EFFECT ON PRODUCTIVITY IN RAINFALL DEPENDENT COMPETITION BETWEEN *VIGNA RADIATA* AND *HARDWICKIA BINATA* IN ARID ZONE AGROFORESTRY

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Introduction

Competition from an established tree is a major factor limiting the successful selection of a model in agroforestry systems. It is a common assumption that competition is mainly for light, with little competition for nutrients in fertile agro-ecoystems. However, many studies (Grime, 1973; Wilson, 1988; Schenk, 2006) investigated that root competition usually affected the balance between competing species more than shoot competition through resource depletion. Facilitation and competition act simultaneosely (Holzpfel and Mahall, 1999; Maestre and Cortina, 2004). Although they improve some environmental conditions, nurse tree will tend to have negative effects on other factors. Trees can, for instance, enhance air humidity and prevent extreme temperature fluctuations, improve soil properties (accumulation of nutrients and organic matter), and reduce the probabilities of mechanical or herbivory damage. On the other hand, nurse plants can impede seedling emergence by litter accumulation (Suding and Goldberg, 1999) and they can limit the potential growth of newly established plants by reducing the availability of light and soil water (Franco and Nobel, 1988), or by excreting allelopathic substances (Callaway *et al.*, 1991).

However, the mechanisms that facilitate successful recruitment and the relative importance of competition aboveground (for light) and belowground (for nutrients or water) are poorly understood. Increase in productivity of an agroforestry system may depend upon net positive balance of facilitation and competition. Experimental evidence based on field trials is necessary for adoption of suitatble strategies in reducing competitive and improving facilitative effects. Such understanding is needed to manage, predict and model changes in pasture species composition over time as well as increase overall productivity of the system. *Hardwickia binata* Roxb. of family Leguminosae (Caesalpinieae), is a multi-purpose tree of great economic value. Because of deep rooting system it was introduced in arid region and thought to be beneficial in enhancing the productivity of dry agriculture land.

Therefore, the present study was carried out to determine interaction effects of *H. binata* trees on *Vigna radiata* crop under rainfed condition in this drought prone area with a working hypothesis that the importance of facilitation relative to competition increases as abiotic stress increases.

Material and Methods

Site conditions: Studies were conducted at the experimental farm of Arid Forest Research Institute, Jodhpur (Latitute 26°45'N, Longitude 72°03E') in Rajasthan, India. Hot and dry summer, hot rainy season, warm autumn and cool winter (dipping down to 2° C) are the characteristics of the site. Summer is the most dominant characterized by high temperature (reaching up to 49° C in the month of May) spreading over March to mid July and experienced strong winds (usually 20-30 km h^{-1}). The period from July to September is the monsoon season, which received an average rainfall of 264.8 mm (average of thirteen years from 1991 to 2003) whereas average annual rainfall during these 13 years was 349.1 mm ranged from 57.9 mm in 2002 to 595.9 in 1994. The rainfall in July, August and September of these years were 132.6 (from 0.0 mm in 2002 to 260.3 mm in 2003), 95.5 (from 4.1mm in 1993 to 201.1 mm in 1997) and 36.7 mm (from 0.8 mm in 1995 to 196.3 mm in 1992) respectively. This indicated a wide variation in rainfall between the years as well as the months. Soil of the experimental site is aridisol "coarse loamy, mixed, hyperthermic of Typic Camborthids" as per the USDA system of classification. The soil texture is loamy sand with soil pH of 8.48, EC of 0.36 dSm^{-1} and soil organic carbon of 0.203 in 0-75 cm soil layer. The depth of the soil is about 80 cm, below which there is a hardpan of calcium carbonate aggregates called 'Kankar' of various sizes. Soil moisture storage in the upper 75 cm layer varies from 120 mm at -0.01 MPa to 35 mm at -1.5 MPa.

Experimental design: A 9-year-old plantation of *Hardwickia binata* Roxb. was selected for the experiment. Different treatment plots were (i) fixed crop plot of *Vigna radiata* only (FC), (ii) rotation crop plot i.e., *V. radiata* rotated by non-legume crops like *Pennisetum glaucum* (RC) in second year, and (iii) sole agriculture crop plot without trees (AC) in three replications. Each plot was of 20 m x 15 m size with 12 experimental plants at the spacing of 5 x 5m. *V. radiata* was sown in both the FC and RC plots on 21 June 2003 after 64.5 mm rain during 18 to 20 June 2003. In each plot, one tree was randomly selected and micro-plots of 1 m^2 area were laid out at 1.0 m (near), 2.5 m (middle of two row of trees) and 3.5m (centre of four trees) from tree for sampling and observations recording on crop yield, soil water and soil nutrients. There were 9 plots (3 treatments X 3 replicates) in randomized block design.

Observation recording: Height, collar diameter and crown spread of *H. binata* trees were recorded in June and December 2003. Per cent increment in growth variables were calculated as: % increment = (x in December - x in June) X 100/ x in June. Where x is height, collar diameter or crown diameter. Photosynthetically active radiations (PAR) were measured at the near micro-plots (under tree canopy) as well as above the agriculture crop in the AC plots in September, 2003 with portable CO_2 gas analyser, model *CI-301* (*CT-301 PS0*; *CID*, Vancouver, USA). Population density of *V. radiata* seedlings was counted on 22 August, 2003 from the micro-plots. Leaf samples of *V. radiata* were collected on 8th and 16th September, 2003 at 14.00 hr and fresh mass was recorded immediately whereas dry mass was recorded after drying the samples at 65 °C and leaf water content (LWC) calculated. Crop was harvested from the micro-plots on 31 October, 2003 and grain, husk (pods after removal of grain) and holm (straw) yields were recorded after drying and winnowing. A relative neighbour effect (RNE) was calculated following the method of Markham and Chanway (1996). RNE = $(X_t - X_c)/x$ where X was the performance variables of target species in absence (t) and presence (c) of adult neighbours (i.e., *H. binata* trees) and x was the higher of X_t or X_c. Negative values of RNE indicated facilitation and positive values competition.

