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Carbon sequestration and nutrient removal by some tree species in an agrisilviculture system in Punjab, India

Baljit Singh* and R.I.S. Gill
Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana-141 004, India
*Corresponding author email: singh-baljit@pau.edu
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Abstract
Trees have a significant potential to mitigate climate change by sequestering atmospheric carbon in the biomass and underneath soil. An investigation was conducted to quantify the biomass production, C and CO_2 storage in the biomass, nutrient content (N, P and K) and their removal by five tree species (5 x 4 m spacing) namely toon (*Toona ciliata*), maharukh (*Ailanthus excelsa*), dek (*Melia azedarach*), poplar (*Populus deltoides*) and eucalyptus (*Eucalyptus tereticornis*) after seven years of growth in an agrisilviculture system (trees intercropped with pearlmillet - wheat rotation) in Punjab. Depthwise (0-15, 15-30 and 30-45 cm) status of soil organic carbon (OC) and available N, P and K in the surface soil (0-15 cm) were also determined before planting and at the time of harvesting of the trees. The DBH and height of poplar and eucalyptus were significantly higher than the other species after seven years of age. The aboveground (stem, branches and leaves) and belowground (roots) fresh biomass was the lowest (100 and 23 t/ha, respectively) in toon and the highest in eucalyptus (255 and 72 t/ha, respectively), whereas the dry biomass was the lowest (49 and 11.2 t/ha, respectively) in toon and the highest in poplar (134 and 33.2 t/ha, respectively). Carbon sequestration by poplar, eucalyptus, dek, maharukh and toon was 54.9, 48.0, 43.3, 20.8 and 19.1 t/ha, respectively. Similarly, CO_2 storage by these species was 201, 176, 159, 77 and 70 t/ha, respectively. The removal of N by different tree species was in the order of poplar (839 kg/ha)>eucalyptus>dek>maharukh>toon (365 kg/ha). Similarly, the removal of P and K from soil was the lowest (P: 30.3 kg/ha, K: 223 kg/ha) by toon and the highest (P: 107 kg/ha, K: 609 kg/ha) by poplar. Soil OC stock seven years after planting was highest under poplar (7.50 t/ha in 0-15 cm depth) and it was higher by 15.6% over its initial level (6.49 t/ha). Available N, P and K were highest under poplar (137.4 kg/ha), dek (15.29 kg/ha) and toon (189.1 kg/ha), respectively at the end of the experiment. Poplar, eucalyptus and dek had higher biomass production and thus more C and CO_2 sequestration than maharukh and toon.

Keywords: Available nutrients, Biomass, Carbon sequestration, Growth parameters, Nutrient removal, Soil OC

Abbreviations: DBH: Diameter at breast height; **GBH:** Girth at breast height; **OC:** Organic carbon

Introduction
Agrisilviculture system is a good alternative to enhance the tree cover and meet the shortage of industrial timber in addition to conserving the environment. Trees in agrisilviculture system offer a significant potential to sequester substantial quantities of atmospheric carbon, thus forming an important option for mitigating change in the climate (Singh *et al.*, 2000; Mohapatra, 2008). Trees capture and store atmospheric carbon dioxide in biomass and the underneath soil. The average amount of C stored in the aboveground components of agroforestry systems had been estimated to range between 0.29-15.21 t/ha/yr (Nair *et al.*, 2009). The importance of agrisilviculture systems in CO_2 mitigation has become more widely recognized from industrialized and developing countries. Similarly, soils play an important role in carbon cycle. Different components of soil organic matter have variable residence time, ranging from very labile to stable forms. The impact of an agrisilviculture system on soil carbon depends on the amount and quality of inputs provided by the tree and non tree components and the soil properties. Higher soil organic carbon and nutrient content in agrisilviculture systems have been observed than the adjacent sites without trees (Pandey *et al.*, 2000; Singh and Sharma, 2007).

