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Labile Carbon Dynamics and Soil Amelioration in Six-year Old *Eucalyptus tereticornis* Plantation in Sodic Soils

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Abstract

Soil salinity and sodicity are serious issues worldwide; amelioration through plantation forestry is a low-cost and effective technique to overcome these abiotic stresses. Increase in soil organic carbon (SOC), soil carbon stock, microbial biomass carbon (MB-C) and permanganate oxidizable carbon (POXC) were considered as indicators for soil amelioration. The objective of the study was to determine the changes in different soil depths (0-15, 15-30, 30-45, 45-60, 60-75, 75-90 and 90-105 cm) and tree canopy cover (mid-canopy, canopy edge and canopy gap) in a 6-year old *Eucalyptus tereticornis* plantation on sodic soils. SOC, MB-C, POXC and soil carbon stock were significantly influenced by soil depth and tree canopy cover. MB-C under mid canopy and canopy edge was statistically similar, whereas, canopy gap had maximum MB-C. POXC was highest under canopy edge followed by canopy gap and lowest in mid canopy. SOC as well as C stock was recorded highest under canopy edge which was significantly higher to mid canopy and canopy gap. The results indicated that *Eucalyptus* based plantation forestry has significant impact on soil carbon sequestration and reclamation of sodic soils, which ultimately enhanced the productivity of the land use system.

Key words: *Eucalyptus tereticornis,* Soil organic carbon, Soil carbon stock, Tree canopy cover

Introduction

Eucalyptus with more than 500 species is one of the widely planted trees for short-rotation plantations due to its fast growth and high yield throughout the world especially in the tropics and subtropics including India. About 7.5 million hectare of land is currently under *Eucalyptus* plantation in India, accounting for about 8% of the global coverage (Abbsi *et al.*, 2004). Because of its tolerance and adaptability to sodic soils; amelioration through this plantation forestry is a low cost and effective technique to overcome this abiotic stress. Carbon inputs in salt-affected soils are likely to increase the soil organic matter, and thus, SOC and finally improve the soil structure and aggregation.

A number of mechanisms have been proposed by which tree plantations can ameliorate the soil salinity and sodicity. These mechanisms include release of organic acids and complex energy sources by roots (Dormaar, 1988) and increase in partial pressure of CO_2 as well as a decrease in soil pH (Qadir *et al.,* 1996). Increased CO_2 concentration in soil releases Ca^{2+} by dissolution of $CaCO_3$. Physical movement of roots within soil also improves soil aeration and porosity favourable for plant growth on sodic soils. In addition, trees also exhibit all of above mentioned mechanisms to control salinity and sodicity, hence can be selected for revegetation of highly salt affected lands. While SOC displays a continuum of turn over times and levels of decomposition, it is frequently partitioned into a number of discrete pools for analysis, namely an active or labile pool, a slow pool and a passive or recalcitrant pool. However, knowledge gap exists on dynamics of SOC pools stabilisation in salt affected soils, amelioration rate through carbon input from different tree canopy cover and their contribution to stabilizing the soil C pool. With this backdrop study was planned to quantify the labile carbon pools, stock and sensitivity analysis under different canopy cover (mid-canopy, canopy edge and canopy gap) of 6-year old *Eucalyptus tereticornis* based plantation forestry. This paper also investigates the changes in physico-chemical and labile carbon dynamics under varying soil depths due to perturbation caused by sodic soils.

Material and Methods

Site description

The study was conducted for estimation of labile carbon pools in soil under *Eucalyptus tereticornis* plantation at Raina Farm, Shahabad, Kurukshetra (29° 57' 30" N, 76° 59' 40"E, 257 m above sea level), Haryana, India. Kurukshetra district has tropical monsoonal climate and the year is divisible into three seasons i.e., warm-wet rainy season (June to September), a cool dry winter season (October to February) and a hot dry summer (March to May). The average annual rainfall of the district is 800 mm. The soil of the research farm was old alluvium (Banger series), which is mainly sandy loam to loam and slightly calcareous in nature.

Soil sampling and physico-chemical analysis

Soil samples were randomly collected from 3 different places at 7 depths (0–15, 15-30, 30-45, 45-60, 60-75, 75-90 and 90–105 cm) of different canopy cover [mid canopy (1m from tree trunk) canopy edge (2.5 m from tree trunk) and canopy gap (4 m from tree trunk)] under 6-year old *Eucalyptus tereticornis* based plantation forestry. At each sampling point, samples were collected below the tree canopy and outside the tree canopy in 4 cardinal directions around the tree. The samples were mixed to obtain a composite sample for each depth. In total, 63 samples (3 canopy cover × 7 depths × 3 replicates) were collected.