To find out the influence of *H. binata* trees on soil nutrients and soil water, soil samples were collected from the micro-plots in September (0-25 cm soil layer) and again in December, 2003 (in 0-25, 25-50 and 50-75 cm soil layers) for soil nutrient analysis. For soil water, sampling was carried out in August (crop growing period), September (crop maturity) and December, 2003 (after crop harvest). A single soil core was taken using a mechanical soil sampler and divided into 0-25, 25-50 and 50-75 cm layers to observe the soil water depletion in different soil layers. Soil water was determined gravimetrically after drying the soil at 105 °C. Gravimetric soil water content was converted to mm using the following equation to give total soil water to the soil depth of 0-75 cm. Soil water (in mm) = % soil water x soil depth in mm x bulk density of soil / 100/ density of water.

Soil sampling and chemical analysis: Soil samples were air dried, ground and passed to a 2 mm mesh sieve and subjected to various analyses. Organic carbon was determined by the partial oxidation method (Walkley and Black, 1934). Available nitrogen (NH_4-N and NO_3-N) was determined after 2 M KCl extractions using UV-VIS spectrophotometer (Systronix model 117, Ahmedabad, India). Extractable phosphorous was determined by the Olson`s extraction method (Jackson, 1973).

Data processing: Data were statistically analyzed using the SPSS statistical package. Response variables were soil water content (SWC), nutrients, leaf water content (LWC), seedling density (number of seedlings m^{-2}) and yield of *V. radiata* (g m^{-2}) per replicate. Soil nutrients in September, 2003 (0-25 cm soil layer), LWC, seedling density, crop yield and their RNEs were analyzed using a two way ANOVA. SWC was square root transformed before analysis (Sokal and Rohlf, 1981). To test for variation in soil water content and nutrients within soil layers, repeated measure ANOVAs was performed using soil water data as the dependent variable. Soil layers were test of within subject effect whereas treatments and micro-plot distances were test of between subject effects. Tree height, collar diameter and crown diameter was analyzed using pair t test to test the difference between FC and RC plots. To obtain the relations between crop production and tree growth variables, SWC and soil nutrients, a Pearson correlation was performed. To obtain homogeneous subsets in treatments, micro-plot distance and soil layers, Duncun Multiple Range Tests (DMRT) were performed for each data set.

Results

Tree growth variables: Paired t test indicated no significant ($P > 0.05$) difference in height, collar diameter and crown diameter between FC and RC plots in both June and December, 2003 (Table 1). However, these growth variables were greater in RC plot than in the FC plots. Per cent increments in tree height, collar diameter and crown diameter during June to December, 2003 was greater ($P > 0.05$) in FC plot than in the RC plots (Table 1). Tree growth variables showed positive correlation ($r = 0.574$, $P < 0.01$, n = 18) with NH_4-N in September, 2003. Tree height showed negative relation ($r = -0.622$, $P < 0.05$) with SWC in 0-25 cm soil layer and positive ($r = 0.491$, $P < 0.05$) in deeper soil layers in August, 2003. Percent increment in collar diameter ($r = 0.540$, $P < 0.05$) and crown diameter ($r = 0.468$, $P < 0.05$) were positively correlated with SWC and SOM, respectively.

Above ground resources: Photosynthetically active radiations (PAR) values were 304.5 and 311.7 μmol m^{-2} s^{-1} in canopy zone area (at the near micro-plots) of FC and RC plots, respectively. PAR value in AC plots (i.e. agriculture crop without trees) was 2282.9 μmol m^{-2} s^{-1}. The reduction in PAR value under the canopy of *H. binata* trees were 86.7 % in FC plot and 86.3% in RC plots when compared with PAR value in the AC plots. There was 327.2 mm rain during July to September with a total number of rainfall days were 26. Main rainfall periods were 6 to 11 July (121.6 mm), 13 to18 July (83.1 mm), 22 to 25 July (19.5 mm), 28 July to 3rd August (37.1 mm), 8 August (11.7 mm) and 25 to 29 August 2003 (52.6mm) (Fig. 1a). There was only 1.6 mm rain in September i.e., on 26 September 2003.

Soil water content and dynamics: Soil water content (SWC) was highest ($P < 0.05$) in August, 2003 and lowest in December, 2003 (Fig. 1b). Highest ($P < 0.05$) SWC was in AC plot in all the months and soil layers (except in 0-25 soil layer in December, 2003). FC/ RC plots showed 37.1%, 25.9% and 20.2% less SWC than in the AC plots in August, September and December, 2003, respectively. Repeated measure ANOVA indicated lowest ($P < 0.05$) SWC in 0-25 that increased in 25-50 and 50-75 cm soil layers in all the three observations i.e., August, September and December, 2003 (Table 2). SWC was greater ($P < 0.05$) in AC plots except in 0-25 cm soil layer in December, 2003 (i.e., greater in RC plots) as compared to the FC and RC plots (Fig. 1b, Table 2). Effect of distance i.e., near, middle and centre micro-plots was not significant ($P > 0.05$). However, SWC was relatively greater at center in August, at middle in September and at near micro-plots in December, 2003 in 0-25 cm soil layer. In 25-50 and 50-75 cm soil layer, SWC was greater at middle and centre micro-plots, respectively as compared to the other micro-plots in all the three observations. SWC was positively correlated with grain ($r = 0.879$, $P < 0.01$), husk ($r = 0.846$, $P < 0.01$) and holm ($r = 0.827$, $P < 0.01$) yield of *V. radiata*.

