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Research Paper

Productivity and profitability of intercrops under four tree species throughout their rotation in north-western India

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ABSTRACT

In an experiment, different crops, viz. pearlmillet [*Pennisetum glaucum* (L.) R. Br.], wheat (*Triticum aestivum* L.), potato (*Solanum tuberosum* L.), Egyptian clover (*Trifolium alexandrinum* L.) and annual turmeric (*Curcuma longa* L.) were evaluated during 2005 to 2011 at Ludhiana, Punjab under 4 agroforestry tree species, viz. necklace poplar (*Populus deltoides* Bartr ex. Marsh.), eucalypt (*Eucalyptus tereticornis* Sm.), *M. composita* Willd. and toon (*Toona ciliata* M. Roem) during first to sixth year of tree age. Tree growth parameters, growth and yield parameters of intercrops and sole crops, soil organic carbon, nutrient status and economics of agroforestry systems were determined. The diameter at breast height (DBH) and height of poplar and eucalypt were higher than the other species after 6 years of age. The fresh stem biomass was the lowest (73 t/ha) in toon and the highest in eucalypt (213 t/ha). The growth and yield of all the crops declined under tree plantations with the increase in growth of trees during each subsequent year. Toon plantation had the minimum adverse effect on understorey crops, whereas eucalypt caused the maximum reduction in yield of all the intercrops. When grown as intercrops under tree block plantations, productivity of turmeric and wheat was better than the other crops under tree species. Amongst different tree-crop combinations, intercropping of turmeric with poplar and eucalypt gave the maximum net returns (₹16,22,225 and ₹14,62,065/ha respectively) followed by poplar–wheat (₹14,30,000/ha). Agroforestry systems also improved the soil fertility status. Soil organic carbon, six years after planting, was the highest under *Melia,* i.e. 21.2% increase over its initial level (2.83 g/kg). Available N and P were the highest under *Melia* (139.1 kg/ha) and poplar (15.65 kg/ha) based agroforestry system, respectively, at the end of the experiment.

Key words : Agroforestry, Economics, Growth parameters, Intercropping, Soil fertility

Agroforestry is currently estimated to be practiced on 25.32 million hectares in India, but it has potential for adoption to much larger areas. It supplies half of the demand of fuelwood, two-thirds of the small timber, 70–80% wood for plywood, 60% raw material for paper-pulp, 9–10% of green fodder besides meeting the subsistence needs of households (Dhyani *et al*., 2013). Tree-based farming system will increase the tree cover and help to bring diversification in agriculture for efficient and judicious use of depleting natural resources. Tree-crop combinations provide several indirect benefits such as enriching the soils and maintaining the ecological balance. Specific advantages of this system are early financial returns, increased cash flow compared to tree plantations and improved ecology. Inter-cultivation of compatible seasonal crops in the interspaces between trees is essential not only for generating continuous supplementary income but also for compensating the loss of agricultural commodities arising from transfer of crop land to tree production. So it is better to integrate both the components rather than monocropping for sustainable production.

Selection of suitable tree species and crops with high yield potential are important aspects in tree-crop intercropping systems. The most common agroforestry tree species grown in India are *Populus deltoides, Eucalyptus tereticornis, Acacia nilotica, Dalbergia sissoo, Azadirachta indica, Bombax ceiba, Cocos nucifera* etc. Tree species, viz. *D. sissoo, A. indica, A. nilotica, Grewia optiva, Morus alba, Ficus* spp. are grown on the boundaries of fields for meeting demand of timber, fodder, fuel etc.

Management practices play a major role in maintaining the identity and sustainability of agroforestry system. As per Manna *et al*. (2008), management practices for agroforestry are: more complex because multiple species have

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varied phenological, physiological and agronomic requirements. The effect of tree species on intercrops is not consistent. The effect may be complimentary or competitive depending on the level of competition between woody component and seasonal crops as well as weather conditions. The report of Kumar *et al*. (1998) indicated that in agroforestry system, *Prosopis cineraria, Acacia albida* and *A. indica* enhanced grain yield of barley by 86.6%, 57.9% and 16.8% respectively, over the control. Likewise, lower reduction in grain yield of mustard in association with *P. cineraria* and *A. leucocephala* as compared with *D. sissoo* and *A. nilotica* due to differential canopy size has been reported by Yadhav *et al*. (2005). Competition for above- and below- ground resources reduces the crop yield substantially. Ecological sustainability and success of any agroforestry system depends on the inter-play and complementarity between negative and positive interactions. It can yield positive results only if positive interactions outweigh the negative interactions.

