Vol. 12, No. 2, pp. 133-142 (2012)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Stability of Soil Aggregates under Different Vegetation Covers in a Vertisol of Central India

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ABSTRACT

Stability of aggregate is the measure of the structural stability of soils. Any reduction in soil aggregate stability is a powerful early indicator of the onset of land degradation. The factors that influence aggregate stability of soils depend on the soil environment, the type, amount and dominance of the stabilizing substances and land uses. Variability in soil organic carbon (SOC) inputs and disturbances together determine soil aggregate stability at a particular point in the landmass. SOC promotes aggregation through the linkage of clay, polyvalent cations and organic matter. It is not the increase in clay content that indicate the stability of soils but the type and amount of clay present in the soils. The stability of clay soils depend on the physical and chemical properties of the clay present in them. The present investigation was carried out by collecting surface soil samples (0-15 cm) under different vegetation covers and from a cultivated soil in a Vertisol of central India. The vegetation covers include *Leucaena, Gliricidia, Eucalyptus*, grassy waterways and cultivated soils of a long-term tillage experiment. Results from the study revealed that among the different vegetation covers compared, the amount of aggregates of ≥ 2mm size was the greatest in *Eucalyptus* and the lowest in *Leucaena* treatments. Amongst all the treatments, the distribution of such aggregates followed the order: Eucalyptus>grasswaterways>Gliricidia>Leucaena>cultivated soil. Maximum amount of aggregates of sizes ≤ 0.25 mm were present in cultivated soil and minimum in soils under Eucalyptus vegetation cover. The soil organic C under different vegetation covers was significantly higher than in the cultivated soil. The stability of aggregates as expressed by mean weight diameter (MWD) was higher in Eucalyptus plant cover compared to cultivated soils. The greater MWD of soil aggregates under different vegetation covers was due to lower degree of disturbance and higher soil organic C content. Significant and positive correlations were observed ($R^2 = 0.61$, $P \leq 0.05$) between MWD of aggregates and soil organic C content under different vegetation covers, and cultivation practice in the studied Vertisol. The present study provides an insight on stability of aggregates and their formation under different vegetation covers in vertisols as aggregate stability affects the root physical environment, the water and nutrient cycles.

Key words: Aggregate fractions, MWD, Vegetation cover, Vertisols, Organic carbon

Introduction

Vertisols are shrink-swell soils with 60-65% clay content and such soils cover about 73 million ha of the sub-humid and semi-arid tropical regions of India and are the predominant soil type particularly in central India. The high water-holding capacity is controlled primarily by the relative proportion of clay and different sized soil aggregates fraction. In general, surface soils show

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low amount of clay that increases with the profile depth. It has been stated that Vertisols showing typical vertic properties only because of the amount of smectite content to the tune of at least 20% (Shirsath *et al.* 2000). The presence of dominating amounts of clay fractions offers more surface charge density, which is an important prerequisite of increasing soil organic C (SOC) as reported by Bhattacharyya *et al.* (2000).

Favorable soil aggregation is important to improve soil fertility and quality with particular emphasis on SOC sequestration, increasing agronomic productivity, enhancing porosity and decreasing erodibility. Stability of aggregate is used as an indicator of soil structure (Six *et al.*, 2000). Aggregation results from the rearrangement of the soil constituent particles, flocculation and cementation and it is arbitrated by SOC, biota, ionic bridging, clay and carbonates and oxide content but not all compounds in soils are responsible for aggregation. Different kinds of organic matter stabilize aggregates of different sizes. Organic matter promotes aggregation through the linkage clay-polycations-organic matter-polycations-clay (Tisdall and Oades, 1982).

