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Land Use Affects the Soil Aggregation Pattern during Restoration of Degraded Land under Tropical Dry Climate

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ABSTRACT

Soil aggregate formation and stability are crucial in safeguarding soil carbon pools, as they form the basic unit of soil structure in terrestrial ecosystems. The impact of different land uses on soil aggregation pattern has widely been studied but is limited under tropical dry climate conditions. This study aimed to determine the soil aggregation pattern at two soil depths (0-15 cm and 15-30cm) in three different plantations (*Peltophorum pterocarpum, Eucalyptus globulus,* and *Acacia nilotica*) established in degraded land under tropical dry climate. The soil aggregates were categorized into microaggregate, mesoaggregate and macroaggregate based on their size fractions which were determined by the wet sieving method. The percent of macroaggregate, mesoaggregate, and microaggregate fractions at 0-15 cm depth ranged from 62.2 – 82.6%, 31.6 – 36.7%, and 1.1 – 4.9 % respectively whereas at 15-30 cm depth, it ranged from 69.7 - 81.7%, 17.1 - 31.6%, and 1.2 - 2.8%. The mean weight diameter values at 0-15 cm and 15-30 cm soil depth ranged from 2.27-3.37mm and 2.85-3.35 mm respectively. The higher percentage of macroaggregate fractions in *Peltophorum pterocarpum* plantation compared to *Eucalyptus globulus,* and *Acacia nilotica* plantations indicated that the *Peltophorum pterocarpum* plantation has slightly more potential to improve aggregate formation and soil structure in the degraded lands under tropical dry climate. In addition, appropriate land use practices can increase soil aggregate stability in the study area.

Keywords Soil aggregate stability, Land degradation, *Acacia nilotica, Eucalyptus globulus, Peltophorum pterocarpum.*

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INTRODUCTION

Soil health and quality is a global issue that demands our immediate attention for environmental conservation and climate change mitigation. Recently held COP 28, a worldwide discussion on 'climate action' recognized the protection of nature and biodiversity, focusing on maintaining soil health, carbon sequestration, limiting the temperature to 1.5 degrees C (2.7 degrees F), reduction of global greenhouse gas emissions to 60% below 2019 levels by 2035. Restoration of degraded lands is a major concern as mentioned in the 15.3 goal of SDGs. Many efforts all over the world has been into play to improve and mitigate land degradation focusing mainly on the restoration of the soil physico-chemical and biological properties. Soil is widely recognized as the largest carbon sink in terrestrial ecosystems, with about 4% of carbon storage being emitted to the atmosphere each year (Li *et al*. 2014, Zhou *et al.* 2020, *Li et al.* 2022, Yang *et al.* 2022). Increasing soil organic matter in land uses has a major role to play throughout these processes (Manpoong *et al.* 2021).

Soil aggregation is a crucial determinant factor for soil behavior and performance, making it vital for sustainable land management. Sustainable agricultural production and environmental quality, as well as sustainable soil use, depend on a healthy soil structure, which is based on aggregation (Costa *et al.* 2018). Soil structure is maintained by regulating root development, nutrient budgets, porosity, exchange of gases, and retention of soil water (Kasper *et al.* 2009, Singer and Munns 2002), it also prevents soil erosion and maintains the fertility of the soil. Soil aggregates have been extensively employed as performance indicators for both soil reclamation and deterioration (Varela *et al*. 2015, Rojas *et al.* 2016). The hierarchical model of soil aggregation proposed by Tisdall and Oades (1982), is predicated on the idea that several processes unite organic materials, silt, sand, and clay to form floccules (Costa *et al.* 2018). Plant roots, microorganisms, and soil organic components like carbohydrates contribute to the formation and stability of macroaggregates in a variety of soils (Nichols and Halvorson 2013, Wang *et al*. 2023)

Land use changes can affect soil aggregation and stability based on management and perturbation intensity (Dlapa *et al.* 2011, Shrestha *et al.* 2007) often leading to land degradation. The increased soil erosion and runoff can negatively impact soil aggregation patterns through removal of the topsoil rich in organic matter and aggregates, leaving behind less structured and degraded soil. Removal of vegetation can significantly alter soil structure and composition, often leading to reduced organic matter and soil aggregation due to soil compaction. Soil organisms, such as earthworms, fungi, and bacteria, are essential for soil aggregation. Different land use systems can impact the diversity and abundance of these soil biota, thus influencing soil aggregation patterns (Manpoong *et al.* 2020).

