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Soil quality and production of low land paddy under agrisilviculture systems in acid soil of West Bengal, India

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Abstract

Seven tree species (*Terminalia arjuna*, *Lagerstroemia parviflora, Salix tetrasperma*, *Pongamia pinnata*, *Bombax ceiba*, *Bixa oreliana* and *Gmelina arborea*) based agrisilviculture systems were established to test their compatibility with respect to production of rice and physio-chemical status of soil in low land – paddy growing area of North Bengal, India. A gradual increase in biological yield was recorded with increase in distance from tree. Grain yield ranged from 3.21 t ha^{-1} in *Pongamia* at 1 m distance from tree to 4.94 t ha^{-1} at 3 m away from Bixa. Harvest index of paddy in control was higher (34.57) as compared to those intercropped with trees. Presence of trees significantly reduced PAR adjoining tree rows. The lowest PAR (1150 µmols^{-1}m^{-2}) was recorded at 1 m distance from *Pongamia* tree. The organic carbon content was greater in *Terminalia* (2.15 %) and least (1.19 %) in sub-surface soil layer of *Salix* based system. Microbial biomass carbon was greatest in surface soil of *Terminalia* (526 mg kg^{-1}) followed by *Gmelina* (408.33 mg kg $^{-1}$) and least in sub-surface soil of *Salix* (280 mg kg^{-1}).

Key words: Acid soil, Agrisilviculture systems, Agroforestry, Canopy management, Low land paddy production, Soil nutrients, Soil quality

Abbreviations: dbh - Diameter at breast height; **HI -** Harvest Index; **MBC -** Microbial biomass carbon; **OC-** Organic carbon; **PAR** – Phosynthetically active radiation

Introduction

Contribution of trees to local farming system is complex and subtle, including non-tangible benefits such as improvement in microclimate, inputs through leachates and nutrient cycling. Incorporation of tree in the farming system had been advocated to improve fertility status of the soil. In tree-based intercropping systems number of interactions within agroforestry systems can arise that may be neutral, beneficial, or potentially detrimental (Ong, 1996). 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. Positive effect of trees had been reported in arid region of Haryana. *Prosopis cineraria*, *Tecomella undulata*, *Acacia albida* and *Azadirachta indica* increased the production of *Hordeum vulgare* (barley). *P. cineraria* enhanced grain yield by 86.0%, *T. undulata* by 48.8%, *A. albida* by 57.9% and *A. indica* by 16.8% over the control (Kumar *et al.*, 1998). Thus, to maximize the potential benefits of tree-based intercropping systems, competitive interactions need to be avoided by proper designing and managing intercropping systems (Thevathasan *et al.,* 2004).

In most parts of eastern region particularly states of Bihar and West Bengal, rice is rainfed and is cultivated during rainy season (June – September). Most of the lands after harvesting paddy are kept fallow. Most of these lands are inundated with water during rainy season and hence no other crop except rice can be cultivated. The soils of northern parts of West Bengal and parts of Bihar are alluvial in nature with poor nutrient content. This study was initiated to identify the trees which can grow well in stagnant water with paddy, have less effect on crop growth and simultaneously improve the fertility status of the soil.

Material and methods

Study area: The study was conducted in experimental plot of Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Pundibari (West Bengal). The region falls in *Terai* zone with subtropical humid climate and is situated between 25^{0}57' and 27.0^0 N latitude and 88^{0}25' E and 89^{0}54' E longitude. Soil texture varies from sandy to silty loam. Soils are gritty, porous and the analysis of initial soil before planting of tree showed that the soil pH was 5.7, EC 0.20 dSm^{-1}, OC 1.15%, nitrogen 258 $kgha^{-1}$, phosphorus 14.5 $kgha^{-1}$, potassium 110 $kgha^{-1}$. The micronutrients *viz.* Cu, Mn, Fe and Zn were 2.46, 4.68, 5.7 and 0.49 ppm, respectively. Average annual rainfall varies from 2100 to 3300 mm, 80 per cent of which is received from south-west monsoon during the rainy season *i.e.,* June to September. The temperature ranges between 7 to 8^{0}C in December - January to 33^{0}C in May.

