Review Article

State of the art: Soil physical attributes

ABSTRACT

Proper soil management interferes with the result of the installed crop. The knowledge of the positive and / or negative influence on the production systems is important to improve the physical, chemical and biological quality of the soil, for that, there are some attributes that act as indicators of soil quality. The practices carried out improperly will result in problems in soil structure, as compaction, lack of availability of water and air in the soil and for plants, soil loss among others. Some properties as soil porosity, soil aggregation, soil compaction and soil water infiltration are used to measure soil quality. In view of this, the use of these attributes as indicators is extremely important for good productivity, since management practices used can directly influence the development of plants.

Keywords: Soil quality, soil properties, soil management.

1. INTRODUCTION

The quality of the soil is variable to its formation, textural composition and type of management adopted, which determines their behavior in the face of anthropogenic activities. The conversion of forest into agricultural areas or pasture areas has been causing serious problems due to the adoption of inadequate management. There are indicators that determine soil quality and verify the effectiveness of the practices adopted [1].

The use of unsuitable practices in the soil can result in serious problems to its structure, aggregate stability, degree of compaction, resulting in insufficient infiltration of water into it, which hinders the availability of the resource to crops, in addition to significantly increase erosive processes. Several attributes must be measured to to evaluate how management influences soil characteristics as well as their relationship to the plant [2].

The understanding of the physical behavior of a soil is of utmost importance, since it guides the proper activities that must be performed in the system, so thatin this manner, it reaches an adequate crops development. This diagnosis involves the arrangement of particles and pores, soil bulk density, aggregation structure, mechanical penetration resistance, soil water infiltration, water availability to plants [3].

2. SOIL POROSITY

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Due to the structure or arrangement between the soil particles, in addition to the fraction or volume of solids, there is also a volume of voids (pores), in which factors such as retention, movement and availability of water, aeration, availability of nutrients, resistance to root penetration, aggregate stability and compaction, to a lesser or greater degree.

According to Teixeira et al. [4], porosity is a physical property defined by the relationship between the pore volume and the total volume of a certain material, and according to Embrapa[5], porosity is constituted by the porous space, after the arrangement of the components of the solid part of the soil and which, under natural conditions, is occupied by water and air, being divided into primary and secondary.

Primary porosity is developed with the sediment or rock, being characterized in the sedimentary rocks by the spaces between clasts or grains (intergranular porosity) or stratification planes. Worth noting that in sedimentary materials, the size and shape of the particles, their degree of selection and the presence of cementation influence the porosity. The secondary porosity develops after the formation of igneous, metamorphic or sedimentary rocks, by fracture or failure during their deformation (fracture porosity) [4].

Sands retain a poor amount of water because their large porous space allows free water drainage from the soils. Clays absorb relatively large amounts of water and their smaller porous spaces hold it against the forces of gravity.

In short, porosity consists of the physical quantity given by the volume of the porous space, constructed by the arrangement of the components of its solid part and which, under natural conditions, is occupied by water and air [6].

Regarding to the distribution and size of the pores is oriented by three types of classification, consisting of macropores (pores with larger diameter, which directly influences the infiltration capacity, soil drainage and its aeration capacity); mesopores (pores with intermediate diameter, responsible for the conduction of water during the redistribution process, that it, after infiltration, when the macropores are emptied); micropores (pores with the smallest diameter responsible for the retention and storage capacity of water and solutes in the soil [7].

According to Lorenzo[6], the macropores (Ma) are results of the arrangement of the aggregates, the action of the mesofauna and roots and the expansion and contraction of the soil mass. They are related to the gas exchange of oxygen and carbon dioxide and to the flow of water by gravity: infiltration, drainage and transport of solutes; and micropores (Mi) are in-aggregated and are related to water retention due to molecular adhesion that entraps gases, vapors or solids in the surface of solid bodies. Kiehl [8] classifies as macro and micropores, pores with larger and smaller diameter, respectively, than 0.06 mm. Several authors include mesopores in this classification as an intermediate class, such as Luxmoore [9], which suggested a classification in which the micropores have a diameter smaller than 0.01 mm; the mesopores have a diameter between 0.01 and 1.0 mm; and the macropores, diameter greater than 1.0 mm.

