Study on Percent soil weight distribution in aggregate size classes at different soil depths in tree plantations

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Abstract: The aggregate size fractions in the soil from different soil depths are given in Table 1 and 2. After slaking, most of the soil aggregates disintegrated into small aggregates (>250µm) and into microaggregates (<250µm). The slaking of soil results in a reduction in number and size of large pores at the soil surface, thereby limiting infilteration of rainfall or irrigation water (Nelson and Oades 1998). Soil aggregates at the surface have a greater degree of vulnerability to the degradation processes because of the stresses generated by rapid water uptake, release of entrapped air, mechanical impact and stirring action caused by the following water applied through irrigation or precipitation (Oster and Jayawardane 1998). The amount of macroaggregates (2mm- 250µm), varied from 1.84 to 6.90% Grevillea robusta; 4.30 to 7.57% Prosopis juliflora and 2.17 to 8.22% Tectona grandis at 0-100cm soil depth. There were significant differences in macroaggregates in the three plantations, which could be attributed due to differences in litter production and level of soil organic matter. For the microaggregates (250µm-53µm), the values ranged from 17.23 to 32.42% Grevillea robusta; 15.0 to 33.81% Prosopis juliflora and 17.12 to 36.53% Tectona grandis tree system. For aggregates associated with silt and clay fractions, the values ranged from 62.28 to 77.44% and 61.19 to 79.07% and 58.36 to 79.41% in Grevillea robusta, Prosopis juliflora and Tectona grandis plantations upto 1m soil depth respectively. In this study, macroaggregates (>250µm) exerted minimal amount of physical protection to soil organic carbon, whereas the clay and silt fractions formed a large fraction of the soil aggregate.

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Introduction:

An aggregate is a naturally occurring cluster or group of soil particles that cohere to each other more strongly than other surrounding particles. The large pores between the aggregates allow rapid movement of water and air as well as root penetration. Model of soil aggregation and SOM distribution in aggregate size classes for grassland soils was proposed by Tisdall and Oades (1982) and Oades (1984). These workers described three size classes of aggregation i.e. primary particles (sand, silt and clay), microaggregates (53µm-250µm) and macroaggrgates (>250µm). Microaggregates are formed by transient organic matter containing polysaccharides and mucigels produced by plants and microbes. Aggregates play a major role in several aspects of soil health i.e. movement and storage of water, soil aeration, physical protection of soil organic matter, prevention of erosion, root penetration and microbial activity (Tisdall and Oades 1982; Tate 1995). Aggregation controls various ecosystem functions such as nutrient cycling and soil water relationship (De Gryze et al 2017; Blanco-Canqui and Lal 2004). The size distribution of soil aggregates is important because the size of aggregates determine their susceptibility to loss of soil organic matter (Tisdall and Oades 1982). Macroaggregates consist of plant roots, fungal hyphae, microbial or plant exudates, and humic materials (Wei et al 2017) and are formed around persistent organic matter or clay particles that encapsulate them (Balesdent et al 2000; Six et al 2002, Chevallier et al 2004; Pulleman et al 2016). Soil organic matter has been considered as a major binding agent that stabilizes soil aggregates (Tisdall and Oades 1982; Hayens and Beare 1997). Soil organic matter is associated with primary particles and micro or macroaggregates in the soil (Tisdall and Oades 1982). Macroaggregates are sensitive to soil disturbance, but microaggregtes are generally more stable and resistance to disturbance. Loss of carbon from macroaggregates is more rapid than microaggregates due to lower protective effects of biophysical and chemical processes (Jastrow and Miller 1998).