An increase in clay content does not always results in increased stability, since clay mineralogy is an important factor in aggregation and stability of high clay soils depends on the physical and chemical properties of the clays. Smectite clays are more dispersible than the kaolinite clays and illitic and kaolinite soils, which contain small amount of smectite, may be dispersible and as susceptible to sealing as smectite soils. Effect of the role of organic matter on aggregate stability in clayey soils rich with smectite types of clay is conflicting. Some researchers reported that the aggregate stability is negatively related to soil organic C (Reichter and Norton, 1994), whereas some others reported a positive and significant relationship between them (Hati *et al*., 2007). Therefore, the present study was aimed at reporting the aggregate stability under different natural vegetation cover (Leucaena, Gliricidia, Eucalyptus and grassy water ways) and compared with that of a cultivated soil in a vertisol under central Indian conditions.

Fast-growing leguminous trees and shrubs like Gliricidia, Cassia, perennial Sesbania and Leucaena are grown in marginal non-agricultural lands or in alley cropping systems for nutrient cycling from the pruned biomass. *Gliricidia* (locally known as mata-raton, *Gliricidia sepium* Jacquin) is a tree grown in India for green leaf manuring and studies have shown an increase in yield due to its application to different crops (Sharma *et al*., 2009). Eucalyptus is a very important plant in social forestry program in India. Apart from that the potential of these trees for agroforestry systems to increase nutrient stocks on soils appears to be important in terms of maintaining or improving soil chemical properties and organic matter and protect the soil surface as related to the processes of litter or fine root production, decomposition and soil organic matter transformation (Datta and Singh, 2007). Loss of nutrients by leaching, erosion and runoff can be minimized by tree derived mulch, litter or foliage and an annual crop or cover of legumes or other vegetation can provide an effective soil cover to arrest soil erosion.

The aggregate dynamics vary among different crops, crop rotations and cover crops. Vegetation cover can influence soil aggregate stability because of contribution of organic matter through amount, nature and composition of litter and plant root turnover, root exudates and rhizodeposition (Pohl *et al*., 2009). Perennial crops generally improve soil structure and aggregation, whereas annual row cropping often results in structural degradation, mainly as a result of a loss of ground cover and organic matter from soil disturbance. Soil degradation is generally accelerated when perennial crop are replaced by annual row crops, primarily due to increased soil disturbance from tillage operations. Soil structure and aggregation are also strongly influenced by processes such as tillage, cropping systems and climate (Guerif *et al*., 2001).

Many studies have shown the potential value of grass in cropping systems for improvement or maintenance of soil structure (Tisdall and Oades, 1982). The effect of different crops on aggregation tends to reflect the crop chemical composition, rooting structure and ability to alter the chemical and biological properties of the soil (Martens, 2000). Cover crops increase C input to the soil, reduce erosion, increase cation exchange capacity (CEC), aggregate stability, water infiltration, and recycle of nutrients. Cover crop residues may also enhance microbial biomass, respiration, and N mineralization and shift in microbial community. Soil aggregation is correlated with biochemical composition of plant residues such as phenols, lignin, proteins, carbohydrate, and alkaline extractable humic acids in the soils and phenolic acids such as vanillin-vanillic acid in the residue (Martens, 2000).

Comparison of stability of aggregates under different soil types and the factors affecting them was reported by many (Reichter and Norton, 1994). However, comparing aggregate stability under different vegetation covers in a vertisol soil is different, as factors affecting aggregate stability and the mechanisms are different under different vegetation cover based on the litter addition, litter quality, shades and microclimate rainfall and soil and environmental temperature that exist under these plant covers. The formation of micro-aggregates reflects the influence of parent material due to the influence of clays on aggregate formation, but macro-aggregate mainly reflects the influence of plants (organic matter) on aggregate formation (Duchafour, 1975). The vertisols of Central India are rich in smectite type of clays and are highly susceptible to wind and water erosion. Thus, the erodibility is highly dependent on top soil surface aggregation. This is why, the present investigation was focused on the changes in vegetation cover and their effects on aggregate formation and stability in a vertisol of Central India.

