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ON

FACTORS AFFECTING SOIL STRUCTURAL STABILITY AND THEIR RELATIONSHIP

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FACTORS AFFECTING SOIL STRUCTURAL STABILITY AND THEIR RELATIONSHIP[1]

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Abstract

Soil structural stability is the measure of the ability of the soil structural units to resist change or the extent to which they remain intact when mechanically stressed by environmental or other factors. This seminar paper is prepared to review about structural stability, factors affecting it and several management practices to maintain a good structural condition. This seminar paper is exclusively a review paper so all the data were collected from secondary sources like books, journals, proceedings, reports, publications etc. It has seen that structural stability is one of the most important factors of soil resistance against degradation which acts as a useful indicator of the suitability of the soil structural condition for favorable crop production. Various factors like climate change, presence of organic matter, tillage and fertilization, type of vegetation and landscape, plants, roots and residues, soil organisms, adsorbed cations etc. can affect soil structural stability. These can modify soil functions like bulk density, porosity, consistence etc. Different management practices such as proper tillage, addition of organic matter, crop rotation, biochar application, vegetation restoration etc. can play a major role in maintaining soil structural stability.

Keywords: Soil structural stability, factors, management strategies

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Chapter 1

INTRODUCTION

Soil is one of the major elements of the biosphere which determines the hydrological, biogeochemical, and erosional cycles and gives various indispensable goods and services to the ecosystems (Keesstra et al., 2016). Yet, soils are often hampered by several degradation factors. Within these factors soil erosion is most prominent and is a clear indication of land deterioration (Annabi et al., 2017).

Soil structural stability pointed towards the resistance that the soil aggregates offer to the disintegrating impact obtained from mechanical and water manipulation (Jury and Horton, 2004). In other words, it may be defined as a measure of the ability of the soil structural units to resist change or the extent to which they remain intact when mechanically stressed by environmental factors (Igwe and Obalum, 2013).

It is one of the most prominent factors of soil resistance contrary to degradation (Jozefaciuk and Czachor, 2014) which impacts the physical behavior of soils like infiltration, erosion and permeability, thus performs as a effective indicator of the suitability of the soil structural state which is favorable for crop production (Lal, 2006; Turgut and Kose, 2015). It is an inherent nature of soils which is an empirical assessment of the competency of a soil aggregate to maintain cohesion and do not break apart by the action of water. The most significant structural stability exhibitors are water dispersible clay, air capacity, the slope of the retention curve at the inflection point, and mean weight diameter of aggregates (Emami et al., 2014).

Soil structural stability is one of the most prominent criteria for conservation of soil and protection of soil environmental operations by which soil capacity to stabilize and store organic C is influenced (Kodesova et al., 2008) as well as distribution in the landscape and soil water storage capacity (Berhe and Kleber, 2013). Besides, an increase in soil structural stability enhances erosive agents and compaction resistance (Chaplot and Cooper, 2015). Actually, to find out the best environment for seed germination and sensitivity of soil, rooting of crops, the soil ability to sequester organic carbon and to crusting and erosion, soil aggregate stability is used (Annabi et al., 2017).

There are many factors that significantly affect soil structural stability like climate, organic matter content, adsorbed cations, tillage, type of vegetation, plant roots, soil organisms, manurial practices and crop rotation, alternate wetting and drying (Shreeja n.d.). It also depends on a number of biological factors, including microbial extracellular polysaccharides, fungal hyphae, soil microbial biomass, plant roots, carbon and nitrogen inputs from fresh organic matter, aromatic humic substances and glomalin-related soil proteins derived from arbuscular mycorrhizae (Garcia-Orenes et al., 2012).

Soil structure, with the presence of well structural stability, is the most pleasing of all soil qualities for sustaining agricultural productivity and for maintaining the quality of the environment. For this reason, it is necessary to have a well understanding about structural stability and its relationship with soil erodibility to guide the management of soils against erosive and similar degradative forces. Proper management is necessary to position these soil resources for continued support of agricultural and allied activities (Igwe and Obalum, 2013).

Considering the above facts, the following objectives were undertaken:

- To know about soil structural stability and identify different factors responsible for soil aggregation, and
- To establish a relationship among the contributory factors along with their management practices.

Chapter 2

MATERIALS AND METHODS

This seminar paper is exclusively a review paper. Therefore, all of the information has been collected from secondary sources with a view to prepare this paper. During the preparation of this paper, I went through various relevant books, journals, proceedings, reports, publications etc. Findings related to my topic have been reviewed with the help of the library facilities of Bangabandhu Sheikh Mujibur Rahman Agricultural University. For collecting recent information internet browsing was also be practiced. Good suggestions, valuable information and kind consideration from my honorable major professor and course instructors were taken to enrich this paper. After collecting necessary information, it has compiled and arranged chronologically for better understanding and clarification.

Chapter 3

REVIEW OF FINDINGS

3.1.1 Soil structural stability:

Soil structural stability means the capability of soil to avert disintegration when staving potency coupled with tillage and water or wind erosion is used. It is a major factor controlling soil erodibility. Because of the hectic potency of rainfall, soil aggregates are staved, leaving fine particles with different size distribution, based on the composition and stability of the aggregates. These products then turn out to be the source ingredients for mobilization of sediment and export with runoff wash and rainfall splash (Shi et al., 2017).

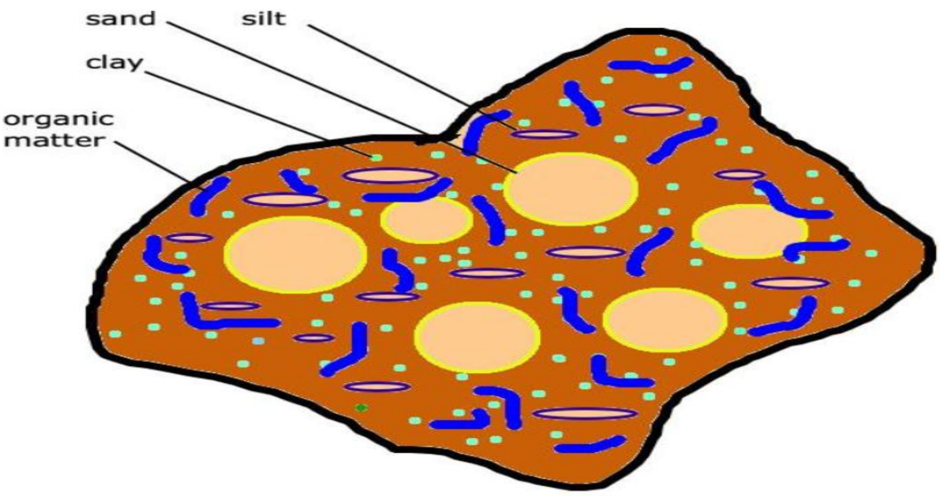


Fig. 1 Soil structural components. (Source: Hetrick et al., 2016)

The structural stability rely on soil organic matter, particle size distribution, soil micro-organisms, vegetation, presence of exchangeable cations and sesquioxides (Figure 1). Soil organic matter is one of the most prominent binding agents which form stable aggregates. Organic materials are important soil additives to improve soil physical properties. Degradation of soil structure occurs mostly due to the decrease in soil organic matter caused by excessive soil cultivation (Simansky, 2013).

