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Aggregate Fractions and Organic Carbon Dynamics in Partially Reclaimed Sodic Soils Growing *Eucalyptus tereticornis*

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Abstract

Plantation forestry emerged as a potential low-cost tool for mitigation of climate change through enhanced soil carbon sequestration. Plantation forestry has definite impact on soil aggregates through better organic carbon dynamics. In view of this a study was carried out in a 4-year old *Eucalyptus tereticornis* plantation to evaluate the impact on soil aggregate fractions and carbon dynamics in partially reclaimed sodic soil. Results indicated that most of the soil quality enhancing properties concentrated at the soil surface (0-15cm) compared to other soil depths. In general, total carbon (TC), total organic carbon (TOC) and oxidizable organic carbon (OC) decreased with soil depths, whereas, no such pattern was observed in case of total inorganic carbon (TIC). Mean TC was 11.9 g kg^{-1}, which was 16.7% and almost 7 times higher than TOC and TIC, respectively. Total water stable aggregates were found to be 10.9 % higher in surface soil (0-15 cm) than in sub-surface soil (15-30 cm). Aggregate associated carbon of meso-aggregates was more than 5 and 2 times higher to those of the 'silt+clay' and micro-aggregates, respectively. Block plantation of *Eucalyptus tereticornis* might be a better option for mitigating greenhouse effects by sequestering atmospheric carbon and improving soil aggregate stability, which improves soil health and enhances the productivity of the system.

Key words: Aggregate indices, Aggregated soil carbon, Soil carbon fractions, Water stable aggregate

Introduction

Plantation forestry has potential to sequester carbon through soil carbon sequestration. Increasing soil organic matter content, and therefore soil organic carbon, can improve soil quality and contribute to mitigating adverse impact of climate change. Soils have the capacity to store carbon, accounting for more carbon than is found in the atmosphere and living plant biomass combined (Jobbagy and Jackson, 2000). Soil aggregate dynamics is a result of interactions of many factors, including the environment, soil management, plant species and soil properties e.g. mineral composition, texture, soil organic carbon concentration, pedogenic processes, microbial activities, exchangeable ions, nutrient reserves, and moisture availability (Kay, 1990). Soil aggregates are important agents of soil organic carbon retention (Haile *et al.,* 2008) and protection against decomposition (Six *et al.,* 2000). Quantity and quality of soil organic carbon fractions have an impact on soil aggregation (Lal, 2003) that in turn physically protect the carbon (C) from degradation by increasing the mean residence time of C. The soil aggregate stability may be affected by soil texture, organic matter, soil and moisture content (Oztas and Fayetorbay, 2003). The abundant water stable aggregates (WSA) in size 0.25-0.1 mm at the upper soil surface layer (0-15 cm) determine the potential for sheet erosion and crust formation (Shouse *et al.,* 1990). For the assessment of physical properties of such soil; and for sustainable establishment of plantation and soil health, it is important to examine WSA distribution across the soil profile. Aggregates occur in a variety of manner and size. These are often grouped into macro-aggregates (>0.25 mm) and micro-aggregates (< 0.25 mm). These groups can be further divided by size depending upon soil properties such as binding agents and carbon and nitrogen (N) distribution (Tisdall and Oades, 1982). Therefore, it is very important to learn how the carbon forms, soil aggregation and aggregated carbon fractions are distributed in the soil profile. In present investigation an attempt was made to study different carbon forms, water stable aggregate and indices and aggregated carbon pattern in varying soil depth of a partially reclaimed soil of Trans Gangetic Plains of India growing 4-year old *Eucalyptus tereticornis.*

Material and Methods

Site description

The study was conducted for estimation of water stable aggregate (%) and carbon fraction 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 in texture and slightly calcareous in nature. The pH_2 of the soil ranged between 8.59 -9.44 (0-105 cm) and increased with soil depth.

Soil sampling and analysis

Soil samples were randomly collected from 3 different locations at 7 depths (0–15, 15-30, 30-45, 45-60, 60-75, 75-90 and 90-105 cm) in 4-year old *Eucalyptus tereticornis* based plantation forestry. At each sampling point, samples were collected below the tree canopy and outside the tree canopy in four cardinal directions around the tree. Soil samples were mixed to obtain a composite sample for each soil depth. One portion of the soil sample passed through a 0.1 mm sieve and used to determine TIC, OC and TC in the soil profile. TC was analyzed using CHN Elemental analyzer (Model Vario EL III); TIC and OC were estimated following the methods of Jackson (1973) and Nelson and Sommers (1996), respectively.