Maintaining and improving soil aggregation is important for sustainable land management. The presence of high organic matter in the soil contributes to the formation of stable aggregates, improves soil structure, increases water-holding capacity, and support overall soil health (Laskar *et al.* 2021, Manpoong and Tripathi 2019). The distribution and proportions of the aggregate sizes can vary depending on soil characteristics and management practices. A well-structured soil with good aggregation would typically have a mixture of macroaggregates, mesoaggregates, and microaggregates. Sustainable land use practices that prioritize soil health and conservation are crucial to maintaining and improving soil aggregation patterns, leading to more productive and resilient ecosystems. Therefore, understanding the soil aggregation pattern in different land uses established in degraded lands is crucial for maintaining and restoring the soil sustainable manner.

MATERIALS AND METHODS

Study area

The study was conducted in Bilaspur district of Chhattisgarh, Central India. The geographical coordinates of *Peltophorum pterocarpum* plantation is 82.138565° E longitude and 22.126672°N latitude, *Eucalyptus globulus* plantation is 82.13968° E longitude and 22.126061° N latitude and *Acacia nilotica* plantation is 82.142034° E longitude and 22.126027° N latitude. The annual rainfall varies from about 1,100 mm to about 1,700 mm, whereas temperature records 47ºC during summer and 11ºC during winter having tropical dry climatic conditions. The dominant land uses in Bilaspur district are cropland, forest, plantations. The forests of the state fall under two major forest types, i.e., Tropical Moist Deciduous Forest and the Tropical Dry Deciduous Forest.

Soil sampling and analysis

Soil samples were collected from three different plantation sites that were around 30 years old viz., *Peltophorum pterocarpum* plantation, *Eucalyptus globulus* plantation, *Acacia nilotica* plantation. A total of 10 soil samples each at 0-15 cm and 15-30 cm depth, representing each plantation were obtained using a shovel to avoid compression and disturbance of the sample. The collected soil samples were air-dried at room temperature for a few hours and then the large clods (>5 cm) were gently broken along natural planes of weakness into natural aggregates. The soils were then air-dried for 2 weeks before being passed through an 8 mm sieve to remove coarse plant residues, roots, and any stones >8 mm. Further, a sub-sample. (thoroughly mixed sample before taking the sub-sample to ensure a representative sub-sample) of 100 g was considered for further analysis.

Aggregate size distribution was determined by mechanical sieving (Kemper and Rosenau 1986) of air-dried soil samples into different size fractions (4.75–8 mm, 2–4.75 mm, 1–2 mm, 0.5–1 mm, 0.25–0.5 mm and <0.25 mm). The sieves were placed in a stack (i.e., 4.75, 2.00, 1.00, 0.50, 0.25, and 0.053 mm) with the largest mesh size on top and a closed recipient at the bottom. The sample was poured onto the top sieve after which the stack was placed within the machine with the top sieve covered by a lid. The stack of sieves was secured tightly in the machine and shook at a speed of 210 cycles min^{-1} for 5 minutes (Diaz-Zorita *et al.* 2007). The sieves were then emptied onto their corresponding metal trays ensuring that all soil was collected on the trays and no soil remains on the sieves. Lastly, the trays were weighed with soil and the weight of soil was recorded after deducting the weight of the empty tray. Further, after obtaining aggregate size fractions, soil aggregates were classified into micro aggregates (<250µm), mesoaggregates (250 µm-2000 µm), and macroaggregates (>2000 µm) as described by Tisdall and Oades (1982). Each aggregate size fraction was calculated as a percent relative to the total dry sample and the mean weight diameter (MWD) for aggregate stability was determined according to the following formula (Kemper and Chepil 1965).

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

Where, MWD is the mean weight diameter of soil aggregates, Xi is the mean diameter of each aggregate size fraction (mm) and Wi is the proportion of total sample weight occurring in each size fraction.

RESULTS AND DISCUSSION

The percentage of macroaggregate fractions was highest compared to mesoaggregate and microaggregate fractions in all the plantations. The variation in soil aggregate fractions at 0-15 cm and 15-30 cm depth in different plantation soils is shown in Table 1. The macroaggregate, mesoaggregate, and microaggregate fractions at 0-15 cm depth ranged from 62.2–82.6%,

Table 1. Aggregate size fractions distribution pattern in different land uses at 0-15 cm and 15-30 cm soil depths.