It is a good exponent of soil permeability and workability. It gives us an idea about how well a soil can overcome erosion by water and raindrop impact, while dry aggregate size distribution can be used to forecast hindrance to erosion by wind and abrasion. It also refers to the shape and size of soil aggregates and the pore spaces between them, which are arranged in a layer of soil. Soils that are well structured, drain well than poorly structured soils and contain good soil tilth (Figure 2).

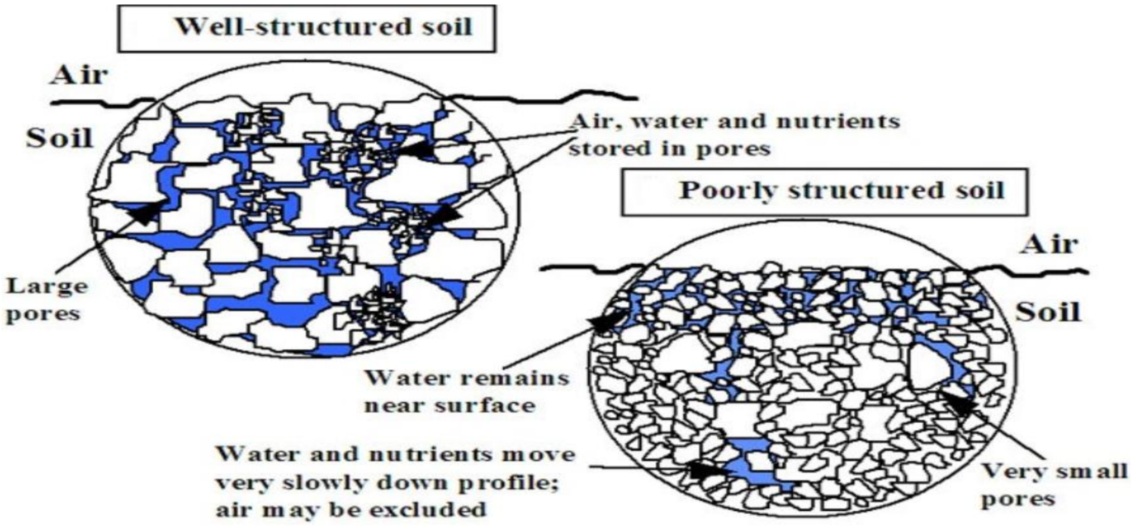


Fig. 2 Well-structured and poorly structured soil. (Source: Johns, 2015)

3.1.2 The main mechanisms behind structural breakdown

Slaking and dispersion are considered to be the main mechanisms behind structural breakdown. In case of slaking the initial breakup of macro-aggregates into micro-aggregates is occurred when immersed in water, caused by pressure due to entrapped air and by differential swelling. Unlike slaking, in case of dispersion the soil colloidal particles are liberated that are more transportable during erosion. This indicates that stability of soil structure may be a better exponent of potential soil erosion hazards (Igwe and Obalum, 2013).

3.1.3 Methods for ascertaining soil structural stability

A number of various courses each applying different types and levels of disruptive energy can be applied in metering structural stability, which may or may not adequately match the type and level of disruptive energy experienced by soil aggregates in the field. By exposing soil aggregates to various methods like ultrasonic vibration (UV), wet sieving (WS), rainfall simulation (RS) and clay dispersion (CD), stability was measured **(**Almajmaie et al., 2017).

3.1.4 Parameters related to the structural stability

The structural stability of soil is the outcome of various numbers of interactions of soil parameters. These include polysaccharides, microorganisms, lipids and humic substances which are known to favors the stability of aggregates in soil. They improve the resistance of aggregates to break-apart and mechanical de-aggregation under the force of raindrops, by enhancing cohesion between soil particles (Anonymous, 2008).

3.1.5 Factors Affecting Soil Structural Stability

Soil Structural Stability depends on the following factors:

- **Climate change:**

The rate of aggregation which in turn changes the different types of structure to a great extent is influenced by climate change. Very little aggregation of primary particles is observed in arid regions whereas the degree of aggregation in semi-arid regions is higher than arid regions (Bhaskaran, n.d.; Shreeja, n.d.). Due to shift in climatic state the physical and chemical behavior of soil influenced which ultimately lead to affect the structure of soil (Table 1).

Table 1 Summary of effects of climate change variables on soil (modified)

Increasing Temperature	Loss of soil organic matter
	Loss of soil structure
	Increase in soil respiration rate
	Increase in mineralization rate
Increasing CO2 Concentration	Increase in soil organic matter
	More availability of carbon to soil microorganisms
Increasing Rainfall	Enhanced surface runoff and erosion
	Increase in soil moisture or soil wetness
	Increased reduction of Fe and nitrates
Reduction in Rainfall	Reduction in soil organic matter
	Soil salinization

(Source: Pareek, 2017)

- **Organic matter:**

Organic matter is the vital medium for the zest of granular- type aggregates in soils. At the time of decomposition of numerous organic compounds and other slimy materials containing cementing, sticky and binding nature are produced and with the action of these materials soil separates bind together and form soil aggregates. It modifies the structure of a clay soil and sandy soil as well. In sandy soil, the sticky and slimy products produced by the associated microorganism and decomposing organic matter acts as a binding agent that cement the sand particles together and form aggregates. In clayey soil, it changes the properties of clay soil by reducing its cohesiveness, by this process clay soil become more crumby (Bhaskaran, n.d.; Shreeja, n.d.).

Variables related to soil carbon like particulate organic carbon (POC), total organic carbon (TOC), hot water extractable carbohydrates (HWEC) and total carbohydrates (TC) influence different structural stability pre-treatments like fast wetting (FW), mechanical breakdown (MB) and slow wetting (SW) pre-treatments (Table 2).

Table 2 Canonical correlation analysis of variables related to carbon and variables of different structural stability pre-treatments

Canonical variable	1	2
R	0.96	0.64
R^2	0.92	0.41
Lambda	34.26	6.66
p- value	6.1E-04	0.35
Variables related to carbon		
POC	-0.24	-2.31
TOC	-0.27	0.91
HWEC	0.94	1.66
TC	0.55	0.25
Structural stability pre- treatments		
FW	0.67	-0.99
MB	0.19	-0.74
SW	0.57	1.56

POC = particulate organic carbon; TOC = total organic carbon; HWEC = hot water-extractable carbohydrates; TC = total carbohydrates; FW = fast wetting; MB = mechanical breakdown; SW = slow wetting pre-treatments.

(Source: Carrizo et al., 2015)

Hanke & Dick, 2017 also found a strong influence of organic C content to soil structural stability. A positive correlation between C content and E_{max} (Higher ultrasonic energy values) (Figure 3) are observed in the C-rich soils (TS and FH), indicating that organic compounds play an important role in structural stability.