Increased soil organic matter input can lead to increased soil aggregate formation (Kong et al 2016) which in turn enhances carbon sequestration by physical protection of soil organic matter inside aggregates (Gillabel et al 2018). Organic matter associated with macroaggregates is more readily mineralized than that associated with microaggregates (Beare et al 1994; Gupta and Germida 1988). Soil organic carbon associated with aggregates is an

important reservoir of carbon, protected from mineralization as it is less subjected to physical, microbial and enzymatic degradation (Trujilo et al 1997). The soil organic carbon in microaggregates is believed to be protected from degradation and is relevant for soil carbon sequestration (Shrestha et al 2004; Udawatta et al 2019). Soil mineralogy varies spatially as a function of climate and parent material and temporally as a function of soil development (Jenny 1941; Torn et al 1997). Most of the organic carbon in soils is degraded to inorganic forms slowly, on timescales from centuries to millennia (Schimel et al 1994). Torn et al (1997) reported that the largest changes in the quantity and turnover of soil organic carbon across landscapes and over long timescales may be due to variation in passive (mineral-stabilized) carbon deep in the soil. Passive carbon pools are controlled by soil mineralogy (Torn et al 1997). Soil minerals that are found in different types of soils affect soil carbon dynamics. Soil mineralogy is therefore, important in determining the quantity of organic carbon stored in soil, its turnover time, and atmosphere–ecosystem carbon fluxes during long-term soil development (Torn et al 1997).

The aim of this study was to analyze soil organic and inorganic carbon pools in grassland and tree plantation soils, aggregate composition and carbon content of soil aggregate fractions. It was also aimed to study differences in clay mineralogy of a sodic soil and reclaimed sodic soils using X-ray diffraction.

Materials and Methods

Soil Sampling for Aggregate Analysis

The soil aggregate size classes were studied using the wet sieving method (Elliott 1986) during April 2016 to October 2018 in different systems. After removing ground floor litter and plant residues, field moist soil cores from 0-5cm, 5-15cm, 15-30cm, 30-45cm, 45-60cm, 60-100cm soil depth were collected, air-dried and gently crumbled manually and sieved (>8mm) to remove root materials. The samples were transported to the laboratory for further analysis. The soil aggregate size classes were studied using the wet sieving method (Elliott 1986).

Analysis of Water Stable Soil Aggregates

Soil aggregates were wet sieved into three size classes (2mm-250µm, 250µm-53µm, and <53µm) by using multiple sub-samples of soil. 25g of air-dried soil was placed on 2mm sieve (nested with 250µm sieve). The sieves were submerged in a column of water, being careful not to allow water to pour in over the top of 2mm sieve. After 10 minutes of soaking, samples were wet sieved with a frequency of 30 strokes per minute. After sieving, aggregates were drained completely (2-4 minutes), dried on the sieve for 30 minutes (to permit removal from the sieve without disruption) and then oven-dried at 65°C. The remaining soil suspension, silt +clay fractions that passed through the 53µm sieve was collected in a pan and dried at 65°C.

Sub-samples of air-dried soil and separated soil aggregates were analyzed for organic carbon by dichromate oxidation method (Kalembasa and Jenkinson 1973).

Arbuscular Mycorrhizal Colonization of Plant Roots

The roots of *Sporobolus marginatus*, *Desmostachya bipinnata* and *Vetiveria zizanioides* were collected by excavating soil cores of 12x12x30cm from the sodic grassland systems at Bichian during September, 2017. The collected roots were washed on 250µm sieve under a fine jet of water. The roots were cut into 1 to 2cm in length and placed in petri dishes. The washed roots were cleared with 10% KOH solution for 12 to 24 hours at room temperature. The KOH was drained out and the roots were washed with 1% HCI and stained in lactic acid glycerol trypan blue (Phillips and Hayman 1970). The stained root segments were mounted on the glass slide and percent root colonization was determined by observing a number of root segments colonized by AM fungi. Percent AM fungal colonization of roots was calculated by the formula given by Gerdmann and Nicolson (1963)

X-Ray Diffraction (XRD) for Clay Mineralogy

The soil samples from 0-15cm soil depth were collected from the protected grassland system, and *Grevillea robusta* tree plantation. The soil samples were air-dried and gently crumbled manually and sieved (2mm) to remove plant debris and root materials. The soil samples of the three sites were further processed by taking five replicates (10g air dried soil) so as to collect sufficient amount of clay for X-ray diffraction (XRD). The organic matter in soil samples was decomposed by the treatment with hot 6% H_2O_2 with constant stirring at low heat by using the hot water bath. For ensuring complete decomposition of soil organic matter, the soil samples were treated two times with the 6% H_2O_2. Then the digested soil samples were transferred to 1 L-sedimentation cylinder with repeated washings with deionized water to raise the volume to one litre and allowed to settle for 12 hrs (overnight). The suspended clay (< 2µm) in the sedimentation cylinders was siphoned out in 500ml corning glass beaker by repeated sedimentation and decantation. The clay suspension collected in the beakers was dried over the hot water bath.