Soil porosity interferes with aeration, conduction and retention of water, resistance to penetration and root branching in the soil and, consequently, in the use of available water and nutrients [10].

Ideal soil must present a volume and size of pores suitable for the entry, movement and retention of water and air to meet crop needs [11]. The distribution of pores in the soil matrix plays a fundamental role in the relationships between the solid, liquid and gaseous phases, determining the spatial and temporal evolution of the processes that involve the movement of water in the soil [12]. According to Ribeiro et al. [12], soil porosity is determined by the way the solid particles are arranged, emphasizing that if they are arranged in close contact, predominance of solids occurs in the sample and the porosity is low; and if, on the contrary, the particles are arranged in aggregates, there is a predominance of voids in the soil sample and the porosity is high.

3. SOIL AND PARTICULATE DENSITY

The diversity of the mineral and organic components presents in the composition of the soils, as well as the proportion between them, determine the density of the material. This physical attribute besides being determinant of the composition is also related to soil texture and aggregation, water infiltration rate and erosion, macroporosity and root development, soil consistency (dry, wet and wet), degree of compaction, which interferes with root development and management techniques and agricultural productivity. The density is oriented by determining the soil density (ratio of the sample mass to the volume occupied by solids, considering the pore space) and the density of particles (ratio of the sample mass to the volume occupied by the particles, disregarding the porous space).

3.1 Soil density

Soil density is defined by the ratio of the mass of dry solids to the soil volume, being affected by crops that alter the structure, consequently the arrangement and volume of the pores. These changes influence soil physical properties, such as aeration porosity, soil water retention, plant water availability and resistance to root penetration [3].

A soil sample of surface horizon, rich in organic matter (substrate), when compared to a portion of any of the horizons in depth, it is perceived that the superficial sampling is lighter. The significant increase in soil density in depth can be explained by the pressures exerted by the upper layers, causing compaction and reduction of pore volume [8].

Association of the concepts of density and porosity, between the masses and the volume of the soil constituents, are developed by porosity, which determines the existent space between the aggregates, occupied by air or water, being calculated from density, the pore space occupied varies in the inverse ratio of soil density [13].

This physical attribute is expressed in grams per cubic centimeters and the amplitudes of variation for each type of soil is within the following limits: clayey soils (0.90 to 1.25 g cm^{-3}); sandy soils (1.25 to 1.60 g cm^{-3}); humic soils (0.75 to 1.00 g cm^{-3}); turfous soils (0.20 to 0.50 g cm^{-3}).

The determination methods are based on obtaining the mass and volume of the soil sample. The mass is easily determined by weighing the dry soil in an oven, and the determination of the volume is varied from the use of some methods, which are described below:

3.1.1 Volumetric ring method

There are several types of samplers, the most usual it's a stainless-steel cylinder with sharp edges, nailed directly into the soil. This method presents certain difficulties in the removal of the ring from the soil, may occurring loss of sample, since there is no soil surplus at the top and bottom of the cylinder under comparable structure conditions, the higher the clay content of a soil, the lower its density, always considering the composition of the soil analyzed [3].

This method has been used since 1914, suitable for well-structured soils. However, when the soil has thick roots or is a compact horizon, it is unfeasible to use and is not recommended in these situations [8].

3.1.2Method of the waterproofed clod

Based on the Archimedes' Law, which defines the buoyancy of a body is equal to the weight of the volume of liquid displaced when it is immersed into it. This method is not recommended for mobilized soils, since in this condition the aggregates will be of equal density to that of before the preparation. The volume of the clods is determined by the volume of water displaced by them immersed in water [8].

This method presents certain disadvantage, due to the possibility of segregating the soil sample during the collection process, thus generating a disregard for the existence of macropores in the clods.

