Soil Organic Carbon, Phosphorus and Potassium in Soils under Poplar Based Agro-Forestry in Punjab

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Soil samples (0-60 cm) were collected from poplar based agro-forestry system varying in age from 2-20 years to study changes in total soil organic C (SOC), available phosphorus (P) and potassium (K). Soil plough layer (0-15 cm) had significantly higher SOC concentration by 34, 61 and 83%, compared with 15-30, 30-45 and 45-60 cm soil depths, respectively. Soil organic C decreased significantly with increasing soil depth, regardless of the age of poplar plantation period. The concentration of available-P and K was significantly higher in the surface soil, and decreased with increasing soil depth. Available-P increased significantly (*p<0.05*) by 16.3-17.7% and available-K by 36.5-52.4% in soil plough layer (0-15 cm) under agro-forestry for 20-yrs, compared with soils under agro-forestry for 2-yrs. Soils under 20-yrs old agro-forestry system had 39.8% and 50.6% higher SOC in 0-7.5 cm and 7.5-15 cm soil depth, compared with soils under 2-yrs old plantation. These results revealed C and nutrients (P and K) sequestration potential of poplar based agro-forestry system.

Introduction

Soil is an important sinks of C as soil organic carbon (SOC), and plays a major role in its cycling in terrestrial ecosystems. As an important component of the C system, SOC acts as a key indicator for assessing soil quality and plays an important role in increasing crop productivity (Gregorich *et al.,* 1994). On a global scale, soils contains 1500 Pg (1 Pg= 10^{15} g) of organic C in the first meter of soil profile. The SOC pool comprise 60% of this total, ~170 Pg of which are stored in 1.7 billion hectares of agricultural croplands worldwide (Paustian *et al.,* 2000; Lal, 2008). Upper 30 cm soil layer stores

almost half of SOC that represents upto 3-times of the C stored in vegetation (Powlson *et al*., 2011), and therefore is considered most vulnerable to be lost as carbon dioxide (CO_2). Because of the historic losses of organic C from croplands, most of cultivated soils are exhausted of SOC and are far away from saturation (Vaccari *et al.,* 2011). Depletion of the SOC pool in cultivated lands has been attributed to lower C input, and higher C outputs through oxidation, leaching of dissolved organic C, and soil erosion (Lal 2004, Ghosh *et al*., 2012). Land-use change in different agro-ecosystems largely determined the potential for SOC storage and ultimately C sequestration in soil (Bronick and Lal, 2005) due to remarkable alterations in organic C inputs and dynamics. Agro-forestry is believed to increase the soil organic matter (SOM) through the addition of above and below-ground biomass to soil.

Poplar (*Populus deltoids*) plantation under agro-forestry annually add 2.9-3.3 Mg biomass ha^{-1} and could supply 2.3 t C ha^{-1} yr^{-1} as roots and leaves (Chauhan *et al*., 2011; Singh and Sharma, 2007). Agro-forestry affects nutrient status of soils via addition of leaf litter and also by plant uptake, and is considered an important option for C sequestration (Albrecht and Kandji, 2003). Nutrient availability in soils is influenced by the addition of organics (Gill and Meelu, 1983; Toor and Bahl, 1997; Sui and Thompson, 2000; Singh *et al*., 2010).

After decomposition, poplar leaf and root biomass adds organic matter to the soil and may alter nutrient availability in soils. The information on the effect of cumulative addition of leaf and root biomass of poplar on SOC and available nutrients is known to lesser extent. Therefore, a study was conducted to investigate the effect of age of poplar based agro-forestry on profile distribution of TOC in sub-tropical soils.

Materials and Methods

Soil samples (0-60 cm depth) were collected from different sites under 2-20 years poplar based agro-forestry in sub-tropical area of Ropar district (Punjab, India) during ( ) . Soil bulk density (D_b) at surface and sub-surface soil layers was determined by core method using metallic cores. Soil cores collected from each sampling were oven dried at 105°C for 24 h, and dry soil weight was recorded (Blake and Hartge 1986). The D_b (Mg m^{-3}) was calculated as: Db=Ws/Vt, Where, '*Ws*' is weight of soil (Mg) and *Vt* is the volume of soil sample (m^3). Soil samples were analyzed for soil pH (1:2 soil: water suspension) with a glass electrode (Elico, India), electrical conductivity (E.C., 1:2 soil: water supernatant) using a conductivity meter (Elico, India). Available P in soil samples was determined by extracting with 0.5M sodium bicarbonate (pH 8.5; 1:20 soil: extractant) (Olsen *et al.,* 1954) and measuring P concentration in the extract colorimeterically (Murphy and Rilay, 1962). Available K in soil samples was extracted with 1N ammonium acetate (pH 7.0) (Mervin and Peech, 1950) followed by flame photometric determination. Total organic carbon (TOC) in soil was determined by using 1N $K_2Cr_2O_7$ solution followed by heating at 150 ^{o}C for 1 hour (Snyder and Trofymow, 1984). Total organic C stock (as Mg C ha^{-1}) in the 0-15 cm soil plough layer was computed by multiplying the respective TOC concentration (%) with measured soil bulk density (Mg m^{-3}) and depth (m) of sampling using the following formula:

$$TOC\ stock\ (Mg\ C\ ha^{-1}) = TOC(\%)x\ Soil\ depth\ (m)x\ Bulk\ density\ (Mg\ m^{-3})x\ 100$$

Statistical analysis

Statistical analysis of soil samples collected under different agro-forestry systems varying in age was performed by one way analysis of

variance (ANOVA) with SPSS for Windows 16.0 (SPSS Inc., Chicago, U.S.A.). Mean separation for different land-uses was performed using the Duncan's multiple range test (DMRT). Differences in land-use mean at *p<0.05* were considered statistically significant.

Results and Discussion

Soils under agro-forestry were non-saline (EC 0.25-0.43 dS m^{-1}) and near neutral to slightly alkaline in reaction (pH 7.87-8.02) (Table 1). Soils were classified as Typic Udorthents and Udic Haplustepts (USDA, 1999). Regardless of the age of poplar plantation, available P was significantly higher in the surface (0-7.5 cm) soil, and decreased significantly with increasing soil depth (Table 1, Figure 1b). Soils under 20-yr agro-forestry had significantly higher available-P, compared with soils under <15 yr poplar plantation. Available K concentration (52-131 mg kg^{-1}) was significantly higher in the surface than the sub-surface soil (Figure 1c). A significant increase in available K concentration with increasing age of poplar plantation was observed in the surface soil. In the sub-surface soil, available-K increased

significantly after 15-yr of poplar plantation. Soils under <10-yr agro-forestry did not exhibit a significant change in available K concentration (Table 2). Higher concentration of available P and K in the surface (0-7.5 cm) soil depth could be ascribed to application of fertilizer-P and K in the surface soil. The deciduous poplar plants shed their leaves before entering dormant stage during winter season (mid-December to end-January) adds large amount biomass and organic matter to the soil (Chauhan *et al.*, 2011; Singh and Sharma, 2007). Increased P availability in soils with increasing age of poplar plantation could be ascribed to P mineralization from added organic matter as leaf litter (Gill and Meelu, 1983; Hundal *et al.,* 1988; Sui and Thompson, 2000). The production of organic acids (Wang *et al.,* 1967), organic anions such as citrate, oxalate and tartrate (Ibia and Udo, 1993) during the process of organic matter decomposition enhance solubility of native and freshly applied P (Toor and Bahl, 1997; Singh *et al.*, 2010). Organic acids tends to compete with phosphate ions for P sorption sites on soil colloidal complex, decreases its fixation and causing a large flush of available P in the soil solution (Singh *et al.*, 2010).

Table.1 Important properties of soil samples collected from fields under poplar based agro-forestry

Soil property	Depth (cm)				
	0-7.5	7.5-15	15-30	30-45	45-60
pH$_{1:2}$	7.94[a] (7.88-8.02)[¶]	7.89[a] (7.87-8.02)	7.88[a] (7.86-7.92)	7.87[a] (7.84-7.93)	7.86[a] (7.84-7.88)
E.C.$_{1:2}$	0.30[a] (0.25-0.35)	0.32[b] (0.26-0.43)	0.30[a] (0.25-0.35)	0.31[a] (0.25-0.36)	0.31[a] (0.26-0.36)
Available-P (mg kg^{-1})	13.9[e] (12.9-15.0)	12.1[d] (11.0-13.3)	9.7[c] (8.3-10.5)	8.2[b] (7.5-8.5)	6.7[a] (5.6-7.9)
Available-K (mg kg^{-1})	118[e] (96-131)	111[d] (83-125)	86[c] (69-103)	72[b] (65-88)	60[a] (52-70)
Bulk density (Mg m^{-3})	1.42[a] (1.38-1.46)	1.44[b] (1.40-1.47)	1.44[b] (1.41-1.49)	1.46[c] (1.43-1.48)	1.47[c] (1.44-1.50)

Values in the parentheses indicate range (minimum-maximum)
Mean values for different soil depths followed by different letter are significant (*p<0.05*) by Duncan's multiple range test (DMRT). *Bars indicate standard error from mean.*

Table.2 Available-P and available K concentration in surface (0-7.5 cm) and
sub-surface (7.5-15 cm) soils under agro-forestry