Material and Methods

Site and soil

The soil samples were collected from area under different vegetation covers (*Leucaena leucaocephala* L., *Gliricidia Sepium*, Jacquin, *Eucalyptus* spp., and grassy waterways (*Cyperus rotundus*, L),) and from tillage treatments at the experimental farm of the Indian Institute of Soil Science, Bhopal, Madhya Pradesh, Central India, located at 23^0 18′ N latitude, 77^0 24′ E longitude and at 485 m above mean sea level. The research farm spreads over an area of 50 ha, a representation of central Indian plateau, where soils are clayey in texture and rich in smectite type of clay and classified as Typic Haplustert. The surface soils are low in available N (alkaline permanganate N, 145 kg ha^{-1}), available P (Olsen P, 10.7 kg ha^{-1}) and high in available K (ammonium acetate K, 325 kg ha^{-1}). The water holding capacity is 62% (w/w), bulk density 1.28 Mg m^{-3} and porosity 45% in the surface (0-15 cm) soil. The region has a subhumid semi-arid climate and receives an annual rainfall of 1100 mm. Major part of precipitation (88%) occurs during monsoon rainy season spreading over from June to September in general.

The detailed descriptions of experimental site are reported in Table 1. There were five treatments taken for this study, from where soil samples were collected. These treatments initially were classified into two broad group viz., soils under vegetation covers and a cultivated soil. Under cultivated soil, samples were collected from a long-term tillage experiment on continuous soybean-wheat cropping system after ten years. The soil under different vegetation covers dates back to more than 10 years of plantation. The grassy waterways are used for excess drainage of rainwater from the experimental field and also for open channel irrigation for irrigating winter crops. The long-term tillage experiments were started in the year 1999. Soil sample was collected from conventional tillage treatment (one summer ploughing with duck foot cultivator, two passes of duck foot cultivator before sowing and sowing by conventional seed drill) for cultivated soil treatment. All the samples were replicated in triplicate for soil physical and chemical properties. For the present study only surface soils (0-15 cm) were analyzed for aggregates formation and stability and soil organic C content.

Soil aggregates and SOC analysis

Various indices have been proposed for expressing the distribution of aggregate sizes such

Table 1. Physical and physic-chemical characteristics of the soil profiles under different vegetation cover

Depth (cm)	Clay (%)	pH (1:2)	EC (dS m^{-1})	Organic C (g kg^{-1})	CEC (Ca^{++} Mg^{++}, Na^{++}, K^{+}) (c mol p (+) kg^{-1})	$CaCO_3$ (%)
Cultivated soils						
0–15	54.5	7.8	0.52	5.22	44.25	2.0
15–30	56.2	7.9	0.62	5.37	46.11	2.1
30–45	57.1	8.1	0.55	5.57	48.33	2.5
45–60	59.0	8.2	0.52	3.98	49.25	2.0
Leucaena Leucocephala						
0–15	55.6	7.5	0.54	9.06	42.55	1.8
15–30	56.0	8.0	0.55	5.47	45.22	2.1
30–45	58.0	8.1	0.61	5.87	46.99	1.5
45–60	60.0	8.3	0.62	4.98	46.85	1.9
Gliricidia Sepium						
0–15	53.2	7.7	0.61	8.16	49.2	1.9
15–30	55.2	7.9	0.59	5.17	51.0	2.1
30–45	57.3	7.9	0.63	5.30	53.1	2.2
45–60	59.1	8.1	0.65	4.22	54.5	2.0
***Eucalyptus* spp.**						
0–15	52.0	7.6	0.59	10.07	49.1	1.8
15–30	53.2	7.8	0.62	5.88	48.8	1.9
30–45	54.9	8.2	0.61	5.69	50.4	2.1
45–60	58.3	8.2	0.60	4.59	52.0	2.0
Grassy waterways						
0–15	55.2	7.4	0.62	8.62	47.2	1.9
15–30	57.2	7.8	0.58	6.02	49.1	1.8
30–45	59.1	8.2	0.59	5.92	50.2	1.9
45–60	60.2	8.1	0.62	4.66	51.1	1.8