	Aggregate size fractions (mm)													
	>4.75		4.75-2		2-0.5		0.25-0.5		0.053-0.25		<0.053		MWD (mm)	
	Soil depth (cm)													
Land uses	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Peltophorum pterocarpum plantation	70.3 ±2.1	70.4 ±3.4	12.3 ±1.3	11.2 ±1.4	16.2 ±1.8	17.1 ±2.2	0.5 ±0.1	0.5 ±0.1	0.36 ±0.08	0.41 ±0.1	0.4 ±0.07	0.40 ±0.04	3.37 ±0.06	3.35 ±0.08
Eucalyptus globulus plantation	51.0 ±5.7	54.1 ±3.1	13.2 ±2.5	15.0 ±1.2	30.7 ±4.4	27.9 ±1.9	1.6 ±0.5	0.9 ±0.1	1.3 ±0.4	0.75 ±0.1	1.9 ±0.5	1.07 ±0.2	2.28 ±0.17	2.95 ±0.07
Acacia nilotica plantation	40.9 ±6.3	47.02 ±4.6	21.3 ±1.6	20.15 ±1.4	36.6 ±4.9	31.5 ±3.4	0.5 ±0.09	0.4 ±0.08	0.4 ±0.09	0.28 ±0.05	0.36 ±0.09	0.5 4±0.1	2.27 ±0.15	2.85 ±0.11

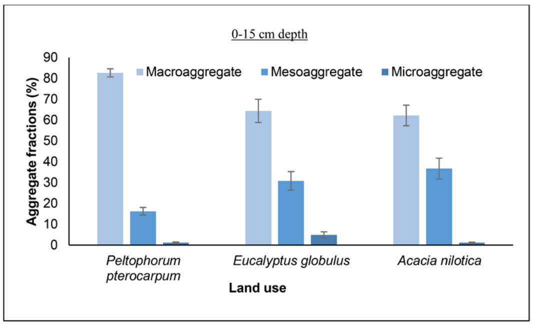

Fig. 1. Variations in macro-, meso- and micro-aggregate at 0-15 cm soil depth in different land uses.

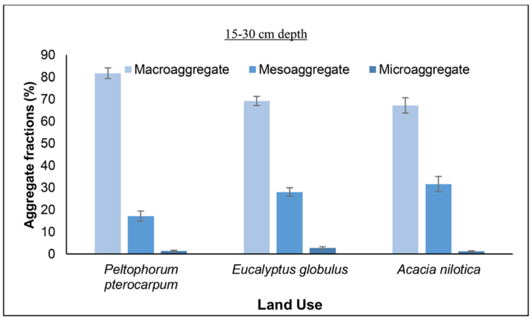

Fig. 2. Variations in macro-, meso- and micro-aggregate at 15-30 cm soil depth in different land uses.

31.6 – 36.7 %, and 1.1– 4.9% respectively (Fig. 1). Macroaggregates ranged from 67.2 – 81.7% at 15-30cm depth, in which the highest fraction (81.7%) was recorded in *Peltophorum pterocarpum*, 69.2% in *Eucalyptus globulus* plantation, and the lowest fraction (67.2%) in *Acacia nilotica* plantation. The mesoaggregate fractions ranged from 17.1 – 31.6% where the highest was observed in *Acacia nilotica* (31.6%), and the lowest fraction in *Peltophorum pterocarpum* (17.1%). The microaggregate fractions recorded 1.2 – 2.8% in all the plantations, the highest fraction (2.8%) was recorded in *Eucalyptus globulus* plantation. 1.4% in *Peltophorum pterocarpum* plantation while the lowest was in *Acacia nilotica* (1.2 %). The distribution of macroaggregate and microaggregate were highest in the *Peltophorum pterocarpum* plantation whereas the lowest was observed in the *Acacia nilotica* plantation. The percentage of macroaggregates was slightly higher at the 0-15 cm depth compared to the 15-30 cm depth across all plantation species (Fig. 2). Mesoaggregates recorded higher at 15-30 cm depth in *Peltophorum pterocarpum* plantation and *Eucalyptus globulus,* while *Acacia nilotica* plantation had a similar percentage at both depths. Microaggregate percentages remain relatively consistent between the two soil depths for all plantation sites.

