International Journal of Plant & Soil Science

22(5): 1-14, 2018; Article no.IJPSS.41056
ISSN: 2320-7035

Stability of Aggregates and the Processes that Help in Their Formation and Stabilization

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Authors' contributions

This work was carried out in collaboration among all authors. All the authors managed the literature searches and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2018/41056
Editor(s):
(1) Surendra Singh Bargali, Professor, Department of Botany, DSB Campus, Kumaun University, Nainital, Uttarakhand, India.
Reviewers:
(1) İlknur Gümüş, Selçuk Üniversity, Turkey.
(2) Mohamed Ahmed Bassouny, Benha University, Egypt.
(3) Jia-wen Zhou, Sichuan University, China.
Complete Peer review History: http://www.sciencedomain.org/review-history/24527

Review Article

Received 18th February 2018
Accepted 30th April 2018
Published 8th May 2018

ABSTRACT

Several soil functions depend on their physical properties, such as, soil structure, porosity, and the distribution of aggregates. Despite the importance that aggregates have, little is known about the dynamics and the behavior during their formation and stabilization. In this way, the present study aimed to gather information about the formation, and the maintenances of aggregates stability, searching factors that influence in their aggregation, aiming to provide information to understand the dynamics of the formation of these aggregates in soil. It was observed several physical, chemical and biological processes, such as the wetting and drying processes, organic matter contents, quantity of iron and aluminum oxides, clays, root system of plants and the activity of organisms and microorganisms, as well as the interrelations between them. It was also observed that the removal

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of vegetation coverage and insertion of agricultural crops are factors that influences significantly in the conditions of the aggregates present in soil. Moreover, some conservation practices of land use and management may increase the stability of the aggregates in relation to the conventional managements, such as no-tillage, crop husbandry integration, rotations and successions of crops, which positively influences the aggregation and stabilization of the aggregates. Therefore, the aforementioned processes, allied to the adoption of conservation and use practices can promote sustainability and improve the quality of agricultural soils, as well as being able to generate benefits in productivity, a factor so much important today.

Keywords: Soil physical properties; soil aggregation; soil conservation; aggregate stability.

1. INTRODUCTION

The soil is characterized as the surface layer of the earth's crust, its importance is directly related to the development of the most varied life forms on the planet. Among the main functions attributed to the soil, it stands out its importance as a source of food production; however, this environmental compartment is also fundamental for the development of many ecosystems [1]. In view of the importance that the soil has for the maintenance of life, it is essential to preserve its structures, so that this occurs, if it is necessary to use techniques that aiming to minimize anthropic impacts on the system, such as the use of conservation management.

Good soil structure is fundamental for plant development, directly interfering in the porosity, water and air availability to the roots, nutrient supply, rainwater percolation, gas exchange, soil mechanical resistance to penetration, and resistance to erosive agents. In addition, maintaining adequate aggregation and stability is indispensable to ensure high agricultural productivity [2] and to improve the sustainability of soils used to agriculture [3]. It is also important to note that the degradation of the physical structure of the soil can lead to soil erosion, which, consequently, leads to loss of mineral material, water, organic matter and nutrients [4].

Many soil functions depend on the distribution of macroaggregates (≥0.25 mm) and microaggregates (<0.25 mm) in soils, and the space between them. However, in spite of the importance that the aggregates have in the soil, little is known about the dynamics of their formation and how they become stable [5].

The change of natural systems to other land uses, such as agricultural use, directly influence in the soil structure, decreasing, for example, the concentrations of organic carbon and total nitrogen in the aggregates [6]. Agricultural management also influences directly the soil structure, since it modifies both the physical attributes and the water dynamic in the soil [7]. In addition, such changes in the soil use regulate the clay and organic matter content (OM), thus, influencing the aggregation of the particles [8].

Soil management systems, such as the conventional tillage system and the no-tillage system, can generate changes in soil structure, including soil aggregation indexes and total organic carbon content [9]. Therefore, the relationship between the different types of management and soil quality can be evaluated through changes in their physical attributes and quantified by means of indicators of the quality of a certain soil over time [10].

Thus, aggregate stability can be used to evaluate the effects of different uses and management on soil quality [11]. In addition, understanding the influence of land uses on soil processes is fundamental to deciding soil management strategies [6]. Since this, the present work aimed to gather information about the formation and stability of aggregates, searching the factors and practices of land use and management that influence soil aggregation, aiming to provide pertinent information to understand the dynamics of the formation of these aggregates in the soil and then to generate a scientific basis for further studies.