In irrigated plains of north-western India, poplar (*P. deltoides)* has been planted on a significant scale and this constitutes the backbone of agroforestry in the Indo-gangetic plain. Total area under poplar-based agroforestry, is estimated to be 3,12,000 ha in states of Punjab, Haryana and Western Uttar Pradesh and is steadily increasing (Singh and Kumar, 2014). This tree species has been extensively experimented with annual and seasonal crops in north-western India, comprising Punjab, Haryana, Uttar Pradesh, Uttrakhand, lower parts of Himachal Pradesh and Jammu and Kashmir. However, eucalypt and *Melia* have the potential of being promising agroforestry tree, species in this region. *Eucalyptus* spp. grow under a wide range of climatic and edaphic conditions in their natural habitats (Dawar *et al*., 2007). Both poplar and *Melia* are winter deciduous trees, hence crops grown under these tree species perform better than eucalypt. Toon is one of the important tropical and subtropical timber producing trees contributing significantly to forest economies (Edmonds, 1993). Due to long juvenile phase of tree-based farming, it offers a vast scope for cultivation of suitable intercrops. The trees may benefit from the inputs and management given to intercrops. Trees vary in their respective growth characteristics, accordingly the performance of intercrops vary under different tree plantations owing to difference in number of factors like growth habits, canopy spreads, allelopathic effect and nature of tree-crop interaction. An ideal tree-based intercropping should aim to produce higher economic return and yields/unit area, offer greater stability in production and meet the domestic needs of the farmers. Trees with diverse features (growth habit, root depth and duration) would be useful to enhance resource utilization and profitability of the intercropping-based production system. To make the agroforestry systems more productive and economically more profitable, 4 agroforestry tree species such as poplar, Malabar neemwood, toon (*T. ciliata*) and eucalypt (*Eucalyptus* hybrid) were evaluated with possible winter, summer and annual crops to find out the suitable tree-crop combinations. The study also aimed at assessing the effect of agroforestry land use practices on soil fertility and economics at end of the rotation.

MATERIALS AND METHODS

The present investigation was carried out at the experimental area of the Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana (30°–54' N and 75°–48' E, with 247 m elevation), Punjab. The climate of the region is subtropical to tropical with long dry season from late September to early June and wet season from July to early September with hot desiccating winds in summer (May–June) and severe cold in winter with occasional ground frost (December–January). At the time of initiating the experiment (January 2005), the site had $p\mathrm{H}_{1:2}$ 8.1, electrical conductivity (EC) 0.39 dS/m, organic carbon (OC) 2.83 g/kg, available N 125.4 kg/ha and P 11.5 kg/ha of the surface soil layer.

Four agroforestry tree species, namely poplar, *M. composita*, toon and eucalypt were planted as block plantation. Poplar and *M. composita* were planted during February 2005, while toon and eucalypt in July 2005 at a spacing of 6 m × 3.5 m.

Wheat, egyptian clover and potato in the winter season, pearlmillet in summer season and turmeric as annual crop were grown as intercrops in tree plantations as well as sole crops, i.e. without trees during 2005 to 2011, i.e. from first to sixth year. The crops were sown between interspaces of tree rows and plot size was co-terminus with trees planted at 6 m × 3.5 m spacing. Wheat @ 100 kg/ha seed was sown during the first fortnight of November along with its control in open conditions. Nitrogen and phosphorus were applied through urea and diammonium phosphate (DAP) @ 225 and 137.5 kg/ha respectively. Crop was harvested manually in the third week of April. The potato tubers of 40–50 g weight were sown on ridges at 60 cm × 20 cm spacing in each plot. Fertilizers, viz. 412.5 kg urea, 385 kg single superphosphate and 100 kg muriate of potash/ha were applied to potato crop. Nitrogen was applied in 2 split doses, first at the time of sowing and second at earthing up. Earthing up in potato crop was done 25–30 days after sowing. Regular and light irrigations were given to the crops throughout the growing season. Potato plants were dehaulmed a month before the harvesting. Egyptian clover seed @ 25 kg/ha was broadcast in standing water during the last week of October and 4 cuts were taken till end of April. Pearlmillet (fodder) was cultivated during summer season (May) using seed rate of 20 kg/ha under trees and open conditions. Turmeric crop was sown in April with seed rate of 1.5 t/ha and harvested in the month of February during subsequent year. All the local recommended practices were followed for the respective crops both under trees and in open each year.

All the trees in plantation were taken for measurement of growth parameters. The height of trees was recorded from base of the tree to growing tip with the help of Ravi's multimeter. Girth at breast height (GBH) was measured by measuring tape at 1.37 m from ground level and converted to diameter at breast height (DBH) using the formula DBH=GBH/ð. Crown spread was recorded after 4 years of plantation and means of all the individual tree species in block plantations are presented in Table 1. The mean tree technique was used for estimation of tree biomass (Fang *et al*., 2010). The technique involves the destructive sampling of trees that best represent the mean size of a plantation. Three trees of each species (one from each replication) were selected for destructive sampling which were having DBH, height and crown dimensions closest to the means of these parameters. Three trees of each species were cut at ground level after about six and half years of planting. Stem was cut into different segments which were weighed for estimation of fresh biomass. Fresh biomass on per hectare basis was estimated assuming 10% mortality (i.e. 450 trees/ha).

The yield and yield attributes of all the crops were recorded. The net economic returns in respect of crops and tree component were worked out considering material cost, labour cost, interest on working capital, depreciation cost and output prices averaged over six years. Monetary returns (₹) were calculated by taking average yield of each treatment.