3.2 Density of particles

This soil physical attribute aims to measure the average density of the mineral and organic particles of the soil, reflecting its average composition. This density is related to the volume effectively occupied by solid matter, without considering the porosity. The mineralogy and soil composition are characteristics that naturally influence the density of individual soil particles [14].

Some incorrectly practices performed may increase soil density, such as excessive tilting or use of poor's conservation practices, which may cause structural alteration, decrease of macroporosity and total porosity, among other damages [15,1].

The problem of having a compacted soil and consequently the increases of its density and resistance, is the difficulty that the root system will have to penetrate and exploit this soil, thus reducing the pore diameter of the soil, reducing permeability and flow of water, as well the air capacity, which may affect the development of plants and the anatomical structures of its roots [16].

The mean values for each soil type depend on its predominant mineral constituents, with a mean variation between the limits of 2.3 to 2.9 g cm^{-3}. The great majority of the soils are composed of quartz, feldspar and colloidal aluminum silicates, whose particle density is around 2.65 g cm^{-3}.

The methods for determining the density of soil particle are based on obtaining the sample mass value and then the volume of present solids, the mass is obtained by simple weighing, and the volume can be obtained by the volumetric flask method, more accurate among existing methods. The differential of this method is the practicality offered, in which it is summarized in a single weighing, pipetting and buret reading, of the displaced volume [8].

4. SOIL AGGREGATION

Aggregate is characterized as a grouping of strongly adhered particles, the size of the aggregate determines its susceptibility to movement by the wind, water and porous space, interfering in the percolation of the water and the volume occupied by the air of the soil, being conditioned from the environment to the growth of the root system of plants. Organic matter is an important cementing agent of soil particles, vegetation and its residues protecting the aggregates from the surface, against disaggregation due to the impact of rainfall and sudden variations of humidity [3].

The soil structure is adequate to allow good flow of water, inner's aeration, resistance to erosion and traffic of machinery, development of living organisms and proper development of plant roots [17].

The soil structure is represented by the aggregation, that is, the result of the interaction between the size, shape and arrangement of the solid particles and porous spaces of the soil, being highly variable and associated with physical, chemical and biological factors [18]. These properties, with the genetic potential of the plants determine the productivity of the crops [19].

The dynamics of soil aggregation is influenced by the soil management system. This management comprises a set of practices that, when rationally used, promote better crop productivity, but when improperly used, cause physical, chemical and biological degradation of the soil and, also, a reduction of productivity [20, 21].

In the last years, soil quality studies have evolved due to the need to evaluate the behavior of different soil attributes [22].

Soil aggregation is one of the attributes used as indicators of soil quality, defined as the ability to sustain agricultural productivity, maintain the quality of the environment, and ensure human, animal and plant health [23]. and is related to important processes, such as erosion resistance and infiltration capacity [24].

Soil erosion is one of the major environmental problems, because in addition to soil and nutrient losses, it is associated with flooding, sedimentation and pollution of water bodies, and this process is affected by different factors such as soil cover and management practices, However, soils with good aggregation are more resistant to erosion [25, 17].

Infiltration is also an important indicator of structuring and aggregation, influencing the improvement of soil support capacity [26]. Besides that, their knowledge is indispensable for the elaboration of an irrigation project, aimed at providing greater yield to the crops, and the better the aggregation, the greater the water infiltration capacity [27].

Another important aspect is the protection of soil organic matter, and its increase is partially determined by the link between the recycling of macroaggregates, formation of microaggregates and stabilization of carbon within the microaggregates. In order to have a good formation and stabilization of these aggregates requires an interaction of several factors such as, for example, soil fauna, roots, inorganic agents and environmental variables [20].

The organic compounds participate in the bonds between individual soil particles, acting as cementing agents of the structural units by their diverse surface characteristics, thus, there is a correlation between the organic matter and the stability of the aggregates, since the organic compounds are the main cementing agents of the soil particles and, at the same time, the state of greater aggregation promotes greater physical protection of the organic matter of the soil thus allowing its accumulation [24, 28].

Cultural practices are primordial when optimum productivity is expected; besides that, an inadequately performed activity can cause degradation of soil and natural resources [29].