On the other hand, the fast growing trees in agrisilviculture systems may lead to considerable removal of nutrients from soil, thus requiring a balanced application of nutrients. A large amount of nutrients accumulated in the biomass components of the standing trees is removed permanently from the site and some quantity is returned to the soil through litterfall (Tandon *et al*., 1996; Negi and Tandon, 1997; Singh *et al*., 2007). The farmers of Punjab are growing fast growing tree species such as poplar, eucalyptus and dek on their agricultural fields. Such species are being grown as blocks or on field boundaries. Therefore, the present investigation was conducted to quantify the biomass production, carbon and CO_2 storage, nutrient content (N, P and K) and their removal by different tree species namely toon (*Toona ciliata*), maharukh (*Ailanthus excelsa*), dek (*Melia azedarach*), poplar (*Populus deltoides*) and eucalyptus (*Eucalyptus tereticornis*) after seven years of growth in an agrisilviculture system in Punjab. Soil organic carbon (OC) and available nutrients in the soil were also determined to find out the impact of the system on soil health.

Materials and Methods

Experimental treatments and observations

The study was conducted in an experiment having five tree species namely toon, maharukh, dek, poplar and eucalyptus planted at a spacing of 5 x 4 m (500 trees/ha) and intercropped with pearl millet-wheat rotation in three replications. The agricultural crops *i.e*. pearl millet and wheat were grown as intercrops in *kharif* (summer) and *rabi* (winter) season, respectively. The nutrients recommended to pearl millet and wheat were applied @ 100 kg/ha N and 125: 60 kg/ha N: P_2O_5, respectively. K was not applied because the soil of the experimental site was not deficient in available K (initial content - 193.3 kg/ha). Pearl millet was grown during initial four years of tree growth whereas wheat for seven years. Girth at breast height (GBH) of trees was measured by measuring tape at 1.37 m from ground level and converted to DBH using the formula DBH = GBH/π. Height of trees (metres) was recorded from base of the tree to growing tip with the help of Ravi Multimeter. Different parameters *i.e*. fresh biomass, dry biomass, carbon, carbon dioxide, nitrogen, phosphorus and potassium contents of the aboveground and belowground components of various tree species were determined after completion of seven years of tree age. The depth wise (0-15, 15-30 and 30-45 cm) status of soil OC and available N, P and K in the surface soil (0-15 cm) were also determined before planting and at the time of harvesting of the trees.

Sampling technique

The mean tree technique was used for estimation of tree biomass and carbon content (Negi and Tandon, 1997; Fang *et al*., 2010). The technique involves the destructive sampling of trees that best represent the mean size of a plantation. The selection of sample trees was based on the average DBH, height and crown features. 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. Crown shape was selected visually in such a way that the crown of selected mean trees represented whole of the population. Three trees of each species were cut at ground level in January 2012 after about seven years of planting. Aboveground part of each sampled tree was divided into three components namely stem, branches and leaves. Stem was cut into different segments which were weighed for estimation of fresh biomass. Similarly whole of branches and leaves were weighed. Roots were extracted by excavating laterally and vertically around the tree stem. Roots were divided into two parts *i.e*. < 5 mm diameter and > 5 mm diameter and their fresh weight was taken. Stem samples from lower, middle and upper part of tree; branches, leaves and root samples were transported to the laboratory for estimation of dry biomass. The samples were oven dried at 60 ± 5°C till a constant weight and weighed. Dry biomass of different components of whole tree was calculated from dry biomass of samples. Carbon (C) content per tree was estimated from dry biomass taking 51% as average C content in the tree components (IPCC, 2000). Carbon dioxide (CO_2) concentration in each tree was calculated by multiplying C concentration by 3.67 (Molecular weight of CO_2/Molecular weight of C). Fresh biomass, dry biomass, carbon and carbon dioxide on per hectare basis was estimated assuming 10% mortality (450 trees/ha).

Plant and soil analysis

For estimation of nutrient concentration (N, P and K) in different components of trees, samples were taken from lower, middle and upper parts of stem from the trees of different growth parameters (lower than, more than and that of trees having mean DBH and height). These samples of stem, branches, leaves and roots were oven dried at 60 ± 5°C. For determination of total N in different components, a known weight of the sample was digested in concentrated H_2SO_4. For determination of P and K, the samples were digested in diacid mixture of HNO_3 and $HClO_4$ in the ratio of 3:1. Nitrogen in the digest was estimated by distillation with Kjeldahl assembly using boric acid indicator solution (Jackson, 1973). Phosphorus concentration in the digest was determined by employing vanadomolybdate phosphoric yellow colour method in the nitric acid system. Potassium in the digest was determined by using a flame photometer. The concentration values of these nutrients were multiplied by dry biomass of different plant parts to get the nutrient content and their removal by different plant parts.