Soil nutrients: Two-way ANOVA for soil organic matter (SOM), available PO_4-P, NH_4-N and NO_3-N in 0-25 cm soil layers in September, 2003 did not differ between the treatments as well as the micro-plots (data not shown). But SOM ($r = -0.874$, $P < 0.01$) and NH_4-N ($r = -0.940$, $P < 0.01$) were negatively, whereas PO_4-P ($r = 0.901$, $P < 0.01$) and NO_3-N ($r = 0.964$, $P < 0.01$) were positively related with crop yield. Repeated measure ANOVA (soil layers) showed changes ($P < 0.01$) in SOM, available PO_4-P, NH_4-N and NO_3-N between the soil layers in December, 2003. These nutrients were highest ($P < 0.01$) in 0-25 cm soil layer and decreased in deeper soil layers (Table 3). SOM and NH_4-N concentration did not differ due to treatments. But these soil variables were lesser ($P < 0.05$ in 0-25 cm soil layer) in AC plot than in the FC and RC plots. PO_4 P and NO_3-N were highest ($P < 0.05$) in AC plots as compared to the FC and

RC plots. Effect of micro-plots distance was not significant ($P > 0.05$) for all the above-mentioned soil variables But SOM and PO_4-P concentration was relatively greater at the near as compared to the middle and the center micro-plots (Table 3). DMRT indicated lowest NH_4-N at the middle in 0-25, at near in 25-50 and at center in 50-75 cm soil layer whereas SOM was lowest at the center in all the soil layers. PO_4-P was lowest at the middle in 0-25 cm and at the centre in 25-50 and 50-75 cm soil layers whereas NO_3-N was lowest at the near in 25-50 and at the middle in 0-25 and 50-75 cm soil layers.

Seedling density and leaf water content of V. radiata: Effect of trees on seedling density of *V. radiata* was observed since the time of germination. Density of germinated seedlings was highest ($P < 0.01$) whereas leaf water content (LWC) was lowest ($P < 0.01$) in the AC plots (Table 4). However, FC and RC plots did not differ ($P > 0.05$) for these variables. Seedling density of *V. radiata* was about 3-fold greater in AC than in FC/RC plots and was positively related ($r = 0.942, P < 0.01$) with crop yield. Seedling density was highest ($P < 0.05$) at centre. LWC was highest ($P < 0.05$) at the near micro-plots and decreased with distance from tree trunk at both the times of observation recording i.e., 8 and 16 September, 2003 (Table 4).

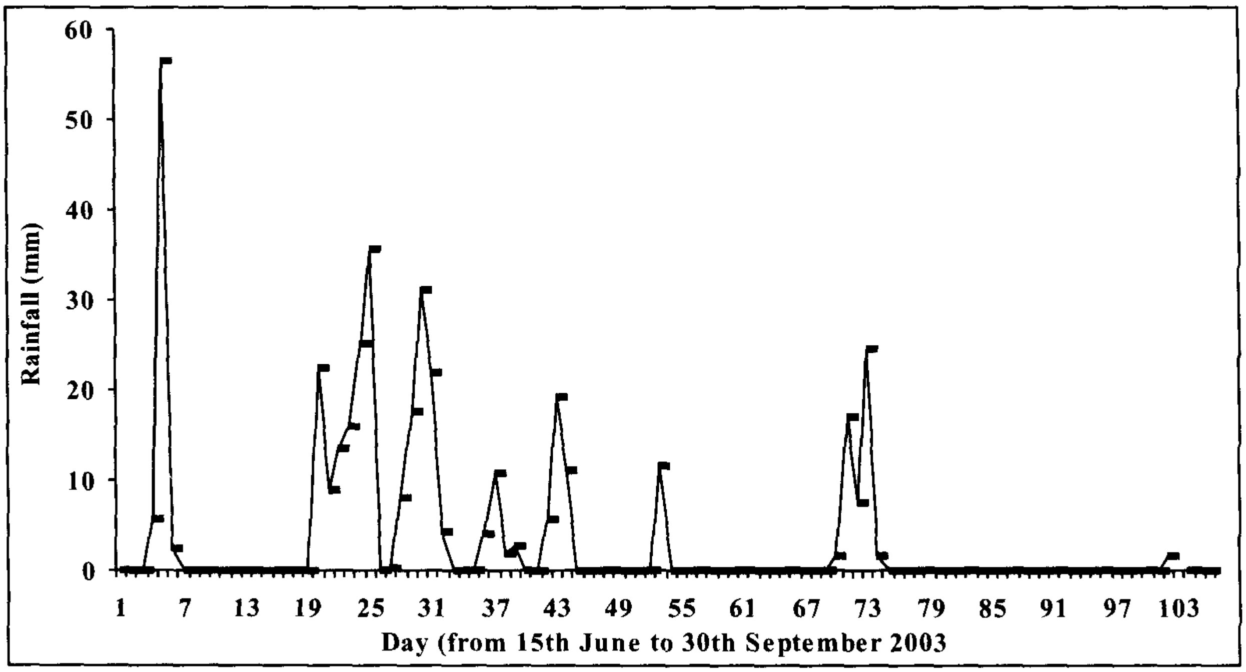
Yield of V. radiata: Grain, husk and holm yield was highest ($P < 0.01$) in AC plots (Table 5). But they did not differ ($P > 0.05$) between FC and RC plots (DMRT). Grain, husk and hold yields were about 14-fold, 5-fold and 3-fold, respectively, greater in AC plots as compared to that in FC/RC plots. Effect of distance on the crop yield was not significant ($P < 0.05$). However, the yields were highest at the center and lowest at the near micro-plots. Per cent contribution of grain, husk and holm was 28.8%, 12.1% and 59.1%, respectively in AC plots whereas it was 8.5%, 9.2% and 82.3% in FC and 8.8%, 9.4% and 81.8% in RC plots. Reduction in grain yield was relatively greater as compared to husk and holm yield in FC/RC plots (Table 5). Total yield of *V. radiata* was positively related with SWC in August ($r = 0.952, P < 0.01$) and September, 2003 ($r = 0.782, P < 0.01$). The crop yield showed negative relation with SOM ($r = -0.911, P < 0.01$) and NH_4-N ($r = -0.917, P < 0.01$) of 0-25 cm soil layer in December, 2003 whereas it had a positive relation PO_4-P ($r = 0.447, P < 0.05$) in all the soil layers and with NO_3-N ($r = 0.444, P < 0.05$) in 0-25 cm soil layer.

Relative neighbour effects: Relative neighbour effects (RNE) values for seedling density ($RNE_{DENSITY}$), and grain (RNE_{GRAIN}), husk (RNE_{HUSK}) and holm (RNE_{HOLM}) yield of *V. radiata* was positive whereas it was negative for leaf water content (RNE_{LWC}) (Fig. 2). It was highest at the middle for $RNE_{DENSITY}$ and at the near for RNE_{LWC} in both FC and RC plots (Fig. 2a and 2b). Competitive effect (positive RNE) was highest for grain and lowest for holm yield. RNE_{GRAIN} was relatively less at middle whereas RNE_{HUSK} and RNE_{HOLM} were lesser at the near as compared to the other sampling micro plots (Fig.2c and 2d).