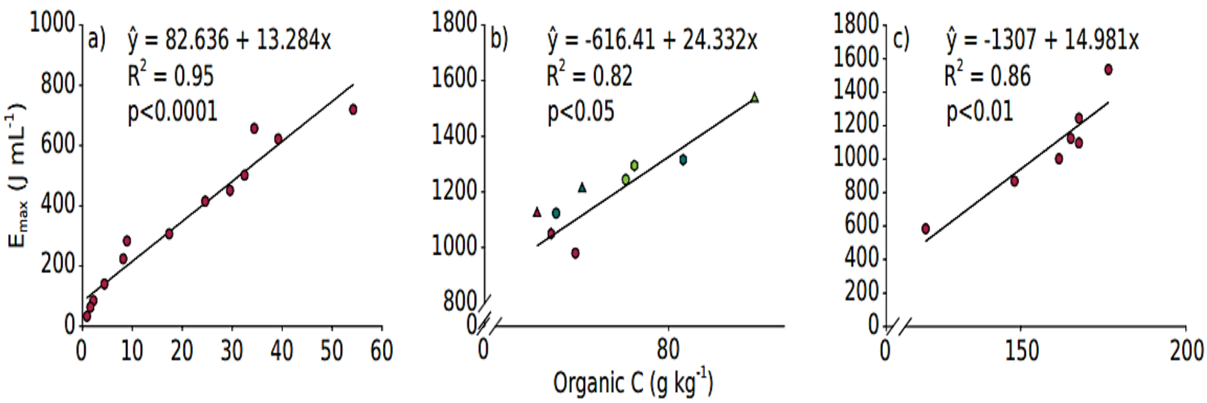


Fig. 3 Linear regressions between the organic C content and dispersion energy levels in a) OX, b) FH and c) TS. (Source: Hanke & Dick, 2017)

Tillage and fertilization:

Because of intensive cultivation infiltration capacity and penetrability are increased, but negatively affect the soil structure. The large sized clods are broken down into smaller fragments and aggregates by the action of cultivation implements. Different fertilizers also affect soil structure. For example, Sodium Nitrate which destroys granulation by the process of affecting the aggregates stability. Few fertilizers can also help in the development of good soil structure (Bhaskaran, n.d.; Shreeja, n.d.).

In case of minimal tillage system, a positive impact is observed on both of the aggregation and sequestration processes of carbon in size fractions of water-stable aggregates, and also in ploughing of crop residues along with NPK fertilizers. But, only NPK fertilizers application had a deterrent effect on the content of SOM. Under the minimal tillage system along with treatment with crop residues and NPK fertilizers, give a significant increase in the total organic carbon contents of the soil by enhancing the size fractions of water-stable aggregates (Simansky, 2013). Compared to conventional tillage, minimal tillage had a positive influence on the mean weight diameter of water-stable aggregates (MWD-WSA). The similar trend was observed in case of the values of stability index (Table 3).

Table 3 Statistical evaluation of total and labile carbon contents in size fractions of water-stable aggregates

Parameters	Treatments of tillage		Treatments of fertilization		
	Conventional tillage	Minimal tillage	Without fertilization	Crop residues and NPK fertilizers	NPK fertilizers
Mean weight diameter of water-stable aggregates	0.73a	0.86a	0.71a	0.90b	0.76a
Index of stability	0.99a	1.01a	0.89a	1.10b	1.02a
Critical level of organic matter	3.02a	3.65b	3.11a	3.75b	3.14a

Different letters between columns (a, b) indicate that treatment means are significantly different at $P < 0.05$ according to LSD multiple-range test

(Source: Simansky, 2013)

Tillage systems together with fertilization showed a statistically significant impact on the critical level of organic matter. Compared to NPK and control (Co), these effects were more positive in minimal tillage (MT) than in conventional tillage (CT) as well as in case of crop residues combined with NPK fertilizer (CR+NPK). The influence of tillage systems and fertilization on the portion of water-stable aggregates (WSA) is shown in Figure 4.

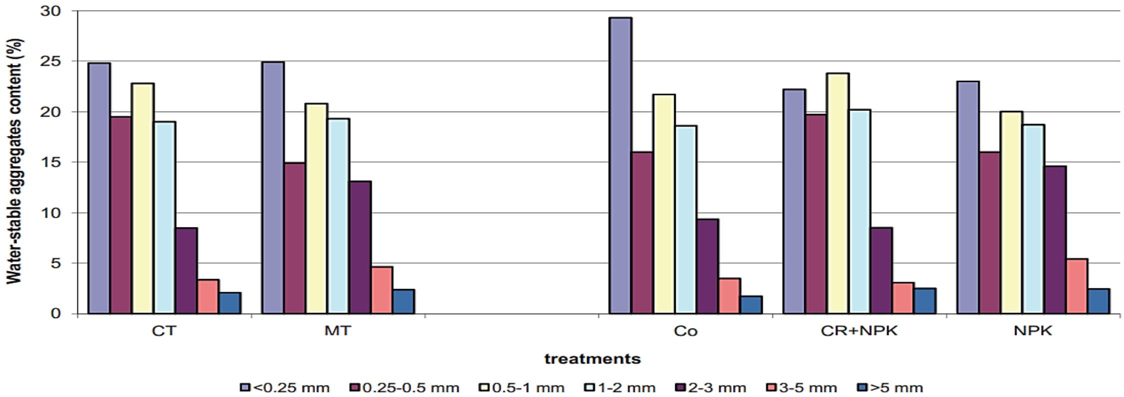


Fig. 4 The portion of water-stable aggregates with dependence on tillage systems and fertilization. (Source: Simansky, 2013)

The highest WSA content was observed in MT (0.5–3 mm) than in CT. In case of NPK treatment, compared with CR+NPK and C_o, the content of WSA was higher as well whereas, positive effect on portion of micro-aggregates was observed with the application of crop residues along with NPK fertilizers.

- **Adsorbed Cations:**

Aggregate formation is also affected by the nature of the cations, which are adsorbed by soil colloids. As for example, in case of dominant adsorbed ion like Na^+, then the particles become dispersed or deflocculated and as a result a formation of very undesirable soil structure is occurred. But, if Ca^+ is the dominant absorbed cation, then flocculation and granulation the soil particles will be occurred and thereby ultimately lead to the formation of good soil structure (Bhaskaran, n.d.; Shreeja, n.d.).

- **Type of Vegetation and land uses:**

Grassland and forest soils generally have high aggregates stability. Compared to other crops like corn, grasses and legumes can enhance the aggregation of soils more (Bhaskaran, n.d.; Shreeja, n.d.). Land uses can also affect the soil properties by changing the characteristics of soil and lead to severe soil degradation and soil erosion. A large number of reports have shown that, various management practices like fertilizer application, plowing etc. have impact on soil structure and other physical properties (Ayoubi et al., 2014). Change in land use can primarily lead to change in soil organic carbon (SOC) content and fractions, which subsequently steer physical, chemical and microbial processes of soil.

