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Microclimate modifications, growth and yield of intercrops under *Hardwickia binata* Roxb. based agroforestry system

(Mikroklimaänderungen, Wachstum und Ertrag von Unterbaukulturen in Agroforestry-Systemen mit *Hardwickia binata* Roxb.)

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Abstract
An experiment was conducted by planting *Hardwickia binata* Roxb. at 200, 400 and 800 trees ha^{-1}, intercrops viz., *Brassica campestris* (mustard) and *Glycine max* (soybean) were sown from the second year onwards in winter and summer respectively at the National Research Centre for Agroforestry, Jhansi, U.P., India with the objectives of evaluating agrosilvicultural potential of the system and to study the effect of tree densities on ecophysiology of understorey crops. Tree growth was affected by both density and intercrop in the initial years of growth. Photosynthetic photon flux density (PPFD) available to the intercrops reduced with increasing densities. Transpiration rate and stomatal conductance in intercrops decreased due to the presence of trees. No significant changes in leaf temperature were observed till the fifth year of the growing season. Yield was significantly higher in pure crop in comparison with all the densities in mustard. Soybean yield under 200 trees ha^{-1} was comparable to that of the pure crop. Trees at the density of 200 trees ha^{-1} provided a conducive microenvironment to the intercrops.

Keywords: *Transpiration rate, stomatal conductance, agroforestry, crop yield, understorey crops, Hardwickia binata, tree density*

Introduction

Gaining production advantages using diversity of crop species within a cropping system has been one of the main goals of agroforestry. The importance of agrosilviculture in attaining this goal had been clearly shown by several workers (Griffin & Maller, 1999; 1999; Trenbath, 1999). *Hardwickia binata* Roxb. of the family leguminosae, subfamily caesalpinoidae is a

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valuable multi-purpose tree in India. The tree yields extremely hard, very heavy and durable timber apart from high quality fuel-wood (Roy, 1996) and rich fodder in terms of crude protein (Singh, 1982).

The use of *Hardwickia binata* as a main tree component in silvipasture (Hazra, 1995) and in agrosilviculture (Khadse & Bharad, 1996a; Gill, 1998) has been studied extensively. The challenge in agrosilviculture has been to plant optimally spaced trees to produce high output at the same time not to compromise on the yield of understorey crops to the extent to which it becomes an uneconomical enterprise (Balandier & Dupraz, 1999). Ecophysiological changes and microclimate variations have been the object of studies in agrisilvicultural systems in the recent past (Irvine, 1998; Wallace, 1994). Stomatal conductance, transpiration rate, canopy and leaf temperature have been shown to change beneficially for the crop in many tree crop interface experiments (Devasagayam & Ebenezer, 1996; SuXin Quan et al., 1994; Barnes & Archer 1996).

Reduced rate of transpiration with a concomitant increase in resistance to water flow in stomata, increase in relative humidity under tree canopy and effective utilization of photosynthetically active radiation transmitted through the tree canopy for sufficient photosynthate production throughout the growth stages of annual understorey crops are the important characteristics one has to look for in agrisilvicultural systems (Wallace, 1994). As trees (mandatory component) mature, apart from changing the microclimate, they create a succession of different opportunities for intercropping thereby reconciling with reduced agricultural productivity and sustainability. Considering all the above aspects the present study was undertaken with the objectives of:

(i) Evaluating a *Hardwickia binata* based agrisilviculture system with soybean and mustard as intercrop for potential profitability in comparison with monocropping;
(ii) To study the effect of tree density per hectare on microclimate variations, growth and yield of the annual intercrops.

Materials and methods

Study site

The study was conducted on the farm of National Research Centre for Agroforestry (NRCAF), Jhansi, Uttar Pradesh, India (24°11′ N latitude and 78°17′ E longitude). Jhansi has a tropical semi-arid climate. Mean annual rainfall is 960 mm with an average of 52 rainy days per year. Most of the rainfall is received during the monsoon season which begins in the last week of June (26th Standard Meteorological Week [SMW]) and remains active till the first week of September (36th SMW). Mean maximum temperature ranges from 47.4°C (June) to 23.5°C (January) and mean minimum temperature from 27.2°C (June) to 4.1°C (December). Evapotranspiration ranges from a high of 13 mm per day in May to a low of 1.5 mm per day in December. The soil of the experimental site is red (yet to be classified under USDA class) with a general fertility level of low organic carbon, low nitrogen and phosphorus and medium to high potassium.