To quantify changes in soil fertility, soil samples (0–15 cm depth) were taken from the site before initiating the experiment (January 2005). After screening the crops for 6 years, samples were again collected under all the trees from all the crops and a composite sample from each tree species was prepared. The soil samples were passed through a 2 mm mesh sieve and subjected to the analysis of chemical properties. The organic carbon content of soil was determined by Walkey and Black's chromic acid digestion and rapid titration method (Piper, 1966). Available nitrogen and phosphorus were determined by alkaline permanganate method (Subbiah and Asija, 1956) and Olsen method respectively (Piper, 1966).

Experiments were laid out in split-plot design by considering tree age as main plots and tree species as sub plots. Different crops grown were randomized in subplots with three replications under each tree block plantation. All data were subjected to the analysis of variance (ANOVA) using statistical analysis software (SAS 9.3, North Carolina) to evaluate the differences between treatments, and where the ANOVA indicated that treatment effects were significant, means were separated at $P \leq 0.05$ with least significance difference (LSD).

RESULTS AND DISCUSSION

Tree growth parameters

Eucalypt trees were the tallest with height of 6.43 m and 24.7 m at the age of 1 and 6 years, respectively followed by poplar trees. (6.84 m and 20.3 m). Toon recorded the minimum gain in height, i.e. 8.43 m, in the span of 6 years. The mean height of *Melia composita* increased from 3.66 m to 15.4 m from first to sixth year of growth. The average DBH was maximum in poplars, followed by eucalypt and minimum in toon after 6 years of growth (Table 1). At the time of harvesting of trees, fresh biomass of tree stems was recorded to be maximum of eucalypt trees (213 t/ha), followed by poplar (182 t/ha) and *Melia* (128 t/ha); while minimum stem biomass was of toon (73 t/ha) trees (Fig. 1).

Performance of crops under trees

Wheat: In north-western India, wheat is the most preferred winter crop in agri-silviculture system. The comparison of crop yield-attributing characters determined that number of tillers/m row length and 1,000-grain weight were significantly low under eucalypt as compared to poplar, or *Melia composita* tree and toon. These parameters declined with increase in age of trees (Tables 2 and 3). Both poplar and *Melia* shed their leaves during November–December and new leaves sprout in March. These trees remain leafless during most of the winter season, whereas eucalypt is an evergreen tree and thus adversely affects the growth of understorey crop. The grain yield of wheat was higher under toon than poplar and *Melia* plantations (Table 4). The smaller size of toon trees had less

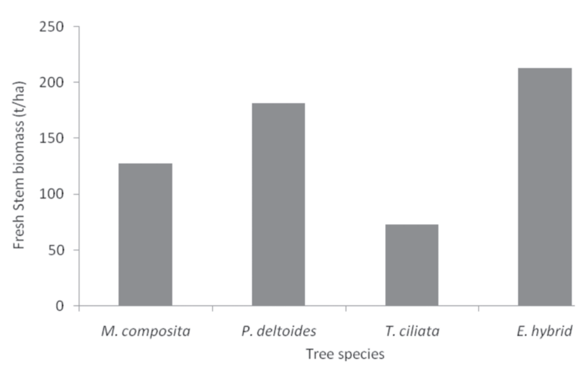

Fig. 1. Fresh stem biomass (t/ha) of tree species at the time of harvesting (M., *Melia*; P., *Populus*; T., *Toona*; E., *Eucalyptus*)

competition for the resources and resulted in higher crop yield under toon than poplar and eucalypt.

The highest and lowest yield of wheat was obtained under toon and eucalypt trees during its first and sixth year of growth respectively (Fig. 2 a). In the alleys, crop grain yield is generally unaffected by the young poplar trees, but grain yield often declines with time the trees grow (Fang *et al.,* 2005; Rivest *et al.,* 2009). The performance of wheat was very poor under eucalypt plantation throughout its rotation. Agroforestry having eucalypt tree could be harmful to crops; Kumar and Nandal (2004) reported that the eucalypt tree belt had more adverse effect on wheat than did the poplar tree belt. Various studies show allelopathic effect of eucalypt leaves on seed germination of crops.

The growth of trees with advancement in their age resulted in gradual yield reduction of the understorey crops (Fig. 3a). The yield of crops decreased consistently and progressively as the age of trees increased, which might be due to increasing competitive interface between trees and crops with the advancing age of trees. The performance of wheat crop was not affected by young toon trees but later on there was reduction in yield up to 62% as compared to open conditions under 6 year- old toon trees (Fig. 3a). While the reductions in yield from open under poplar and *Melia* trees ranged from 5 to 49% and 4 to 45% respectively. With increase in age of plantation the quantum of litterfall increases (0.4–5.9 t/ha in 1- and 6- year- old plantation of poplars) and its adverse effect on plant stand of understorey crop also increased. Maximum proportion (55–60%) of leaf shedding took place in December in a very short period after sowing of wheat in November. It formed a matrix on floor that not only prevented the penetration of light but also act as physical barrier to emerging seedlings. This often resulted in poor plant population of wheat. During wheat crop maturity (March–April) poplar starts sprouting and shade the crop which decreased the light intensity and it becomes one of the limiting factors for reduction in wheat grain yield under poplar interspaces as compared to sole crop (Gill *et al*., 2009).