Conventional preparation breaks the aggregates in the prepared layer and accelerates the decomposition of the organic matter, reflecting negatively in the resistance of the soil aggregates. Bertol et al. [30], evaluating the physical properties of the soil under conventional tillage and direct sowing in rotation and succession of crops, compared to the native ones, verified that the physical properties are altered with the management, in which conventional cultivation resulted in a lower organic carbon content, implying a greater soil degradation when compared to direct sowing.

Studies made by Loss et al. [31] also observed when analyzing total organic carbon and soil aggregation in an agroecological and conventional no-tillage system of onion, that the use of single or intercropping cover crops in the planting system was efficient to recover and increase the weighted average diameter (WMD), geometric mean diameter (DMG) indices in relation to the conventional tillage system, in which forage turnip increased the aggregation of the soil in the layer of 10-20 in relation to the other treatments.

The intensity of the structural stability of the aggregates varies according to the type of soil and the cultural practices applied at the place of cultivation. When there is soil rotation, the percentage of aggregates in the larger diameter classes reduces, consequently, there is an increase in the class of smaller diameter, resulting in a negative effect on stability of the aggregates [18].

In places arising from civil works the common denominator of degraded areas is the removal of the superficial horizon containing organic matter, causing serious physical, chemical and biological problems to soil [26].

An alternative to maintaining or recovering soil quality, is the usage of conservation practices, as the no-tillage system, which, due to the absence of soil rotation and maintenance of the straw on the surface, contributes to the improvement of soil aggregation. soil and consequently for the increase of carbon stocks in the soil, being more effective when associated to the use of cover crops, either by rotation or succession of crops [32].

According to Loss et al., (2014), analyzing the aggregation, light organic matter and mineralizable carbon in soil aggregates, found that the conventional tillage system reduced the aggregation index (WMD and DMG) and the organic matter content and total organic carbon in relation to the forest area and using the direct tillage system and pasture it was possible to recover these original values.

5. MECHANICAL RESISTANCE TO ROOT PENETRATION

Soil compaction is an old problem and has been intensified with the expansion of the agricultural frontier and the usage of basically two annual crops, mainly by use of heavier machinery and agricultural implements for the management of soils and exploited crops [33,34]. Soil compaction refers to the compression of the unsaturated soil during which there is an increase of its density because of the reduction of its volume, resulting from the expulsion of air from the pores, causing a denser rearrangement of the soil particles and consequent reduction of porosity [35].

Thus, the increase of soil density becomes a limiting factor for the development of the plants and, consequently, harming the achievement of higher yield indices [36,37], due to the decrease of the water infiltration capacity [38], the low development of the root system [39] due to the mechanical impedance, which results in a lower volume of soil explored, a reduction in nutrient availability and losses of nitrogen by denitrification [38], causing the increase of CO_2 and phytotoxins [40].

The limitation to root growth, is clearly guided[41], within classes determined by the values found in the resistance analysis (Mpa) as without limitation (<1,1); little limitation (1.1 - 2.5); some limitations (2.6 - 5); serious limitations (5.5 - 10); roots hardly grow (10,1-15); roots do not grow (> 15).

The decomposition of a soil is done through the application of organic matter into it in order to reduce its density, and green fertilization can be used [42,43], animal manures, compost prepared on the farm, vegetable cakes and various industrial wastes [15,44], among others.

Several methods are used to recognize soil compaction, for example: trench opening, vegetation cover visualization, soil density and soil penetration resistance.

The trench opening consists in the observation of the root system, especially in relation to subsurface compaction or grid footing. When there is subsurface compaction it is possible to observe a great concentration of roots in the superficial layer, by not being able to cross the compacted layer [45].

There is also the determination of soil density, which is the ratio between the mass of a dry soil sample and the volume occupied by this sample, but the density values may vary from soil to soil and difficult to correlate with plant growth [45].