The soil samples were air dried and ground to pass through a 2 mm sieve. The samples were analysed for basic physico-chemical properties, soil OC, available N, P and K by standard methods. The available N in the soil samples was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956), OC by Walkley and Black method, available P by Olsen method and available K by neutral normal ammonium acetate method (Jackson, 1973). These properties (0-15 cm layer) at the time of initiation of the experiment were: pH (1:2) - 8.1, EC - 0.39 dS/m, OC - 2.83 g/kg, available N -125.4 kg/ha, available P - 11.51 kg/ha, available K -193.3 kg/ha and textural class-loamy sand. For determination of soil OC stock (t/ha), bulk density (BD) of the different soil layers (0-15, 15-30 and 30-45 cm) was determined with the help of cylindrical iron rings. Soil OC concentration (g/kg) in the soil samples was converted to total soil OC storage in different layers as described below:

$$\text{Soil OC storage (t/ha) in 15 cm soil layer} = \frac{SOC}{1000} \times BD \times 1500$$

Where, BD is the bulk density of 15 cm soil layer (t/m^3); 1500 is the volume of 15 cm soil layer (m^3) of a hectare; SOC is soil organic carbon in g/kg.

Statistical analysis

The data were subjected to statistical analysis using ANOVA technique in randomized block design taking different tree species as treatments. Mean separation was done with the critical difference (CD) test at 5% level of significance (Panse and Sukhatme, 1985). All statistical analyses were performed using CPCS-1 statistical software developed by Punjab Agricultural University, Ludhiana.

Results and Discussion

Growth parameters and biomass of trees

The growth parameters (DBH and height) of different tree species varied significantly during different years (Table 1). The DBH of poplar (24.84 cm) and eucalyptus (24.20 cm) was statistically at par but significantly higher than the other species whereas the DBH of toon was the lowest (17.20 cm) after seven years of age. The height of eucalyptus (25.77 m) was the highest and in toon the lowest (12.82 m). Among different tree species, the species ranking was poplar > eucalyptus > maharukh > dek > toon for DBH and eucalyptus > poplar > dek > maharukh > toon for height after 7-year growth of tree species. The variation in growth parameters of the tree species might be due to different genetic makeup and thus their variable growth potential as the environmental and cultural conditions were similar for all the species in the study. Dhyani and Tripathi (1999) observed that *Albizia falcataria* (Albizia) and *Alnus nepalensis* (Alder) had better height and diameter than *Prunus cerasoides* (Cherry) after 7 years of growth in north-east India and their performance was better in intercropped situation than pure trees. Jaimini and Tikka (2001) evaluated fifteen multipurpose tree species for growth and biomass production in Gujarat and observed that *Eucalyptus tereticornis* and *Albizia lebbeck* attained the maximum height after eleven years of age whereas *Tecomella undulata* and *Acacia nilotica* were slow in growth.