2. AGGREGATES

Soils are formed by primary structures; being then: sand, clay and silt - which when agglomerated form secondary particles and when combined with organic and inorganic materials are called aggregates or also structural units. The formation of the aggregates occurs by several factors, among them it is possible to highlight the approximation of the primary particles by means of forces or by cementing these particles by organic and/or mineral cementing substances that are present in the soils [12]. The aggregation of small aggregates, particles smaller than 250 μm, is responsible for the formation of macroaggregates, which according to [13] are particles that are larger than 250 μm.

The formation of aggregates is characterized when two or more primary particles are grouped with a force greater than the force of union between the adjacent particles; and for this to occur it is necessary, in addition to the presence of cementing substances, the flocculation of the clay [3].

The soil aggregate dimension directly influences its structure [2]. When, for example, a high flow occurs in the production system, with the insertion of a large quantity of organic compounds, the soil is able to self-organize in macroaggregates. The macroaggregates show complex and diversified structures, promoting resistance to water and wind erosion; infiltration and water retention in soil; carbon sequestration; cation retention capacity; increased nutrient stock; adsorption and complexation of organic and inorganic compounds; favoring of soil biota; promoting the cycling of chemical elements; and resistance to disturbances and resilience. Therefore, the soil presents better quality and can fulfill its functions [14].

On the other hand [14], when the flow is reduced. the soil organizes itself into smaller and simpler structures; the microaggregates, which can generate structure deterioration; water and wind erosion; leaching of nutrients and organic and inorganic compounds; contamination of surface and groundwater; release of carbon dioxide into the atmosphere; decrease in soil biota; decrease in the diversity of the soil system; and reduction of resistance to disturbances and resilience. So, that the soil does not have the capacity to perform its functions, reducing its quality.

In this sense, according to [15], soil aggregation will also indicate its conditions in relation to aeration and gas exchange, water infiltration, water and nutrient retention, as well as root development of plants. In this way, it can be assumed that soil aggregation is the result of numerous factors, among them the environment in which the soil is inserted, the influences received by plants, mineral composition, texture, geological processes, activities of microfauna, concentration and amount of nutrients, among others [16].

3. STABILITY OF AGGREGATES AND THE PROCCESS THAT HELP IN THE FORMATION AND STABILIZATION

The stability of aggregates represents the ability of the particles to withstand the processes of mechanical disaggregation [17]. It is important to improve soil structure by providing porous spaces for root development, soil fauna, gas circulation and water percolation [2], as well as preventing soil erosion [18]. In this sense, the resistance to the degradation of soil particles is directly related to the forces acting on them. An example is the external forces that cause compaction, such as the use of agricultural machinery and the impact of rain drops, or even forces and the absence of aggregating material [19,20].

The principal factors involved in the formation and stability of aggregates are the mineral fraction, soil fauna, roots, microorganisms and inorganic agents [2], as well as soil texture, mineralogy, types of organic matter and humidity [21]. Among the main influences of soil aggregate stability it can be highlighted water infiltration and retention, aeration and gas exchange, resistance to root penetration, sealing and surface crumbling, and also water and wind erosion. Thus, when reduced, stability will indicate aggregate breakage and consequently reduction of soil porosity and permeability, reducing infiltration and increasing runoff. In addition to this condition, more stable aggregates will allow permeability maintenance and soil infiltration capacity [19,22].

The stabilization of the aggregates can be positively influenced by some processes, among them the physical, chemical and biological processes. In this sense, physical forces involved in the wetting and drying process, the compression action by the roots and interactions between organic and mineral material allow the formation of aggregates along with the action of flocculating and cementing agents; such as iron and aluminum oxides, organic matter, plants and microfauna that live in the soil [23].

Several agricultural management techniques can promote the arrangement and consolidation of aggregates in the soil, these techniques may be physical, chemical or biological. For example: a) reduction in soil preparation; b) biomass elevation, plant diversity and exudates; c) raising of agricultural residues on the soil surface; d) reduction of the use of inorganic fertilizers and pesticides; e) sustainable management of planting [5].