as mean weight diameter (MWD);, geometric mean diameter, coefficient of aggregation and many more. MWD is widely used index to integrate aggregate size distributions obtained by mechanical sieving. In most studies, MWD measurements showed an important variation under different cropping and tillage practices. To analyze aggregate stability, moist soil samples were allowed to air dry at room temperature. Mean weight diameter (MWD) was determined by Yoder's wet sieving method (van Bavel, 1953). For this, 40 g air-dried, 4-8 mm size range aggregate samples were used. The wet sieving of the air dry soil sample was carried out using a nest of sieves with mesh openings of 4.00, 2.00, 1.00, 0.50, 0.25 and 0.125 mm, respectively. Aggregate size distribution was determined based on the weight of aggregates retained in each sieve class with respect to the total soil sample weight. The size distribution of aggregates was characterized by mean weight diameter (MWD) which was estimated using the following equation;

$$\text{MWD} = \sum_{i-1}^{n} WiXi \qquad \ldots(1)$$

where, Wi is the proportion of the total dry sample weight, X_i is the mean diameter of any particular size range of aggregates separated by sieving and equal to $(X_i + X_{i\text{-}1}) / 2$. The SOC content was determined by wet digestion method of Walkley and Black (1939).

In this study, all data were statistically analyzed. Aggregate size distributions in different treatments were compared using Duncan Multiple Range Test (DMRT) statistical procedure.

Results and Discussion

The results from aggregates size distribution showed that the fragment size, in terms of percentage, under vegetation cover was skewed toward bigger size fractions whereas, under cultivated soil fragment, size was skewed toward smaller size fraction (Fig. 1). Distribution of aggregates indicated that the highest proportions were in the ≥ 2.0mm diameter class for soils under all types of vegetation covers. The fraction of soil as aggregates ≥ 2.0mm under crop plant cover was the greatest (43%) under the Eucalyptus cover, followed by grassy waterways (37%), Leucaena (26%) and lowest under Gliricidia (25%), whereas under cultivated system, aggregates ≥2.0mm were the lowest (15%). It happens because of mechanical disruption of soil aggregates due to disturbance of soils by tillage implement and exposure and oxidation of soil organic matter. Pinheiro *et al* (2004) also observed that aggregates are distributed mainly in the smaller diameter class in the treatments that are subjected to more intensively mechanically disrupted tillage.

Vegetation cover is one of the key factors influencing soil aggregate stability. This is due to positive feedback of the vegetation on soil quality due to contributions of organic matter from the litter. Also, vegetation decreases weathering, enhances rainwater infiltration and offers more favourable micro-climate beneath plants due to shadow. These conditions should generate a more active fauna and flora and as a consequence, study aggregates (Zhang, 1994). Among vegetation cover treatments, Eucalyptus showed maximum amount of aggregates ≥2.0mm (Fig. 1). Soils under Eucalyptus plantations are known to have high aggregate stability because of its leaves residues contain high amount of polyphenolic compounds such as 1, 8 - cineole (Bhatti, 2007). Residues with higher amount of phenolic acids contribute to higher C in soil, stimulate synthesis of humic acid and consequently promote better aggregation (Bhatti, 2007). There was no