The aboveground (stem, branches and leaves), belowground (roots) and total fresh biomass was the lowest (100, 23 and 123 t/ha, respectively) in toon and the highest in case of eucalyptus (255, 72 and 327 t/ha, respectively) (Table 2). Among different aboveground components, fresh weight of stem, branches and leaves was significantly higher in case of eucalyptus, dek and poplar, respectively and the lowest in case of toon. On the other hand, dry biomass of tree species have different trend than fresh biomass due to variation in moisture content of these tree species. The greatest moisture content in stem, branches and leaves was in maharukh (62, 65, and 76%, respectively); in stem, the lowest was in dek and poplar (34 and 41%, respectively) and in branches, the lowest was also in dek and poplar (40% in both species) whereas in leaves, eucalyptus had minimum moisture content (46%). The aboveground, belowground (roots) and total dry biomass was the lowest (49, 11.2 and 60 t/ha, respectively) in toon and the highest in poplar (134, 33.2 and 167 t/ha, respectively) (Table 3). The higher dry biomass of poplar than eucalyptus may be due to lower moisture content of stem and branches of poplar than eucalyptus. Among different aboveground components dry biomass of stem, branches and leaves was higher in case of poplar, dek and eucalyptus, respectively than other tree species. The dry biomass of stem and leaves was the lowest in toon whereas maharukh had the lowest dry weight of branches. Dry biomass of roots > 5 mm diameter was maximum in poplar and minimum in toon whereas biomass of roots < 5mm diameter was the lowest in maharukh and the highest in case of dek. Nadagouda *et al*. (1997) observed the performance of seven tree species namely, *Acacia auriculiformis, Azadirachta indica, Dendrocalamus strictus, Dalbergia sissoo, Eucalyptus* *tereticornis, Leucaena leucocephala* and *Tectona grandis* in Karnataka and observed that *Eucalyptus* produced the highest wood yield (105 t/ha) and *Tectona grandis* the lowest (28.1 t/ha) after 5 years of growth. Kaur *et al.* (2002) observed significant variation in the biomass production by three tree species namely *Acacia nilotica, Dalbergia sissoo* and *Prosopis juliflora* in northwestern India.

Carbon and carbon dioxide sequestration by trees

The carbon and carbon dioxide content and their sequestration in different tree components varied significantly among various tree species (Tables 4 and 5). The C content in aboveground, belowgroundand total biomass of trees was the lowest in toon (25.1, 5.7 and 30.8 t/ha, respectively) and the highest (68.0, 16.9 and 84.9 t/ha, respectively) in poplar. Likewise, the CO_2 content in aboveground, belowground and total biomass of trees was the lowest in toon and the highest in poplar. The highest C and CO_2 in poplar were due to higher dry biomass of poplar than the other tree species. Among different aboveground components, C and CO_2 in stem, branches and leaves were higher in case of poplar, dek and eucalyptus, respectively than other tree species. The C and CO_2 in stem and leaves were the lowest in toon whereas in branches, these were the lowest in maharukh. Their content in roots > 5 mm diameter were maximum in

Table 1. Growth parameters of various tree species planted in February/March 2005 during different years in an agrisilviculture system at Ludhiana, Punjab

Tree species	Jan 2006	Jan 2007	Jan 2008	Jan 2009	Jan 2010	Jan 2011	Jan 2012
DBH (cm)							
Toona ciliata	2.27	5.58	10.82	14.06	15.33	16.36	17.20
Ailanthus excelsa	2.56	6.15	13.56	17.62	19.43	21.34	22.29
Melia azedarach	4.07	9.56	13.17	15.13	17.42	19.31	21.66
Populus deltoides	6.00	11.06	16.87	19.82	21.91	23.15	24.84
Eucalyptus tereticornis	5.67	12.63	16.57	19.51	21.29	23.06	24.20
CD (P=0.05)	0.38	0.45	0.42	0.66	0.72	0.77	0.75
Height (m)							
Toona ciliata	1.62	3.02	3.53	5.41	9.65	11.64	12.82
Ailanthus excelsa	1.44	2.16	4.17	7.73	10.88	12.81	14.13
Melia azedarach	3.66	5.63	8.56	10.23	13.60	16.38	18.68
Populus deltoides	6.84	9.76	11.53	14.75	17.85	20.43	22.30
Eucalyptus tereticornis	6.51	9.95	12.58	15.60	19.62	23.36	25.77
CD (P=0.05)	0.34	0.37	0.38	0.45	0.68	0.73	0.88

Table 2. Fresh biomass (t/ha) of above and below ground components of different tree species after 7 years of age

Tree species	Aboveground				Belowground			Grand Total
	Stem	Branches	Leaves	Total	Roots		Total	
					(<5mm)	(>5mm)		
Toona ciliata	73	22.3	4.8	100	1.26	21.7	23.0	123
Ailanthus excelsa	108	23.6	16.4	148	1.13	56.3	57.4	205
Melia azedarach	128	36.5	12.2	177	1.17	37.1	38.3	215
Populus deltoides	182	31.1	22.1	235	1.08	55.3	56.4	292
Eucalyptus tereticornis	213	25.7	16.1	255	1.26	70.7	72.0	327
CD (P=0.05)	7.5	4.1	2.4	10.7	0.10	3.1	3.5	16.9