The other part of the air dried un-processed samples was passed through a 5-mm sieve and used for estimating aggregate size distribution by wet sieving method (Yoder, 1936) using a nest of sieves with pore diameter 2.0, 1.0, 0.5, 0.25, 0.12 and 0.05 mm for the separation of four aggregate size classes namely coarse macro-aggregate (> 2.0 mm), meso-aggregate (2.0–0.25 mm), micro-aggregate (0.25–0.05 mm) and 'silt + clay' sized fractions (< 0.05 mm). One sample was kept for determination of water stable aggregates, whereas, the other was used for estimating primary particles after dispersion with 0.5% (w/v) sodium hexa-metaphosphate in 1:3 (soil:solution) ratio by mechanically stirring the suspension for 15 min. before the vertical oscillation of the apparatus for 30 min. at a frequency of 50 cycles per min^2 ensuring top sieve remains immersed throughout the full stroke. Before starting the oscillation, soil was kept immersed in water for 2 min. Sieves were then taken out and kept 5 min to drain out the water. The water stable aggregates (without dispersion) and the primary particles (with dispersion) of different sizes were collected from the respective sieves separately and weighed after oven drying at 50 °C for 24 h. Dry soil aggregates were passed through 0.15 mm sieve. Parameters expressing the status of aggregation were determined as follows:

Water stable aggregate percentage

Water stable aggregate percentage was calculated after getting the weight of soil particles (without dispersion) of each size groups as follows:

$$\text{WSA (\%)} = \frac{[(\text{weight ofsoil} + \text{sand}) * \text{i} - (\text{weight ofsand}) * \text{i}]}{\text{weight ofsample}}$$

where, *i* denotes the size of the sieve. The percentage of water stable macro-aggregates (WSMacA) and water stable micro-aggregates (WSMicA) is the summation of soil aggregate size fractions of > 0.25 mm and < 0.25 mm, respectively.

Mean weight diameter

Mean weight diameter (MWD) of the water stable aggregate (after correction of sand content) was estimated as-

$$\text{MWD} = \frac{\sum_{i=1}^{n} \text{XiWi}}{\sum_{i=1}^{n} \text{Wi}}$$

Where, *n* is the number of fractions (0.1-0.25, 0.25-0.5, 0.5-1.0, 1.0-2.0, > 2.0 mm, *Xi* is the mean diameter (mm) of the sieve size class (0.175, 0.375, 0.75, 1.5 and 2.0mm) and *Wi* is the weight of soil (g) retained on each sieve.

Geometric mean diameter

Geometric mean diameter (GMD) is an exponential index of water stable aggregates and expressed as-

$$\text{GMD} = \exp\left[\frac{\sum_{i=1}^{n} Wi \log Xi}{\sum_{i=1}^{n} Wi}\right]$$

Where, *n* is the number of fractions same as MWD size, *Xi* is the mean diameter (mm) of the sieve size class same as MWD size and *Wi* is the weight of soil (g) retained on each sieve.

Aggregate ratio

By using wet sieving method, aggregates were fractioned into water stable macro-aggregates (>0.25 mm) and micro-aggregates (<0.25 mm) categories and their ratio was designated as aggregate ratio.

$$\text{Aggregate Ratio} = \frac{[\text{Percentage of water stable macro} - \text{aggregates}]}{[\text{Percentage of water stable micro} - \text{aggregates}]}$$

Percent aggregate stability

The degree of soil aggregation was represented by the index percent aggregate stability (AS) as below-

$$\text{AS} = \frac{(\text{Percent soil particles} > 0.25\text{ mm} - \text{Percent primary particle} > 0.25\text{mm})}{(\text{Percent primary particle} < 0.25\text{ mm})}$$

Aggregate associated carbon

After taking the weight of oven-dried (60°C) aggregated particles, the samples were used for the