Soil pH and EC was determined in 1:2 soil-water suspensions. Soil samples were analyzed for SOC by the Nelson and Sommers (1996) method. Bulk density was determined using metal core samplers of 4.0 cm in height and 5.0 cm in internal diameter at all the depths studied. Samples were then oven-dried separately at 105 °C for 48 h. Bulk density of soil was calculated by dividing oven-dried weight of the sample by the volume of core sampler. The amount of carbon stored per hectare was obtained by multiplying the values of soil depth (cm), bulk density (g cm^{-3}), and the percentage of SOC content.

Soil microbial biomass carbon (MB-C) was determined using the fumigation extraction methods (Vance *et al.,* 1987). The sieved, field moist soil sub-samples (equivalent to 50 g oven dry soil) were fumigated with alcohol free chloroform in vacuum desiccators and stored in the dark for 24 h. After removing the fumigant (by repeated de-evacuation of chloroform from the soils), the samples were extracted with 200 ml 0.5*M* K_2SO_4 for 30 minute on a shaking machine. The un-fumigated soil samples were extracted similarly at the start of experiment. The filtered soil extracts of both fumigated and un-fumigated samples were analyzed for organic C using the acid dichromate method. MB-C was estimated by multiplying by 2.64 with EC (extractable carbon), where EC is the difference between carbon extracted from fumigated and un-fumigated samples both expressed in the same measurement unit.

Permanganate oxidizable carbon (POXC) analyses were based on method developed by Weil *et al.* (2003). A detailed protocol of this method can be found at: http:// lter.kbs.msu.edu/protocols/133 (verified 6 Jan. 2012). Briefly, 2.5 g of air-dried soil was weighed into polypropylene 50- ml screw-top centrifuge tubes. To each tube, 18 ml of deionized water and 2 ml of 0.2 *M* $KMnO_4$ stock solution were added and tubes were shaken for exactly 2 min at 240 oscillations per minute on an oscillating shaker. Tubes were removed from the shaker and allowed to settle for exactly 10 min. After 10 min, 0.5 ml of the supernatant were transferred into a second 50- ml centrifuge tube and mixed with 49.5 ml of deionized water. An aliquot (200 μ l) of each sample was loaded into a 96-well plate containing a set of internal standards, including a blank of deionized water, four standard stock solutions (0.00005, 0.0001, 0.00015, and 0.0002 mol l^{-1} $KMnO_4$), a soil standard and a solution standard. All internal standards were analytically replicated on each plate. Sample absorbance was read with Spectra Max M5 using Softmax Pro software (Molecular Devices, Sunnyvale, CA) at 550 nm. POXC was determined using following equation:

$$\text{POXC (mg/kg soil)} = [0.02 \text{ mol l}^{-1} - (a+b\times Abs)] \times (9000 \text{ mg C mol}^{-1}) (0.02 \text{ l solution})$$

where, 0.02 mol/l is the concentration of the initial $KMnO_4$ solution, 'a' is the intercept and 'b' is the slope of the standard curve, Abs is the absorbance of the unknown soil sample, 9000 mg is the amount of C oxidized by 1 mol of MnO_4 changing from Mn^{7+} to Mn^{4+}, 0.02 l is the volume of $KMnO_4$ solution reacted, and Wt is the mass of soil (kg) used in the reaction.

Statistical analyses

All the data were subjected to variance analysis using statistical software (SAS Version 9.3, SAS Institute Inc., Cary, NC, USA). The mean pair wise comparisons were based on the Duncan's multiple range test (DMRT). Correlation analysis was performed to determine the relationship between the traits using the Pearson coefficient procedure.