Table 4 Soil structural stability indices (i.e., MWD, GMD and D50) as affected by land use in surface (0-5 cm) and sub-surface (5-25 cm) layers

Land use	MWD (mm)		GMD (mm)		D50 (mm)	
	cm 0-5	cm 5-25	cm 0-5	cm 5-25	cm 0-5	cm 5-25
Rangeland with good condition	a(0.4)2.8	a(0.2)2.5	a(0.2)1.1	a(0.1)0.9	a(0.8)2.3	a(0.1)1.6
Rangeland with poor condition	b(0.2)1.4	b(0.1)0.7	b(0.1)0.5	b(0.4)0.6	b(0.1)0.4	b(0.1)0.4

Dry farmland	c(0.1)0.4	c(0.1)0.4	c(0.1)0.4	c(0.1)0.2	c(0.1)0.1	c(0.1)0.1
Abandoned land	c(0.1)0.5	c(0.1)0.5	bc(0.1)0.5	c(0.1)0.2	bc(0.1)0.2	bc(0.1)0.2

Mean and standard deviation (SD, shown in parentheses) are provided in the table; Within each column, mean values with different letters are significantly different between land uses (Tukey's test at $P = 0.05$) (Source: Kabir et al., 2017)

The propensity of alter the soil organic matter were more or less similar in case of soil structural stability in different land uses and in both soil layers. Which are as follows: rangeland with good condition>rangeland with poor condition>abandoned land>dry farmlands (Kabir et al., 2017).

The changes in land uses from rangelands to dry farmlands show deterrent impact on soil structural stability and lead to accelerated erosion. In rangelands, soil structural stability and organic matter content were significantly higher than that of other land uses. Decrease in structural stability in dry farmlands is the result of plowing and tillage. Short-term absence of tillage in abandoned land showed positive influence on structural stability of soil (Table 4).

Plants, Roots and Residues

Roots and root hairs have large number of granules remains attached to them, which help to form crumby structure. Products secreted from the roots of different plants may also have positive effect by acting as cementing agents, which binds the soil particles together and ultimately helps to the formation of good soil structure (Bhaskaran, n.d.; Shreeja, n.d.). Beside these the following function of roots and its residues affect soil structure:

- Gelatinous organic compounds and exudates which are excreted from roots, serve as a link.
- Soil particles to attach together with the presence of root hairs. For example: Grass and cereal roots vs other roots
- The soil particles are also held together by the pressure exerted by the roots.
- Plant tops and residues acts as a shade to the soil and thus prevent it from extreme and sudden changes in temperature and moisture as well as rain drop impedance. Plant residues also acts as a food to prime aggregate builders (microbes).

Adding organic matter in the soil helps the increase of substances which play major role in aggregate stability and reduces slaking and mechanical breakdown process (Carrizo et al., 2015). The greater POC enhancement was found with the presence of plant and residues (+pl +res) with 61 % in the Typic Hapludoll, Santa Isabel series, whereas 48 % in the Typic Argiudoll, Esperanza series, showing the high sensitivity of this variable to changes in land management. Concentrations of HWEC and TC increased in the following order: without presence of plant and without residues (-pl –res) < without presence of plant and with presence of residues (-pl +res) < with presence of plant and without presence of residues (+pl –res) < with the presence of plant and residues (+pl +res) in Typic Hapludoll, Santa Isabel series (Table 5).

Table 5 Effect of plant roots and residues on Total organic carbon (TOC), particulate organic carbon (POC), hot water extractable carbohydrates (HWEC), total carbohydrates (TC), glomalin-related soil proteins (GRSP) and easily extractable soil proteins (EE-GRSP)

Variables	Typic Hapludoll, Santa Isabel series			
	-pl –res	-pl +res	+pl –res	+pl +res
TOC (g kg^{-1})	17.9 Aa	18.5 Aa	18.5 Aa	18.6 Aa
POC (g kg^{-1})	3.3 Ac	3.8 Ab	4.1 Ab	5.3 Aa
HWEC (mg C kg^{-1})	28.1 Ad	33.7 Ac	50.5 Ab	54.4 Aa
TC (mg C kg^{-1})	1059.7 Ad	1282.0 Ac	1203.3 Ab	1430.7 Aa
GRSP (mg g^{-1})	3.35 Ac	3.54 Ab	3.51 Ab	3.62 Aa
EE-GRSP (mg g^{-1})	0.93 Ac	1.06 Ab	1.09 Ab	1.27 Aa
	Typic Argiudoll, Esperanza series			
TOC (g kg^{-1})	16.1 Ba	17.0 Ba	16.7 Ba	17.5 Ba
POC (g kg^{-1})	2.9 Bc	3.4 Bb	3.5 Bb	4.3 Ba
HWEC (mg C kg^{-1})	24.3 Bc	21.7 Bc	36.9 Bb	43.4 Ba
TC (mg C kg^{-1})	859.3 Bd	1170.7 Bc	1035.0 Bb	1276.0 Ba
GRSP (mg g^{-1})	1.11 Bd	1.25 Bc	1.83 Bb	1.86 Ba
EE-GRSP (mg g^{-1})	0.92 Ac	1.06 Ab	1.08 Ab	1.24 Aa

Different lowercase letters indicate differences between treatments for the same soil. Uppercase letters indicate differences between soils for the same treatment. Tukey test ($p < 0.001$).

(Source: Carrizo et al., 2015)

The best result was found when both sources of carbon were combined, i.e. +pl +res (96 %). Fungal activity estimated through GRSP and EEGRSP, showed a similar pattern to that of POC. In both of the soils the +pl +res treatment showed a positive impact on EE-GRSP production (Table 5). In contrary, with the presence of active roots either alone or together with residues enhanced the production of GRSP in Typic Argiudoll, Esperanza series (69 %). The addition of residues (organic matter) to the soil enhances the activity of decomposer microorganisms which mainly produce polysaccharides, whereas the presence of active roots enhances the activity of arbuscular mycorrhizal fungi and the generation of HWEC.

- **Animals**:

The chief agents that play major role in the mechanism of aggregation of finer particles are mainly consisted of soil fauna, small animals like earthworms, moles and insects etc. (Bhaskaran, n.d.; Shreeja, n.d.).

- **Soil Organisms:**

The incorporation of organic materials greatly enhances the microbial activity to the soil. Different soil organisms like insects, moles, earthworm etc. burrow the soil and ultimately play important role in the aggregation process of soil separates through their other secretary products. Besides them, fungi, algae, actinomycetes etc. enhances in keeping the soil particles together. Fungi and actinomycetes do it by increasing mechanical binding with their mycelia. Cementation is enhanced by bacteria by products synthesized during decomposition (Bhaskaran, n.d.; Shreeja, n.d.). Arbuscular mycorrhizal fungi produce abundant amount of glomalin, which are hydrophobic and recalcitrant by nature and ultimately contribute to the formation of stable aggregate. These substances also reduce dispersion and slaking by changing the aggregate wetting rate and ultimately increase soil structural stability (Figure 5). Polysaccharides, produced by soil microbes, are transient binding agents which help to make soil aggregates stable (Malozo et al., 2016).