Experimental layout: Agrisilviculture system was established in the year 2005 for lowlands to develop a paddy based agroforestry system in terai zone of West Bengal. *Terminalia arjuna* (Arjun), *Lagerstroemia parviflora* (Jarul) and *Salix tetrasperma* (Jal sissoo), *Pongamia pinnata*, *Bombax ceiba* (simul), *Bixa oreliana* (bixa) and *Gmelina arborea* (gamar) based agrisilviculture systems were established. Five months old polythene bag raised seedlings were planted in field in the month of August in 30 cm^3 pits at 6x6 m spacing. Paddy (*cv* Swarna) was transplanted in July, 2010 following the standard package and practices.

For each tree species, 5 trees were randomly chosen within the experiment. Paddy was grown in between the rows of the trees. Only crop, not shaded by any trees at any time throughout the cropping season, was taken as control plot. Observations were taken at 1 m, 2 m and 3 m distance from the tree.

Data collection: Observations were taken on tree height, dbh, crown spread, Photosynthetic Active radiation, grain yield and straw yield for two rice growing season and mean of the values have been presented. The PAR was measured at an interval of 10 days between 11 a.m to 12 noon, using 'Plant Canopy Analyser' at three positions corresponding to the three distances and at one location in the open area.

Assessment of crops yield and Harvest Index (HI): Crop yield was assessed at three distances from tree stem (1 m, 2 m and 3 m) and in the control plot by weighing all the grains (kg ha^{-1}). Straws of paddy at each zone, grains of 30 panicles per zone and in control plots were collected, weighed and dried in an oven at 80^{0}C for 48 h and again weighed. HI was calculated as the ratio of the dry grain weight (kg ha^{-1}) divided by the total dry matter weight (kg ha^{-1}).

Soil sampling and analysis: Soil sampling was done at two soil depths (0 – 15 cm and 15 – 30 cm). After harvest of kharif crop, soil samples were collected, air-dried and ground to pass through a 2-mm sieve.

A combined glass–calomel electrode was used to determine the pH of aqueous suspensions (1:2.5 soil: solution ratio). Electrical conductivity (dSm^{-1}) was measured in the supernatant liquid of soil water suspension (1:2) with conductivity bridge (Richards, 1954). Soil organic carbon was determined using the wet digestion method. Available N was measured by the alkaline permanganate method as described by Subbiah and Asija (1956). Available phosphorus was determined by the Bray II method (Bray and Kurtz, 1945). Potassium content was determined by flame photometer (Rich, 1965). Available micronutrient content (Cu, Mn, Fe and Zn) were determined by DTPA extraction method (Lindsay and Norvell, 1978), followed by determination in Atomic absorption spectrophotometer.

Soil biological properties: Microbial biomass carbon (MBC) determinations were made by using chloroform fumigation technique as described by Jenkinson and Powlson (1976), Jenkinson and Ladd (1981).

Statistical Analysis: For statistical analysis, Microsoft Excel (Microsoft Corporation, USA) and MSTATC packages were used. The relationships between soil properties and soil fertility indices were determined by Pearson's correlation matrix using SPSS window version 14 (SPSS Inc., Chicago, USA).

Results and Discussion

Tree Growth Characteristics: Maximum height recorded was 5.23 m in *G. arborea*, followed by *T. arjuna* (4.74 m), *P. pinnata* (4.41 m), *S. tetrosperma* (3.82 m), *L. parviflora* (3.79 m) and *B. ceiba* (3.83 m). The girth at breast height varied from 3.38 cm to 12.54 cm being maximum in *T. arjuna* (12.54 cm) closely followed by *G. arborea* (11.38) and lowest in *B. ceiba* (3.38 cm). In *T. arjuna* bole volume was maximum (3.43 m^3ha^{-1}) followed by *G. arborea* (2.82 m^3ha^{-1}) and lowest in *B. ceiba* (0.24 m^3ha^{-1}). The width of crown (W-E) ranged from 1.77 m in *B. ceiba* to 5.2 m in *T. arjuna* and from 2.24 m in *B. ceiba* to 7.05 m in N-S direction (Fig. 1).