Discussion

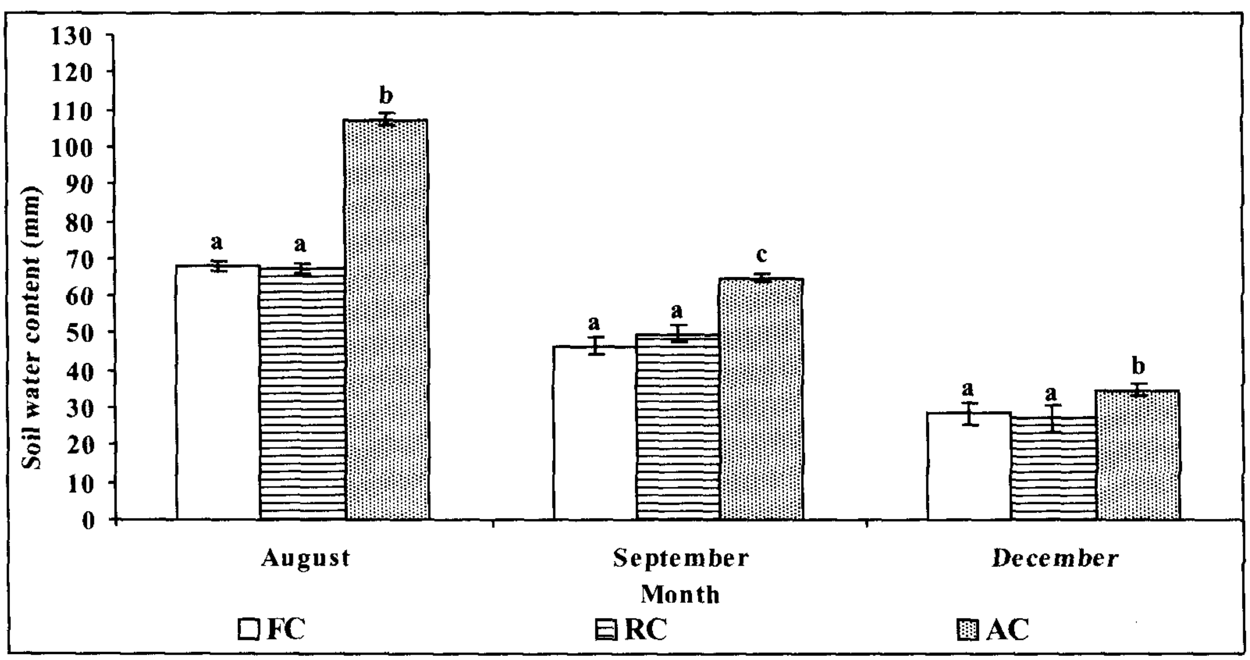
Interaction between tree and the associated crop for growth resources like light, water and nutrients affected resource availability and crop yield. Taller and thicker tree in the RC as compared to the trees in RC plots were due to greater

Fig. 1a



Rainfall during cropping period

Fig. 1b



Soil water content in 0-75 cms oil layer

Rainfall distribution and soil water content in 0-75 cm soil layer. (a), rainfall during 15 June to 30 September *2003*; (b), variations in soil water content during monsoon (July to September) and post monsoon period. Columns within month indicated by different letters differ significantly at $P < 0.05$. FC: fixed crop *V. radiata* only; RC, rotation crop in which *V. radiata* was rotated by non-legume crop; and AC, sole agriculture crop without tree (control).

utilization of soil resources. However, a positive correlation of per cent increment in collar diameter ($r = 0.540$, $P < 0.05$) and crown diameter ($r = 0.468$, $P < 0.05$) with SWC and SOM, respectively suggested beneficial effects of these resources on the tree growth.

Soil water content: Rainfall influenced soil water availability resulting in greater soil water in August as compared to those in September and December 2003 (Fig. 1). The reduction in SWC from August to December was both due to plant (crop + tree) water use as well as the evaporation. Significantly low soil water availability in FC and RC plots as compared to the AC plots suggested soil water use by *H. binata* trees. Low soil water in 0-25 cm soil layer was due to utilization by tree and agriculture crop (Table 2), though reduction in SWC in this soil layer through canopy interception of rainfall and surface evaporation cannot be ruled out (Gibson and Bachelard, 1986). Though varied with crop size soil water use by *V. radiata* in FC/RC plots was about 36% of that in AC plot when related with seedling density suggesting that most of the soil water was used by *H. binata* resulting in a competitive effects on crop yield. A negative relation ($r = -0.622$, $P < 0.05$) between SWC in 0-25 cm soil layer in August and tree height suggests competitive use of soil water by trees. Highest SWC at the center in August, at middle in September and at near micro-plots in December, 2003 in 0-25 cm soil layer indicated that soil water use from this layer decreased with increase in soil water stress as observed in the other studies (Callaway *et al.*, 2002). Such type of increase in SWC under the canopy of *H. binata* in December was either due to reduced soil water use by trees or due to 'hydraulic lift' in which tree extracted water from deeper soil layer and redistribute it in the upper soil layer. Fuentes *et al.* (1984) also recorded an increase in soil water availability as a result of facilitative influence of neighbours. Relatively low input of water through rain between 18 August and 4 September (Fig. 1) and high water use by tree in the rooting zone probably made a gradient in soil water use. Relatively greater reduction in SWC in 25-50 cm soil layer in September, 2003 indicated that tree and probably *V. radiata* used soil water from this soil layer. Decrease in SWC in 50-75 cm soil layer in December, 2003 was indicative of soil water use from this layer. This suggests that *H. binata* utilize soil water from topsoil layer during adequate soil water availability whereas it utilizes deeper soil water when soil water stress prevails in upper soil layers. However, utilization of soil water by tree and crop during August and September (crop growing period) from same soil layers might result in competitive effect and reduced crop yield. Competition for water and nutrients indicated overlapping of fibrous roots of *H. binata* trees and crop as observed in other studies (Wallace *et al.*, 1980; Singh and Rathod, 2002).