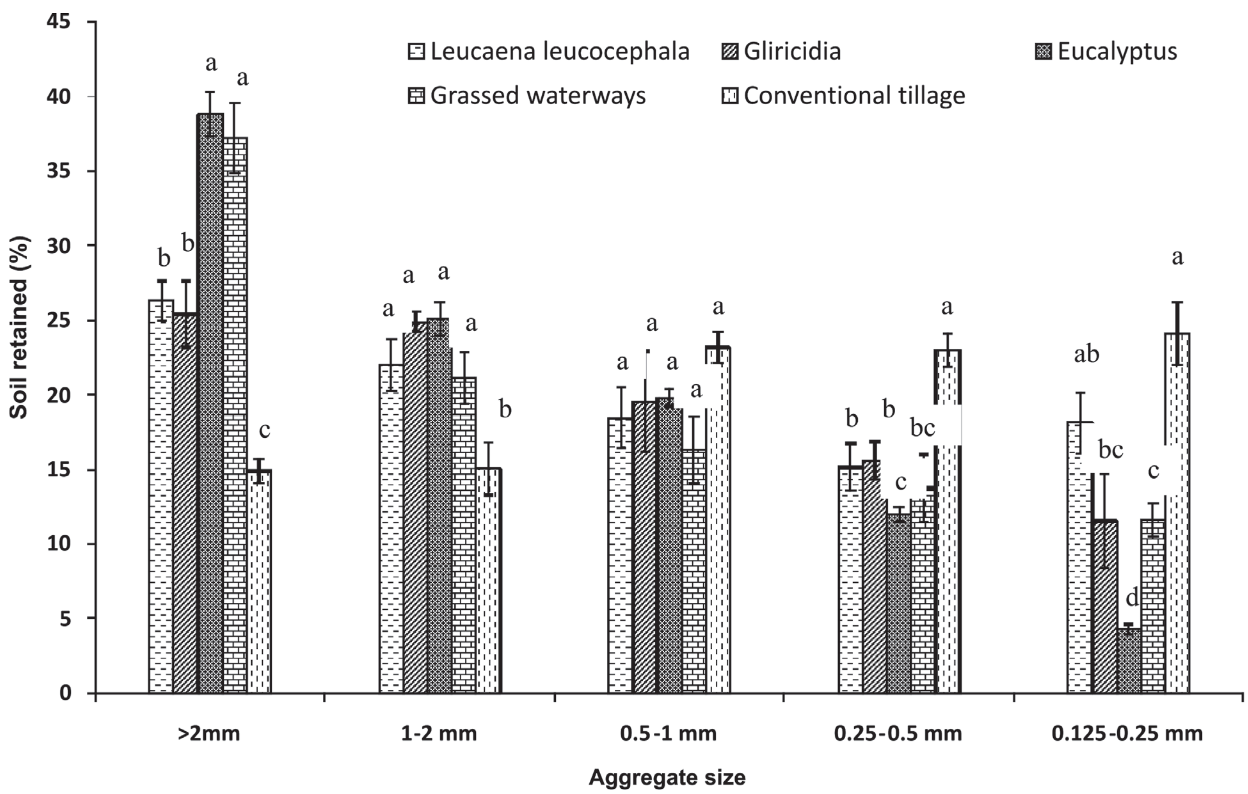

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Fig. 1. Effect of vegetation covers on soil aggregate size distribution

statistical difference between aggregates of ≥2.0mm size in soils from Eucalyptus and grassy waterways. However, aggregates of ≥2.0mm size in these treatments were significantly higher than that in soils under Leucaena and Gliricidia plant covers (Fig. 1).

In comparison to vegetation cover, the grassy waterways have a very high amount of aggregation ≥ 2 mm (Fig. 1), higher than the soils under Leucaena and Gliricidia. The root system of grasses must be improving the aggregate stability and this may be because, although the perennial trees and shrubs (Eucalyptus and Gliricidia) are far more developed than the grasses, the root system of grasses is more intense and dense. Extensive fibrous root system of grasses produces higher level of macro-aggregation, >250 μm up to several mm diameter by holding the aggregates together, through exertion of drying effect on soil particles, and excretion of organic substances that act as binding glue. Perennial grasses are generally associated with high microbial biomass and carbohydrate production which also stimulates micro-aggregation (Gale *et al*., 200). Many studies have also shown the potential values of grass cover in improving soil structure. In vertisols, drying grass roots add C input and thus, stimulate microbial biomass (Tisdall and Oades, 1982). Chevallier *et al*., (2001) reported that the restoration of soil C stock in a vertisol under pasture was caused by abundant of grass roots. The positive effect of labile organic matter on development of structure in vertisol was shown by McGarry (1996). Water stable aggregates 5-25 μm were associated with organic debris or colloids of bacteria producing extracellular polysaccharides. Plant roots affect macro-aggregation through organic debris and colloids whereas micro-aggregation is mainly influenced by extracellular polysaccharides produced by bacteria (Albrecht *et al*., 1998). According to Six *et al*. (2000) clayey soils rich in swelling clays under native vegetation exhibit two levels of hierarchy aggregation: C-depleted micro-aggregates are bound together by organic binding agents with C-rich macro-aggregates.