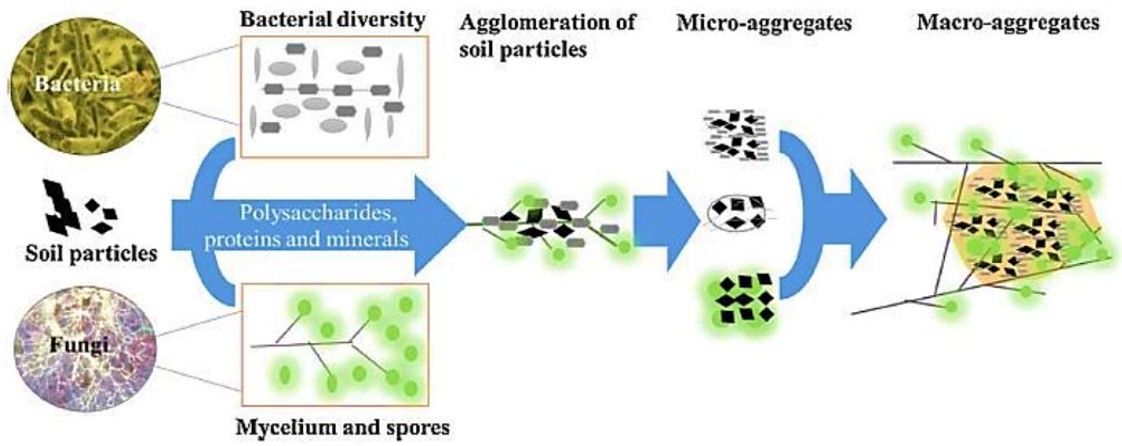


Fig. 5 An overview on the role of microbes in the binding of soil particles, formation of micro- and macro-aggregate. (Source: Rashid et al., 2016)

The appearance of polysaccharides and fungal activity linked to the production of glomalin protein which acts in reducing soil degradation, mainly the slaking mechanisms (Figure 5). Its effects were combined with increases in aggregate cohesion and changes in the rate of wetting (Malozo et al., 2016).

Table 6 Canonical correlation analysis of fungal variables and various structural stability pre-treatments

Canonical variable	1	2
R	0.87	0.59
R^2	0.88	0.35
Lambda	43.05	13.46
p-value	2.9E-04	0.68
Fungal variables		
GRSP	0.06	-1.03
EE-GRSP	0.98	0.31
Structural stability pre-treatments		
FW	0.46	0.25
MB	0.37	-1.58
SW	0.28	1.34

GRSP = glomalin-related soil proteins; EE-GRSP = easily extractable soil proteins; FW = fast wetting; MB = mechanical breakdown; SW = slow wetting pre-treatments.

(Source: Carrizo et al., 2015)

In relation to fungal variables, the first canonical correlation accounts for 88 % of the variability between these two groups of variables (Table 6). The most influential fungal variable on MWD of the different pre-treatments was EE-GRSP. EE-GRSP fraction was positively associated to soil structural stability ($p < 0.001$). EE-GRSP decreased all aggregate breakdown mechanisms, even if the effect was greater on the slaking (Table 6).

- **Manurial Practices and Crop Rotation:**

The cultivation of green manuring and grass crops can improve the soil structure to a greater extent. In sandy loam, the crop rotations like wheat-jowar and wheat-maize were found to improve the soil structure (Bhaskaran, n.d.; Shreeja, n.d.).

- **Alternate Wetting and Drying:**

Alterations in the moisture content of soils significantly affect the formation of development of different types of soil structure and stable aggregates. If the wetting and drying processes are rapid then re-wetting and dehydration of a soil mass cannot be uniform. When such unequal strains occur throughout the mass, then soil will tend to form clods and granules of different sizes. Beside this when a dry soil is wetted, the soil colloids undergo swell on absorbing water. In the time of drying, shrinkage produced in the soil mass gives rise to cracks, which break up into clods and granules of different sizes (Bhaskaran, n.d.; Shreeja, n.d.).

3.2.1 Relationship of structural stability to soil functions: (Bhaskaran, n.d.; Hetrick et al., 2016)

- Bulk density alters with the presence of pore space in soil. Structure greatly influences pore spaces. Soil with crumby structure with more total pore spaces has low bulk density whereas platy structure with less total pore spaces has high bulk density.

- It is changed easily. Pore spaces are less prominent in platy structure, whereas pore spaces are more in crumby structure.
- By providing well aeration and percolation of water in the soil, crumby structure helps in maintaining optimum temperature in contrast to platy structure.
- Soils with poor drainage conditions are generally bluish and greenish in color. Free drainage is hampered in platy structure.
- Soil structure also affect consistence of soil. Platy structured soils exhibits strong plasticity.
- Structural stability changes may act as early exponent of soil recovery or degradation.
- Biological activity, organic matter content, and nutrient cycling in soil are the exponents of structural stability.
- Decomposition of fresh organic matter by micro-organisms gives products act as a binding agent and bind small aggregates into large aggregates (>2-5 mm). These large aggregates act as a better exponent of changes in the quality of soil.
- Stable aggregates, large in amount, suggest better soil quality. With the increase of the proportion of large to small aggregates, soil quality generally increases.
- A large range of pore space, together with small pores within and large pores between aggregates can be provided by stable aggregates. For water, air, nutrient, and biota to move within soil, it is essential. Large pores together with large, stable aggregates favor appropriate aeration and high infiltration rates, necessary for plant growth (Figure 6).

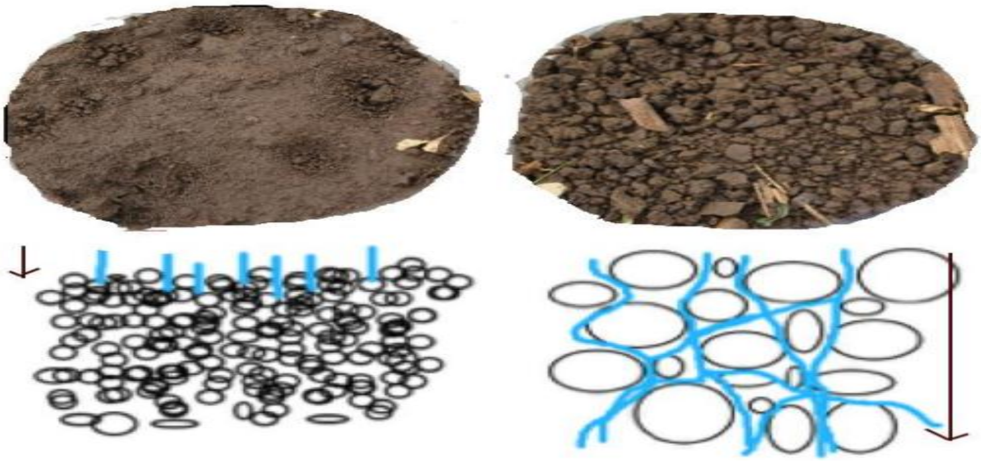


Fig. 6 Unstable aggregates lead to reduced infiltration and surface sealing (left). Stable aggregates permit better infiltration (right). (Source: Hetrick et al., 2016)

3.2.2 Management practices for maintaining soil structural stability

Field management, including tillage operations, addition of organic amendments, planting and harvesting methods etc. can impact both aggregate size distribution and stability **(**Hetrick et al., 2016). Brief description of some management practices for maintaining soil structural stability is as follows:

- **Proper Tillage**

Tillage mainly destroys aggregates in two ways one is by physically breaking down the aggregates apart and other is by stirring air into the soil and thus stimulates microbes in enhancing the rate of decomposition of organic matter. Soil organic matter which is lost to the atmosphere over time, as carbon dioxide, can cause less organic material to bind soil aggregates together. Various conservation practices which reduce the amount of soil disturbance like minimal or conservation tillage can play an efficient role in the reduction of organic matter as well as aggregate destruction.