Table 3. Dry biomass (t/ha) of above and below ground components of different tree species after 7 years of age

Tree species	Aboveground				Belowground			Grand Total
	Stem	Branches	Leaves	Total	Roots		Total	
					(<5mm)	(>5mm)		
Toona ciliata	37	10.1	1.59	49	0.60	10.6	11.2	60
Ailanthus excelsa	41	8.2	3.99	53	0.41	21.4	21.8	75
Melia azedarach	85	22.0	5.16	112	0.73	24.0	24.7	137
Populus deltoides	108	18.8	6.87	134	0.62	32.6	33.2	167
Eucalyptus tereticornis	94	11.0	8.67	114	0.56	30.5	31.1	145
CD (P=0.05)	3.8	2.5	0.96	5.0	0.07	2.9	3.0	4.7

poplar and minimum in toon whereas in roots < 5 mm diameter their content was the lowest in maharukh and the highest in case of dek. All the components of these tree species cannot be considered as sequestering C and CO_2, because all the components are either not removed from the fields or have different end utilization. Leaves fall on the ground and enrich the soil, branches are used mainly as fuelwood, large roots are removed but used for fuel or coal making and smaller roots decompose in the soil. Stem is removed after harvesting of the trees and has various multiple commercial uses. Therefore, C and CO_2 stored in the stem portion of trees can be considered as sequestered C and CO_2. Thus, C and CO_2 sequestration in the different tree species was in the order of poplar > eucalyptus > dek > maharukh >toon (Tables 4 and 5). Carbon storage by three tree species (*Acacia nilotica, Dalbergia sissoo* and *Prosopis juliflora*) was observed in a silvipastoral system by Kaur *et al*. (2002). They observed that carbon storage increased significantly due to integration of *Dalbergia* and *Prosopis* in the system. They observed that the aboveground carbon content was greater in bole and branches as compared to foliage. Reddy *et al*. (2009) observed that among different tree species in Andhra Pradesh, the carbon sequestration by different components of *Luecaena leucocephala* was the highest (7 t/ha/yr) and it was followed by *Eucalyptus camaldulensis* (5.35 t/ha/yr) and *Albizia lebbeck* (2.98 t/ha/yr).

Nutrient removal by trees

The nutrient (N, P and K) content of different components of trees indicated that the content of these nutrients was the highest in stem portion of all the tree species (Tables 6-8). The total N content in aboveground parts varied from 273 kg/ha in maharukh to 706 kg/ha in poplar and in roots from 80 kg/ha in toon to 197 kg/ha in eucalyptus (Table 6). The grand total content of N was minimum in toon and maximum in poplar. Among aboveground components, N content was higher in stem of all the tree species as compared to branches and leaves. Kaur *et al*. (2002) observed that the aboveground nitrogen content was greater in bole and branches as compared to foliage. Considering return of leaves to soil and decomposition of small roots in the soil, the removal (through stem, branches and large roots) of N by the different tree species was in the order of poplar>eucalyptus>dek>maharukh>toon. The total P content in aboveground parts varied from 25.9 kg/ha in toon to 101.7 kg/ha in poplar and in roots from 6.3 kg/ha in toon to 32.4 kg/ha in eucalyptus (Table 7). The P content varied significantly among tree species in different components of trees. Like N, the removal of P from soil was the lowest in toon and the highest in poplar. The total K content in aboveground parts was the lowest in toon and the highest in poplar (Table 8). Among aboveground components, K varied from 138 kg/ha (toon) to 397 kg/ha (poplar) in stem, 28 kg/ha (maharukh) to 87 kg/ha (dek) in branches and 8 kg/ha (toon) to 51 kg/ha (eucalyptus) in leaves. The removal of K from soil was the lowest (223 kg/ha) in toon and the highest (609 kg/ha) in poplar. The lowest removal of nutrients by toon and the highest by poplar may be primarily due to the lowest and the highest dry biomass of these tree species, respectively. Among nutrients, the removal of N was maximum and that of P minimum by all the tree species. Negi and Tondon (1997) observed that among three nutrients (N, P and K), N content was maximum and K minimum in different components of poplar plantations. Tandon *et al.* (1996) studied the distribution of nutrients (N, P, K, Ca and Mg) in various plant parts of eucalyptus and observed that a major portion of nutrients were stored in the bole.