In order to solve this problem, it can use the relative density, which is the ratio of the soil density to the maximum density, reached on the compacted sample in the Procter test or in the uniaxial compression test. Hakansson and Lipiec [46] affirm that the relative density isolates the effect of the texture in the density of the soil, being possible to compare soils of different textures as the level of compaction.

For determination of the resistance of soil to penetration, can be used penetrographs or penetrometers, the penetrometer perform specific evaluations of resistance to penetration, penetrographs record the resistance throughout the soil profile. Both equipment uses the same principle of operation, varying only model, having various types as the impact's ones, the torque spring and the prints that use load cells [45].

Soil compaction has become a global problem as a result of intensive cultivation, increased use of heavy machinery, short crop rotations, and inadequate soil management practices [47, 48].

The damages include both the compression as the shear of structure of the pores of the soil, so that simple indexes, as changes in the density of the soil, generally provide an indicator of bad damage to compaction [49, 50].

Soil resistance and aeration are dynamic parameters mainly affected by soil structure, texture and water content. The interactions between water content and soil density on soil resistance and aeration make it difficult to characterize soil compaction effects, considering individual soil properties [47].

It is important to cultivate the soil with the correct humidity, so that compaction is minimized [51]. As soil density increases and total porosity decreases, soil resistance to root penetration increases, preventing root growth and restricting water and air circulation throughout the profile resulting in poor aeration of the root system [48].

Intensive traffic in agricultural machinery is common in most agricultural operations, even in no-tillage systems. Plowing, harvesting and spreading chemicals or fertilizers are common operations on most farms. Most, when not all these operations are carried out by heavy wheeled machines. Soil compaction by wheels is characterized by a decrease in soil porosity located in the area below the wheel and formation of grooves in the soil surface [51, 52, 53].

The compaction's degree depends on the mechanical strength of the soil, which is influenced by intrinsic properties of it, as texture and soil organic matter content; structure of the plow layer on the wheel and its state of water; and loading, which depends on axle load, tire size and speed, as well tire solo interaction [51, 53].

Increasing the pressure on the soil increases the chances of soil compaction. Increasing the frequency of machine passes over a soil increases its bulk density and cone index, resulting in soil compaction and inadequate soil physical conditions for seed emergence. However, most of the total compaction of the soil is caused by the first pass or initial passages of the machine and 10 passages can affect the soil up to 50 cm depth [53, 52].

The depth of compaction varies widely from 10 to 60 cm but is more obvious in the surface soil (about 10 cm). Though, cone index increments (penetrometer reading) between 16 and 76% may occur in the first 40 cm of the surface layer, and the bulk density may also increase, but increases were limited to a depth of 15 cm. However, in a pasture situation, differences between heavy and light loads in the lower depth range (surface soil) were not found [51].

Soil type also influences soil compaction. In soil with thick texture, the dominant stress penetration was in the vertical direction, while in thinner textured soil the propagation of stress was multidirectional. However, they suggested that in soil with good structure (aggregate soil) the compaction due to the axle load was not as deep. The effects of axle load on soil compaction have been researched by many workers around the world in the last decade [51].

Animal trampling can cause compaction and degradation of soil structure. The compaction caused by the grazing of animals through the action of the hull will probably be more widespread in the pickets compared to the compaction caused by mechanical implements that are limited under the rails. The trampling of the animals in relation to soil compaction can affect soil density, hydraulic conductivity, macropore volume and resistance to soil penetration. The effects of grazing animals on soil physical properties, nitrogen and soil carbon were discussed in detail in the literature [53].

Improved land management techniques are vital to ensure that soil physical conditions are not compromised and practices that increase organic content, reduce crop yield and sustain agricultural land use [51].

Crops of coverage with aggressive and extensive root systems help in the formation of soil aggregates, thus facilitating root growth of later crops and increased water infiltration. Soil aggregation is generally improved by management systems, including crops with a high capacity to form roots and increase soil organic matter. The contribution of SOM to the formation of stable aggregates is attributed to processes such as the formation of cationic bridges, cementation between particles and stability promoted by root and microbial exudates around and within aggregates. Therefore, this could be a mechanism whereby the use of rotating hedge plants with the main crop would have a lasting effect on the alleviation of soil physical limitations [48].