Soil nutrients: Building up of the soil nutrient level is the improvement of soil organic matter and other nutrients through litter addition by the trees and associated vegetation and turnover of roots. Relatively low nutrient concentration in December, 2003 as compared to that in September, 2003 was due to their utilization in tree/crop growth. In December, 2003, significantly greater $P < 0.01$) SOM, PO_4-P, NH_4-N and NO_3-N in 0-25 cm as compared to 25-50 and 50-75 cm soil layers was attributed to be due to greater accumulation of organic matter through litter addition (Table 3). Litter addition and soil water

Table 1

Average growth of H. binata under different plots under agroforestry.

Growth variable (cm)	June 2003		December 2003		Growth increments (%)	
	FC	RC	FC	RC	FC	RC
Height	582±15.9	628±33.5	627±20.3	657 ±21.9	7.7±1.2	4.7±2.3
Crown diameter	323±18.6	468±53.4	387±3.3	497±47.0	20.3±6.0	6.5±2.9
Collar diameter	11.43±0.12	14.27±1.23	12.83±0.59	15.01±1.21	12.2±4.2	5.8±0.9

Values are mean of three replicates ±SE. FC: tree with *V. radiata* and RC, rotation crop in which *V. radiata* was rotated by non-legume crop.

Table 2

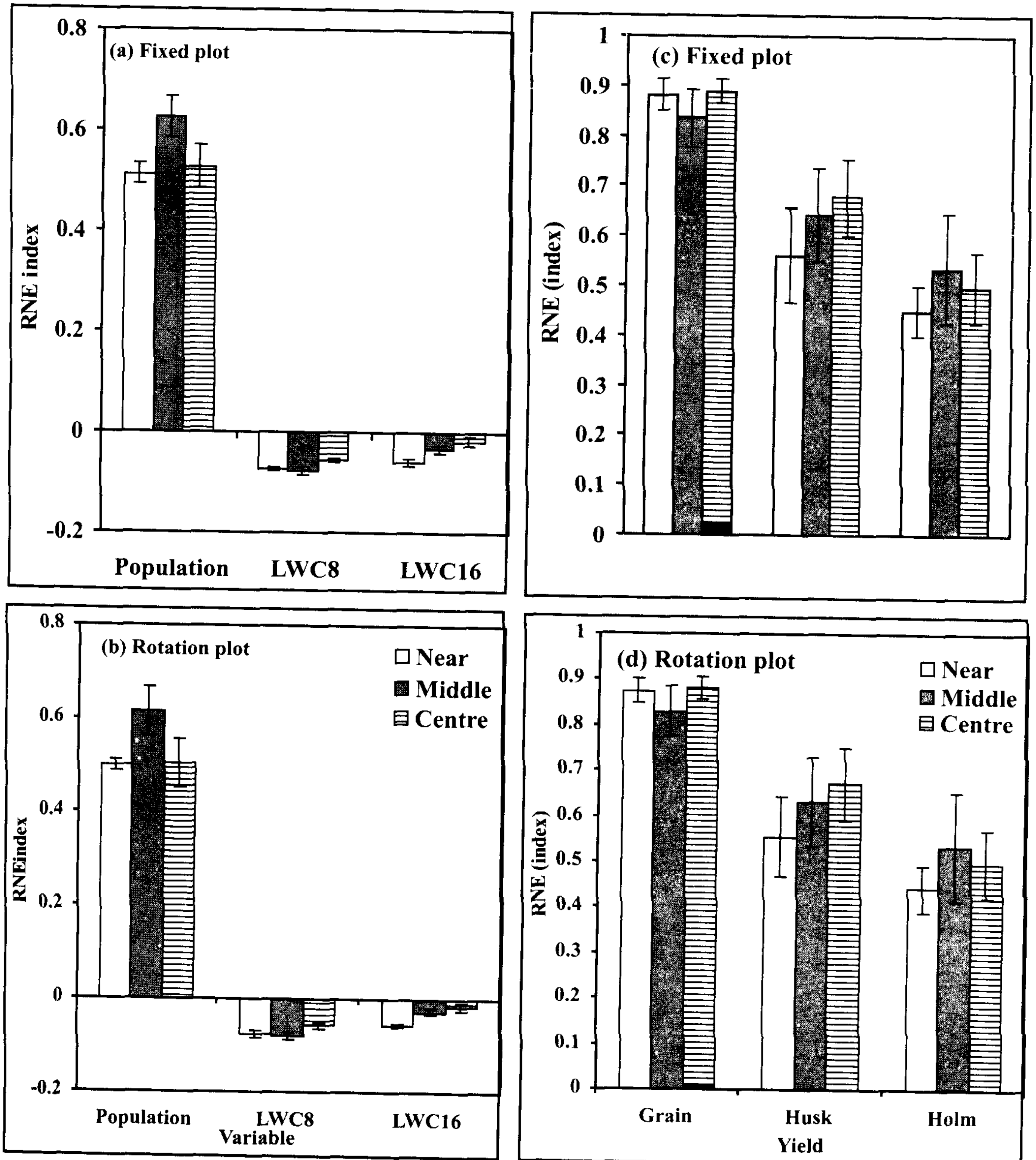
Effect of Hardwickia binata trees on soil water status (%, w/w) during crop growing and crop harvesting period.