Soils in Leucaena and Gliricidia treatments showed maximum amount of aggregates ≥2.0mm than in cultivated soils. Both Leucaena and Gliricidia are fast-growing, nitrogen-fixing trees and through the decomposed litter provide a favorable environment for biological organisms (fungi, bacteria and actinomycetes), which help in nutrient recycling and in improvement in SOC (Imogie *et al*., 2008) (Fig. 2). Fungi also have direct effect on aggregate stability by holding micro aggregates through their hyphae, whereas bacteria and actinomycetes produce polysaccharides which favour aggregation (Chaney and Swift, 1986). The high stability of

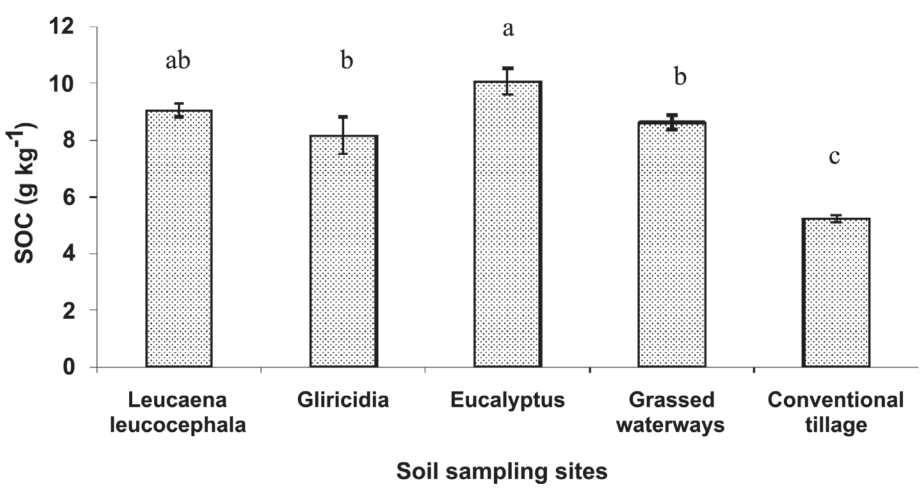

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Fig. 2. Soil organic C (SOC) content under different vegetation covers in the studied vertisol

aggregates under different vegetation covers than cultivated soils could be attributed to biochemical component and properties of plant leaves (Martens, 2000), the amount of leaf-falls that lead to change in SOC status and rooting pattern and ability to alter the chemical and biological properties of the soil. These effects tend to be short-lived under conventional tillage regimes. This is also reflected through higher MWD of soil aggregates under vegetation cover treatments than that of cultivated soils (Fig. 3).

The effect of vegetation cover and tillage practices on 0.5-1 mm aggregate size distribution was also non-significant. It is generally accepted that soil aggregation and organic matter accumulation are interrelated, i.e. organic matter stabilizes soil aggregates and soil aggregates immobilize SOM (Tisdall and Oades 1982; Six *et al*. 2000). In the present study, SOC under the conventional tillage (cultivated soil) was 5.22 g kg^{-1} which was lowest among all the treatments. The lowest SOC lowest under cultivated soil was attributed to the exposure through and rapid oxidation of soil organic matter due to intensive tillage operation. That may be the reason for non significant differences in 1-2 mm and 0.5-1 mm aggregate size in aggregates under all other treatments except cultivated soil.