- **Organic Matter Addition**

Adding organic materials, like manure or mulch residues, can supply the soil with both nutrients and organic matter, while developing stable aggregate over time. This may be the result of greater amounts of organic carbon combined with greater microbial activity that ultimately leads to the increase of production of aggregate glues in soil.

- **Crop Rotation**

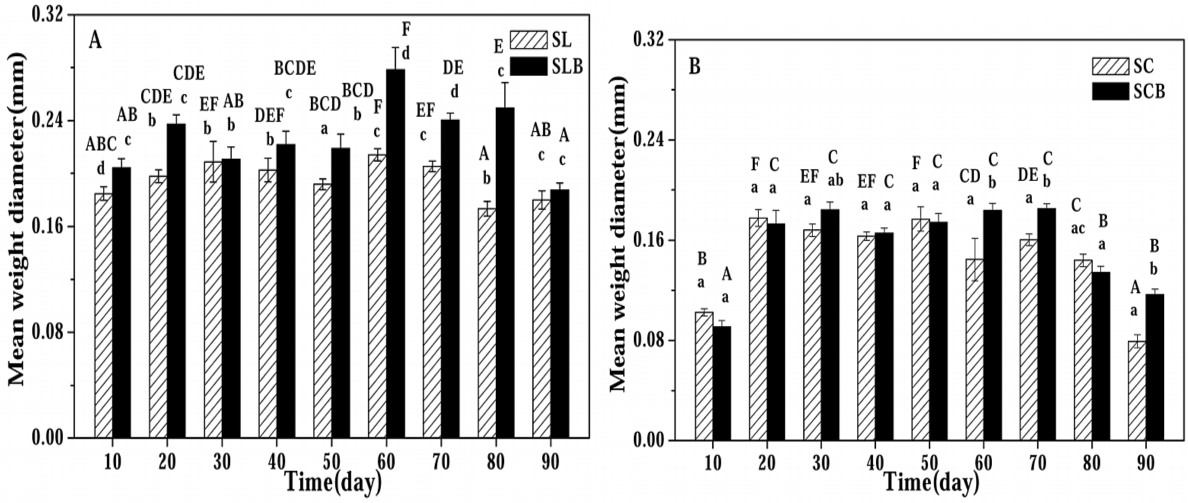
Crop rotation and use of cover crops can also enhance aggregate stability. The impact of rain and wind can be minimized by the crops that leave surface residues such as rice or corn stalks and making a barrier to physical destruction such as runoff and direct surface impact of surface aggregates of soil. Cover crops like grass or alfalfa keep the soil covered, thus allowing for more accumulation of organic matter in soil over time. Perennial crops produce deep and extensive root systems after their establishment. Thus, cover and perennial crops in a rotation can contribute to buildup of organic matter over time. This addition of organic matter promotes stability to the soil aggregates.

- **Application of biochar amendment**

Biochar addition increases the formation of macro-aggregates efficiently and saturated hydraulic conductivities of the soils to some extent. With biochar amendment, residual water contents decreased and saturated water contents increased which ultimately attributes to the change in soil structure. These alterations with biochar application affect the soil water retention mechanism to a great extent. In case of alteration in the soil water retention curves and soil aggregate formation, the sandy loam soil showed more sensitivity than the silty clay soil towards the application of biochar (Ouyang et al., 2013).

Application of biochar influences the availability of soil organic matter, the water holding capacity, and the bioavailable nutrition elements. These can enhance the microbial activities in soil and thereby helps in the formation of soil aggregate and stability (Downie *et al*., 2009).

Biochar addition efficiently promotes the formation and stabilization of macro-aggregates in soil. Amount of macro-aggregates increased during early incubation stage, touched apex in the middle, and then at the later stage decreased. The amount of macro-aggregates in SLB



increased to the highest (154.9 g kg^{-1} soil) after 60 day of incubation (Figure 7). The MWD values of the sandy loam soil were enhanced significantly ($p < 0.05$) by the biochar addition in most of the sampling days. For the silty clay soil (SC), the MWD differences between the SC and SCB treatments were found significant ($p < 0.05$) at the later incubation stage only (Ouyang et al., 2013).

Fig. 7 Effects of biochar applications on soil mean weight diameter values of (A) a sandy loam soil and (B) a silty clay soil within different incubation periods.

(Source: Ouyang et al., 2013)

Quicklime application

Application of quicklime gives significant and momentary increase of stable aggregates. In soils with high clay content and cation exchange capacity (CEC), application of quicklime improves aggregate stability more efficiently.

Table 7 Soil acidity (pH) and water content response to lime application over time

Site	Days after application	pH (in 0.01 M CaCl2)			Water content (% w/w)		
		control	$CaCO_3$	CaO	control	$CaCO_3$	CaO
Strengberg	2	6.8 abc	7.4 c	9.6 d	23.7	23.3	24.0

	30	6.5 a	6.8 abc	7.2 bc	22.8	22.7	22.4
	86	6.6 ab	6.5 a	6.8 ab	22.3	22.7	23.5
Pollham	2	7.3 ab	7.4 ab	10.5 c	24.4	25.7	24.1
	30	7.2 ab	7.2 ab	7.7 b	22.1	23.7	23.1
	86	7.0 ab	7.0 a	7.0 ab	25.0	24.9	24.8
Kemeten	2	5.4 a	7.0 d	8.3 e	25.9	25.3	24.9
	30	5.4 a	6.5 cd	6.9 d	20.3	19.4	20.1
	86	5.6 ab	6.1b c	6.3 bcd	22.6	22.0	21.9

Different letters for the same site indicate differences in multiple comparison of mean by Tukey HSD ($p < 0.05$ with a confdence level of 95%); the p values for 'lime' (form of lime), 'time' (time after application) and 'lime x time' are from a 2-way ANOVA (confidence level of 95%) and indicate signifcance of the individual factors or their interaction.

