	40.29	43.34
2002											
30 DAS	19.20	20.14	22.16	22.31	23.23	13.58	14.71	20.33	21.37	22.40	25.12
60 DAS	31.13	31.65	51.78	52.52	53.60	28.41	29.45	50.34	52.35	52.60	55.71
At harvest	28.25	29.67	43.21	45.33	46.45	25.54	26.51	42.17	45.37	46.37	50.30

Table VIb. Light intercepted (%) by the intercrop (mustard) at different distances from the tree base in *Albizia procera* based agroforestry system in selected treatment.

	Pruning of trees up to 70% plant height					Trees allow to grow normally					
Duration	0.5 m	1.0 m	2.0 m	3.0 m	4.0 m	0.5 m	1.0 m	2.0 m	3.0 m	4.0 m	Pure crop
2000–01											
15 DAS	7.10	7.39	9.33	9.87	10.40	6.02	6.35	8.44	9.35	10.46	13.20
30 DAS	8.08	8.24	9.64	10.41	10.40	7.36	7.42	9.61	9.88	10.61	16.34
60 DAS	22.11	22.37	24.13	25.22	25.78	18.58	19.24	23.83	25.32	25.42	32.41
90 DAS	42.25	42.59	48.42	48.53	49.39	36.69	37.27	47.53	48.46	48.64	57.75
At harvest	34.11	34.80	44.31	45.33	46.17	30.22	31.38	44.31	45.17	45.19	54.42
2001–02											
15 DAS	7.11	7.36	10.59	11.22	11.46	6.14	6.46	9.44	11.14	11.36	15.01
30 DAS	16.39	16.62	23.24	24.47	24.51	14.31	14.65	22.24	24.32	24.50	27.32
60 DAS	18.24	18.35	27.66	28.34	28.61	15.63	16.50	26.66	28.22	28.45	34.14
90 DAS	45.52	46.30	61.68	62.46	62.89	41.17	41.66	60.35	62.29	62.64	68.74
At harvest	35.39	36.53	43.71	44.71	45.62	29.49	31.57	43.24	44.26	44.51	51.10

Table VII. Root length density and specific root length at different distances from the tree base.

Treatment	Root length density (cm root length / cm^3 soil volume)			Specific root length (meter root length / g dry weight of roots)		
	0.5 m	1.0 m	2.0 m	0.5 m	1.0 m	2.0 m
			2001			
Trees allow to grow normally + crop	0.054	0.039	–	5.367	6.700	–
Pruning of trees up to 70% plant height + crop	0.042	0.031	–	5.112	6.354	–
Trees allow to grow normally + soil barrier + crop	–	–	–	–	–	–
Pruning of trees up to 70% height + soil barrier + crop	–	–	–	–	–	–
			2002			
Trees allow to grow normally + crop	0.092	0.066	0.037	7.978	9.841	10.725
Pruning of trees up to 70% plant height + crop	0.081	0.064	0.035	7.399	8.908	11.072
Trees allow to grow normally + soil barrier + crop	–	–	–	–	–	–
Pruning of trees up to 70% height + soil barrier + crop	–	–	–	–	–	–

after a year of planting was observed up to 1.0 m. The root length density was higher at 0.5 m away from tree base and it decreased with subsequent increase in distances from tree base. Similarly, specific root length was less at 0.5 m away from tree base and it increased with increasing distances from tree base (Table VII).

Discussion

Effect of intercrops (blackgram and mustard) on growth of trees

In general, the growth performance of trees was better in those treatments in which trees were growing normally and wherein associated crop (mustard) received irrigation as per their requirement during both the years. This was probably due to *Albizia procera* benefiting from the irrigation given to the mustard crop. The results are in conformity with those obtained with eucalyptus seedlings in which fertilizer and weeding given to the agricultural crop also benefited to the growth of eucalyptus seedlings when compared to the eucalyptus monoculture (Couto & Gomes, 1995). Pruning of trees up to 70% plant height and soil barrier did not show any influence on the growth of trees after one or two years of plantation. The growth performance of pure trees was better than that of the tree-crop system during the first year. But during the second year, the growth of trees in the tree-crop system was similar to the pure trees. The results here were similar to the observation made with agricultural crops such as sugarcane, maize, redgram, sorghum etc. inter-planted with trees. Their related cultivation practices affect the trees in several ways and they compete with saplings for nutrients, water, light and space, particularly during the first few years (Dwivedi, 1992). In an another study, Sharma & Singh (1992) also observed that several tree species inter-planted with sugarcane, maize and sorghum in Haryana and western Uttar Pradesh in India, the growth rate of saplings planted on the bund was less in comparison to those growing in open.

Effect of trees on growth, yield attributes and yield of intercrop (blackgram)

In general, germination and growth of crop (blackgram) in the first row from the tree base were less compared to the second, third and fourth rows from tree base after one year of tree plantation. However, in pruning, these parameters were slightly higher than the trees allowed to grow normally. Sharma et al. (2000) observed that the reduction in plant population of wheat crop due to poplar at 0–3 m distances from tree line was 34.2% over control and this reduction was less with increasing distances from the tree line. Many other studies have revealed the adverse effect on growth and yield of crop by tree component in the tree-crop system under different level of stresses and caused by growth behaviour and age of tree (Ralhan et al., 1992; Puri & Sharma, 2002; Puri et al., 1994; Schroth, 1999; Dhyani & Tripathi, 1999; Chirwa et al., 2003).