3.1 Drying and Moistening of Particles

Among the factors that may help in the approximation of the primary particles it can be cited the drying and moistening of the constituent particles of the soils. According to [16], the drying and the wetting of the soil are factors that are directly related to the climate of a certain region, the temperatures and precipitations, for example, contribute to the stabilization of the particles.

When soil drying occurs, the sand particles approach and consequently, the soil has its volume reduced by contraction. This contraction exerted under the particles will cause cracks to open in energy-weaker places. Faced with a natural situation, where there are constant periods of drought and rain, or irrigation in the field, numerous cycles of opening and closing of structures occur, which allows the network of cracks to become more extensive and the aggregates that are located between the cracks become better defined [1].

The relationship between aggregate stabilization and climate, understood through cycles that create cracks and pressures on the soil, such as drying and moistening by irrigation, precipitation or even freezing cycles, allow large masses of soil to be compressed into well-defined structural units. However, according to [1], the effects of these influences are higher in soils with high content of expansive clays, as is the case of Vertisols and Chernosols.

Among the drying and moistening processes, besides the influence of climatic influences, plant roots influence the absorption of water, a fact that clearly exemplifies the interaction between several processes, in this case, biological and physical in the formation and stabilization of aggregates [24].

3.2 Organic Matter

Among the process that influence the stability of the aggregates, it can bee highlighted the introduction of organic matter (OM) to the soils and the consequences created by this insertion. In this sense, it is possible to observe that the aggregates in the soil with high levels of OM are much more stable than those with low levels of OM. The aggregates with low level of OM crumble when they are saturated with water, however, those with high levels of OM keep stable in the presence of water, as can be showed in Fig. 1.

According to [25] influences the mechanisms of the different aggregate formats, in this sense, the amount of organic matter present in the soil will allow more or less aggregation.

The influence that OM has on the formation of aggregates is made possible based in the molecular structure and the decomposition rates of the OM fractions present in the soil, since these can be divided into 3 different categories. One of these fractions being temporary (degradable), other transient (partially decomposed or stabilized physically and/or chemically), and other resistant (highly decomposed physically and/or chemically). These categories of OM may play different roles in the formation of aggregates and stabilization of them. Typically, OM is composed of temporary or transient agents influencing the structure and acting as a 'glue' used in the formation of aggregates, whereas OM that is chemically stabilized (considered resistant) involves issues related to soil stability [5].

The OM plays an important role in the formation and stabilization of soil aggregation as a function of the connections of organic polymers with the inorganic surface by means of polyvalent cations [26]. The authors further mention that the incorporation of OM to the soil increases its porosity, reducing its density and dissipating the energy of applied loads, favoring the entrance of air and the drainage of water.

Authors such as [27], also suggest that there are two main mechanisms that are related to the increase of the stability of the aggregates by the action of OM to the soil. The first mechanism is related to the formation of bonds between OM and mineral particles and the second one by the action of OM in the soil influencing the decrease of the water intake in the aggregate and, consequently, reducing the break by the expulsion of the air in instantaneous form [28].

Due to the influence of OM on soil aggregation, the same type of the soil may have its properties, such as aggregation, affected by the different forms of management applied. The no-tillage

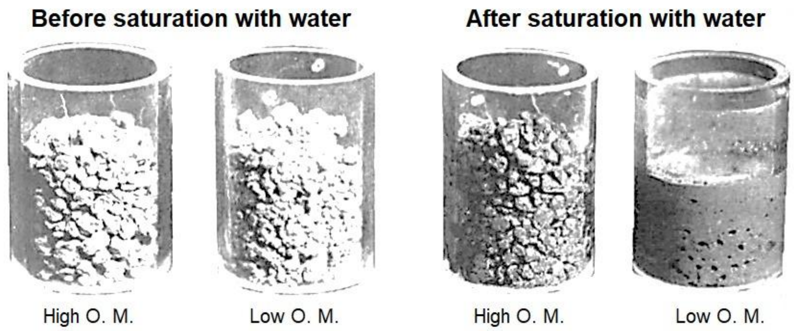

Fig. 1. Soil with high levels of organic matter are more stable after water saturation than soil with low levels of organic matter
(Image Source: Adapted from Brady & Weil [1])

system, for example, provides the maintenance of OM on the soil surface and, consequently, improves aggregation over conventional planting [29]. In the conventional plantation, the aggregates will be disrupted by soil preparation, thus accelerating the loss of organic carbon by the oxidation of organic matter [30]. This situation was verified in a study conducted by [31], these authors observed that in soils covered by native forest with high OM contents, they present a high rate of aggregation and high carbon content when compared to soils with conventional crops.