Table 1. Different soil carbon fractions with varying soil depths under 4-year *Eucalyptus tereticornis* plantation

Soil depth (cm)	Soil carbon fractions			
	TC ($g\ kg^{-1}$)	TIC ($g\ kg^{-1}$)	TOC ($g\ kg^{-1}$)	OC ($g\ kg^{-1}$)
0-15	15.5[a]	1.78[d]	13.7[a]	6.72[a]
15-30	14.2[b]	1.67[e]	12.6[b]	6.50[b]
30-45	13.8[c]	1.92[b]	11.8[c]	5.62[c]
45-60	11.3[d]	1.91[b]	9.41[d]	2.44[d]
60-75	11.4[d]	1.97[a]	9.41[d]	2.08[e]
75-90	9.90[e]	1.82[c]	8.08[e]	1.95[f]
90-105	8.54[f]	1.91[b]	6.63[f]	0.84[g]
Mean	11.9	1.71	10.2	3.73
CV (%)	0.26	0.68	0.25	0.21

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

estimation of aggregate associated organic carbon by the method described by Nelson and Sommers (1996). In the present study, very coarse, coarse, fine and 'silt+clay' associated carbon have been designated according to the size of the sieves i.e. >2.0 mm, 2.0-0.25 mm, 0.25-0.05 mm and <0.05 mm, respectively and expressed in $g\ kg^{-1}$ soil aggregates.

Statistical analysis

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.

Results and Discussion

Different forms of soil carbon

Block plantation of *Eucalyptus tereticornis* significantly influenced the TC and OC content in all the soil depths (Table 1). Results indicated that most of the soil quality enhancing properties concentrated at the soil surface (0-15 cm) compared to the other soil depths. In general, TC and OC decreased with soil depth, whereas no such trend was observed in the case of TIC. Across the soil depths, mean TC was 11.9 $g\ kg^{-1}$, which was 16.7% and almost 7 times higher than TOC and TIC, respectively. Greater carbon input from litter fall, dead roots, and root exudates from 0-45 cm soil depth showed higher TC and OC content in the soil. Similar results were also reported by Bhalla and Gupta (2013). The TIC has the potential to help in the establishment of vegetation as well as sequestration of organic carbon in the soils. A meta-analysis study conducted by Laganiere *et al.* (2010) showed that_afforestation/reforestation activities can impact the SOC in various different ways depending on parameters such as land history, type of tree species, soil type, site preparation and climate.

Distribution of water stable aggregates and aggregate indices

In the present investigation the distribution of water stable aggregates influenced (significant at p=0.05) with the soil depth. The total water stable aggregates and macro-aggregates were higher in surface layer than in sub-surface layers (Table 2). Total water stable aggregates were found to be 10.9 % higher in surface soil (0-15 cm) than in sub-surface soil (15-30 cm) and it was about 3 times higher than the lowest soil depth (90-105 cm). Choudhury *et al.* (2014) and Das *et al.* (2014) also reported that soil

Table 2. Different fractions and indices of water stable aggregates in varying soil depths under 4-year *Eucalyptus tereticornis* plantation

Soil depth (cm)	Fractions and indices of water stable aggregates						
	Percent Total WSA	Percent WSMacA (>0.25 mm)	Percent WSMicA (<0.25 mm)	MWD (mm)	GMD (mm)	AR	AS
0-15	50.66[a]	33.54[a]	17.17[b]	0.53[c]	0.47[e]	1.94[e]	0.21[e]
15-30	45.70[c]	29.90[c]	15.87[c]	0.61[b]	0.53[d]	1.87[f]	0.19[ef]
30-45	47.62[b]	33.24[b]	14.63[d]	0.62[b]	0.56[c]	2.25[d]	0.19[f]
45-60	36.15[d]	10.70[g]	24.76[a]	0.36[d]	0.23[f]	0.43[g]	0.22[d]
60-75	32.95[e]	23.86[d]	9.15[e]	0.52[c]	0.46[e]	2.55[c]	0.27[c]
75-90	14.59[g]	12.82[f]	1.91[g]	1.06[a]	0.93[a]	6.74[a]	0.41[a]
90-105	17.42[f]	13.25[e]	4.32[f]	0.62[b]	0.61[b]	3.07[b]	0.36[b]
Mean	35.01	22.47	12.54	0.62	0.54	2.69	0.26
CV (%)	0.28	0.05	1.65	1.83	0.73	0.69	2.71