The < 2µm clay fraction that was wholly separated from the soil was used to examine the clay mineralogical composition by the X-ray diffraction (XRD) method. Oriented separated clay samples were

prepared to determine the clay mineral constituents. Two pre-treatment were made for each, glycolated, glycolated-heated (at 550^0 C for 4 hrs in a Muffle furnace) treatments. The XRD analysis of soil samples was carried out at SAIF (Sophisticated Applied Instrumentation Forum), Chandigarh. XRD analysis was performed using XPERT-PRO model diffractometer with Cu as anode material using CuKα radiations at 45KV and 40mA and at a scanning speed of 0.017 in a continuous scanning mode over a range of the 2θ range 4º to 40º (untreated samples) and 4º 2θ to 60º 2θ position (glycolated samples) Relative mineral contents in clay fractions were semi quantitatively estimated on the basis of XRD peak intensities. In the present estimation the peak height was used as the peak intensity by assuming the relative proportion of the minerals of samples normalized to 100% and the same proportionality between the peak intensity and the content for each mineral.

Scanning Electron Micrographs of Clay and Soil

After XRD analysis of the untreated clay samples of a typic salonatric calciothrids soil of the protected grassland system. The powdered clay sample was fixed onto a SEM stub. A very minute clay sample was used for the normal cylindrical sample holder of 1cm diameter. The sample was mounted on a flat surface of the stub and gold coated using vacuum gold scintillator prior to taking the scanning electron micrograph. Scanning Electron Micrographs of the clay sample were taken in back-scatter electron mode of the SEM, to highlight the clay mineral.

Results

Soil Aggregates in Tree plantations, Grassland System and Cropland Soils.

The aggregate size fractions in the soil from different soil depths are given in Table 1 and 2. After slaking, most of the soil aggregates disintegrated into small aggregates (>250µm) and into microaggregates (<250µm). The slaking of soil results in a reduction in number and size of large pores at the soil surface, thereby limiting infilteration of rainfall or irrigation water (Nelson and Oades 1998). Soil aggregates at the surface have a greater degree of vulnerability to the degradation processes because of the stresses generated by rapid water uptake, release of entrapped air, mechanical impact and stirring action caused by the following water applied through irrigation or precipitation (Oster and Jayawardane 1998). The amount of macroaggregates (2mm- 250µm), varied from 1.84 to 6.90% *Grevillea robusta*; 4.30 to 7.57% *Prosopis juliflora* and 2.17 to 8.22% *Tectona grandis* at 0-100cm soil depth. There were significant differences in macroaggregates in the three plantations, which could be attributed due to differences in litter production and level of soil organic matter. For the microaggregates (250µm-53µm), the values ranged from 17.23 to 32.42% *Grevillea robusta*; 15.0 to 33.81% *Prosopis juliflora* and 17.12 to 36.53% *Tectona grandis* tree system. For aggregates associated with silt and clay fractions, the values ranged from 62.28 to 77.44% and 61.19 to 79.07% and 58.36 to 79.41% in *Grevillea robusta, Prosopis juliflora* and *Tectona grandis* plantations upto 1m soil depth respectively. In this study, macroaggregates (>250µm) exerted minimal amount of physical protection to soil organic carbon, whereas the clay and silt fractions formed a large fraction of the soil aggregates (Table 1).

In the grassland system, macroaggregates form 4.92 to 15.61% of total soil aggregates. For the microaggregates (250µm-53µm) upto 1m soil depth, the values ranged from 9.53 to 24.83%, while for silt and clay fractions, the values varied from 59.56 to 83.45% (Table 2).