6. INFILTRATION OF WATER IN SOIL

Infiltration is a process by which water crosses the surface of the soil and redistributes in its profile. An important process for the supply of underground aquifers, determining the water balance in the root zone of the crops, directly interfering in the runoff, responsible for erosion and flooding processes. The infiltration of water is a physical attribute sensitive to changes in soil planning, management and conservation.

. The distribution of water in the soil profile, submitted to a hydraulic load on the surface, is distinguished in four respective zones to the increase of depth, according to Brandão [54].

Saturation zone: is located below the surface of the soil, usually a narrow layer, in which the soil is saturated.

Transition zone: layer characterized by marked decrease of humidity.

Transmission zone: region where the water is transmitted, characterized by increasing thickness with the continuous increase of application of water load, with small variation of humidity in relation to space and time.

Moistening zone: narrow layer, with great reduction of humidity with increasing depth.

Moistening front is the visible limit of soil water movement, as a reflection of the variation of moisture exists in the system (soil), which is also affected by the physical, chemical and biological conditions of the soil.

The infiltration process has relations of dependence with some factors in which they can be divided into classes being, soil related factors, surface related and soil preparation / management. These relations of dependence exert a function in the properties related to the porous space of soil composition, combined with the flowing fluid, determining the hydraulic conductivity, as well the occurrence of the surface crushing process caused by the impact of the raindrops on the soil, which allows the rearrangement of the particles, densification and consolidation of a surface structure, modifying the thickness of the surface layer [55].

Soils with a sandy (thick) texture, have a higher amount of macropores, when compared to clayey (fine) soils, in which they present higher hydraulic conductivity and infiltration rate, the contribution of the clay as an inorganic solid having loads is great value for the structuring and aggregation of the soil.

The aggregation of soil particles contributes positively to the process of infiltration of water in the soil, besides promoting spaces to soil organisms. Infiltration is an important attribute that controls the leaching, flow and availability of water to crops. Lack of residue coverage and direct exposure of soil to high intensity rains result in poor aggregation, providing crust formation, as well reducing the availability of water to crops, contributing to poor water quality [56]

The type of soil surface cover is a determinant factor for the infiltration process, being responsible for the increase of the macroporosity of the surface layer, reduces surface crumbling, promotes a high infiltration potential and considerably reduces water and soil losses.

Water infiltration in the soil can contribute to a better understanding of the erosive dynamics, since the lower the infiltration rate the greater the possibility of surface runoff, reflecting the degree of soil compaction [57]

Studies by Marchini et al. [26] showed that the values of the infiltration rate ranged from 19.62 for exposed soil and 36.06 cm^{-1} for Gonçalo Alves + Bean. The superiority of the treatment with vegetal cover can be explained, by the factors of soil revolving, due to the preparation for the sowing, or by the effect of the roots of the green manure.

Influence of the factors related to the surface in the infiltration process was found by Bonini et al. [58], where the crop-livestock-forest system presented lower rates of water infiltration when compared to the eucalyptus forest and the crop-livestock system, this behavior can be attributed to the higher compaction of these systems, verified by the high values of resistance to root penetration.

Similar results were also observed by Marchão [39], where the crop-livestock system presented higher infiltration rates because of three main effects: absence of preparation during the grazing cycle, presence of a dense root system and an increase in activity microbial and macrofauna of the soil.

The water infiltration process must be determined by simple methods with the potential to adequately represent the soil conditions [54].

In hydrological studies, infiltration rate determination equipment is used, with specific attributions, with the ring infiltrator, rainfall simulator and infiltrometer of mini-disk.

7. FINAL CONSIDERATIONS

Physical attributes reveal soil quality and indicate whether the management is appropriate. Attributes as soil mechanical resistance and water infiltration in the soil are fast and with low data acquisition costs. Already the porosity and density of the soil together with the aggregation, take time for the determination of the same and are costly. Analyzing soil attributes is extremely important for good productivity, since inappropriately used practices can influence plant development

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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