Table 4. Carbon content and sequestration (t/ha) in above and below ground components of different tree species after 7 years of age

Tree species	Aboveground				Belowground				Carbon sequestration
	Stem	Branches	Leaves	Total	Roots (<5mm)	Roots (>5mm)	Total	Grand Total	
Toona ciliata	19.1	5.16	0.81	25.1	0.31	5.4	5.7	30.8	19.1
Ailanthus excelsa	20.8	4.18	2.03	27.0	0.21	10.9	11.1	38.1	20.8
Melia azedarach	43.3	11.23	2.63	57.2	0.37	12.2	12.6	69.7	43.3
Populus deltoides	54.9	9.57	3.50	68.0	0.31	16.6	16.9	84.9	54.9
Eucalyptus tereticornis	48.0	5.62	4.42	58.0	0.28	15.5	15.8	73.9	48.0
CD (P=0.05)	2.0	1.24	0.49	2.6	0.04	1.5	1.5	2.4	2.0

Table 5. Carbon dioxide content and sequestration (t/ha) in above and below ground components of different tree species after 7 years of age

Tree species	Aboveground				Belowground				CO_2 sequestration
	Stem	Branches	Leaves	Total	Roots (<5mm)	Roots (>5mm)	Total	Grand Total	
Toona ciliata	70	18.9	2.98	92	1.12	19.9	21.0	113	70
Ailanthus excelsa	77	15.3	7.46	100	0.77	40.0	40.8	141	77
Melia azedarach	159	41.2	9.65	210	1.36	44.9	46.3	256	159
Populus deltoides	201	35.1	12.86	249	1.15	61.1	62.2	311	201
Eucalyptus tereticornis	176	20.6	16.23	213	1.04	57.0	58.0	271	176
CD (P=0.05)	7.1	4.6	1.81	9.4	0.14	5.5	5.5	8.9	7.1

Table 6. Nitrogen content and removal (kg/ha) by above and below ground components of different tree species after 7 years of age

Tree species	Aboveground				Belowground				N* removal
	Stem	Branches	Leaves	Total	Roots (<5mm)	Roots (>5mm)	Total	Grand Total	
Toona ciliata	221	70	16	307	5.7	74	80	387	365
Ailanthus excelsa	190	53	30	273	3.5	149	153	426	392
Melia azedarach	462	130	40	632	5.3	157	162	794	749
Populus deltoides	551	108	47	706	4.2	180	184	890	839
Eucalyptus tereticornis	504	70	72	646	4.3	192	197	842	766
CD (P=0.05)	15.0	4.2	4.0	15.4	0.3	7.2	7.2	19.8	18.1

* Stem + branches + roots having >5 mm diameter

Table 7. Phosphorus content and removal (kg/ha) by above and below ground components of different tree species after 7 years of age

Tree species	Aboveground				Belowground				P* removal
	Stem	Branches	Leaves	Total	Roots (<5mm)	Roots (>5mm)	Total	Grand Total	
Toona ciliata	17.9	6.48	1.53	25.9	0.43	5.9	6.3	32.2	30.3
Ailanthus excelsa	22.9	5.24	5.10	33.2	0.46	22.2	22.7	55.9	50.3
Melia azedarach	40.8	15.86	6.19	62.9	0.52	11.5	12.0	74.9	68.2
Populus deltoides	77.5	16.52	7.69	101.7	0.50	13.1	13.6	115.3	107.1
Eucalyptus tereticornis	37.6	7.94	7.63	53.2	0.67	31.7	32.4	85.5	77.2
CD (P=0.05)	4.8	1.38	1.47	6.7	0.08	2.5	2.5	7.5	7.2

* Stem + branches + roots having >5 mm diameter

Table 8. Potassium content and removal (kg/ha) by above and below ground components of different tree species after 7 years of age