The OM added to soil promotes the aggregation of mineral particles. Thus, a higher OM content in the system results in a higher structural quality. When there is an increment of OM due to the maintenance of cultural remains (straw) on the surface and low soil rotation, the favoring of the formation of aggregates in the largest size class (>2 mm) occurs, in addition, the recuperation oh the degraded soils is promoted [2].

One form of OM insertion is the application of animal waste to the soil. This technique has presented promising results, since these wastes act on the physical properties of the soil - such as the reduction of soil density and elevation of porosity, water retention, infiltration and aggregation - the results vary according to the amount of waste applied, the dose and the form of application [4].

The increase of OM in soils has been the object of study by some authors, such as [23]. These authors studied the influence of OM on the average diameter of clay minerals in soils with basaltic origin, when they developed their studies with four types of soils that had differences in stages of pedogenetic evolution, they observed that OM in the soil was responsible for part of the variation of the average diameter of the crystals of the minerals in the clay fraction of the studied soils. For these authors, the fact that for Gibbonite, there are no significant differences in the attributes of OM on the mean diameter of the crystal, may have a close connection with the fact that most of the double hydroxyl groups arranged reduce the interaction of the soil with OM.

Other authors, such as [8], when studying the influence of OM and clay on aggregation as a function of different soil uses, with the following treatments: 1) native forest; 2) Mimosa caesalpiniaefolia planting and 3) pasture with Brachiaria, all in slope area, verified that the exchange of native vegetation by pasture promoted reductions in the amounts of OM, humina, dry and wet macroaggregates, diameter of dry and humid aggregates in the studied depths (0.0-2.5 cm, 2.5-5.0 cm, 5.0-10.0 cm and 10.0-20.0 cm).

Some authors, such as [32], studying the physical attributes and the organic carbon content in: 1) natural arboreal *cerrado*; 2) mixed system initially converted to agricultural use and the last 15 years of pasture and 3) pasture cultivated 30 years ago. In this study the results showed that the land use influences directly the dynamics of OM, and the transformation of native vegetation from *cerrado* to cultivated systems promoted changes in OM content, carbon stock in the soil, decreased of total porosity values and increased soil density. However, in that study, occurred in the treatment 2, reduction of carbon content when compared to treatment with native vegetation, while treatment 3 demonstrated physical attributes more similar to that of native forest treatment [32].

3.3 Oxides of Iron and Aluminum

Among the agents that allow the formation and stabilization of aggregates, iron and aluminum oxides are also outstanding. These two compounds, when present with low crystallinity, are considered important stabilizers of aggregates in soils, due to their high specific surface area, which provides the formation of stable organomineral complexes with high organic carbon content, according to [33].

Although in the case of soils with less weathering, the main aggregate stabilizing agent is organic matter, and in very weathered soils, for example, Oxisols, among the main stabilizing agents of the aggregates and their cementation are aluminum iron oxides [27,34]. Since this, soils that present mineralogy with predominance of minerals classified as 1:1; iron oxides and high crystalline aluminum, allow the complexation and adsorption of electronegative groups of organic matter with positive charges of the oxides. While in soils considered as type 2:1 the formation of cationic bridges allows a greater interaction between organic matter and minerals [33].

In the classes of larger aggregates, OM is the main stabilizing agent, while in the classes of aggregates smaller than 2 mm the iron oxides stand out as cementing agents [35].

3.4 Clay

Besides the factors already mentioned, another component that helps in the formation and stabilization of the aggregates is the content of clay present in the soils. [36], in their studies revealed that the stability of aggregates in the Latosols evaluated decreased with the increase of kaolinite content. This fact explains the differentiated dynamic of tropical and temperate climate soils. Soils of temperate climate present lower aggregate stability, due to the higher proportion of silicate clay present in relation to the iron and aluminum oxides; which provide higher stability of aggregates in the Latosols of tropical climate

3.5 Cations

Although the importance of clay and organic matter overlap the cations, in relation the stability of aggregates [37], cations are also necessary due to their nature, since they have the capacity to saturate the clay, and also they are compounds that have flocculating characteristics, promoting aggregation. Among the cations with these characteristics, it can be mentioned aluminum (Al), calcium (Ca), hydrogen (H) and magnesium (Mg) [38].