(Source: Keiblinger et al., 2016)

The liming effect of the added limestone and quicklime materials was assessed by monitoring alteration in soil acidity (Table 7). The addition of $CaCO_3$ caused an increase in pH but slowly. On the other hand, the addition of CaO resulted in an immediate and much stronger rise of soil pH (Table 7). This is the indication for the quicker reaction of CaO compared to $CaCO_3$ due to having higher solubility.

The highest effect was found for site Kemeten which showed a relative increase in stable aggregates between 59 and 65% compared to the control. The smallest increase was observed in stable aggregates for site Pollham, where it was only 5 and 11% compared to the control for the 2nd and 3rd sampling, respectively. The influence of quicklime application on soil aggregate stability mainly related to the clay content and cation exchange capacity (CEC) of soils (Figure 8).

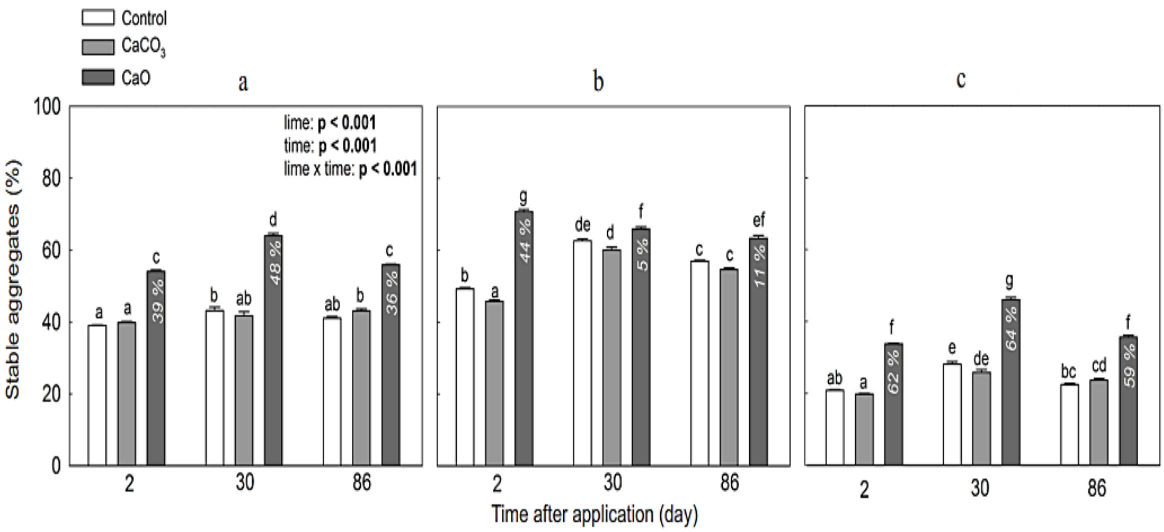


Fig. 8 Stable aggregates in mass % for the sites: a – Strengberg, b – Pollham and c – Kemeten. Different letters for the same site indicate differences in multiple comparison of mean by Tukey HSD ($p < 0.05$). (Source: Keiblinger et al., 2016)

Use of Soil Conditioners:

The most important structural stability indicators includes air capacity (AC), water dispersible clay (WDC), the slope of the retention curve at the inflection point (Sgi index), and mean weight diameter of aggregates (MWD). It was found by Emami et al. (2014) that use of soil conditioners significantly increase soil structural stability indicators ($P<0.05$). Urban solid waste compost (MC), Vermi-compost (VC), poultry manure (PM), and gypsum powder (G) are used as soil conditioner. It was seen that due to addition of these conditioners, the values of AC, WDC, Sgi index, and MWD increased. According to Figure 9a CROSS value is 32.02 in the control treatment which decreased significantly due to addition of conditioners ($p<0.05$). The highest decrease was observed in G treatment; it reached 14.78 and 15.97 in G and MC treatments, respectively. On the other hand studied conditioners significantly ($p<0.05$) increased Sgi index (Figure 9c), air capacity (Figure 9d), MWD (Figure 9e), compared to the control.

In case of different treatments on water dispersible clay content it was observed that organic conditioners along with gypsum powder decreased water dispersible clay contents significantly ($p<0.05$) over control treatment (Figure 9). The WDC value in control was 92.64% and it decreased to 20.82% in G treatment.

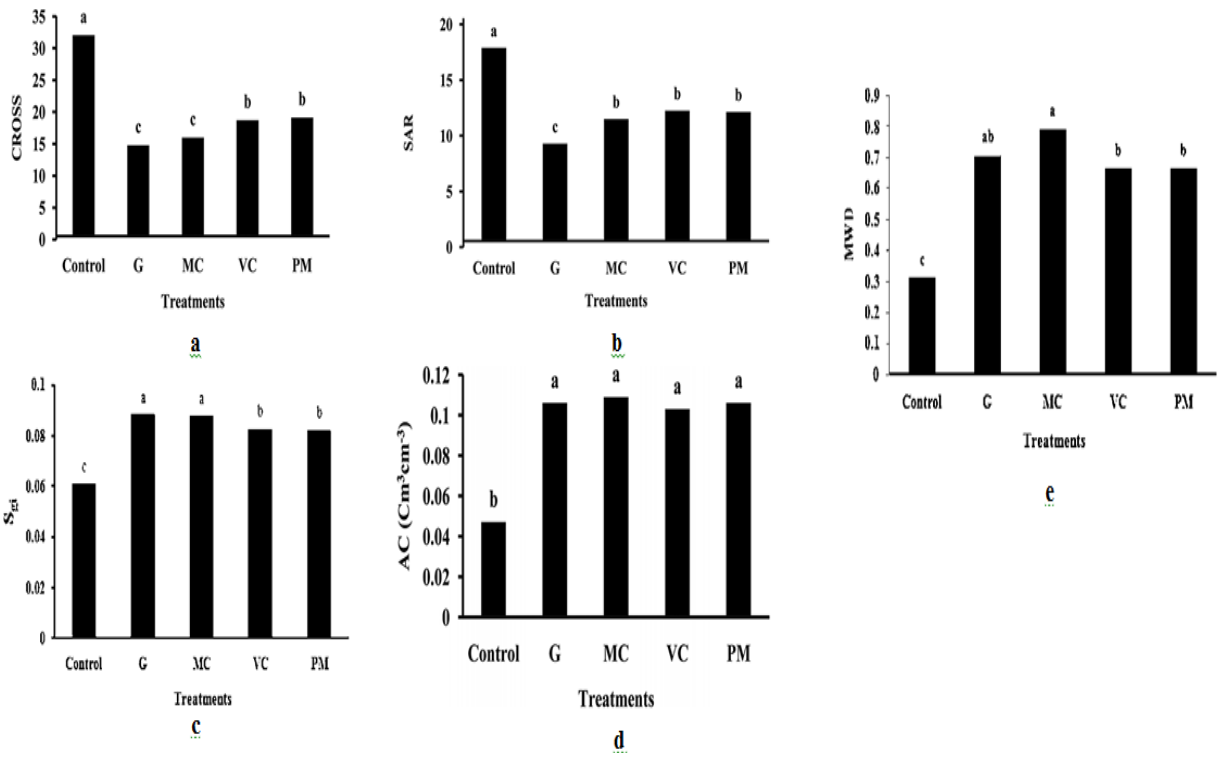


Fig. 9 Effect of experimental treatments on CROSS, SAR, Sgi index, AC and MWD (G indicates Gypsum, MC Urban Solid Waste Compost, VC Vermin Compost, and

PM Poultry Manure. Treatments indicated by the same letters in each column are not significantly different at *p<0.05*). (Source: Emami et al., 2014)

Vegetation restoration

The type of vegetation greatly influenced the stability of the soil aggregates. The soil depth also influence the soil aggregates stability. The PAD of the aggregates found maximum in the BL (27.24 %) minimum in the WL (16.27 %). The MWD and GMD values of the dry-sieving and wet-sieving aggregates were both ranked, in descending order, as WL > GL > SL > BL (Table 8).