It was found that the percentage of macroaggregates increased in the soil in the wheat system. The percentage of macroaggregates in wheat varied from 5.22 to 11.87%. The microaggregates in size classes of 250µm-53µm formed 23.96 to 32.12% of the total soil aggregates in the wheat. The percentage of microaggregates (250µm-53µm) was slightly low in rice system as compared to wheat system. In the rice crop, the macroaggregates ranged from 5.12 to 11.87%. The microaggregates associated with clay and silt fractions varied from 56.01 to 70.86% (in wheat) and from 56.18 to 70.92% (in rice). There were marked effect of soil depth on percent soil weight distribution in different aggregate size fractions in the soil of both rice and wheat cropping system. The proportion of macroaggregates was higher at lower depth (Table 2).

The concentration of carbon in soil aggregate fractions followed the order: Small macroaggregates > microaggregates > silt and clay fractions. Organic carbon in soil aggregates varied significantly among the size fractions and the soil depth ($p<0.01$). There was significant increase in carbon concentration (%) with increasing aggregate size class. The total carbon concentration was greater in microaggregates (250µm-53µm) as compared to silt and clay associated to soil fractions (<53µm) (Table 3). In tree plantations, carbon concentration in different size fractions ranged from 0.07 to 1.35% in *Grevillea robusta*, 0.06 to 1.06% in *Prosopis juliflora* and 0.04 to 0.66% in *Tectona grandis* plantation. The carbon content of silt and clay fractions varied from 0.07 to 0.60% in *Grevillea robusta* and 0.04 to 0.30% in *Tectona grandis* tree plantation upto 1m soil depth. In *Prosopis juliflora,* the carbon in silt and clay fractions varied from 0.06 to 0.43% (Table 3).

Table 1: Percent soil weight distribution in aggregate size classes at different soil depths in tree plantations.

Soil depth (cm)	Percent weight in soil aggregates		
	2 mm – 250 µm	250µm – 53 µm	<53µm
Grevillea robusta			
0 – 5	5.28±0.69	17.23±1.11	77.44±1.0
5 – 15	3.96±0.46	20.01±0.73	76.03±0.28
15 – 30	1.84±0.12	24.42±0.99	73.74±1.09
30 – 45	3.50±0.44	28.72±1.71	67.78±1.69
45 – 60	3.49±0.35	32.42±1.45	64.09±1.59
60 – 100	6.90±0.48	30.82±1.97	62.28±1.70
CV (%)	22.10	10.92	5.48
LSD (p>0.05)	1.25	4.15	5.74
Prosopis juliflora			
0 – 5	5.93±1.59	15.0±3.09	79.07±4.56
5 – 15	4.65±1.28	17.37±1.75	77.99±2.84
15 – 30	4.30±1.04	19.63±1.35	76.07±2.27
30 – 45	7.57±0.21	28.12±2.26	64.31±2.23
45 – 60	5.00±0.47	33.81±2.13	61.19±2.46
60 – 100	6.13±0.19	31.81±0.62	62.06±0.75
CV (%)	34.52	16.61	7.88
LSD (p>0.05)	5.54	6.00	8.21
Tectona grandis			
0 – 5	3.45±0.24	17.12±2.40	79.41±1.88
5 – 15	3.03±0.15	17.73±0.60	79.21±2.20
15 – 30	2.17±0.14	26.88±1.85	70.70±2.39
30 – 45	4.40±0.14	28.12±1.18	67.48±1.29
45 – 60	5.11±0.66	36.53±1.56	58.36±1.60
60 – 100	8.22±0.26	32.03±1.52	59.75±2.40
CV (%)	14.93	12.27	5.80
LSD (p>0.05)	0.64	4.81	5.96

Table 2: Percent soil weight distribution in aggregate size classes at different soil depths in the grassland and cropping system.