Reduction in crop productivity is due to the competition for light (Fang *et al*., 2005), water (Wanvestraut *et al*., 2004) and nutrients (Allen *et al*., 2004) at the tree-crop interface, and the magnitude of the competition for each of these resources often differs in terms of the pedo-climatic conditions under which the tree-based intercropping system develops, as well as the age and species composition of the system (Rivest *et al*., 2009). Thus with the increase in age of trees there is increase in height of plants and crown spread (Table 1) which corresponds to increase in shade to underneath crops leading to decrease in grain yield.

Potato: The data on number of tubers/plant and tuber weight/plant under different tree species revealed that it was tuber number/plant that contributed more towards tuber yield than tuber weight/plant (Tables 2 and 3). Amongst the different trees, tubers/plant were maximum under *Melia* plantation than rest of the tree species whereas tuber weight remained at par with each other. There was significant reduction in tuber weight/plant under higher aged plantation irrespective of the tree species (Table 2).

The performance of potato crop under young toon plantation (1st and 2nd year) was at par with open conditions (Fig. 2b). This is due to initial slow growth of toon trees. Averaged over 6 years, the highest yield of potato was

Table 1. Tree growth parameters of different tree species from 1st to 6th year of their age

Plantation age (years)	*Melia composita*	*Populus deltoides*	*Toona*	*Eucalyptus tereticornis*
		Height (m)		
1	3.66	6.84	3.07	6.43
2	6.05	10.19	3.38	10.05
3	8.78	13.66	4.15	12.74
4	10.73	13.59	5.48	15.31
5	14.16	16.41	10.38	21.30
6	15.4	20.3	11.5	24.70
		Diameter at breast height (cm)		
1	4.07	6.00	3.63	5.87
2	8.88	12.17	6.58	12.74
3	13.36	16.87	12.17	16.67
4	15.3	19.5	14.5	20.30
5	17.2	20.9	16.1	20.88
6	18.6	23.6	17.3	23.40
Crown spread (m^2)				
4	33.18	16.27	13.60	16.92

obtained under *Melia* (17.2 t/ha) and the lowest under eucalypt (14.5 t/ha) (Table 4). However, there was no statistical difference in yield between poplar and *Melia*. The challenge in agroforestry system is to retain the positive effects of tree species while limiting the negative effects of competition with crops. Deciduous (*Paulownia fortunei*) and semi-deciduous (*Alnus acuminata*) trees are thought to be less competitive with crops than evergreen species (*Grevillea robusta*) owing to their divergent leafing phenology (Muthuri *et al.,* 2005). Trees which are leafless during the active growth phase of understory crops are particularly preferred. Accordingly, poplar, a fast-growing deciduous tree, is less competitive with winter crops (Puri and Nair, 2004), as they are leafless during winter. Being an evergreen tree species, eucalypt reduced the light availability and adversely affected the understorey crop. Potato yield reduced with advancement in age of plantations due to reduction in yield-contributing parameters. There was maximum reduction (10.5–60.5%) in yield of potato intercropped with eucalypt in the span of 6 years than rest of the tree plantations (Fig. 3a).

Egyptian clover: Toon plantations being slow growing in nature did not show any adverse effect on production of egyptian clover fodder during 1st and 2nd year, the yield being at par with open conditions; however, fodder yield was significantly low under *Melia* and poplar plantations. The fodder yield of egyptian clover was minimum under eucalypt plantation at the end of rotation of trees than rest of tree species (Fig. 2c). The maximum fodder yield was observed under toon plantation at the end of rotation which was at par with fodder yield under poplar plantation.

In poplar, yield reduction of egyptian clover (fodder) was 14.9% in the first year and 55% in the sixth year. Under *Melia* trees, the yield reduced from 22.3 to 59.3% across 6 years (Fig 3a). The corresponding values for toon plantations were 10 to 53.9%. There was 41.3% reduction in yield during the third year under *Melia* and 44.6% under poplar. Under toon trees during initial years of plantation, performance of Egyptian clover and potato crops remained at par with open conditions. However, later on reduction of egyptian clover fodder was more severe under 6 year- old toon plantation (66%) than open fields. Maximum reduction in yield of all understorey crops was observed under higher aged eucalypt plantation.