Experimental particulars

One-year-old nursery grown seedlings of *Hardwickia binata* were planted in pits of 30 cm^3 filled with well decomposed farmyard manure, silt and soil at the ratio of 1:1:3 in 1992. Factorial randomized block design was used for the experiment involving three densities of trees *viz*. 200 tree ha $^{-1}$, 400 trees ha $^{-1}$ and 800 trees ha $^{-1}$, three treatments (pure tree, tree + crop and pure crop control) with four replications. The plot size was 20 m x 10 m each. Trees were pruned in July – August every year starting from the third year onwards. Intercrops *Brassica campestris* (mustard) and *Glycine max* (soybean) were both planted at 30 cm x 10 cm spacing in winter and summer respectively. The crops were irrigated, fertilized and managed according to recommended package of practice for the region. Intercropping was started from the second year onwards.

Tree growth

Tree growth data viz., height, collar diameter and diameter at breast height (dbh) of four fixed sample trees were recorded on a quarterly basis in all the treatments.

Photosynthetic photon flux density (PPFD), microclimate, growth and yield of intercrops

PPFD was measured in all the treatments. Two quantum sensors (LI-190S-1) for simultaneous measurements from LI-1600M and LI-6200 (LI-COR, inc. Lincoln, Nebraska, USA) were placed between four adjacent trees plots and at the top of the canopy in pure crop plots. Three measurements were taken at half hourly intervals between 1000hrs to 1500hrs on each of the observation days. Observations were recorded on a monthly basis throughout the year in pure tree plots and at 20 days interval throughout the growth phase of the crop under tree + crop treatments. Transpiration rate (E), stomatal conductance (G_c), leaf temperature (T_{leaf}) and relative humidity (RH) was recorded in both the intercrops using LI-1600M steady state porometer (LI-COR, inc. Lincoln, Nebraska, USA) fitted with standard broadleaf aperture (2 x 2 cm^2) from the top most fully expanded leaf in four plants randomly selected from each plot. Means of these measurements were taken as the representative data for the date of observation. Observations were recorded at 20 day intervals throughout the growth phase of the crops and mean values were taken as representative data for the particular cropping season. Plant height was recorded at podfilling stage in both the crops from seven plants randomly selected from each plot. Crop yield under agrosilviculture was measured along a transect across the tree-crop interface as proposed by Huxley (1985).

Statistical analysis

Analysis of variance of the data obtained from each of the replications was conducted using Systat statistical package (Wilkinson et al., 1996). The significance of the difference between means of treatments was determined using critical difference test at 5% probability level.

Results

Tree growth in pure tree plots

Tree growth in terms of height, collar diameter and dbh exhibited no significant difference in the first two years in all the three densities (see Table I). Significant difference in tree height, collar diameter and dbh started to emerge from third year onwards. Tree height was significantly higher (528.8 – 678.9 cm) in 800 trees ha $^{-1}$ than 400 and 200 trees ha $^{-1}$ during these years. Collar diameter was higher in 800 trees ha $^{-1}$ and 200 trees ha $^{-1}$ (8.83 and 8.80 cm respectively) than in 400 trees ha $^{-1}$ during the third and fourth year of growth but rapid increase in the collar diameter in 400 trees ha $^{-1}$ was seen during the fifth and sixth

Table I. Growth of *Hardwickia binata* as influenced by tree density and understorey crop*.