Treat * Depth	Dist	18 August 2003			4 September 2003			4 December 2003		
		0-25	25-50	50-75	0-25	25-50	50-75	0-25	25-50	50-75
FC	Near	4.73 ±0.14	5.75 ±0.57	6.62 ±0.47	3.55 ±0.12	3.99 ±0.16	4.71 ±0.44	1.33 ±0.12	1.70 ±0.27	3.61 ±0.21
	Middle	4.99 ±0.34	6.14 ±0.32	7.00 ±0.19	3.58 ±0.26	4.45 ±0.26	4.24 ±0.22	1.31 ±0.10	2.94 ±0.37	3.54 ±0.23
	Centre	5.32 ±0.34	6.41 ±0.55	7.20 ±0.13	3.50 ±0.10	4.39 ±0.26	4.85 ±0.07	1.23 ±0.12	2.71 ±0.44	3.57 ±0.32
RC	Near	4.84 ±0.36	5.82 ±0.57	6.83 ±0.55	3.98 ±0.46	4.56 ±0.15	4.65 ±0.22	1.45 ±0.17	2.46 ±0.12	3.56 ±0.25
	Middle	4.90 ±0.29	6.32 ±0.60	7.10 ±0.56	4.01 ±0.42	4.51 ±0.29	4.49 ±0.25	1.31 ±0.03	2.46 ±0.15	3.19 ±0.08
	Centre	4.72 ±0.05	6.15 ±0.19	7.17 ±0.65	4.16 ±0.46	4.50 ±0.24	4.91 ±0.53	1.28 ±0.08	2.56 ±0.14	3.49 ±0.22
AC	Near	8.49 ±0.13	9.61 ±0.19	10.37 ±0.20	4.90 ±0.36	6.59 ±0.09	6.07 ±0.43	1.31 ±0.01	3.17 ±0.15	4.73 ±0.03
	Middle	8.52 ±0.17	9.78 ±0.12	10.41 ±0.08	4.95 ±0.37	6.26 ±0.34	6.26 ±0.36	1.29 ±1.29	3.37 ±0.07	4.63 ±0.03
	Centre	8.70 ±0.15	9.45 ±0.05	10.46 ±0.19	4.82 ±0.04	5.93 ±0.29	6.19 ±0.49	1.29 ±0.02	3.32 ±0.07	4.85 ±0.03

Repeated Measure ANOVA		F value	P value	F value	P value	F value	P value
Test of within	Soil depth	77.06	<0.001	26.90	<0.001	666.46	<0.001
Test of between subject effects	Treatment	236.74	<0.001	66.22	<0.001	24.18	<0.001
	Distance	1.28	NS	0.07	NS	0.03	NS
	T x D	0.45	NS	0.41	NS	0.36	NS

Values are mean of three replicates ± SE. FC: fixed crop *V. radiata* only; RC, rotation crop in which *V. radiata* was rotated by non-legume crop; and AC, sole agriculture crop without tree.

Fig. 2



LWC: leaf water content on 8 and 16 August 2003. Error bars are ± SE of three replicates.

Relative neighbour effects of *H. binata* on seedling population, leaf water content and yield of *V. radiata*.

Table 3

Effect of Hardwickia binata trees on soil nutrients in December 2003 (after crop harvesting).

Treat.	Distance	Soil organic matter (%)			NH_4-N (mg kg^{-1})			NO_3-N (mg kg^{-1})			PO_4-P (mg kg^{-1})		
Depth		0-25	25-50	50-75	0-25	25-50	50-75	0-25	25-50	50-75	0-25	25-50	50-75
FC	Near	0.356	0.240	0.144	4.84	3.30	2.64	3.25	2.14	2.10	14.27	11.59	10.52
		(0.007)	(0.022)	(0.025)	(0.04)	(0.19)	(0.10)	(0.04)	(0.08)	(0.10)	(0.03)	(0.15)	(0.42)
	Middle	0.358	0.248	0.116	4.74	3.25	2.57	3.07	2.28	2.04	14.60	11.53	10.35
		(0.009)	(0.022)	(0.002)	(0.06)	(0.14)	(0.17)	(0.21)	(0.14)	(0.09)	(0.11)	(0.41)	(0.44)
	Centre	0.350	0.222	0.116	4.78	3.73	2.58	3.43	2.69	2.20	13.86	10.89	10.43
		(0.006)	(0.008)	(0.001)	(0.04)	(0.49)	(0.23)	(0.10)	(0.42)	(0.05)	(0.35)	(0.35)	(0.15)
RC	Near	0.359	0.202	0.123	4.77	3.37	2.77	3.54	2.38	2.18	14.03	11.77	10.50
		(0.008)	(0.006)	(0.007)	(0.08)	(0.13)	(0.22)	(0.09)	(0.02)	(0.04)	(0.45)	(0.22)	(0.22)
	Middle	0.349	0.227	0.118	4.82	3.71	2.49	3.19	2.25	2.23	14.68	11.00	10.12
		(0.003)	(0.035)	(0.005)	(0.06)	(0.90)	(0.24)	(0.37)	(0.06)	(0.05)	(0.29)	(0.23)	(0.19)
	Centre	0.349	0.221	0.007	4.95	3.06	2.34	2.95	2.21	2.19	14.63	10.66	9.50
		(0.007)	(0.022)	(0.005)	(0.05)	(0.10)	(0.26)	(0.30)	(0.04)	(0.03)	(0.41)	(0.26)	(0.15)
AC	Near	0.310	0.242	0.120	4.20	3.28	2.32	3.61	2.51	2.20	16.23	11.58	11.02
		(0.001)	(0.023)	(0.004)	(0.01)	(0.16)	(0.17)	(0.05)	(0.06)	(0.07)	(0.10)	(0.71)	(0.37)
	Middle	0.309	0.253	0.129	4.20	3.27	2.80	3.51	2.60	2.11	14.35	12.22	11.16
		(0.003)	(0.020)	(0.002)	(0.10)	(0.18)	(0.93)	(0.16)	(0.06)	(0.15)	(1.49)	(0.14)	(0.57)
	Centre	0.308	0.231	0.120	4.22	3.20	2.67	3.66	2.32	2.38	15.77	12.18	10.84
		(0.004)	(0.009)	(0.001)	(0.11)	(0.07)	(0.23)	(0.09)	(0.08)	(0.10)	(0.53)	(0.31)	(0.71)
Repeated Measure ANOVA			F value	P value	F value	P value		F value	P value		F value	P value	
Test of within		Soil depth	663.86	<0.001	166.32	<0.001		168.70	<0.001		213.06	<0.001	
Test o f between		Treatment	2.45	NS	2.71	0.093		4.22	<0.05		10.69	<0.01	
subject effects		Distance	1.08	NS	0.06	NS		0.69	NS		1.00	NS	
		T x D	0.28	NS	0.58	NS		2.21	NS		0.67	NS	

Treatments as in Table 2.