Pearlmillet: Fodder yield of pearlmillet was higher under toon plantation compared to poplar and *Melia* during different years of tree growth (Fig. 2 d). The trees reduced the crop yield, as the canopy advanced in age. Eucalypt species were usually considered as having less understorey vegetation than the other types of forest stands due to its competition and hydrophobic effects. The potential of growth, adaptability and yield of crops is largely controlled by environmental factors such as water, temperature, photoperiod, radiation, shading and soil nutrient status (Kakiuchi and Kobata, 2004; Kasajima *et al*., 2007). Radiation is an important factor affecting crop photosynthesis, biomass production and economic yield (Kakiuchi and Kobata, 2004). Sanou *et al*. (2012) reported that as PAR decreased, the yield of pearlmillet shade intolerant

Table 2. Crop growth parameters under tree block plantations during different years

Treatments	Wheat			Potato		Turmeric	
	Tillers/m row length (no.)	Ear length (cm)	1,000-grain weight (g)	Tubers/ plant (no.)	Tuber weight/ plant (g)	Rhizome/ plant (no.)	Rhizome weight/plant (g)
Tree species							
M. composita	92.9	7.76	40.9	7.35	310.9	13.5	115.2
P. deltoides	88.0	8.12	40.4	6.63	287.1	12.1	107.2
T. ciliata	92.6	7.72	40.3 c	6.88	284.7	11.9	105.2
E. tereticornis	76.6	7.65	37.5	6.08	246.6	10.0	85.6
Open	104.6	9.17	47.0	12.2	529.1	17.7	184.7
SEm±	2.19	0.15	0.31	0.13	9.09	0.40	5.68
CD (P=0.05)	7.14	0.48	3.19	0.44	29.7	1.32	18.5
Plantation age							
1	97.6	9.02	44.2	8.37	385.3	16.8	170.5
2	95.5	8.41	43.6	8.14	384.2	15.6	163.3
3	97.2	7.41	42.1	8.12	342.4	14.5	150.8
4	88.7	8.0	41.2	7.86	308.8	11.9	96.1
5	84.1	7.90	38.8	7.40	288.9	11.3	71.7
6	81.6	7.75	37.1	7.06	281.1	9.5	65.0
SEm±	2.56	0.15	0.25	0.28	8.94	0.78	4.31
CD (P=0.05)	7.28	0.34	2.20	0.82	25.4	2.22	12.25

crop decreased, whereas the yield of taro, *a shade-tolerant crop,* increased under *Adansonia digitata trees*. Shade imposes a limitation on growth and development of crop plants but varies with shade tolerance of crops. After fourth year, there was drastic reduction in yield of fodder under poplar and *Melia*. This is mainly due to intense shade under canopy leading to etiolated growth of plants which do not mature properly.

Higher reduction in yield in pearlmillet than turmeric indicates better suitability of turmeric under tree canopies (Fig. 3b). Fodder yield of pearlmillet was higher under toon plantation than and *Melia* during different years of