Tree density (Trees ha $^{-1}$)	Treatment	Parameter(cm)	1992	1993	1994	1995	1996	1997
800	Tree	Tree height	151.00	275.48	410.56	528.89	599.10	678.8
				(124.48)	(135.08)	(118.33)	(70.21)	(79.7)
		Collar diameter	3.97	6.37	8.83	11.21	13.84	16.15
				(2.47)	(2.46)	(2.38)	(2.63)	(2.31)
		Dbh	-	-	-	8.94	9.76	13.42
	Tree + crop	Tree height	115.70	222.78	347.80	446.94	546.00	615.00
				(107.08)	(125.02)	(99.4)	(99.06)	(69)
		Collar diameter	2.88	4.91	7.30	9.59	12.96	15.57
				(2.03)	(2.39)	(2.29)	(3.37)	(2.61)
		Dbh	-	-	-	7.44	7.53	11.29
400	Tree	Tree height	130.50	227.22	378.27	479.88	559.40	627.00
				(97.5)	(141.05)	(101.58)	(79.52)	(67.6)
		Collar diameter	3.48	5.13	8.44	10.88	13.73	17.10
				(1.65)	(3.31)	(2.44)	(2.85)	(3.37)
		Dbh	-	-	-	8.53	9.05	13.29
	Tree + crop	Tree height	120.00	234.33	370.50	438.33	546.10	623.50
				(114.33)	(135.67)	(67.83)	(107.77)	(77.4)
		Collar diameter	2.95	4.79	8.00	9.77	12.87	16.10
				(1.81)	(3.21)	(1.77)	(3.10)	(3.29)
		Dbh	-	-	-	7.27	8.01	12.41
200	Tree	Tree height	147.63	252.89	398.13	494.61	576.00	642.70
				(105.26)	(146.00)	(96.48)	(81.39)	(66.7)
		Collar diameter	3.39	5.84	8.8	11.20	14.41	17.02
				(2.45)	(2.96)	(2.40)	(3.21)	(2.61)
		dbh	-	-	-	8.20	9.07	13.77
	Tree + crop	Tree height	126.50	251.44	381.36	475.99	568.4	632.30
				(124.94)	(129.92)	(94.63)	(92.41)	(63.9)
		Collar diameter	3.10	4.72	8.00	10.25	13.64	17.56
				(1.62)	(3.28)	(2.25)	(3.39)	(3.39)
		dbh	-	-	-	8.32	10.07	13.66
CD At $p = 0.05$		Tree height	NS	NS	NS	23.283	18.791	9.327
Tree density		Collar diameter	NS	NS	0.173	0.275	0.568	0.621
		dbh	_	_	_	NS	NS	0.243

(*continued*).

Table I. (*continued*).

Tree density (Trees ha $^{-1}$)	Treatment	Parameter(cm)	1992	1993	1994	1995	1996	1997
Treatment (Tree, tree + crop)		Tree height	10.724	13.318	30.180	23.672	NS	NS
		Collar diameter	0.281	0.132	NS	NS	NS	NS
		Dbh	_	_	_	NS	NS	NS
Interaction (Tree density x treatment)		Tree height	17.23	21.394	11.382	28.210	NS	NS
		Collar diameter	0.431	0.528	0.428	NS	NS	NS
		Dbh	_	_	_	1.543	NS	NS

*Mustard as winter crop and soybean as summer crop. Figures in parenthesis are mean annual increments.

years. There was no significant variation in dbh due to density till the fifth year. Two hundred trees ha^{-1} showed a higher dbh (13.7 cm) than the rest in the sixth year.

Tree growth in agrisilviculture

Significantly higher tree growth in terms of height in 200 trees ha^{-1} was evident in the first year through the fourth year after which, during the fifth and sixth year there was no significant difference in tree height (see Table I). Collar diameter, on the other hand, did not show any significant variation in the first year of growth although 200 tree ha^{-1} generally showed higher values. There was no effect of tree densities on dbh in agrisilviculture plots. Interaction between tree density and treatments (tree and tree + crop) was evident in the initial years of growth in all the parameters recorded, whereas significant interaction effect was not observed in the later years of growth starting from the fourth year in the case of collar diameter and fifth year in the case of both height and dbh.

PPFD, microclimate, growth and yield in intercrops

All the parameters recorded in both mustard and soybean intercrops under different densities of *H. binata* showed significant differences over pure crop (see Tables II and III). Transpiration rate was significantly higher in pure crop stands (28.9 and 33.45 mg m^{-2} s^{-1} in mustard and soybean respectively) than under different tree densities. The differences over pure crop in transpiration rate increased from 0.42 mg m^{-2} s^{-1} to a maximum of 3.0 mg m^{-2} s^{-1} in 200 trees ha^{-1} and 800 tree ha^{-1} respectively in mustard as tree growth progressed. A similar trend was observed in soybean although a slightly higher difference (3.8 mg m^{-2} s^{-1}) was seen in the final season. Leaf temperature did not vary significantly among the different densities of *H. binata* although it did show significantly higher values (23.86 and 32.13°C in mustard and soybean respectively) in pure crop stands. Relative humidity was lower (41.77%) in pure crop and tree density did not have a significant effect on mustard intercrop whereas soybean under 800 tress ha^{-1} showed significantly higher RH than under 200 tress ha^{-1} and pure crop stand. Differences in leaf temperature of mustard under different densities over pure crop increased progressively till the fourth year reaching a maximum of 1.31°C in 1995–96 seasons and thereafter registered a decline. On the other hand soybean under 800 trees ha^{-1} showed steady values ranging from 1.53°C to 1.64°C.