Crop yield and HI: Biological yields of rice grown in control plots (without trees) was 15.086 t ha^{-1} which was slightly lower than yield obtained at 3 m distance in *S. tetrasperma* (15.62 t ha-1) and *Bixa oreliana* (15.34 t ha-1) based agroforestry systems. However, in all other distance and species combination the control plots had a higher biological yield (Table 1). The least biological yield was recorded in *P. pinnata* (11.03 t ha-1) at 1 m distance from the tree. A gradual increase in yield was recorded with increase in distance from tree. Grain yield ranged from 3.21 t ha^{-1} in *P. pinnata* at 1 m distance from tree to 4.94 t ha^{-1} at 3 m away from *Bixa oreliana* showing statistical variations. The grain yield in control (4.87 t ha^{-1}) was slightly lower than recorded at 3 m distance in *G. arborea* (4.89 t ha^{-1}), *S. tetrosperma* (4.92 t ha^{-1}) and *B. oreliana* (4.94 t ha^{-1}) based agrisilvicultural systems. The lowest grain yield was 3.21 t ha^{-1} at 1 m distance from the tree in *P. pinnata* based agrisilviculture system. Harvest index of paddy in control was higher (34.57) as compared to those intercropped with trees. Competitive effect on harvest index was higher in *P. pinnata* at 1 m distance as the harvest index was minimum (24.98). Among tree–crop combinations, the lowest competitive effect on paddy was found at 3 m distance from the plant in *B. oreliana* (34.56) closely followed by *S. tetrosperma* (34.44). No Statistical differences in Harvest index were observed among treatments, despite widely ranging values. Pairwise t-test was applied for grain yield (Table 2). It was observed that grain yield at 3 m distance and control had no difference in all the species.

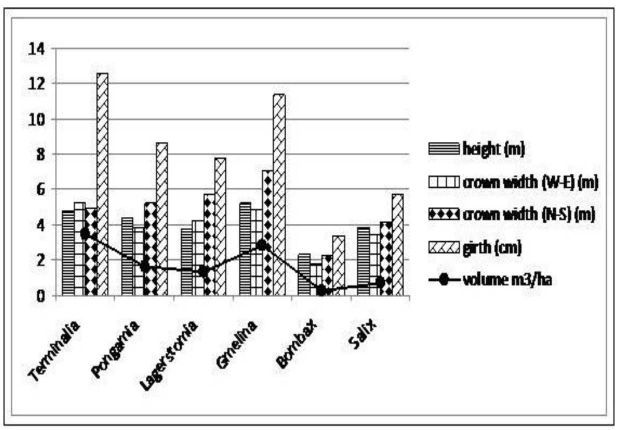

Fig 1. Growth characteristics of trees

PAR and crown architecture: The maximum value of PAR was 1466.6 µmols^{-1}m^{-2} in control plots and it was followed by 1460 µmols^{-1}m^{-2} in *B. oreliana*, 1450 µmols^{-1}m^{-2} in *S. tetrasperma*, 1416 µmols^{-1}m^{-2} in *G. arborea* and 1395 µmols^{-1}m^{-2} in *B. ceiba*, at 3 m distance from tree. The lowest PAR (1150 µmols^{-1}m^{-2}) was recorded at 1 m distance from tree trunk in *P. pinnata* based system (Table 1). Differences for PAR were significant between the treatments. PAR, crown width and distance from the tree were plotted in different axis to obtain contour graphs (Fig. 2). The relationship between PAR and grain yield was worked out by fitting a regression equation (Fig. 3). The R^2 value between PAR and grain yield was highly significant.