Results and Discussion

Physico-chemical and labile carbon fraction variation under different canopy cover

In the present study, the soils under mid canopy, canopy edge and canopy gap was evaluated for their amelioration potential for sodic soils by 6-year old *Eucalyptus tereticornis* based plantation. Electrical conductivity was statistically significant among the canopy cover and was found to be 5.30 % lower in canopy edge than canopy gap. This may be due to higher litter accumulation and release of phenol compound in the soil. pH_2 was statistically lower in mid canopy than canopy edge and canopy gap. These results showed that the soil is more acidic in character near the plant stem. This can be explained with a fact that as we move away from main stem of tree, the organic matter due to fallen leaves is

Table 1. Comparative study of different active pools of carbon and other soil parameters under canopy cover of 6-year old *Eucalyptus tereticornis* plantation

Canopy cover	EC_2 (dS m^{-1})	pH_2	MB-C (μg g^{-1})	POXC (mg kg^{-1})	SOC (%)	C stock (Mg C ha^{-1})
			Labile carbon forms and other soil parameters			
Mid canopy (1 m from trunk)	0.39^{ab}	8.88^{b}	227^{b}	548^{c}	0.36^{b}	7.33^{b}
Canopy edge (2.5 m from trunk)	0.38^{b}	9.13^{a}	203^{b}	600^{a}	0.45^{a}	9.78^{a}
Canopy gap (4 m from trunk)	0.40^{a}	9.20^{a}	306^{a}	575^{b}	0.30^{b}	6.46^{b}
Mean	0.39	9.07	245	574.17	0.37	7.85
Soil parameters			Pearson's correlation coefficients for association			
EC_2 (dS/m)	1	0.729^{**}	-0.822^{**}	-0.803^{**}	-0.818^{**}	-0.776^{**}
pH_2		1	-0.565^{**}	-0.742^{**}	-0.698^{**}	-0.586^{**}
MB-C (μg g^{-1})			1	0.709^{**}	0.855^{**}	0.863^{**}
POXC (mg kg^{-1})				1	0.818^{**}	0.709^{**}
SOC (%)					1	0.976^{**}
Carbon stock (Mg C ha^{-1})						1

Small letters within the same column show the significant difference at p = 0.05 according to Duncan's Multiple Range Test for separation of mean

decreased as compared to organic matter present near stem. The organic matter is decomposed under bacterial action and acidic species are produced which are responsible for the decrease of pH near stem (Noureen *et al.,* 2008).

MB-C under mid canopy and canopy edge was statistically similar, whereas, canopy gap had maximum MB-C. POXC was statistically significant in all the treatment studied. POXC was highest under canopy edge followed by canopy gap and lowest in mid canopy. SOC as well as C stock was recorded highest under canopy edge which was significantly higher to mid canopy and canopy gap. Values for SOC and carbon stock were statistically at par, when mid canopy and canopy gap were compared. SOC under canopy edge was 50 and 25 % higher as compared to canopy gap and mid canopy, respectively. Our findings are in agreement with the studies of Wasonga, *et al.* (2003), who have also reported that the soil organic matter in the mid-canopy zone was significantly higher than in the sub-canopy and adjacent open zones during both dry and wet season. Similarly, Noureen *et al.* (2008) has also reported the presence of higher organic content under the canopy cover of *Calligonum polygonoides* in Cholistan Desert of Pakistan.

Electrical conductivity and pH_2 were negatively correlated with MB-C, POXC, SOC and carbon stock. Whereas, electrical conductivity was positively correlated with pH_2 (r= 0.729). MB-C showed highest positive correlation with carbon stock (r= 0.863). Whereas, POXC showed highest positive correlation with SOC (r= 0. 818). Our results are in conformity with Jokela *et al.* (2009).

Vertical distribution of physico-chemical parameters and labile carbon fractions under different tree canopy cover

Electrical conductivity and pH_2 increased with soil depth irrespective of the tree canopy cover. Lowest and highest EC_2 of the upper soil surface was 0.345 and 0.371 dS m^{-1} pertained to canopy edge and canopy gap, respectively. Whereas, pH_2 at upper soil depth was recorded lowest (8.16 dS m^{-1}) and highest (8.97 dS m^{-1}) under mid canopy and canopy gap, respectively (Fig. 1). The decrease in soil pH and EC might be due to the root exudates and products of decomposition of leaf litter of *Eucalyptus tereticornis* (Mishra *et al.,* 2002). Similar findings were also reported by Baber *et al.* (2006) under tree canopy of *Eucalyptus camaldulensis.*