Table II. Microclimate changes, growth and yield in mustard crop (winter) grown under different densities of *Hardwickia binata* (Mean of four cropping seasons).

Tree density (Trees ha^{-1})	PPFD (μMole s^{-1} cm^{-2})	Leaf temperature (°C)	RH (%)	Stomatal conductance (m moles m^{-2} s^{-1})	Transpiration rate (mg m^{-2} s^{-1}.)	Plant height (cm)	Yield (Kg ha^{-1})
800	1227.75	23.13	43.68	247.3	26.86	128.01	869.5
400	1278.50	23.28	43.56	249.5	26.88	130.16	919.8
200	1315.75	23.36	43.15	251.2	27.22	129.55	909.5
Pure Crop	1402.75	23.86	41.77	259.1	28.92	132.66	940.3
CD at $p = 0.05$	43.627	0.25	1.241	2.01	1.431	2.431	020.38

Growth and yield of intercrops

Plant height was significantly higher in pure stands and no significant difference was observed under different densities of *H. binata* (see Tables II and III). The differences in plant height over pure crop reduced under 400 trees ha^{-1} in comparison with 200 trees ha^{-1} thereafter increasing under 800 tree ha^{-1} both in mustard and soybean. Yield of mustard in pure crops was significantly higher than under the three densities. Yield under 200 trees ha^{-1}and 400 tree ha^{-1} (909 and 910 Kg ha^{-1} respectively) were not significantly different. Lowest yield was seen under 800 trees ha^{-1} in both mustard and soybean (869 and 996 Kg ha^{-1} respectively). Yield of soybean was not significantly reduced in 200 trees ha^{-1} when compared to pure crop whereas 400 trees ha^{-1} and 800 trees ha^{-1} showed significant reduction in yield in comparison with pure crop. Yield reduction of up to 73 and 86 Kg ha^{-1} was observed under 800 trees ha^{-1} in mustard and soybean respectively. Reduction in yield under 400 trees ha^{-1} was lesser (20 Kg ha^{-1}) than under 200 trees ha^{-1}(30 Kg ha^{-1}).

Discussion

Tree growth

Tree density exhibited different patterns of increments in height, collar diameter and dbh in pure stands. Each of these parameters showed compensatory adaptations with tree height being least influenced by higher densities and intercrop. The ability of the tree to grow taller in denser stands and in girth in less denser stands was evident; this is in confirmation with Hummel (2000). This could be due to the natural adaptive mechanism to density stress by the trees (Hiura et al., 1998). Growth pattern of trees was more affected by planting density than by the presence of intercrops, but not on pure plots. This could be attributed to the fact that although a definite effect of competition (inter and intra specific) is envisaged, their manifestation is different (Henry & Aarssen, 1999) and is mainly dependant on the strength of the competitive source. Here the intercrops were less strong in influencing tree than the neighbouring tree themselves.

PPFD, microclimate, growth and yield in intercrops

Higher number of trees ha^{-1} reduced the incident radiation available to the intercrop, which was lower in mustard than in soybean because of the denser crop cover and season.

Table III. Microclimate changes, growth and yield in soybean crop (summer) grown under different densities of *Hardwickia binata* (Mean of three cropping seasons).