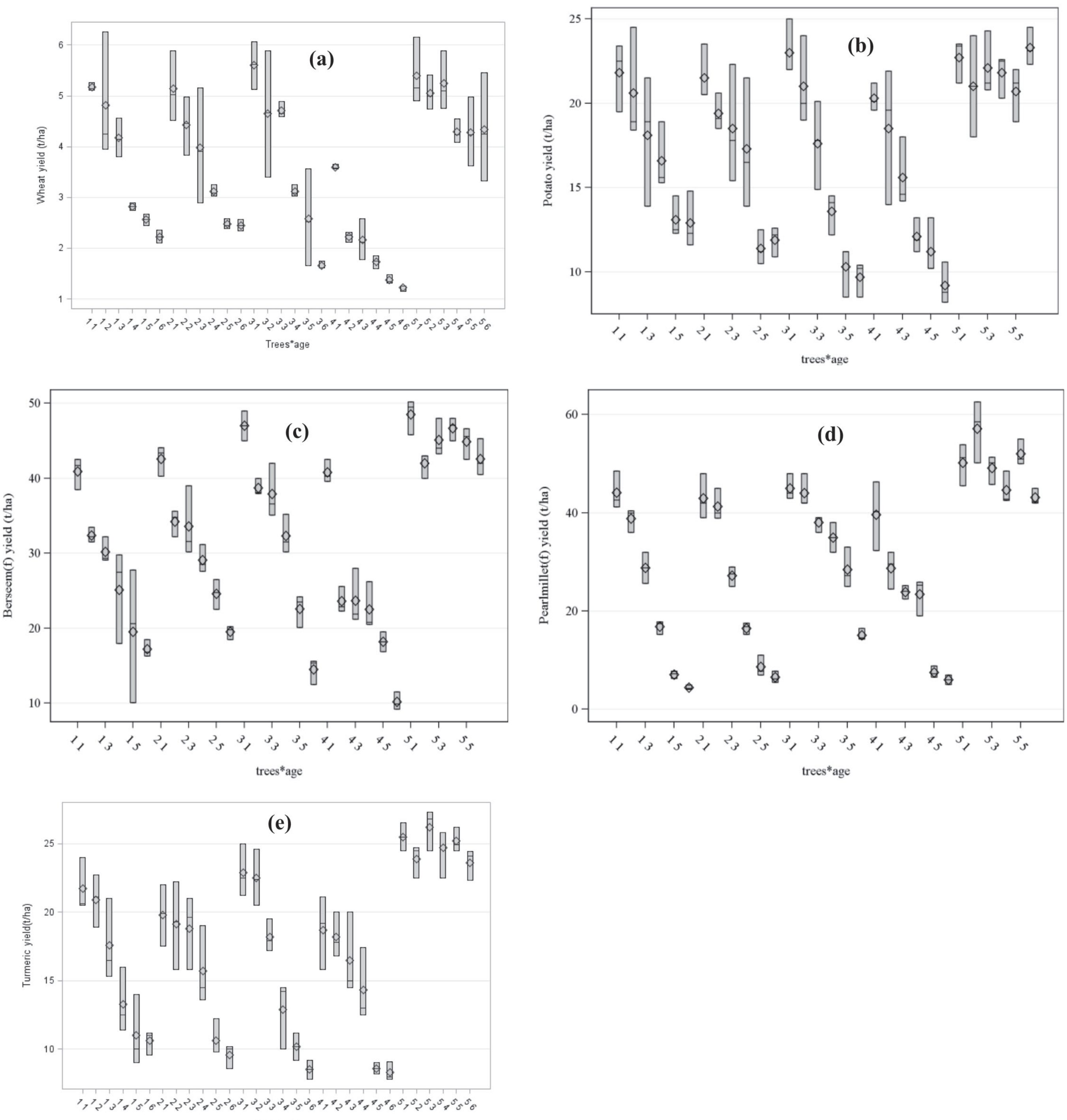

Fig. 2 (a-e). Interaction effect of tree species and their age on crop yield. On x-axis, first digit represents tree species (1, *Melia*; 2, poplar; 3, toon; 4, eucalypt; 5, open). The second digit represents plantation age (1–6: 1st to 6th year of tree growth, respectively).

tree growth. There was 41.3% reduction in yield during the third year under *Melia* and 44.6% under poplar. The trees reduced crop yield, as the canopy spreads with advance in age. The cultivation of pearlmillet under trees after the third year is not feasible due to dense shade of trees during the summer season, as indicated by more than 80% reduction in yield. Kotowskil *et al*. (2000) reported that light availability and intensity had a large effect than water level on biomass production of most plant species.

Turmeric: Turmeric yield was significantly higher under open conditions than that under tree plantations during all the 6 years. During the first year, the yield was significantly higher under toon than *Melia,* but at par with poplar. However during the second year, turmeric yield reduced significantly under poplar and *Melia* as compared to toon trees (Fig 2e). Though turmeric is shade-tolerant crop, there is always an extent of shade that is beneficial, beyond certain limit the shade hampers the yield of turmeric crop. Hossain *et al.* (2009) reported that, turmeric is a partial shade-tolerant plant that could be cultivated at around 59–73% relative light intensity (RLI) for higher yield and curcumin content. However, the degree of RLI required for better turmeric cultivation may vary with the place, year and irradiance level. Under intense shade, the vegetative growth of crop was good but the rhizome formation was very poor leading to drastic reduction in turmeric yield. During the initial years, the crown spread of toon trees was less than that of the poplar and *Melia*.

The per cent yield reduction increased over time across the 6 years, which indicated the development of competitive interface because of shading with increase in age of trees (Fig. 3b). Likewise, the micro-environmental modification under tree canopy and resultant effect on physiology and yield of turmeric grown under poplar canopy was investigated by Dhillon *et al*. (2010). The averaged turmeric yield of six years under poplar, *Melia* and toon was at par and significantly higher than under eucalypts.

There was 14.9% reduction in turmeric yield under 1 year- old poplars and it declined up to 55% in the sixth year. Under *Melia* trees the yield reduced from 22.3% in the first year to 59.3% after 6 years. The corresponding values for toon plantations were 10 to 63.9% respectively. It can be inferred from above results that yields declined

Table 3. Interaction results of crop growth parameters affected by tree species and their age

Crops	Tree species × age of trees	
	F test	P value
Wheat		
Tiller/m row length	1.36	0.1896
Ear length	2.88	0.0013
100-grain weight (g)	1.35	0.1906
Wheat yield	0.26	0.9991
Egyptian clover (fodder) yield	8.27	<.0001
Potato		
Tubers/plant (no.)	1.12	0.3614
Tuber weight/plant (g)	3.56	0.0001
Potato yield	5.39	<.0001
Turmeric		
Rhizome/plant (no.)	7.77	<.0001
Rhizome weight/plant (g)	6.65	<.0001
Turmeric yield	8.75	<.0001
Pearlmillet (fodder) yield	14.61	<.0001