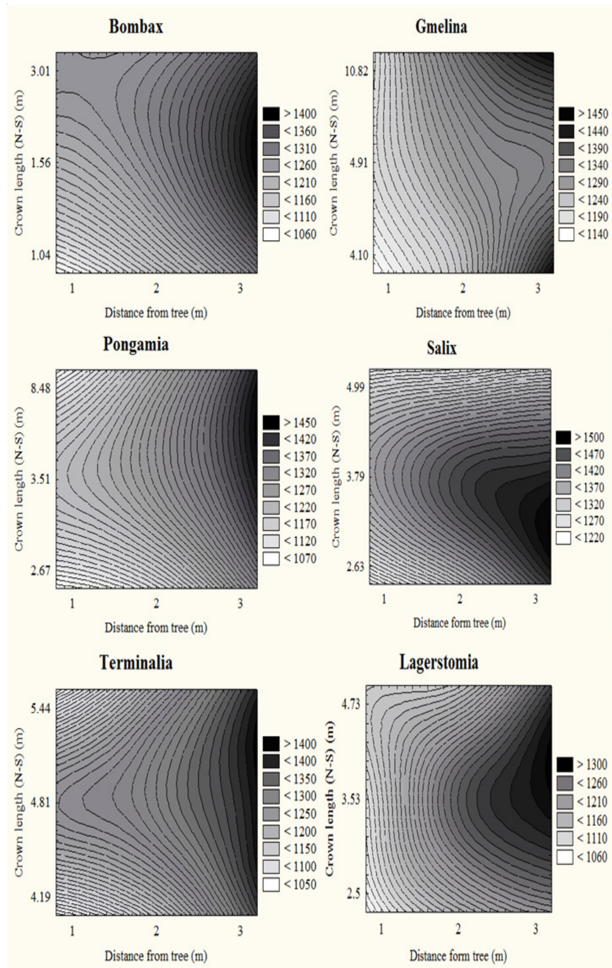

Fig. 2. Spatial variation in crown length and PAR under different treatments

It was found that *S. tetrosperma* provides better growing condition for the paddy as it had lesser spread of crown (3.79 m) as compared to *G. arborea* (5.96 m), *T. arjuna* (5.08 m), *L. parviflora* (4.96 m) and *P. pinnata* (4.52 m). *S. tetrosperma* has less crown density followed by *G. arborea*, *B. ceiba* and least of *P. pinnata*. *S. tetrosperma* has an added advantage that it sheds most of its leaves when its roots are submerged in water and provides better growing condition for paddy. Leaf shedding is a response of the *Salix* as a survival mechanism under submerged condition (Panwar *et al.*, 2011a,b).

Effects of land-Use systems on soil physiochemical properties: There was no significant influence of land-use systems and soil depth on soil pH and EC. Soil pH varied from 5.62 in *P. pinnata* to 5.99 in *T. arjuna* based system and EC from 0.16 in Salix to 0.34 in *G. arborea*

(Table 3). The OC content was greater in *T. arjuna* (2.15%) followed by *G. arborea* (1.91 %). The least value for OC (1.19 %) was in subsurface soil layer of *S. tetrosperma* based system. As a general trend, the OC was less in the sub-surface soil layer.

Table 1. Growth and yield attribute of paddy under different Agrisilviculture systems

Treatment		Harvest Index	Grain yield	PAR (µmols^{-1}m^{-2})	Biological yield
Salix tetrosperma	1 m	31.041	4.2358	1295	14.21
	2 m	32.965	4.6733	1374	14.872
	3 m	34.437	4.9257	1450	15.621
Bixa oreliana	1 m	30.319	4.0191	1196	12.932
	2 m	33.211	4.7239	1380	14.52
	3 m	34.563	4.9415	1460	15.34
Bombax ceiba	1 m	30.426	4.0853	1240	13.371
	2 m	32.691	4.6072	1374	13.87
	3 m	34.201	4.8074	1395	14.53
Pongamia pinnata	1 m	24.987	3.2148	1150	11.03
	2 m	30.419	4.0613	1209	13.453
	3 m	33.494	4.783	1380	14.56
Lagerstroemia parviflora	1 m	27.327	3.3876	1180	12.056
	2 m	30.834	4.2011	1290	13.403
	3 m	32.086	4.3881	1365	14.361
Terminalia arjuna	1 m	26.683	3.4688	1170	12.136
	2 m	30.781	4.182	1258	13.387
	3 m	31.721	4.3288	1355	14.31
Gmelina arborea	1 m	29.915	3.8528	1198	13.65
	2 m	31.65	4.2635	1330	13.96
	3 m	34.237	4.8971	1416	14.52
$LSD_{0.05}$		17.252	1.265	203.380	4.172
	Control	34.57	4.87	1466.66	15.086

Table 2. Soil properties under different treatments

	pH		EC (dS/m)		OC (%)		N (Kg/ha)	
Soil layer (cm)	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Salix tetrosperma	5.93	5.82	0.16	0.22	1.52	1.19	268.33	245.32
Bixa oreliana	5.85	5.67	0.22	0.18	1.35	1.24	258.30	266.25
Bombax ceiba	5.78	5.89	0.21	0.17	1.71	1.53	315.00	295.01
Pongamia pinnata	5.62	5.75	0.20	0.21	1.65	1.25	288.00	275.67
Lagerstroemia parviflora	5.65	5.82	0.19	0.16	1.72	1.53	322.33	280.67
Terminalia arjuna	5.99	5.80	0.21	0.18	2.15	1.78	375.33	299.00
Gmelina arborea	5.75	5.82	0.34	0.18	1.91	1.25	344.67	324.65
$LSD_{0.05}$	L=NS	D=NS	L= NS	D=NS	L=0.108	D=0.101	L=22.22	D=17.54
	L × D = NS		L× D = NS		L × D = NS		L × D = NS	