No correlation of the organic carbon with the aggregation was observed in the depth 10-20 cm of the soil [39], reason for which it was attributed, among other factors, to the nature of the cations present and its flocculation power. Another factor is the interaction between polyvalent cations with clay and humified OM, and to the behavior of aluminum depending on the pH of the soil solution. The authors also concluded that Al could have greater affinity for some negative soil charges, rather than Ca and Mg, and this would displace the latter elements into the solution and form more stable organic complexes.

Moreover, according to [40], if adequate concentrations of the cations are maintained, the soil clays remain flocculated, which minimizes soil structure deterioration and keeps the aggregates stable. This would require relatively small amounts of Ca and slightly higher concentrations of Mg. About sodium (Na), maintenance of flocculation would involve concentrations so high that would affect the productivity of crops, and the use of the same is not indicated.

Another important point is that liming; when carried out in soils with a low zero load point (close to 4) and predominance of kaolinite, or even in soils with high point and higher amounts of iron and aluminum oxides, reduces the flocculating effect of trivalent cations. Then, this makes these soils more susceptible to physical disaggregation; reason why the practice should be used with moderation [41].

Studies by [37] aiming to verify the influence of physical, chemical and biological attributes on the stability of aggregates in Latosols under no-tillage system for more than four years showed that potassium cation appeared more frequently associated with soil aggregation and iron cation was the most stabilization of aggregates.

3.6 Organisms and Microorganims

Information about how land uses affect the activities of microorganisms associated with aggregates, although very important, are limited

[6]. Some studies have been developed in this sense to investigate the biological components and the function that these components exert in the soil.

The ecosystem function of the soil comes from the development, activity and biological maintenance of the soil that derive from the vegetal cover. Since this cover inserts carbon (through the process of senescence or fall of part of the plant - leaves, for example), root exudates, mucilage and root residues, as well as the plant root activity itself, which acts in the formation of aggregates [42].

Macroscopic and microscopic organisms such as plants, earthworms, insects, fungi and bacteria play very important roles in the formation of soil aggregates, as well as their stabilization. The movement of organisms in the soil can modify the arrangement of soil elements. Other soil constituents, such as OM, roots, fungal hyphae and biomolecules influence in a chemical and physical way in the soil, and the bodies, exudates and residues of these organisms act together in the formation and stabilization of the soil, or also as precursors for subsequent chemical reactions. In this way, biological activities may also involve chemical and physical reactions, but biotic factors may be considered biological [5].

In the studies of [42], for example, the authors evaluated the effects of different crops and management practices on soil structure, diversity and metabolic activity of microorganisms as a function of the treatments. The treatments of this study were: a) permanent pasture; b) permanent fallow and c) rotation of barley, wheat and peas. They observed that treatment with permanent pasture presented the most complex soil structure with 61% of the aggregates in the largest size class. According to the authors, this treatment demonstrated superior metabolic activity to the other treatments due to the high carbon content in the upper layer of the soil, which was due to the lack of disturbance, by the constant addition of OM in the soil, and due to the presence of a rich and stable community of microorganisms. For the authors, continuous plant growth combined with low soil disturbance promoted a larger macroaggregated scale structure resulting in greater capacity to perform the function of the soil ecosystem.

Another important population that influences the composition of soil aggregates is the earthworm communities, since they accelerate the decomposition processes, contributing to the formation of aggregates and processes of nutrient cycling, involving the nitrogen, phosphorus and carbon cycles. In addition, these organisms influence the fertility of the soil, as they participate in processes such as regulation of soil structure, decomposition of OM, and in the modification of the activities of microbial communities through digestion and stimulation. These organisms fragment the substrate in the feed process and raise the specific surface area of the OM, which is later colonized by microorganisms [43].

The macrorganisms accelerate the decomposition causing humidification (caused jointly by the reduction of the particles, by the elevation of intestinal microorganisms in the earthworms and by the aeration provoked by the activities of these annelids), in this way, the oxidation of OM is transforming it into more stable forms [5,43].

Among the fungi that helps in the formation and stabilization of aggregates, the mycorrhizal fungi stand out, as observed by [44], they can be found naturally in soils and these fungi help in the fixation of nutrients and consequently in the cementation of aggregates [45]. In addition, there is much information in the literature proving that these fungi may be very important in stimulating the growth of some species [46].