Age of plantation	Available-P (mg kg⁻¹)		Available-K (mg kg⁻¹)	
	0-7.5 cm	7.5-15 cm	0-7.5 cm	7.5-15 cm
2-yr	12.9[a]	11.3[a]	96[a]	82[a]
5-yr	13.3[a]	11.5[a]	119[b]	115[b]
10-yr	14.0[b]	11.0[a]	121[b]	115[b]
15-yr	14.6[c]	13.2[b]	125[c]	118[b]
20-yr	15.0[c]	13.3[b]	131[d]	125[c]

Mean values for different soil depths followed by different letter are significant (*p<0.05*) by Duncan's multiple range test (DMRT). *Bars indicate standard error from mean.*

Figure.1 Profile distribution of total soil organic carbon (SOC) (A), available-P (B) and
available-K (C) in soils under different age of agro-forestry in Ropar district of Punjab (India).
Mean values for a soil depth followed by different letter are significant (*p<0.05*) by Duncan's
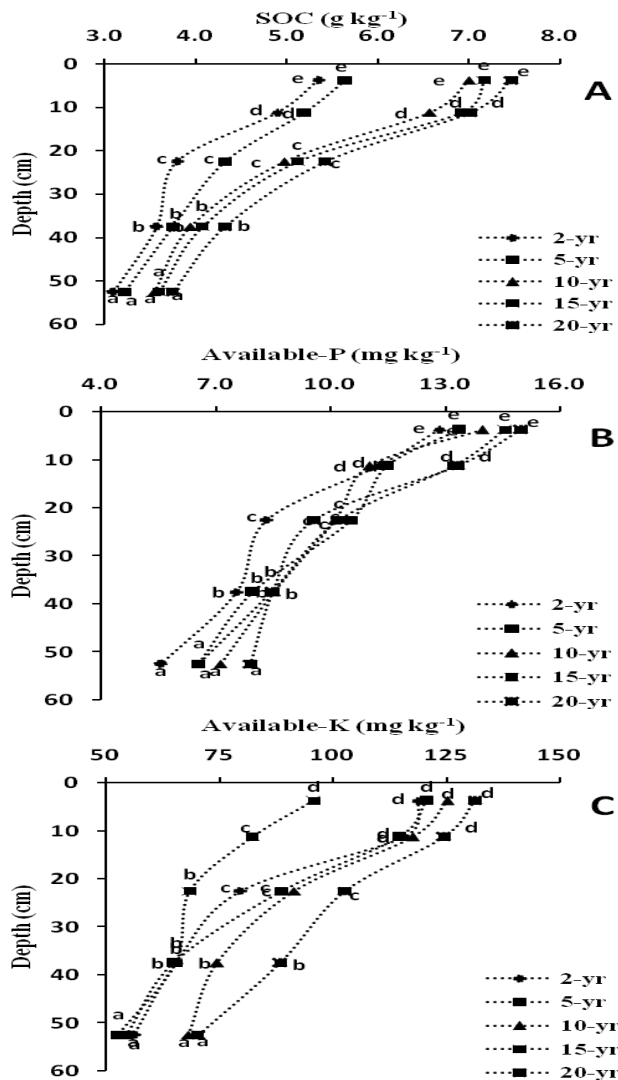multiple range test (DMRT)

Figure.2 Total soil organic carbon (SOC) stocks in surface (0-7.5 cm) and sub-surface (7.5-15 cm) soil depths under different age of agro-forestry. Mean values followed by different letter are significant (*p<0.05*) by Duncan's multiple range test (DMRT). *Bars indicate standard error from mean*
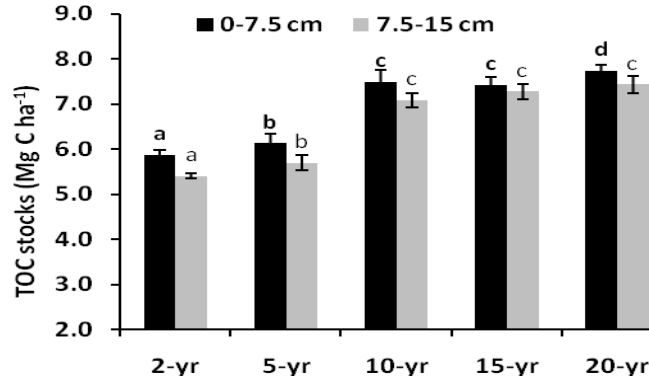