Table 4. Crop yield (t/ha) under tree block plantations during different years

Treatment	Crop yield (t/ha)				
	Wheat	Potato	Egyptian clover	Pearlmillet	Turmeric
Trees					
M. composita	3.63	17.2	27.6	23.3	15.9
P. deltoides	3.60	16.7	30.6	23.9	15.6
T. ciliata	3.72	15.9	32.2	34.3	15.9
E. tereticornis	2.05	14.5	23.2	21.5	14.1
Open	4.77	21.9	44.9	49.3	24.9
SEm±	0.05	0.39	0.67	0.71	0.39
CD (P=0.05)	0.33	1.29	2.19	2.31	1.27
Plantation age (year)					
1	4.98	21.9	43.9	44.4	21.7
2	4.23	20.1	34.2	41.9	20.9
3	4.05	18.4	34.1	33.4	19.4
4	3.02	16.3	31.1	27.3	16.1
5	2.65	13.3	25.9	20.7	13.7
6	2.38	13.4	20.8	15.0	12.2
SEm±	0.12	0.43	0.967	0.75	0.36
CD (P=0.05)	0.33	1.22	1.91	2.13	1.02

significantly with the increase in age of plantations due to negative interaction between the tree and the crop. The comparison yield-attributing factors of turmeric revealed that, the rhizome weight/plant contributed more to the lower rhizome yield under eucalypt than number of rhizomes/plant.

Soil fertility

Soil organic carbon, available N and P varied significantly under tree species. Soil OC and available nutrients improved under all the tree species after 6 years compared to the initial status (Table 5). The highest increase of 21.2% in OC was observed under *Melia* over the initial content (2.83 g/kg), whereas the increase was the lowest in eucalypt (13.4%). Similarly, the increase in available N was the highest under *Melia* over the initial status. The increase in available P over the initial status was the maximum in poplar (36%) and the minimum in eucalypt (19.3%). Nair *et al*. (2009) found that in comparison to monocropping systems, trees in agroforestry systems can enhance soil organic matter levels by adding a substantial quantity of organic carbon which, in turn, rejuvenate soil fertility upon decomposition. Masoodi *et al*. (2013) reported that, soils developing under *U. wallichiana* were more fertile and had 6.5%, 22.7% and 19.3% more available N, P and K content compared to soils developing under *P. deltoides*. The differential increase in soil OC and available nutrients under various tree species may be owing to variable addition and decomposition of litterfall as well as variable nutrient uptake by the intercrops and the trees.

Table 5. Soil organic carbon and available nutrients under different tree species 6 years after planting

Tree species	Soil properties		
	Organic carbon (g/kg)	Available N (kg/ha)	Available P (kg/ha)
M. composita	3.43	139.1	14.6
P. deltoides	3.25	135.5	15.6
Toona ciliata	3.23	135.8	15.0
E. tereticornis	3.21	130.3	13.7
SEm±	0.027	1.68	0.38
CD (P=0.05)	0.08	5.3	1.2
Initial	2.83	125.4	11.5

Economics

Profitability from different intercropping combinations depends on their comparative performance under trees as well as their market prices (Table 6). As the crops performed well under toon trees during initial 2–3 years, accordingly their returns were high and in later years the

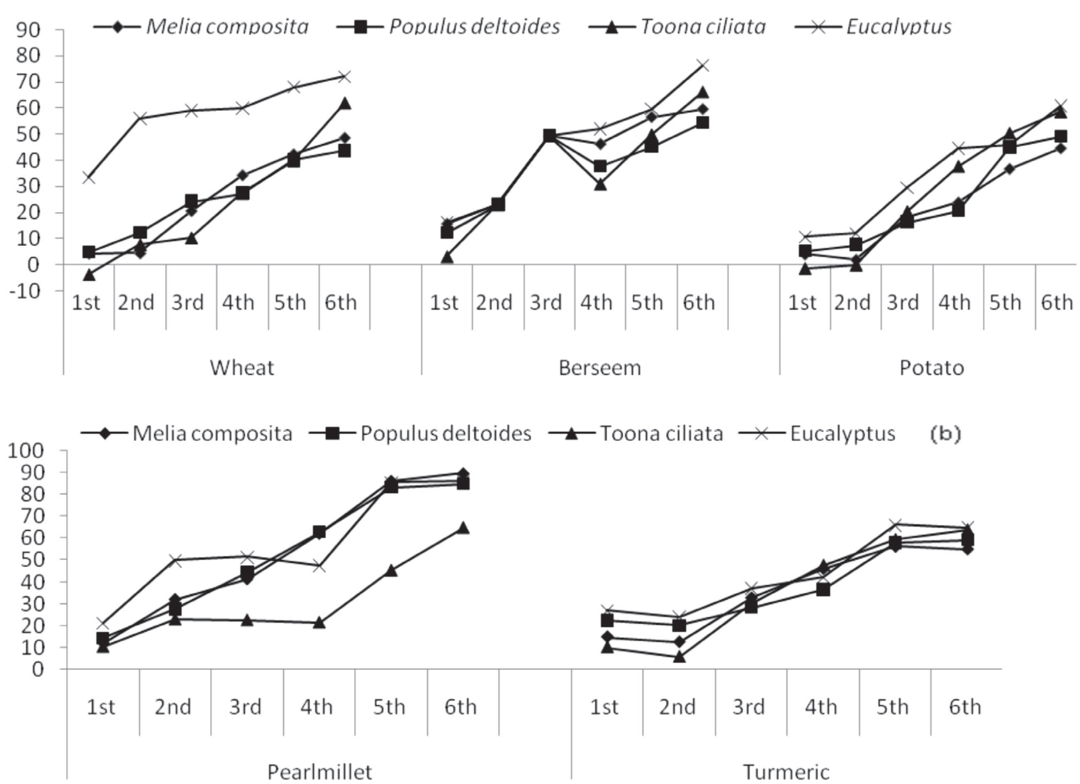

Fig. 3. (a-b). Reduction (%) in yield of crops under tree species (1st to 6th year of age) compared to sole crops