Values are mean of three replicates ±SE in parentheses. NS, not-significant at $P < 0.05$.

availability regulated the formation of stable and labile soil organic matter pools resulted in increased SOM (Vitousek and Sandford, 1986, Singh, 2005). Low ($P <$ 0.05, DMRT) availability of SOM and NH_4-N in AC plots as compared to the FC and RC plots was due to absence of tree litter addition. However, reduced concentration of SOM and NH_4-N was probably resulted from mineralization in presence of greater SWC in AC plots (Table 2) that favoured NO_3-N and PO_4-P availability. Lowest availability of SOM at the center, which was outside the canopy zone of trees was due to least availability of tree litter. Whereas lowest availability PO_4-P and NO_3-N ($P <$ 0.05) at the near than at middle and at the center micro-plots was resulted from their

Table 4

Effect of over canopy of tree on number of germinated seedlings and leaf water status of Vigna radiata in post dawn (14.00 hr) period.

Treatment	Distance	Seedling population	8 September 2003	16 September 2003
FC	Near	6.33±0.67a	72.21 ± 0.06c	69.63 ± 0.16c
	Middle	8.67±0.88b	71.34 ± 0.20b	68.62 ± 0.14b
	Centre	11.67±0.88c	70.12 ± 0.04a	67.57 ± 0.28a
	Mean	8.89	71.22	68.6 1
RC	Near	6.67±0.67a	72.20 ± 0.45c	69.41 ± 0.14c
	Middle	9.00±1.03b	71.60 ± 0.02b	68.23 ± 0.08b
	Centre	12.33±0.33c	70.19 ± 0.03a	67.50 ± 0.28a
	Mean	9.33	71.33	68.38
AC	Near	21.33±0.33a	66.81 ± 0.11a	65.49 ± 0.30a
	Middle	27.00±1.16b	65.77 ± 0.51a	66.33 ± 0.42a
	Centre	27.08±1.23b	66.01 ± 0.31a	66.36 ± 0.23a
	Mean	25.14	66.20	66.06
Two way ANOVA				
F value	Treatment	355.5	546.3	97.2
	Distance	32.9	44.3	13.2
	T x D	1.6	5.0	11.7
P value	Treatment	<0.001	<0.001	<0.001
	Distance	<0.001	<0.001	<0.001
	T x D	NS	<0.01	<0. 001

Treatments as in Table 2.
Values within columns followed by different letters differ significantly at $P < 0.05$.

Values are mean of three replicates ±SE. FC: fixed crop *V. radiata* only; RC, rotation crop in which *V. radiata* was rotated by non-legume crop; and AC, sole agriculture crop without tree (control).

use in tree/ crop growth. Browald (1997) also observed higher concentration of NH_4-N and lower concentration of NO_3-N at closer distance of trees indicating an efficient uptake of nitrate and enhanced mineralization closer to trees. However, lowest availability of NH_4-N and NO_3-N at the near in 25-50 cm soil layers as compared to the other soil layers suggesting withdrawal of these nutrients from this layer as observed in SWC depletion discussed above.

Light resource and leaf water status: Significantly ($P < 0.01$) low PAR under the canopy of *H. binata* influenced leaf water content (LWC) of *V. radiata* seedlings. Greater ($P < 0.05$) LWC at the near as compared to the seedlings of *V. radiata* at

Table 5

Effect of over canopy tree on average yield (g m^{-2}) of V. radiata.

Treat	Distance	Husk(g m^2)	Grain (g m^{-2})	Holm (g m^{-2})	Total (g m^{-2})
FC	Near	10.33±1.36a (8.29%)	10.33±0.73a (8.34%)	103.17±8.29c (83.33%)	123.83±10.19c (100%)
	Middle	12.67±0.93a (9.55%)	11.00±0.29a (8.34%)	109.17±7.82bc (82.11%)	132.83±8.66bc (100%)
	Centre	14.00±1.32a (9.67%)	11.33±0.44a (8.90%)	119.50±10.04ab (82.43%)	144.83±11.29ab (100%)
	Mean	12.33	10.89	110.61	133.83
RC	Near	10.83±1.74a (8.31%)	11.50±0.29a (9.01%)	106.50±6.38c (82.68%)	128.83±7.89c (100%)
	Middle	13.50±0.58a (9.95%)	11.83±0.44a (8.73%)	110.50±6.56bc (81.32%)	135.83±7.48bc (100%)
	Centre	14.67±0.93a (9.99%)	12.83±0.33a (8.78%)	119.50±8.53ab (81.24%)	147.00±9.71ab (100%)
	Mean	13.00	12.05	112.17	137.22
AC	Near	58.50±9.26a (11.36%)	159.8±4.49a (30.78%)	301.00±17.77a (57.86%)	519.33±13.09 (100%)
	Middle	67.83±8.95a (12.19%)	152.3±9.91ab (27.26%)	345.50±48.00bc (60.55%)	565.67±30.74 (100%)
	Centre	72.33±7.80a (12.71%)	162.0±4.48bc (28.37%)	338.67±29.20b (58.92%)	573.00±19.96 (100%)
	Mean	66.22	158.13	328.39	552.67
Two way ANOVA F value					
	Treatment	109.7**	1382.9**	109.8**	770.7**
	Distance	1.51NS	0.66NS	0.99NS	3.31 (P=0.06)
	T x D	0.34NS	0.52NS	0.31NS	0.65NS

** One-way ANOVA of the data for FC, RC and AC plots indicated significant ($P < 0.01$) difference due to treatment.
Values within columns followed by different letters differ significantly at $P < 0.05$.

Values are mean of three replicates +SE. Values in parentheses are per cent contribution of crop component to the total yield. FC: fixed crop *V. radiata* only; RC, rotation crop in which *V. radiata* was rotated by non-legume crop; and AC, sole agriculture crop without tree (control).

middle and the centre micro-plots was due to greater reduction in PAR and was probably resulted from reduced transpiration loss of *V. radiata* caused by shading effects of over canopy *H. binata*. A negative RNE_{LWC} indicated facilitative effects of *H. binata* tree by increasing water status of the associated crops (Fig. 2a and 2b). A decreased PAR and increased productivity under canopy of savanna trees is the most common pattern in tropical tree communities with low density, low rainfall and moderate soil fertility sites (Belsky *et al.*, 1993).