	P_2O_5 (kg/ha)		K_2O_5 (kg/ha)		MBC (mg kg^{-1})	
Soil layer (cm)	0-15	15-30	0-15	15-30	0-15	15-30
Salix tetrosperma	18.16	17.59	122.15	105.2	292.00	280.25
Bixa oreliana	15.45	13.11	105.52	95.55	269.33	258.67
Bombax ceiba	14.64	12.88	136.42	116.07	347.32	299.00
Pongamia pinnata	15.00	13.03	178.67	147.43	355.00	358.67
Lagerstroemia parviflora	21.48	19.95	218.67	168.07	358.33	329.67
Terminalia arjuna	24.24	24.35	238.7	238.1	526.33	465.00
Gmelina arborea	20.26	13.04	131.87	120.9	408.33	399.00
$LSD_{0.05}$	L=1.09	D=NS	L=11.50	D= .87	L=30.12	D=23.50
	L × D = NS		L × D = NS		L × D = NS	

Table 3. Concentration of micronutrients under different treatments

System	Soil layer							
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
	Cu (ppm)		Mn (ppm)		Fe (ppm)		Zn (ppm)	
Salix tetrosperma	1.71	1.63	4.60	4.58	5.60	5.50	0.49	0.44
Bixa oreliana	1.80	1.74	1.18	3.03	4.49	3.99	0.48	0.21
Bombax ceiba	2.77	1.29	3.98	4.74	7.46	4.21	0.57	0.54
Pongamia pinnata	2.76	2.64	4.99	5.01	9.74	8.48	0.75	0.63
Lagerstroemia parviflora	3.73	2.68	6.07	5.68	10.46	10.23	0.91	0.77
Terminalia arjuna	2.98	2.86	7.33	5.82	10.75	10.03	1.37	1.26
Gmelina arborea	2.90	2.90	4.15	4.35	9.73	7.30	0.79	0.50
$LSD_{0.05}$	L= 0.125	LxD = NS	L= 0.325	LxD= NS	L= 0.425	LxD=0.125	LxD = NS	L = 0.08

Available N and P contents were significantly influenced by land use and soil depths (Table 2). Nitrogen was greatest (375 kg ha^{-1}) in surface soil of *T. arjuna* and least (245 kg ha^{-1}) in *Salix tetrosperma* based system. Nitrogen content tended to decrease significantly with increasing soil depth, however, depth had no effect on Phosphorous variation. Available potassium significantly differed with land use and depth. Available potassium was highest (238.7 kg ha^{-1}) and almostequal in surface and subsurface soil (238.1 kg ha^{-1}) in *Terminalia arjuna* and least (95.55 kg ha^{-1}) in subsurface soil of *Bixa oreliana*.

MBC was greatest in surface soil of *T. arjuna* (526 mg kg^{-1}) followed by *Gmelina arborea* (408.33 mg kg^{-1}) and least in subsurface soil of *Salix tetrosperma* (280 mg kg^{-1}) (Table 2). The soil properties were also studied in paddy based monocropping system having Swaran variety to compare it with agroforestry systems. The values of pH, EC,OC, N, P, exchangeable K and MBC at 0-15 cm were 5.2, 0.20 dSm^{-1}, 1.6%, 286 kg ha^{-1}, 16.05 kg ha^{-1}, 110 kg ha^{-1}, 251 mg kg^{-1} , respectively. The values of the parameters at 15-30 cm are 5.3, 0.20 dSm^{-1}, 0.4%, 248 kg ha^{-1}, 15.22 kg ha^{-1}, 102 kg ha^{-1}, 235.3 mg kg^{-1}, respectively.

Effects of land use on available micronutrients: There was a significant effect of different species on micronutrient (Cu, Zn, Mn, and Fe) content. Cu content was greatest (3.73 ppm) in surface soil of *T. arjuna* and least (1.29 ppm) in sub-surface soil of *B. ceiba* (Table 3). Zinc content varied from 0.21 ppm in the subsurface surface soil layer of *Bixa* to 1.37 ppm in surface soil layer of *T. arjuna*. Manganese content ranged from 1.18 ppm in *Bixa* to 7.33 ppm in *T. a arjuna*. Available Fe varied from 3.99 ppm in sub surface soil of *Bixa* to 10.75 ppm in surface soil of *T. arjuna*. Except for Fe, all the rest of the micronutrients did not show any consistent trend both for land use or soil layer.