Irrespective of tree canopy cover, MB-C decreased with increased soil depth. MB-C under canopy edge was lower by 30.8 and 9.10 % as compared to canopy gap and mid canopy, respectively (Fig. 1). Reduced MB-C under canopy edge may be due to allelochemicals released by the litter debris and its subsequent leaching to the soil profile. Our results match with the findings of Zhang and Fu (2010). SOC, POXC and soil carbon stock decreased with soil depth. Canopy edge showed greater soil amelioration through maximum organic inputs from litter fall, dead root debris and root exudates followed by mid canopy and least in canopy gap (Fig. 2). This might be due lower organic source availability from leaf and root debris away from the tree trunk. F-statistics was used for sensitivity analysis of labile carbon fractions under block plantation of 6-year old *Eucalyptus tereticornis* (data not shown). Among the labile carbon fractions studied, POXC

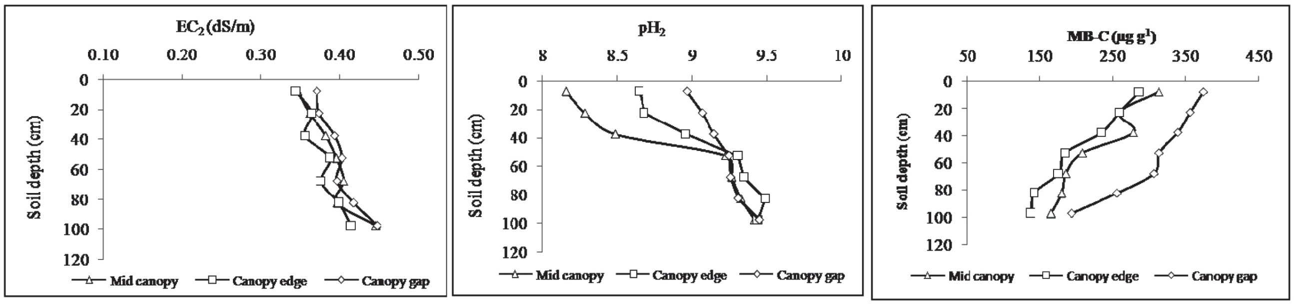

Fig. 1. Soil pH_2, EC_2 and MB-C in different soil depths under 6-year old *Eucalyptus tereticornis* based plantation forestry

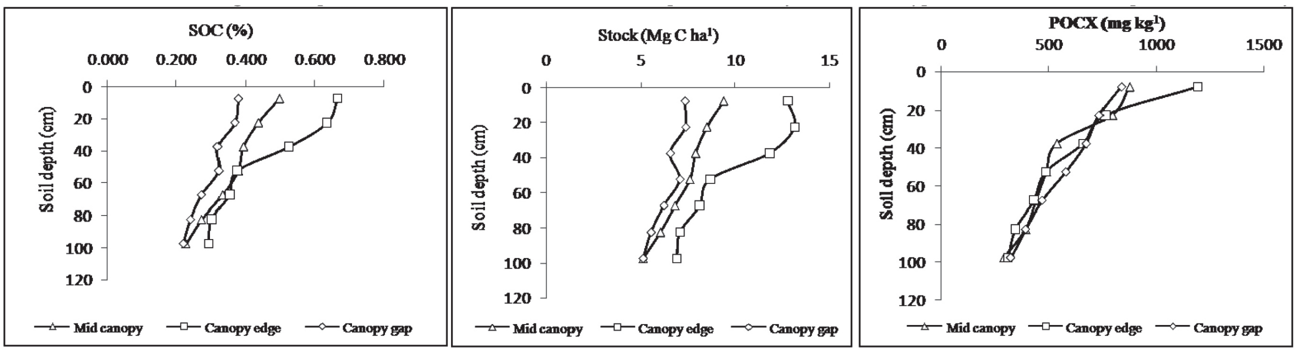

Fig. 2. Soil organic carbon, stock and POXC in different soil depths under 6-year old *Eucalyptus tereticornis* based plantation forestry

was found to be highly sensitive followed by MB-C in terms of tree canopy cover. POXC was also found to be highly sensitive followed by SOC in terms of soil depth. Similar results were also reported by Culman *et al.* (2010).

Conclusions

Eucalyptus tereticornis is a moderately salt-tolerant species and has the capability to improve the soil health in terms of organic C, carbon stock, POXC and to reduce the soil pH. Therefore, it is suggested that moderate sodicity problems in soils could be alleviated by growing *Eucalyptus tereticornis* besides enhancing soil fertility which ultimately improves the profitability of the farmers.

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