In addition to the ability to degrade organic and inorganic pollutants in contaminated soils [46], arbuscular mycorrhizal fungi have an important link with soil carbon fixation, due to its effects on plant nutrient absorption, culminating in the elevation of vegetal biomass in some species (mainly in pioneer and initial secondary species). In this way, this association can contribute to input of OM in the soil [45], and consequently making one improvement in the aggregate formation [8].

In other studies, such as those performed by [47], the authors observed that the resistance of the aggregates could be attributed not only to the presence of polysaccharides; which increases the cohesion of the particles, but also to the effect of physical entanglement derived from root and fungal hyphae. These hyphae impact the soil structure physically and biochemically (by producing glycoprotein). Fungal structures, such as spores and hyphae, also serve as a way of soil carbon entry [45].

However, the search for a more sustainable agriculture through conservationist management, such as the no-tillage system, allows the use of biochemical soil processes, such as the use of arbuscular mycorrhizal fungi, which promote a strong elevation of the specific surface of assimilation of roots of plants [48], indirectly influencing soil aggregation.

3.7 Roots of Plants

The root system of plants influences positively the stability of aggregates in the soil [49], and the association of this with organisms and microorganisms can help positively in the stabilization of the aggregates, as can be seen in the Fig. 2. The roots of the brachiaria, for example, are very efficient in promoting the adequate structuring of the soil, being considered as the main aggregating agent of particles in tropical soils, either by the release of exudates or the interweaving of small clods, forming larger structures and increasing stability of aggregates. It is important to mention that the work done by the roots cannot be substituted by the addition of residues of the aerial part of the soil surface [18].

The authors also commented that the release of exudates promotes greater activity of microorganisms improving the effects already mentioned. The authors also cite that the effects are even higher when the brachiaria is grazed, since the removal of the aerial part activates the release of exudates. In addition, positive effects of the root system of this group of plants were verified in both clayey soils and in sandy soils, and the beneficial effects provided increased productivity of the subsequent crop, soybean.

Studies by [50] have demonstrated that active roots of *Brachiaria ruziziensis* are more effective in increasing OM in the surface layers, promoting soil aggregation and increasing the stability index of aggregates than simple mulching without crop.

[24] also confirmed the significant effect of the brachiaria root system on the formation and stabilization of aggregates, attributing this to the process of union of smaller aggregates for the formation of larger aggregates by the action of the roots.

The attributes of soil quality in areas covered with crotalaria, millet, sorghum, brachiaria and fallow by no-tillage with a 10 years difference interval in an area under no-tillage for 12 years were studied by [10]. In this study, the best soil aggregation occurred in areas covered with sorghum, being the highest aggregation indices (weighted mean and geometric diameter and aggregate stability indices) observed in the lowest evaluated depth (0.10 m) in the evaluated years - 2002 and 2012, with a significant difference for sorghum that was higher ($p<0.05$) and lower in the area with crotalaria.

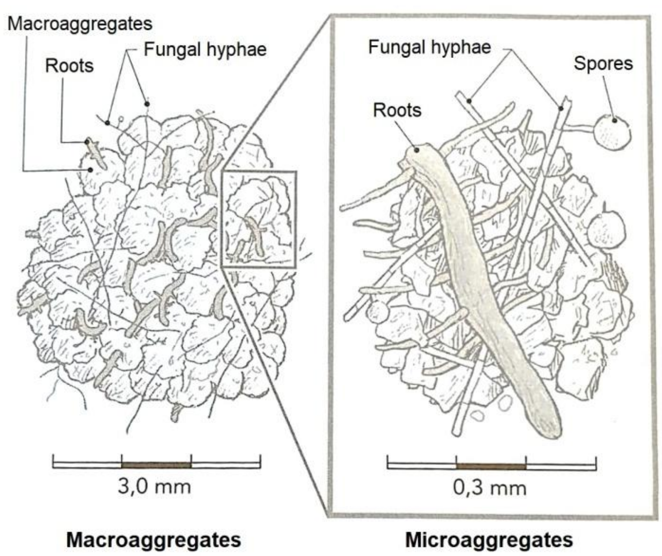

Fig. 2. Fungal hyphae and roots as factors that contribute to the formation and stabilization of the macroaggregates and micoaggregates in the soil
(Image Source: Adapted from Brady & Weil [1])

For these authors, the statistical difference is related to the root development of these plants, since more than 80% of the fasciculate root system of the Poaceae develop to a depth of 0.20 m, while the pivotal system of the Fabaceae reaches greater depths, however, it develops little laterally, thus reducing its soil aggregation capacity.