Paddy yield was affected by the presence and extent of proximity to trees. Yield of paddy increased with increase in distance from the tree trunk in all the species signifying the negative effect of the tree on crop production. Such trend had been reported for most of the species. Bayala *et al.*, (2002) also reported that millet yield decreased from the open area to the trunk of ne´re´ trees because of the effect of shade. Total soybean grain yield was 85, 84, 75 and 65% under Albizia, mandarin alder and cherry, respectively, compared to its yield as sole crop (without trees). The PAR data obtained in the present study correlates with the yield obtained. Comparatively higher grain yield in *S. tetrosperma* and *B. oreliana* compared to corresponding distances in other species is attributed to the management practices and phenology of the species. *Bixa oreliana* is managed and maintained as hedge and hence shading effect is less whereas in *S. tetrosperna,* leaves start appearing only when the grains are about to start maturing (Panwar and Chakravarty, 2011). *P. pinnata*, *T. arjuna* have dense foliage which intercepts more light as compared to *S. tetrosperma*, *G. arborea* and *B. ceiba* having sparse canopy allow more light to penetrate the canopy which helps in good growth of the associated crop. The data further reveals that the grain production was slightly higher at 3m distance from tree in *S. tetrosperma*, *B. oreliana* and *G. arborea* based agrisilviculture system. This is attributed to positive effect of tree on improving soil fertility provided light is not a limitation factor. The HI of paddy decreased by 27.72 % in *P. pinnata* followed by 22 % reduction in *T. arjuna* at 1 m distance from tree trunk as compared to control. The least reduction (10. 20 %) at 1 m distance was in *S. tetrosperma*. Kho *et al.,* (2001) also reported a negligible production reduction (3%) due to light and water limitations on millet under *Faidherbia albida* because this species sheds its leaves during the rainy season and thus reduces its competition for light and other resources with associated crops.

PAR reduction was higher (21.59 %) under *P. pinnata* at 1 m distance from tree trunk as compared to PAR in open area (control) followed by *T. arjuna* (20.22 %) at 1 m distance from tree trunk. The difference between the tree species could be explained by a difference in height, crown density and shape (Bellow and Nair, 2003) and out of the seven species tested *P. pinnata* and *T. arjuna* have the highest crown density.

The enrichment of OC content under *T. arjuna* could be due to higher litter fall and in *Gmelina* due to early decomposable leaves. The surface soil layer tended to be richer in OC than subsoil layers in all land uses, due to litter fall**.** Pal *et al. (*2013) examined the impact of landuse on soil fertility in an Alfisol, at Dharamshala district of NW Hima-layan region, India. The forest had a higher fertility index and soil evaluation factor followed by grassland, horticulture, agriculture as compared to wasteland. It is evident from the study that forest based land use increased OC, exchangeable cations, available nutrients and microbial activities. A significant and positive relationship between carbon sequestered with organic carbon, microbial biomass carbon, microbial biomass nitrogen and microbial biomass phosphorus have been reported by Pal and Panwar (2013) under different land uses of degraded Shivalik, India. Increased carbon sequestration in different land uses led to 30% increase in microbial biomass carbon and 50% increase in microbial biomass phosphorus. An increase in soil fertility indices, microbial biomass carbon, microbial biomass nitrogen, dehydrogenase activity in response to increased organic carbon content under different land uses were reported by Panwar *et al.* (2011a,b) in an Entisol of humid subtropical India.

N buildup in different tree-based land use over agricultural land is attributed to more accumulation of biomass through litter fall and root biomass. In tree-based land-use system, the greater P content could be due to recycling of P through mining by the tree species and subsequently recycling by way of surface litter fall. An increase in soil organic C under trees through organic matter inputs *via* leaf litter and dead roots have been reported by Pandey *et al.,* (2000). Increased soil C and clay can contribute interactively to increased total and available forms of N and P. The inconsistency of micronutrients, particularly Cu and Zn, with respect to soil depth had also been reported by Sharma *et al.* (2009) and Panwar *et al.,* (2011a,b). MBC had a direct correlation with the amount of organic carbon. Kaur *et al.* (2000) reported that in moderately alkaline soils in Karnal, MBC which was low in rice–berseem crop, increased in soils under tree plantation and soil C increased by 11–52% because of integration of trees and crops.

Conclusion

The study indicated that *Salix tetrosperma* followed by *Bixa oreliana* and *Bombax ceiba* are the best trees as compared to other species with respect to crop production and simultaneously improving soil status over control. Canopy management is also of utmost importance to get good production of associated crop. The canopy management should necessarily start from the initial stages as a yield loss of 10 -33 % was obtained in five year old plantations.

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