Table 6. Net returns (× 10³₹/ha) from crops under trees during different years

Tree species	Age (years) 1	2	3	4	5	6	Total	Grand Total *
Wheat								
Melia composita	46.9	43.8	37.9	25.6	23.2	20.2	197.7	933.1
Populus deltoides	46.7	40.1	36.1	28.3	22.4	22.3	196.0	1,430.0
Toona ciliata	50.9	42.2	42.8	28.4	23.5	15.1	202.9	681.4
Eucalyptus tereticornis	37.1	22.8	35.8	26.5	19.4	16.7	158.3	1,294.7
				Potato				
Melia composita	47.4	49.8	41.6	35.0	8.0	10.3	192.3	927.7
Populus deltoides	46.8	47.0	42.5	36.5	7.0	9.5	189.3	1,423.2
Toona ciliata	50.7	50.8	40.4	28.7	6.3	7.8	184.7	663.2
Eucalyptus tereticornis	48.2	47.9	40.4	28.7	6.3	7.2	178.9	1,315.4
				Egyptian clover				
Melia composita	42.1	29.6	27.3	20.4	13.4	8.1	141.1	876.6
Populus deltoides	43.8	31.2	30.4	23.6	16.9	9.2	155.4	1,389.4
Toona ciliata	48.4	35.4	34.3	26.2	15.5	6.9	166.8	645.3
Eucalyptus tereticornis	42.0	22.4	21.6	18.3	12.5	4.8	121.7	1,258.2
				Pearlmillet				
Melia composita	31,625	26.8	17.9	7,095	-	-	78,760	814.2
Populus deltoides	30,635	29.1	16.4	4,290	-	-	80,465	1,314.5
Toona ciliata	25,300	24.7	21.4	19,690	-	-	1,15,610	594.1
Eucalyptus tereticornis	30,360	30.6	15.3	4,510	-	-	80,905	1,217.4
				Turmeric				
Melia composita	1,07,635	100.1	84.4	55.4	25.9	18.8	392.3	1.127.8
Populus deltoides	98,175	92.4	90.2	65.4	25.0	17.0	388.2	1.622.2
Toona ciliata	1,13,575	108.8	87.3	53.7	24.0	15.0	402.6	881.1
Eucalyptus tereticornis	99,660	90.4	72.4	43.3	20.5	14.0	340.4	1.476.9

*Includes net return from *Melia*, poplar, toon and eucalypt, i.e. 7,35,515; 12,33,980; 4,78,500 and 11,36,520₹/ha (Based on market price of merchantable stem @ 6,000; 7,000; 7,000 and 5,500₹/t for *Melia*, poplar, toon and eucalypt respectively).

profits were better under *Melia* and poplar plantations. Total net returns of wheat and egyptian clover after 6 years were maximum in toon-based agroforestry system and from potato was maximum in *Melia*-based agroforestry system. During the summer season, the cultivation of pearlmillet fodder was not found economical under poplar and *Melia* in 5th and 6th year. Overall the net returns from turmeric were found to be maximum under toon during 6 years.

The net returns from merchantable stem were highest of poplar plantation followed by eucalypt trees. At the end of rotation amongst different agroforestry systems, intercropping of turmeric in poplar and eucalypt block plantation proved to be highly remunerative, followed by poplar + wheat. Harvesting of tree component being of non-perishable nature, could be advanced or delayed depending at market price of wood. Most of tree species are sold on weight basis, so holding trees for 1 or 2 years even end up giving higher profit to farmers. The reduced yield of the crops under the tree canopies, lowers down the annual profitability margin than sole crop cultivation, but the overall profitability of the intercropping system after tree harvesting is substantially high than traditional crop cultivation. Several studies in different parts of the country indicated that agroforestry is more profitable to farmers than agriculture or forestry for a particular area of land (Samra *et al.*, 1999). This encourages the farmers to invest in this sector and considers it a best performing low risk asset in near future.

It can be concluded that toon had the lowest growth rate, whereas eucalypt and poplar had higher growth parameters than the other tree species. Toon plantation had the minimum adverse effect on the intercrops, where as eucalyptus caused maximum reduction in yield of all the intercrops. The best tree crop combination giving the higher economic return was poplar–turmeric followed by *Eucalyptus*–turmeric. Therefore, deciduous trees and shade bearing crops should be preferred for higher productivity and profitability in agroforestry systems.

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