The authors [19], also observed the influence of the roots on the results obtained when comparing the stability of the aggregates in areas of native forest, sugarcane and pasture. The authors obtained significant differences in the percentage of aggregates and among others, the authors explain that in areas with sugarcane cover, a beneficial effect was observed caused by sugarcane roots, increasing the concentration of aggregates of larger diameter in relation to the pasture area, thus influencing the statistical difference observed.

In addition, the roots of certain plants can be correlated with the lowest values of soil density, as evidenced by [29]. These authors, when studying different forms of no-tillage, observed in their studies lower values of density for the treatment with livestock farming integration (when compared to the simple conventional tillage system). For the authors this result has a relation with the well developed root system of brachiaria, which favors the aggregation of the soil and the greater contribution of organic matter by the root system, thus increasing the porosity of the soil, reducing consequently the density values.

Moreover, the roots of the plants have a fundamental importance in the survival and nutrition of these plants, since, among others, they can be associated to arbuscular mycorrhizal fungi [45], which have significant importance in the root development of plants as mentioned previously.

3.8 Soil Management and Use Practices

In addition to the characteristics mentioned above, the use and management practices are fundamental when it comes to soil structure and aggregate stability. The soil structure can be significantly modified through management practices, and practices that reduce soil rupture increase aggregation and structural development [16]. Due to the physical integrity of the soil, together with the OM accumulation, no-till system is considered advantageous over the conventional system [18].

In a way, independent of the country or region studied, many authors have observed trends in soil aggregation and disaggregation, and no-tillage tends to conserve soil aggregates better than conventional tillage, which includes soil revolving [51]. Therefore, with the adoption of no-tillage system, the decline of the structural quality of cultivated soils can be interrupted and the degraded soils can be recovered. Among the effects of no-tillage can be cited the promotion of a higher weighted average diameter of the aggregates, as well as the protection of the labile fraction of OM due to non-tillage, which also favors aggregation of the soil [2].

In the studies of [7], it was observed that no-tillage demonstrated improvements in the structure of the dystroferric Red Latosol, in relation to conventional tillage, demonstrating greater aggregate stability, hydraulic conductivity and total pore area, contributing to soil and water conservation in the productive systems.

Comparing three areas with different cropping systems - (1) tillage on millet straw, (2) deforestation, cleaning and soil preparation with harrow and leveling grids for rice planting, and (3) prepare of the soil with harrow and leveling grades and soybean monoculture, [52] verified that the area under no-tillage presented a higher percentage of larger aggregates.

Likewise [17], studying three bean cultivation areas with different management (pasture area and forest area), observed that the aggregate stability indexes were higher in the forest, pasture and of bean cultivation with less soil rotation, while the areas of bean with intensive soil rotation presented smaller weighted average diameters. The same authors [17] also mention that intensive cultivation and soil rotation, common practices in the conventional system, are responsible for the reduction of OM contents in agricultural areas because this is eventually oxidized rapidly.

To [53], that conventional soil preparation damages soil structure, causes increased density, dispersed clay in water, resistance to penetration, as well as reduction of soil porosity and the weighted average diameter of the aggregates. In contrast, the authors mention that no-till improves these physical properties, which is advantageous and approaches the characteristics of cultivated areas to those of native forest.

In order to measure the effects of the addition of crop residues and root activity on the aggregation agents and disaggregation mechanisms in two soil types, with different carbon contents and textures grown under no-tillage, [47] observed that the increase in OM and the presence of vegetative cover with active roots increase the presence of the aggregating components, reducing the processes of disaggregation in the two evaluated soils.

Comparing the treatments of no-tillage and conventional tillage, [51] observed that no-tillage accumulated higher total organic carbon content in the soil in relation to the conventional tillage system, for the successions studied and for maize cultivation although all were less than the control treatment - the native forest. However, the results indicated that no - tillage associated to grass showed better physical indicators, maintaining soil aggregation similar to native forest, while conventional tillage reduced aggregation.