Tree species	Aboveground				Belowground				K* removal
	Stem	Branches	Leaves	Total	Roots (<5mm)	Roots (>5mm)	Total	Grand Total	
Toona ciliata	138	39	8	185	2.8	46	49	234	223
Ailanthus excelsa	143	28	19	190	1.7	85	87	277	256
Melia azedarach	325	87	28	440	3.1	76	79	519	488
Populus deltoides	397	83	36	516	3.2	129	132	648	609
Eucalyptus tereticornis	296	42	51	389	2.7	143	146	535	481
CD (P=0.05)	22.5	3.8	2.8	23.8	0.8	6.8	6.8	24.3	24.2

* Stem + branches + roots having >5 mm diameter

Table 9. Soil organic carbon and available nutrients in the surface soil depth (0-15 cm) under different tree species at the time of planting and harvesting of trees

Tree species	Organic carbon (g/kg)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Toona ciliata	3.08	134.5	13.80	189.1
Ailanthus excelsa	3.06	128.1	13.15	187.5
Melia azedarach	3.19	132.3	15.29	178.5
Populus deltoides	3.35	137.4	14.19	185.0
Eucalyptus tereticornis	3.20	128.1	12.96	181.4
CD (P=0.05)	0.18	6.34	1.35	7.06
Initial	2.83	125.4	11.51	193.3

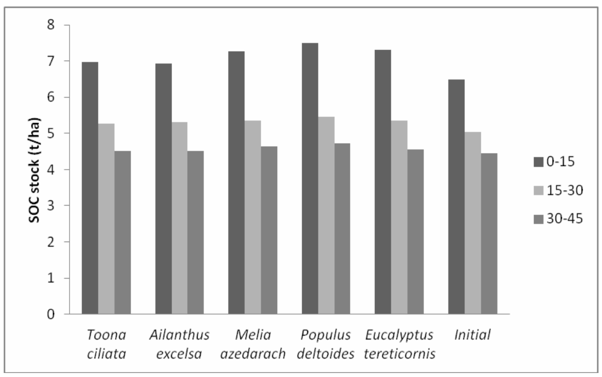

Fig 1. Soil organic carbon (SOC) stock in different soil depths under various tree species at the time of planting and harvesting of trees at Ludhiana, Punjab

Soil OC and available nutrients

The soil OC and available nutrients (N, P and K) varied significantly under various tree species (Table 9). Soil OC was higher under all the tree species at the time of harvesting of trees over its initial level (Table 9, Fig. 1). Soil OC stock in surface layer was the highest under poplar (7.50 t/ha) and the lowest under maharukh (6.93 t/ha) and it was higher by 15.6% in poplar and 6.8% in maharukh over its initial level (6.49 t/ha) (Fig. 1). In the lower depths, soil OC stock was also higher under poplar than the other tree species. It was higher by 8.1 and 6.5% in 15-30 and 30-45 cm soil depth, respectively over its initial level (5.04 and 4.44 t/ha, respectively). The available N and P were higher under trees over their initial level (Table 9). Available N and P were the highest under poplar and dek, respectively. Conversely, the available K content decreased under various tree species over its initial level and the decrease was the highest under dek and the lowest under toon. Despite uptake of K from the soil by trees and crops, a minor change in available K status of soil may be due to release of K from the mineral and non exchangeable forms of K that are present in a significant amount in the Punjab soils (Brar, 1998). The variation in the soil OC and available nutrients under different tree species might be due to the variation in litterfall addition and its decomposition, concentration of these elements in the litter and uptake of these elements by trees and crops (Hosur *et al.*, 1997; Nadagouda *et al.*, 1997; Gill *et al.*, 2009).

Conclusions

It can be concluded from the above results that poplar, eucalyptus and dek have considerably better growth and higher potential of biomass production, C and CO_2 sequestration than maharukh and toon. However, there is higher removal of N, P and K from the soil by these tree species than the others, but that is compensated by higher storage of C and CO_2 in the biomass and soil. Thus, in addition to fulfilling the demand of society for wood and wood products, the trees can mitigate the climate change through C sequestration.

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