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 aggregates decreased with soil depth. Although, the higher total water stable aggregates in surface layer could be due to more organic matter because of tree residues. Macro (>0.25 mm) and micro (<0.25 mm) water stable aggregates were 66.2 and 33.8% of total water stable aggregates in 0-15 cm soil depths, respectively. It is documented that increased water stable aggregates in soil, improved the nutrient status especially nitrogen and carbon (Qiang *et al.,* 2007). Indices such as MWD, GMD, AR and AS were found to be statistically higher in 75-90 cm soil depth. This may be due to the hard pan layer of calcium carbonate at this soil depth. Adding organic matter improves aggregate stability and soil porosity which in turn promotes water infiltration, enhances salt leaching, decreases the exchangeable sodium percentage and electrical conductivity and increases the soil microbiological activities (Tejada *et al.,* 2006). Unfortunately, most soils of semi-arid regions are poor in organic matter. Therefore, organic amendment has been widely used to increase the soil organic matter content (Fernandez *et al.,* 2009). The effectiveness of organic inputs on improving soil structural stability is not only dependent on the quantity but also on the quality of adding organic materials specially their rate of decomposability and their capacity to induce soil microbial activity (Abiven *et al.,* 2009).

Soil organic carbon and its distribution in different size aggregates

In the present study, aggregate associated carbon of meso-aggregates was more than 5 and 2 times higher to those of the 'silt+clay' and micro-aggregates, respectively (Table 3). The meso-/macro-aggregates are generally formed by soil particles held together by organic residues (Tisdall and Oades, 1982). Li *et al.,* 2007 also reported that aggregates of size 2.0–0.25 mm in diameter was found to be the main carrier of organic carbon, however, 'silt+clay' fraction in the soil plays a key-role in the protection of soil organic matter. The soil carbon associated with micro-aggregates is believed to be protected from degradation and is relevant for soil carbon sequestration (Six *et al.,* 2002). The formation of aggregates occurs through flocculation of clay colloids and their cementation by organic and inorganic materials (Jimenez and Lal, 2006). Several factors affect this process, like land use and management, soil mineralogy, texture, quantity and quality of the organic matter incorporated, diversity and abundance of soil organisms (bacteria, fungi, earthworms and others). Soils thus can be fractionated according to the aggregates that configure their structure. In our study, the highest SOC concentrations were obtained in the 'silt + clay', which are important in the longer term due to the complex associations of C with the structure of clays (Jimenez and Lal, 2006).

Table 3. Soil organic carbon retained by various particle size of water stable aggregates under 4-year *Eucalyptus tereticornis* plantation

Soil depth (cm)	Particulate carbon (g kg^{-1})		
	'Silt+Clay'AC (<0.05 mm)	MicAC (0.25-0.05 mm)	MesoAC (2.0-0.25 mm)
0-15	2.52	3.56	13.37
15-30	1.34	6.68	5.94
30-45	0.30	0.59	2.82
45-60	0.00	0.15	1.04
Mean	1.04	2.75	5.79

Where, 'silt+clay'AC= Silt and clay associate carbon; MicAC= micro-aggregated carbon; MesoAC= meso-aggregated carbon

Conclusions

Total organic and total inorganic carbon under 4-year old *Eucalyptus tereticornis* was 88.4 and 11.6 % in upper soil depth. Total water stable aggregates and macro-aggregates were also decreased with increased soil depth; however, no such pattern was observed in the case of micro-aggregates. Under 4-year old *Eucalyptus* plantation meso-aggregated carbon was 5 and 2 times higher than 'silt+clay' associated carbon and micro-aggregated carbon, respectively. Forestry plantations under partially reclaimed sodic soils require more research for better understanding the mechanism of aggregate stability and carbon dynamics.

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References

Abiven S, Menasseri S and Chenu C (2009). The effects of organic inputs over time on soil aggregate stability: A literature analysis. *Soil Biol. Biochem.* **41**: 1-12.