Similarly the competitive effects of tree line on yield attributes were observed up to the second row. This might be due to the fact that tree canopy during first and second year could not affect the penetration of light beyond the second row from tree base. Light availability is the most important limiting factor for the performance of under storey annual crops particularly where upper storey perennials form a dense over storey canopy (Miah et al.,1995). Several other studies have also given similar results in which low light intensity was one of the important constraints for higher yield (Tanaka et al., 1964; Stansel et al., 1965; Vankateswarlu & Srinivasan, 1978).

Effect of trees on growth, yield attributes and yield of intercrop (mustard)

Germination and growth of crop did not vary significantly within the treatments during both the years. The growth and plant population near by the tree base (first row) indicates that after four months of tree plantation (planted during July 2000) did not exert any adverse effect on germination of crop either in first or in second row and so on. This was mainly due to the fact that the tree did not establish well themselves and their root and shoot development was not enough to compete for water and nutrients. Khybri et al. (1992) also recorded the depressing effect of tree near by the tree base, which subsequently increased with advanced age of trees. The yield attributes and yield of crop were comparatively less up to second row as compared to third and fourth row from tree base. Distances of tree line from crop significantly affected the crop yield up to a distances of 4 to 6 m depending upon age and growth of tree as evinced by earlier reports (Khybri et al., 1992, Chauhan et al., 1995; Yadav et al., 1993; Sharma et al., 2000) but reduction in yield near the tree base (0 – 3 m) was higher as compared to further away from tree base (4 – 6 m) in wheat, and mustard with various tree species. The growth and yield of crop was higher in pruning of trees up to 70% plant height as compared to the rest of the treatments during both the years irrespective of irrigation and soil barrier. Those treatments which received irrigation as per requirement of crop; the yield and yield attributes were higher than that of the crop which received only irrigation at flowering stage during both the years. Overall, growth and yield were higher in pure crop as compared to the tree-crop system.

Light intercepted by the intercrops (blackgram and mustard) in tree-crop system

Light intercepted by the under storey crops (blackgram and mustard) in tree-crop system at 0.5 m away from tree base was less as compared to1.0, 2.0, 3.0 and 4.0 m away from tree base. In general the light intercepted by the crop in tree-crop system was less as compared to pure crop. The light interception was comparatively higher in pruning of tree up to 70% plant height as compared to trees allowed to grow normally. It indicated that 70% pruning had transmitted more light as compared to trees allowed to grow normally. Similar results were observed by Thakur and Singh (2002) in the case of *Morus alba*, in which 75% canopy removal allowed more light transmission as compared to 0, 25 and 50% canopy removal. In another study, light intensity was minimum in *A. auriculiformis* without pruning, but the intensity underwent a sharp rise on pruning (Datta & Dhiman, 2001). Several studies have already proved that the light interception in tree-crop system is less as compared to open field (Hazra & Patil, 1986; Behari et al., 1994; Basawaraju & Gururaja Rao, 2000; Devaranavadagi et al., 2002). The light interception in crop was gradually increased with increasing distances from tree base in the present experiment.

Root length density and specific root length

The horizontal movement of roots after a year of planting was observed up to 1.0 m in all the treatments except soil barrier. This was mainly due to the fact that soil barrier was fully able to restrict the movement of root. Root length density was higher 0.5 m away from tree base and it decreased with subsequent increase in distances from tree base. Similarly, specific root length was less at 0.5 m away from tree base and it increased with increasing distances from tree base. Similar observations were also made by van Noordwijk et al.,1996, Vanlauwe et al., 2002, 1996, Ram Newaj et al., 2000, Ram Newaj et al., 2001, and Toky et al., 1989. Many other workers (Mekonnen et al., 1997.; Newman, 1966; Toky & Bist, 1992; Dhyani et al., 1990; Odhiambo et al., 1999) had also reported that, in general, the root density declines with vertical depth and distance from tree. The root length density and specific root length were less in pruning of trees up to 70% plant height as compared to trees allowed to grow normally.

With regard to overall growth , yield and resource capture by the crops under *Albizia procera* the treatment pruning of trees up to 70% plant height and irrigation as per requirement of crop was the best treatment followed by pruning of tree up to 70% plant height + soil barrier + crop irrespective of irrigation. The results observed in these treatments clearly imply that capture of both storable and un-storable resources were complementary in these treatments both spatially and temporally in a phased manner.

Conclusion

The grain yield was significantly affected by the presence of trees. The maximum grain yield was observed in irrigated crops under pruned trees which indicates that the un-storable resources namely light was effectively utilized (spatial complementarities) by both the components of the system. The presence of a soil barrier of galvanized iron sheet around the trees effectively reduced competition for stored resources (water and nutrient) giving way to temporal complementarities during the 1st year of tree growth as well as spatial complementarities during the later years of tree and crop growth. The placing of galvanized iron sheet around the tree base can be recommended to the farmers of semi arid regions to exploit the full potential of *Albizia procera*-based agroforestry systems.

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