The mean weight diameter (MWD) of different plantation soils at 0-15 cm and 15-30 cm soil depths are shown in Table 1.The MWD at 0-15 cm and 15-30 cm soil depth ranged from 2.27-3.37 mm and 2.85-3.35 mm respectively. The highest MWD at 0-15 cm was recorded in *Peltophorum pterocarpum* plantation (3.37 mm) while the lowest was observed in *Acacia nilotica* plantation (2.27 mm) with a slightly higher value in the *Eucalyptus globulus* plantation (2.28 mm). MWD values at 15-30 cm depth was also higher in *Peltophorum pterocarpum* plantation (3.35 mm) than in *Eucalyptus globulus* (2.95 mm) and *Acacia nilotica* plantation (2.85 mm). Greater MWD in *Peltophorum pterocarpum* plantation corresponds to higher stability of soil aggregates. Clay content acts as a cementing agent (Somasundaram *et al.* 2012, Fink *et al.* 2016) and therefore, the stability of soils depends on the physico-chemical properties of the clay and associated minerals (Denef and Six 2005). A high content of iron and aluminium oxides has been found to enhance aggregate stability (Bissonnais *et al.* 2018).

Several reports states that the formation of soil aggregate occurs mainly because of physical forces, while the stabilization of soil aggregates is produced due to quantity and quality of inorganic and organic stabilizing agents (Fink *et al.* 2016, Boix-Fayos *et al.* 2001). The fine root distribution pattern and penetration into the soil could also contribute to the variation in formation and the stability of soil aggregates (Erktan *et al.* 2016). The results suggested that the *Peltophorum pterocarpum* plantation has the highest percentage of macroaggregates, while *Acacia nilotica* plantation has the highest percentage of mesoaggregates. *Eucalyptus globulus* plantation, on the other hand, seems to have a relatively higher proportion of microaggregates compared to the other two plantations. An *et al.* (2010) observed low soil aggregate stability under farmland and bare fallow land compared to forest plots. The soil aggregation and carbon storage of no tillage land and forest succession ecosystems are generally higher at the soil surface, but only forest succession ecosystems enhanced aggregation in sub surface soil without increasing carbon storage (Devine *et al.* 2014). Singh *et al.* (2015) concludes that while reduced tillage can enhance the structure of clay soils, there are typically few opportunities in cereal monoculture systems of the boreal area to enhance topsoil carbon sequestration through reduced tillage or straw management techniques.

The composition of soil aggregates can significantly impact soil health, fertility, and overall ecosystem functioning. Different tree species have varying effects on soil aggregation, and understanding these relationships can be valuable for sustainable land management and ecosystem restoration efforts. The highest percentage of macroaggregates at both soil depths in *Peltophorum pterocarpum* plantation compared to *Eucalyptus globulus* and *Acacia nilotica* is possibly due to higher quantity inputs of leaf organic matter (Mishra *et al*. 2014).

Maximum distribution of mesoaggregates percentage in *Eucalyptus globulus* plantation shows the higher ability of the tree roots to promote the formation of mesoaggregates than microaggregate. Implementing agroforestry practices that combine trees with crops or livestock can lead to greater organic matter inputs and mesoaggregate development. *Acacia nilotica* plantation has relatively consistent values of microaggregates at both soil depths which could be due to its deep and extensive root system. The roots of these trees can penetrate deep into the soil, which helps in stabilizing the soil structure and reducing erosion. The root system also plays a role in promoting the formation and maintenance of microaggregates throughout the soil profile. *Acacia nilotica* trees are known to produce a significant amount of organic matter in the form of litter (e.g., leaves, branches) that falls to the ground.

CONCLUSION

The study suggested that different tree species have varying impacts on distribution of soil aggregation fractions. *Peltophorum pterocarpum* plantation has greater potential to form macroaggregate fractions as compared to the *Eucalyptus globulus* and *Acacia nilotica* plantations. Higher macroaggregate fractions and MWD in *Peltophorum pterocarpum* plantation indicated greater soil stability and appears to have the most improved soil structure. Further long-term monitoring and assessment in the soil properties are necessary to fully understand the underlying potential of restoring degraded soils.

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