Soil depth (cm)	Percent soil weight in soil aggregates		
	2 mm – 250 µm	250µm – 53 µm	<53µm
Grassland system			
0 – 5	7.03±0.91	9.53±0.66	83.45±1.38
5 – 15	4.92±0.58	17.73±1.11	77.23±2.01
15 – 30	7.77±0.32	20.97±2.97	71.21±1.64
30 – 45	12.07±0.89	21.35±0.63	66.58±0.96
45 – 60	14.17±0.97	24.66±2.17	61.17±2.13
60 – 100	15.61±1.21	24.83±1.70	59.56±2.03
CV (%)	17.20	17.11	4.97
LSD (p>0.05)	4.48	4.91	5.18
Cropping system Wheat			
0 – 5	5.22±0.67	23.96±1.02	70.86±1.53
5 – 15	6.30±0.62	25.82±1.09	67.87±0.71
15 – 30	6.58±0.40	27.60±0.81	65.82±1.03
30 – 45	8.47±0.21	29.25±0.99	62.28±1.07
45 – 60	9.78±0.51	30.78±0.95	59.44±1.07
60 – 100	11.87±.19	32.12±1.20	56.01±1.03
CV (%)	11.78	7.39	3.42
LSD (p>0.05)	1.33	3.03	3.26
Cropping system Rice			
0 – 5	5.12±0.27	23.96±1.02	70.92±1.19
5 – 15	7.04±0.77	25.89±1.07	67.07±1.06
15 – 30	7.24±0.28	28.12±0.81	64.64±1.06
30 – 45	8.37±0.22	29.25±0.99	62.38±1.01
45 – 60	9.48±0.79	29.79±2.07	60.73±2.81
60 – 100	11.87±0.19	31.95±1.30	56.18±1.4
CV (%)	12.19	9.15	4.90
LSD (p>0.05)	1.48	3.80	4.66

Table 3: Organic carbon distribution in aggregate size classes at different soil depths in tree plantations.

Soil depth (cm)	Organic carbon (%)			
	Soil carbon (%)	2 mm – 250 µm	250µm – 53 µm	<53µm
Grevillea robusta				
0 – 5	1.06±0.04	1.35±0.02	0.89±0.04	0.60±0.03
5 – 15	0.86±0.03	1.06±0.09	0.63±0.09	0.57±0.05
15 – 30	0.52±0.03	0.74±0.02	0.42±0.01	0.36±0.01
30 – 45	0.37±0.01	0.51±0.02	0.29±0.01	0.20±0.01
45 – 60	0.19±0.01	0.29±0.01	0.19±0.01	0.14±0.01
60 – 100	0.12±0.01	0.17±0.01	0.11±0.01	0.07±0.01
CV (%)	10.00	12.92	20.89	16.38
LSD (p>0.05)	0.05	0.13	0.13	0.08
Prosopis juliflora				
0 – 5	0.84±0.04	1.06±0.22	0.58±0.11	0.43±0.07
5 – 15	0.54±0.02	0.87±0.13	0.38±0.05	0.34±0.05
15 – 30	0.37±0.02	0.60±0.11	0.26±0.06	0.23±0.03
30 – 45	0.23±0.01	0.42±0.01	0.30±0.01	0.18±0.01
45 – 60	0.19±0.01	0.28±0.01	0.16±0.01	0.07±0.01
60 – 100	0.10±0.01	0.16±0.01	0.09±0.01	0.06±0.01
CV (%)	13.70	40.38	38.81	35.02
LSD (p>0.05)	0.08	0.34	0.17	0.11
Tectona grandis				
0 – 5	0.36±0.01	0.66±0.03	0.57±0.03	0.30±0.01
5 – 15	0.28±0.02	0.53±0.06	0.25±0.02	0.24±0.03
15 – 30	0.18±0.02	0.45±0.04	0.18±0.02	0.17±0.02
30 – 45	0.17±0.02	0.29±0.02	0.18±0.01	0.08±0.01
45 – 60	0.14±0.01	0.18±0.01	0.10±0.009	0.06±0.009
60 – 100	0.08±0.01	0.14±0.02	0.07±0.01	0.04±0.01
CV (%)	15.23	18.73	17.88	27.00
LSD (p>0.05)	0.05	0.10	0.06	0.06

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