Bhalla E and Gupta SR (2013). the role of forestry plantations in soil carbon sequestration in a reserved forest in North-Western India. *American-Eurasian J. Agric. & Environ. Sci.* **13(7)**: 1019-1026.

Choudhury SG, Srivastava S, Singh R, Chaudhari SK, Sharma DK, Singh SK and Sarkar D (2014). Tillage and residue management effect on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil. *Soil Tillage Research* **136**: 76-83.

Das B, Chakraborty D, Singh VK, Aggarwal P, Singh R, Dwivedi BS and Mishra RP (2014). Effect of integrated nutrient management practice on soil aggregate properties, its stability and aggregate associated carbon content in an intensive rice-wheat system. *Soil Tillage Research* **136**: 9-18.

Fernandez JM, Plaza C, García-Gil JC and Polo A (2009). Biochemical properties and barley yield in a semiarid Mediterranean soil amended with two kinds of sewage sludge. *Appl. Soil Ecol*. **42**:18-24.

Haile SG, Nair PKR and Nair VD (2008). Carbon storage of different soil-size fractions in Florida silvopastoral systems. *J. Environ. Qual.* **37**: 1789-1797.

Jackson ML (1973). Soil Chemical Analysis. Prentice Hall India Pvt. Ltd., New Delhi, pp. 498.

Jimenez JJ and Lal R (2006). Mechanisms of C sequestration in soils of *Latin America. Crit. Rev. Plant Sci.* **25**: 337-365.

Jobbagy EG and Jackson RB (2000). The vertical distribution of organic carbon and its relation to climate and vegetation. *Ecol. Appl.* **10**: 423-436.

Kay BD (1990). Rates of change of soil structure under different cropping system. *Advances in Soil Science* **12**: 1-52.

Laganiere J, Angers DA and Pare D (2010). Carbon accumulation in agricultural soils after afforestation: A meta analysis. *Global Change Biology* **16**(1): 439-453.

Lal R (2003). Offsetting globle CO_2 emissions by restoration of degraded soils and intensification of world agriculture and forestry. *Land Degrad. Dev.***14**: 309-322.

Li XG, Wang ZhF, Ma QF and Li FM (2007). Crop cultivation and intensive grazing affect organic C pools and aggregate stability in arid grassland soil. *Soil Tillage Res.* **95**: 172-181.

Lorenz K, Lal R and Donald LS (2005). The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration 765in subsoil horizons. *Adv. Agron.* **88**: 35-66.

Nelson DW and Sommers LE (1996). Total carbon, organic carbon and organic matter In: Sparks DL.(ed). *Methods of Soil Analysis Part 3 – Chemical Methods.* Chapter 34, Soil Science Society of America and American Society of Agronomy, 677 S Segoe Rd, Madison, WI 53771, 1996.

Oztas T and Fayetorbay F (2003). Effect of freezing and thawing processes on soil aggregate stability. *Catena* **52**: 1-8.

Qiang Ma, Wan-Tai Yu, Shao-Hua Zhao and Lu Zhang (2007). Relationalship between water-stable aggregates and nutrients in black soil after reclamation. *Pedosphere* **17(4)**: 538-544.

Shouse PJ, Gerik TJ, Russel, WB and Cassel DK (1990). Spatial distribution of soil particle size and aggregate stability index in a clay soil. *Soil Sci.* **149**: 351-360.

Six J, Conant RT, Paul EA and Paustian K (2002). Stabilization mechanisms of soil organic *Implications for C-saturation of Soils* **241**: 155-176.

Six J, Elliott ET and Paulstain K (2000). Soil micro aggregate turnover and micro aggregate formation: A mechanism for C sequestration under no tillage agriculture. *Soil Biology and Biochemistry* **32**: 2099-2103.

Tejada M, Garcia C, Gonzalez JL and Hernandez MT (2006). Use of organic amendment as a strategy for saline soil remediation: Influence on the physical, chemical and biological properties of soil. *Soil Biol. Biochem.* **38:** 1413-1421.

Tisdall JM and Oades JM (1982). Organic matter and water-stable aggregates in soils. *Journal of Soil Sciences* **33**: 141-163.

Yoder RE (1936). A direct method of aggregate analysis of soil and the study of the physical nature of erosion losses. *J. Am. Soc. Agron.* **28**: 337-351.

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