Figure.3 Relationship between soil bulk density (D_b) and total soil organic carbon (SOC) in soils under poplar based agro-forestry in Ropar district of Punjab. *Bars indicate standard error from mean*

$$y = 1.61x^{-0.06}$$
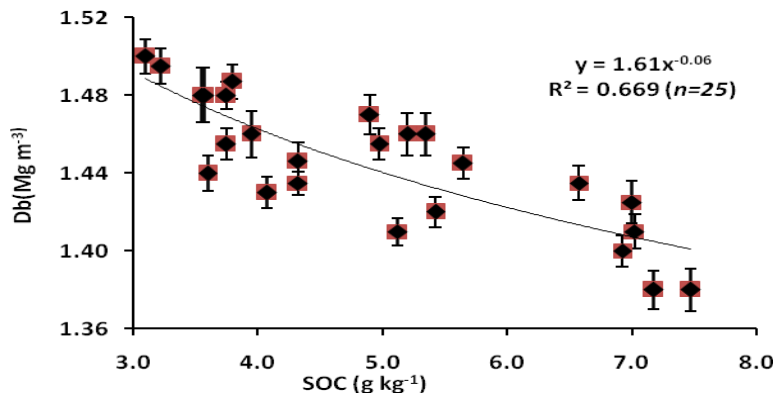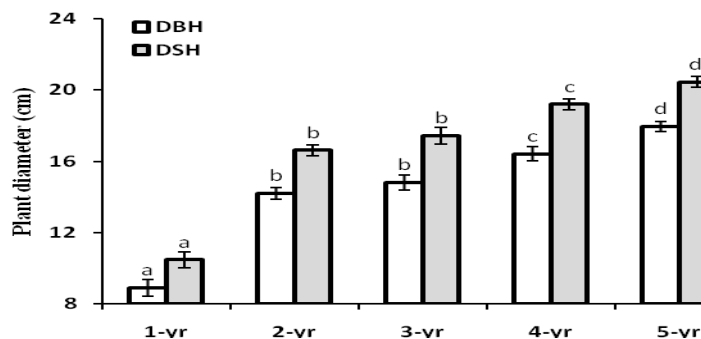$$R^2 = 0.669 \, (n=25)$$

Figure.4 Diameter at breast height (DBH) and diameter at scum height (DSH) of poplar (*Populus deltoids*) plants in relation to age of plantation. Mean values followed by different letter are significant (*p<0.05*) by Duncan's multiple range test (DMRT). *Bars indicate standard error from mean*

Total organic C concentration in the surface soils was significantly higher than the sub-surface soil, regardless of the age of agro-forestry system (Figure 1a). In general, TOC decreased with increasing soil depth. In a plough layer (0-15 cm), SOC pool was significantly ($p<0.05$) higher by ~34, 61 and 83% than in 15-30, 30-45 and 45-60 cm soil depths, respectively. Surface (0-7.5 cm) soil depth had ~0.4 g kg^{-1} (~7%) higher SOC concentration, compared with 7.5-15 cm soil depth. Higher TOC concentration in the surface (0-7.5 cm) than sub-surface soil layers, regardless of the age of agro-forestry could be due to higher C being contributed by plant roots in 0-7.5 cm soil depth, owing to higher root density and incorporation of leaf litter. A linear significant relationship between C input and SOC concentration across different treatments has also been well documented (Larson *et al*., 1972; Paustian *et al*., 1997).

The TOC was higher in soils under 20-yr agro-forestry, compared the soils under relatively younger agro-forestry system. Total organic C stocks in surface soil under 20-yr agro-forestry system were significantly higher, although TOC stocks in soils under 10-and 15-yr of agro-forestry did not differ significantly (Figure 2). In the sub-surface soil, TOC stocks were significantly higher under agro-forestry older than 10-yr, while TOC stocks did not differ significantly under 10-, 15-and 20-yr agro-forestry system.

Soil bulk density (D_b) of the surface soil ranged from 1.38 to 1.46 Mg m^{-3} and 1.40 to 1.47 Mg m^{-3} in the sub-surface soil. Bulk density was significantly higher for 45-60 cm soil depth, compared with top soil (0-45 cm). Soils under 20-yr agro-forestry had lower D_b, compared with other sites (Table 1). Soil D_b decreased as a function of increasing SOC content (Figure 3). Decrease in D_b of soils under 20-yr agro-forestry system was due to addition of organic matter to soil as leaf litter and root biomass input. Halvorson *et al.,* (1999) ascribed this decrease in soil D_b in response to added organic matter to the higher C concentration and increased root biomass which resulted in better soil aeration and aggregation. The fibrous nature of added organic matter acts as a fairly rigid framework preventing closer packing of soil separates, and thereby decreases soil D_b (Adams, 1973).

In conclusion, long-term adoption of agro-forestry system increased TOC, available-P and available-K concentration in the surface soil increased with increase in age of agro-forestry system, and decrease with increasing soil depth. Agro-forestry system could enhance C sequestration and improve soil physical condition.

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