After restoration of vegetation, the organic carbon contents, MWD, and GMD increased, and the PAD and D values decreased. This indicates the increase of SOC content, which enhances the formation of soil aggregates and increase soil aggregates stability.

Table 8 Soil structural stability and vegetation types

Vegetation types	Layer cm^{-1}	$WSA_{>0.25}$ (%)	PAD (%)	MWD (mm) Dry	MWD (mm) Wet	GMD (mm) Dry	GMD (mm) Wet	*D* Dry	*D* Wet
BL	0–20	71.68Ab	21.5Cb	4.183Ad	1.588Ac	3.181Ac	0.699Ac	2.163Aa	2.649Ba
	20–40	68.21ABb	28.34Ba	4.085Ad	1.304ABc	2.627Bd	0.626Bc	2.192Aa	2.690ABa
	40–60	64.07Bb	31.87Aa	3.243Bd	1.169Bc	1.966Cd	0.535Cc	2.227Aa	2.725Aa
GL	0–20	83.36Aa	13.59Cc	5.335Ab	1.966Ab	3.882Ab	1.061Ab	2.037Aa	2.487Bc
	20–40	80.81Ba	16.33Bb	5.011ABb	1.642Bb	3.605ABb	0.913Ab	2.091Aa	2.505ABc
	40–60	74.31Ca	19.43Ac	4.883Bb	1.498Bb	3.384Bb	0.881Ab	2.121Aa	2.580Ac
SL	0–20	73.86Ab	23.13Ca	4.655Ac	1.697Ac	3.35Ac	0.71Ac	2.112Aa	2.603Ab
	20–40	68.69Bb	26.87Ba	4.467Ac	1.473ABbc	3.107ABc	0.638ABc	2.187Aa	2.623Ab
	40–60	66.5Bb	28.26Ab	4.415Ac	1.252Bc	2.842Bc	0.588Bc	2.224Aa	2.678Ab
WL	0–20	86.72Aa	10.68Bd	6.101Aa	3.618Aa	4.934Aa	1.981Aa	1.994Aa	2.425Bc
	20–40	81.03Ba	17.02Bb	5.882Aa	3.027Ba	4.534Ba	1.503Ba	2.045Aa	2.522ABc
	40–60	76.36Ca	21.1Ac	5.41Ba	2.505Ba	4.087Ca	1.151Ca	2.074Aa	2.556Ac

Note: different small letters in the same column mean significant differences in same layer of different land cover types at 0.05 level; different capital letters in the same column mean significant differences in different soil layer of same land cover types at 0.05 level, the same in the Table 4.

(Source: Tang et al., 2016)

Application of tea waste and farmyard manure

Application of tea waste and farmyard manure efficiently enhanced aggregate stability of recently deposited sediment, therefore it is suggested that for structural stabilization of sediments TW and FYM can be used.

It was observed in the findings of Turgut and Kose (2015) that application of both TW and FYM increased aggregate stability of sediments (Figure 10). Besides, it was found that TW application enhanced the aggregate stability significantly better than the application of FYM (F = 3.91; p<0.05).

The findings of the study indicated that in terms of aggregate stability, (i) TW is more efficient than FYM, (ii) addition of TW and FYM resulted in significant enhancement in the aggregate stability of sediments, (iv) FYM increased aggregate stability in shorter time while it took longer time to in case of tea waste treatment.

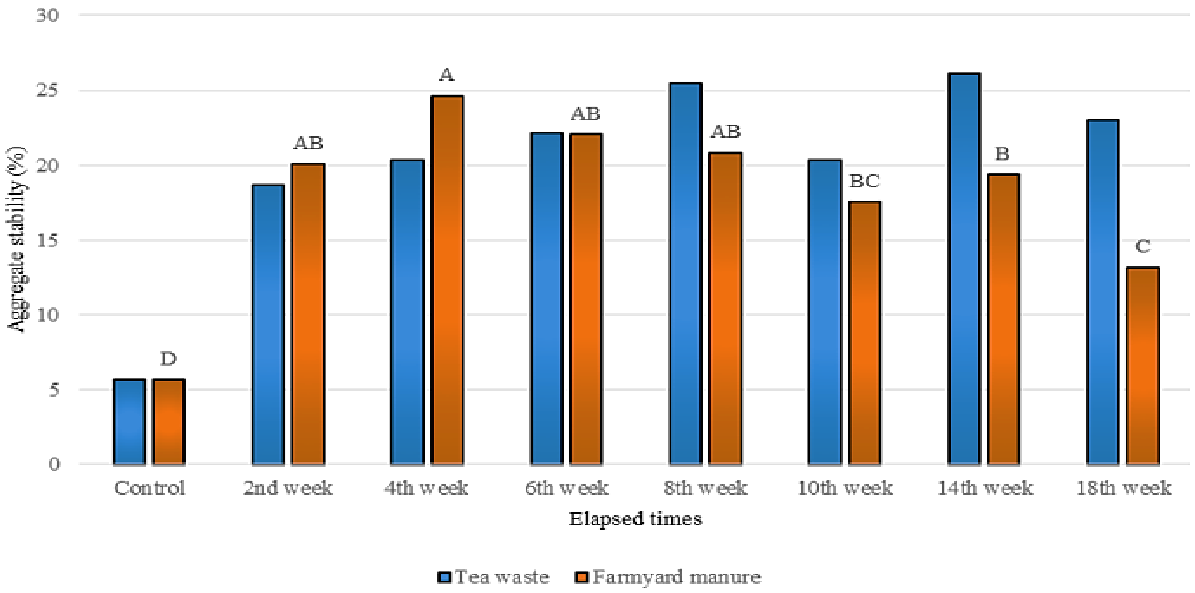


Fig. 10 Changes in aggregate stability depending on elapsed times after application. The means with different letters indicate significant differences among elapsed times (*p*<0.01). (Source: Turgut and Kose, 2015)

Chapter 4

CONCLUSION

- Soil structural stability is one of the most important factors of soil resistance against degradation. Various factors like climate change, presence of organic matter, tillage and fertilization etc. can affect soil structural stability.
- These factors modify soil functions like bulk density, porosity, consistence etc. By using different management practices we can improve soil structural stability.

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