Yield of V. radiata: Significantly low density of *V. radiata* plants on 22 August, 2003 in tree-integrated plots (FC and RC) as compared to sole crop plot (AC) indicated a tree-influenced reduction in crop population. A dry spell of 15 days (from date of crop sowing on 21 June, 2003) probably caused a reduction in soil water in FC and RC plots resulted from soil water use by trees affecting germination, population and growth of *V. radiata* seedlings (personal observation). Reduced growth and population of vegetation have been recorded in other deserts (Franco and Nobel, 1989), drought affected fields (Wilson and Tilman, 1991) and in alpine vegetation (Wilson, 1993).

Highest ($P < 0.01$) high yield of *V. radiata* in AC plots suggested adequate soil water and nutrient availability. A positive correlation between soil water content and crop yield suggested the inference. Reduced soil water in FC and RC resulted from competitive use by tree reduced crop yield (Table 2 and Table 5). Increase in grain, husk and holm yield with increase in distance from *H. binata* trees indicated a reduction in competitive effect with distance. The competition was for resource utilization like soil water and nutrients. Non-significant ($P > 0.05$) difference in soil nutrients between treatments in September, 2003 suggested negligible role of soil nutrients in crop yield variations. This indicated that the competition was mainly for soil water use. A regular rain of adequate supply of water for crop probably enhanced competitive use of soil water both by trees and agricultural crop from the same soil layer. Such type of water use by the integrated tree reduces soil water availability for the crop affecting agriculture production. Reduction in yield in order of grain > husk > holm suggested that effect of competition was more on grain yield. Utilization of soil water by tree from the same layer where agriculture crop concentrated its root indicating competition that needs silviculture management to isolate the tree rooting zone to enhance crop yield.

Conclusively, *H. binata* influenced microclimate by reducing solar radiation and enhancing crop water content. Though tree had positive influence on soil nutrients and soil water during stress period but competition for soil water negatively affected yield of *V. radiata*. Thus, a water supply though rain adequate to agriculture crop only resulted in high completion between tree and crop for soil water use thereby reduced population and growth of *V. radiata* and ultimately the crop yield. Thus, a farmer cannot enhance crop production by integrating *H. binata* tree in the year of rainfall adequate only for agriculture crop that cause soil water use both by the tree and the crop from same soil layer. Silviculture practices like trenching around tree trunk to reduce overlapping of roots of trees and crop and therefore competition for resources may be beneficial for crop production when *H. binata* is integrated in agriculture land.

SUMMARY

A 9-year-old *Hardwickia binata* Roxb. plants at a spacing of 5m x 5m was intercropped with *V. radiata* (L.) Wilczek in 2003 to study interactive effects of trees on resource use and crop production. Tree height, collar diameter and crown diameter did not differ ($P < 0.05$) between the treatments. Soil water content (SWC) was highest ($P < 0.01$) in August and lowest in December, 2003 depending upon rainfall. SWC was highest ($P < 0.05$) in AC plots and reduced in FC/ RC plots by 37.1%, 25.9% and 20.2% in August, September and December, 2003, respectively resulted from tree. Lowest SWC in 0-25 cm soil layer and at 1 m from tree suggested competitive use of soil water by the trees reducing crop yield (by 97%). Despite an increase in leaf water content, reduction in grain was relatively greater than husk and holm. Soil organic matter, PO_4-P, NO_3-N and NH_4-N did not differ among the treatments and distances but these nutrients were highest ($P < 0.01$) in 0-25 soil layers suggesting trees role in nutrient enrichment.

Key words: **Rainfall dependent competition, *Hardwickia binata*, *Vigna radiata*, Aridzone agroforestry.**

शुष्क प्रदेश कृषिवानिकी प्रणाली में कृषि वानिकी में *विग्ना रेडियाटा* और *हार्डविकिया बायनाटा* में वर्षा पर निर्भर रहते परस्पर स्पर्धा

जी. सिंह

सारांश

5 मी. X 5 मी. फासला छोड़कर *हार्डविकिया बायनाटा* राक्स. के पादप लगाए 9–वर्षीय पादपों के बीच बीच में 2003 में *वि. रेडियाटा (लि.)* विल्जेक के पौधे वृक्षों की संसाधनों और फसल उत्पादन पर पड़ते अन्त क्रिया प्रभावों का अध्ययन करने के लिए लगाए गए। वृक्ष-ऊंचाई, मूल संधि पर व्यास और छत्र के व्यास पर किए गए उपचारों से कोई अन्तर पड़ता नही देखा गया (पी <0.05)। मृदा जल तत्त्व अगस्त में सर्वाधिक (पी <0.01) तथा दिसम्बर 2003 में न्यूनतम रहा जो वर्षा होने पर निर्भर था। मृदा जल तत्त्व एसीभूखंडों में अधिकतम (पी <0.05) था जो एफसी/आरसी भूखण्डों में अगस्त, सितंबर और दिसंबर, 2003 क्रमश: 37.1%, 25.09% और 20.2% कम हो गया जो वृक्षों के कारण हुआ। मृदा स्तर 0.25 सेमी. और वृक्ष से 1 मी. दूरी पर मृदाजल तत्त्व न्यूनतम रहने से संकेत मिलता है कि वृक्षों द्वारा मृदा जल का प्रतिस्पर्धी उपयोग किया जाने से फसल की प्राप्ति (97%) घट गई। पत्तियों के जल तत्त्व में वृद्धि होने के बावजूद छिलके और पाण्डुजा की तुलना में दोनों में हुई कमी अपेक्षित या ज्यादा रही। मृदा का जैव पदार्थ, PO_4-P, NO_3-N, और NH_4-N), में विभिन्न उपचारों और दूरियों में कोई अन्तर रहते नही देखा गया, परन्तु ये पोष्याहार 0.25 सेमी. मृदास्तर में अधिकतम रहते मिले जिससे पोष्याहार वर्धन में वृक्षों की भूमिका रहने का संकेत मिलता है।

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