As compared to aggregates ≥ 2.0 mm, maximum amount of micro aggregates (<0.25 mm) were present in soils under cultivated soil (24%) and minimum under Eucalyptus (4.3%). Under cultivated soil, intensive ploughing causes a negative effect on soil aggregation (Du *et al.,* 2009). According to Six *et al*. (1999), the disruption of aggregation due to tillage increase macro-aggregates turnover and reduce formation of stable micro-aggregates, leading to exposure of existing aggregates to microbial processes and accelerated organic carbon turnover with consequent reduced SOC accumulation. Therefore, during the rainy season the SOC content was lower under cultivated soil compared to soils under vegetation covers.

Similar pattern of soil organic carbon under all treatments has been observed in the present study i.e. soil with the highest amount of organic C (Fig. 2) has the highest amount of soil aggregates retained in 2 and 4 mm mesh sieves and this has been also reflected in the value of MWD of aggregates too (Fig. 3). This indicates that soil organic carbon promotes aggregation in ≥2.0mm aggregate size fraction. The MWD was greater in treatments where different undisturbed vegetation stands like Leucaena, Eucalyptus, Gliricidia and grassy waterways compared to the disturbed cultivated soils. In ≥2 mm fraction

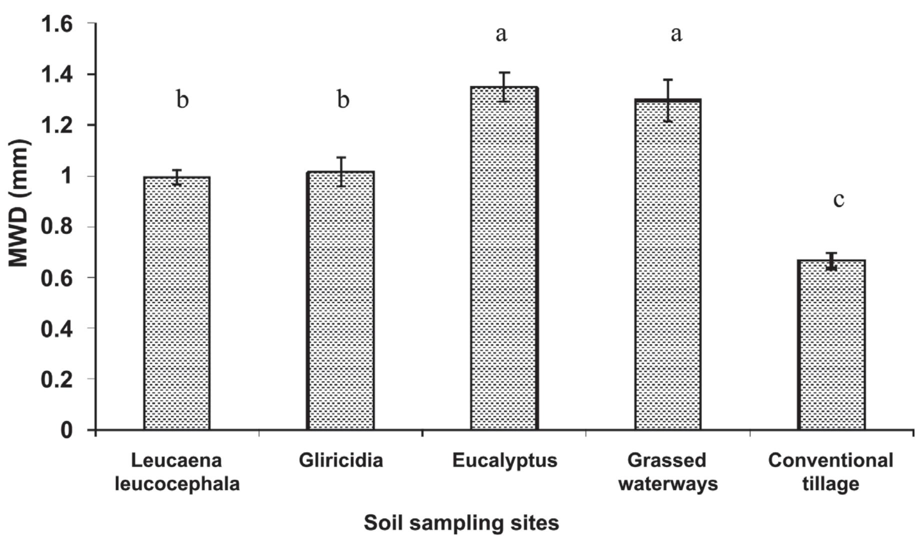

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Fig. 3. Mean weight diameter (MWD) of soil aggregates under different vegetation covers