The difference in the comparison between soils with native forest and cultivated soils is expected, because in native forest areas the soil structures are preserved for a long period of time, favoring the increase of the aggregate quantity in the larger size class [11]. Which occurs due to the lack or low anthropic influence on the soil, as well as the products resulting from the higher OM content. In addition to the factors cited, the time of adoption of the no-tillage system is important, since the percentage of aggregates larger than 2 mm increased along the time of the adoption system [54].

Greater benefits can be obtained if the no-tillage system is associated with crop-livestock integration, as studied by [55] who concluded that the use of *Urochloa brizantha* in succession to no-till soybean for the five-year period favored the increase of aggregation when compared to other cropping systems.

In a similar study, conducted by [29], it was verified that the use of brachiaria in a no-tillage system with crop-livestock integration provided good vegetation cover to the soil, reducing or preventing the direct action of rain drops and keeping soil moisture and temperature more uniform. Also, improving the root development of the cultures and promoting greater microbial activity; factors that contribute to the aggregation of the soil in comparison to the areas of no-till without brachiaria.

Studying the differences in the soil related to the management of conventional tillage system and the no-tillage system of vegetables [9] observed that the use of cover crops in the onion tillage system favors the recovery and elevation of the contents of total organic carbon, weighted average and geometric diameters and the sensitivity index in relation to the conventional tillage system. It was also observed that the substitution of the system of conventional planting of the soil by the system of direct planting of vegetables with cover plants increased the formation of macroaggregates stable in water, with subsequent increase of the weighted average diameter, geometric mean diameter and the sensitivity index.

The permanent or rotational pasture management systems with no-tillage crop provide for the formation of larger stable aggregates, when compared to systems with only crops or with crop-pasture rotation in cycles greater than three years [56]. Since the area of permanent pasture and crop-pasture rotation in two-year cycles resembled, and even surpassed, the weighted mean deviation values of areas with natural vegetation. In addition, [2] commented that the rotation of crops, favors a better structuring of the soil, due to the variety of root systems implanted.

Soil preparation systems that take into account crop rotation are very important, since crop rotation positively favors the stability and size of the aggregates. Due to the energy and matter fluxes present in the soil, the formation of aggregates occurs in a growing way. In this sense, the formation of microaggregates will first occur which relates mainly to the interaction between mineral matter and organic compounds. Over time, the formation of macroaggregates (more complex and stable structures) occurs as a function of other factors, such as the growth of plant roots, fungal hyphae together with plant residues, insects and other organisms that inhabit the soil [56].

In a study in a Quartzian Neosol and a Red Average Argisol, [20] mentioned that the nature of the soils, associated to the lack of adequate management practices, result in the disintegration of the aggregates and increases soil susceptibility to the water and wind erosion. As a solution, the authors recommend the implantation of appropriately managed perennial pastures to avoid animal trampling, or the implantation of annual crops of plants with pivotal roots, besides the implantation of no-tillage. These measures are essential for the conservation of aggregating agents and, especially, the stability of aggregates.

To conclude, it is important to mention that the establishment of conservation management systems, whose objective is the sustainability and improvement of the soil, are of great interest to economic activity [2] and can bring benefits in productivity.

4. CONCLUSION

The importance of the soil is unquestionable especially when is considered the relation between its quality and the development of human activities in the present time. Among the attributes of the soil that determine its quality, influence on its physical parameters and favor agricultural productivity, it can be mentioned the formation and stability of aggregates.

Several physical, chemical and biological processes are directly related to the formation and stability of the aggregates. Among them it can be mentioned the climate - through the processes of wetting and drying, the contents of organic matter that act on the binding forces between the mineral particles, the amount of iron and aluminum oxides; especially in old soils, the type of clays present, the root system of plants; by the formation of exudates, mainly grasses that have well developed roots, and the presence of microorganisms and organisms, such as hyphae, fungi, earthworms, among others. In addition, it is worth commenting that the different processes mentioned act in an associated way, favoring joint formation and stability of the aggregates.

In the present study, the importance of adequate land use and management practices, such as the no-tillage system - due to the reduced soil rotation and the presence of straw on the surface, and the association of the system with integration of livestock farming, through successions with grasses or cultivation of cover crops. These practices, especially when performed for longer periods, interfere with soil structure including the formation, stabilization and maintenance of aggregates.

Therefore, the aforementioned physical, chemical and biological processes, allied to the adoption of conservationist practices of use and management, promote sustainability and improve the quality of agricultural soils, as well as being able to generate benefits in productivity a factor so popular today.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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