Tree density (Trees ha^{-1})	PPFD (μMole s^{-1} cm^{-1})	Leaf temperature (°C)	RH (%)	Stomatal conductance (m moles m^{-2} s^{-1})	Transpiration rate (mg m^{-2} s^{-1}.)	Plant height (cm)	Yield (Kg ha^{-1})
800	1361.33	30.40	71.32	218.3	30.21	70.89	996.3
400	1412.00	30.68	69.20	224.1	30.56	73.62	1056.4
200	1454.00	30.95	67.03	226.7	31.02	72.37	1069.7
Pure Crop	1519.67	32.13	65.78	238.4	33.45	77.95	1089.2
CD at $p = 0.05$	38.795	1.436	1.887	2.42	1.863	3.572	24.83

Transpiration rates were lower in agrisilviculture as was stomatal conductance, with increasing density lowering it further. This was due to the direct consequence of shade under the tree canopy, which in turn increased concomitantly with increased tree density. These results are in agreement with Vandana and Bhatt (1999). Leaf temperature is known to be affected positively by incident radiation and negatively by transpiration rate (Hirano et al., 1995; Duferene & Suagier, 1993). Higher leaf temperatures seen in pure crop were a consequence of direct sunlight and absence of shade. Crops were able to maintain optimum leaf temperature in spite of reduced transpiration due to the presence of trees in agrisilviculture. Four hundred trees ha^{-1} created a conducive microclimate for crop growth by effecting a transpiration rate and leaf temperature compromise. The reduction in leaf temperature differences over pure crop in both mustard and soybean after the third season was due to decrease in the rate of increase of shade as trees matured. It was seen here that the ability of the tree canopy to help the understorey crop maintaining optimum leaf temperature in spite of reduced transpiration decreased as seasons progressed. This could be due to the stronger influence of transpiration rate on leaf temperature than tree shade in the later years of tree growth. The increase in relative humidity under agrisilviculture was due to the over all effect of all the gas exchange parameters coupled with the cooler microenvironment provided by the tree canopy cover. Stomata in turn responded to this change thereby creating a cycle of effects. It is possible here that stomatal response to relative humidity relied more on sensing the transpiration rate itself rather than relative humidity. This is consistent with the model proposed by Van Wijk et al. (2000). Monsoon rains increased all the microclimate parameters in the soybean crop as compared to mustard wherein water availability in the form of rainfall was much lower.

Yield reduction was evident under higher densities, which is in accordance with Yin and He (1997). The reduction in plant height at podfill and yield of mustard crop in agrisilviculture was due to interspecies competition and reduced PPFD. Yield in mustard was not adversely affected by increase in tree density from 200 to 400 trees ha^{-1} which shows that mustard did not respond negatively to higher degrees of shade up to 400 trees ha^{-1}. On the other hand, 200 trees ha^{-1} did not statistically influence yield in soybean as compared with pure crop. This could be due to positive countering effect of trees by providing a conducive microenvironment with special reference to increased relative humidity which is in confirmation with Mortley et al. (2000) and Wang Zhoug Lin (1998) and also due to the natural adaptation of soybean to low levels of shade. The effect was negated by resource competition above 200 trees ha^{-1}. The marginal to low reduction in yield of both crops under lower densities was also due to the conical canopy structure (partly due to management and partly inherent) of the tree which facilitated radiation penetration more than the higher densities. This is in accordance with the results reported by Khadse and Bharad (1996b) and Huang (1998).

Conclusion

The economic and ecological advantages of growing trees with crops depend equally on both the resource use efficiency of the tree and the ability of the tree to provide a conducive microclimate to the understorey crop and on crop behaviour. The importance of quantifying these advantages is more profound in semi-arid regions where irrigated sole cropping of the much-needed grain legume and oilseed is apparently economically sound. The results obtained in the study puts forth a viable and adoptable alternative to the farmer. The choice of *H. binata*, a hard wood tree with high economic off-season production (fuel, fire, furniture wood and fodder) clearly balances the deficit from the trade-off in resource acquisition which causes a marginal to small yield loss in the understorey crop. Furthermore its canopy architecture is well suited for agrisilviculture. The understorey crops responded well to the microclimate created by the trees. The overstorey tree canopy here has played a significant role in reducing the fraction of rainfall/irrigation water transpired by the understorey crop and at the same time countered the adverse effects of reduced transpiration. Above all, a density of 200 trees ha $^{-1}$ has not interfered with light resource capture by the understorey crop, so as to create large yield deficits. Although a density of 200 trees ha $^{-1}$ is clearly the best option that emerged from the study, a density anywhere between 200 – 400 trees ha $^{-1}$ can be adopted by the farmer due to its potential monetary benefits to him and ecological benefits to his field. The study has in part resolved the debate on the efficacy of agroforestry systems in the semi-arid regions by establishing the benefits of a biophysical boundary with special reference to tree density, crop combinations and microclimate regime.

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