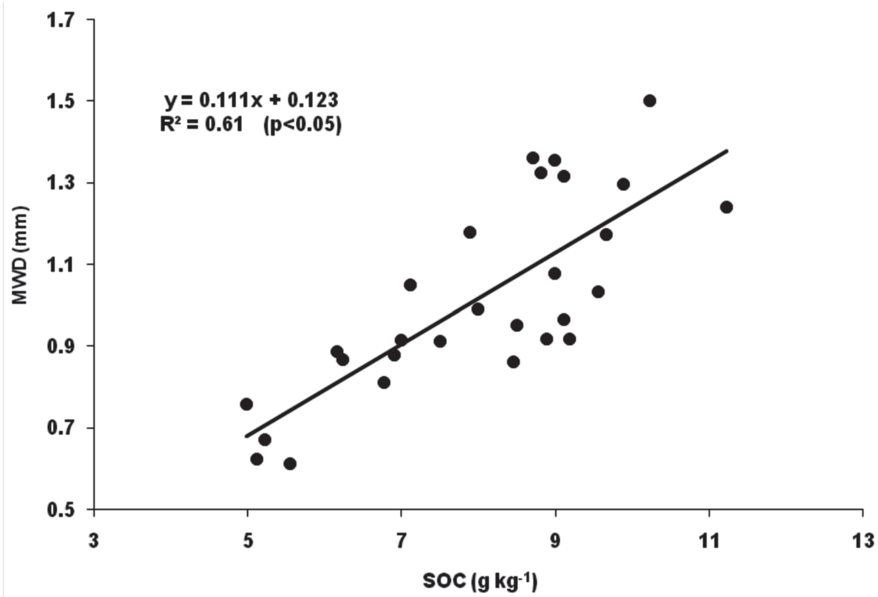

Fig. 4. Relationship between MWD and SOC content in the studied vertisol

range aggregates, particles are also held together by a fine network of roots and hypae. However in a mollisol soils, Martens (2000) reported that soil with the greatest amount of organic carbon has the greatest amount of aggregates remaining in the 2 and 4 mm sieve. He also reported that addition of the seven organic residues of crop plant origin increased MWD for the soil at all incubation times when compared to the control (no residue added). Soil organic C has been considered one of the main agents favoring soil aggregation in a latosol in Brazil and its distribution intended to be greater in the >2.0 mm class than other size classes (Pinheiro *et al*., 2004).

The stability of soils with higher clay content depends on the physical and chemical properties of the clay. Interestingly MWD was positively correlated to CEC for highly weathered soils, and negatively related in case of the swelling soils (Reichter and Norton, 1994). This suggests that for swelling soils, higher CEC may decrease aggregate stability as a result of increased amount of hydrated cations and degree of swelling, a reflection of the mineral composition of the soils. Organic C was not correlated with aggregate stability for swelling soils. This does not imply that organic matter is not important in clayey soil structure; but is importance in different level of structure (Warkentin, 1982). According to him, in course and medium textured soils, organic matter stabilizes micro-peds (50-100 μ) and aggregates (0.5 – 5 mm); for clayey soils organic matter acts as conglomerate (1 – 50 μ) and micro-peds (50 – 500 μ). However, in our study, the MWD in the vertisol is positively and significantly correlated with soil organic C (R^2 = 0.61*) (Fig. 4). This is in agreement with the earlier work reported by Hati *et al*. (2007) in vertisol soils. In these studies, different rates of distillery effluents was applied as irrigation water to soybean-wheat cropping system in a vertisol of central India and their effects on soil properties such as MWD, organic C and microbial biomass C were studied. Hati *et al*., 2007 reported that the increase in soil microbial biomass C due to addition of organic matter lead to increased microbial activity. They reported that the MWD is significantly and positively correlated with microbial biomass C (R^2 = 0.81**). Though, the smectite type of clay reduces the stability of clayey soils, it is likely that the relatively high soil organic C from different contributed vegetation covers increased the aggregate stability. In the present study, there was an increase in macro-aggregates (>250 μm diameter) distribution under different vegetation cover (Fig. 1) which suggested that aggregate stabilization occurs through formation of macro-aggregate. Macro-aggregates (>250 µm diameter) may have cores of plant organic fragments such as plant roots and fungal hyphae for encrustation by mineral particles as a mechanism in aggregate stabilization (Oades and Waters, 1991). Also, in soils dominated by the presence of 2:1 type of clay minerals, the aggregate stability is affected mainly by polyvalent metal-organic matter complexes that form bridges with the negatively charged clay platelets (Six *et al*., 2000).

Conclusions

The present study highlighted the importance of vegetation cover and cultivation practices on soil aggregation and SOC. The aggregate stability in terms of MWD was found to be different under different vegetation cover treatments. Among the different vegetation cover, aggregate stability was the highest under *Eucalyptus* plantation. This was substantiated by the presence of maximum amount of soil aggregates of ≥2.0 mm size fraction as well as increased soil organic C content as compared to soils under cultivated crops, owing to lesser disturbances of soils and accumulation of higher amount of soil organic matter through roots and leaf-fall with increased macro-aggregate formation.

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Received: 27 June 2012; Accepted: 28 August 2012