

Strategies to increase the capacity of soil infiltration and water retention

ABSTRACT

Water is one of the most important natural resources for the development of agricultural and livestock activities, since these economic activities are highly dependent on the natural resource test for their development. Adopting strategies that optimize the processes of infiltration and water retention in agricultural systems have a direct influence on the productivity and yield of agricultural areas and consequently on the sustainability of the systems. In this sense, the present work aimed to gather information and discuss some important aspects to understand how the infiltration and retention of water happens in the soil and which agricultural management should be adopted in order to optimize them. The main processes that interfere in the direct and indirect infiltration and retention of water in the soil are related to texture, structure, porosity, organic matter content, clay type, retention capacity and hydraulic conductivity; precipitation, humidity, temperatures, microstructure, compaction and surface roughness of the soil. As a way to improve these processes, we highlight the management that promote the addition of organic matter to the soil, conservation techniques of soil preparation, crop rotation and straw production and control of irrigation and drainage processes. The adoption of the management increases retention capacity and promotes the conservation of water in the soils, generating benefits to the productivity of the cultivated areas, making them over time, less susceptible to inclement weather and sustainable, factors so much preconized nowadays.

Keywords: Soil water conservation; Soil Physics; Conservation and management of soil

1. INTRODUCTION

Among all the difficulties for the expansion of the agriculture, the water availability is a factor with a huge importance, once the crops are the biggest consumers. Worldwide, the agriculture consumes about 69% of all the water derived from rivers, lakes subterranean aquafer whereas the industry percentage represents 24% and the human consume the remaining 7% [1].

The process of infiltration, retention and availability of water are important to the maintenance of the agricultural crops, aquafer recharge and maintenance of springs.

Human activities that are done with economic aims on the soil, influence directly these processes and as near to the natural conditions the soils are, better will be the conditions where these processes will happen. So, the studies focused on agricultural management which favor the infiltration and retention of water in the soil with quality are important to the society.

This research aims to discuss some important aspects to comprehend how the infiltration and retention of water happen in the soil and which agricultural managements must be adopted to optimize these processes.

2. REVIEW

2.1 Water infiltration in the soil

Infiltration is the process of input water on the soil by the superficial layer in the vertical and descendent way [2] or, the passage of water from the surface to the inside of the soil. The water

suffers the action of gravity and descends through soil profiles, so, it precedes the storage and retention of water in the soils [3]. According to Angelotti Netto and Fernandes [4] the infiltration can be considered the properties that best mirrors the physical conditions of the soil and its structural stability.

The process of water entry in the soils is important to recharge the aquifers, maintain the base flux of rivers, permanence of water in the river basin, bigger availability of water to the development and maintenance of the vegetal cover.

Percolation is the process where the water circulates in the soil, not following, necessarily, a descendent flux. Once infiltrated the water start to percolate in the aeration zone, reaching the saturation zone [5, 6]. When the contribution of water ceases on the surface, the infiltration stops, the humidity inside the soil is redistributed going to a profile in the soil with lower water content in the surface and higher in the deeper layers [7, 8].

The entry of water in dry soils is maxim in the beginning of the rainy period when the precipitation rates are higher than the infiltration, it suffers a exponential decrease until it reaches a constant tax of water entry in the soil (basic infiltration) [6, 9].

The infiltration rate is described as the quantity of water that go through a unit area of the soil surface for a unit of time. Many of the problems related to erosion, mass movement, siltation, and the quantity of water are affected by the infiltration rates because as higher is the capacity of the soil to absorb rain water, higher will be the runoff and, therefore, lower will be the erosivity of this phenomenon [9]. It is also important to the processes of irrigation, drain and construction of public politics [10].

The infiltration process can be affected for some factors such as the ones linked to the soil from which we can mention: texture, structure, porosity, organic matter content, kind of clay, retention capacity and hydraulic conductivity; natural factors as the precipitation, humidity, changes of the seasons and temperatures and last, factors linked to the surface that modify the interface water-air, and occasion changes in the water, among those we mention the management, agricultural crops and irrigation and drain processes [11, 10, 9, 7].

2.2 Factors that interfere in the soil capacity to infiltrate water

2.2.1 Texture, structure and soil porosity

Santos and Pereira [12] highlight that the texture, structure and porosity are determinant properties in the penetration and movement of water in the soil profile, once they determine the quantity and disposal of the spaces for the water penetration.

The structure is referred to the particle arrangement (granular, laminar, blocks, prismatic), it defines the geometry of the soil porous space.

The pores space or porosity of the soil is the volumetric fraction of the soil filled with water and air. The kind of pores is related to its origin, the round ones have a biological origin, the irregular are formed from the humidification, drying and pression on the soil. The round pores tend to be continuous and with a predominant direction to the surface. Pores have different dimensions and can be classified as: macropores (until 0,08 mm), micropores (smaller than 0,08 mm), however, the classification of kinds of pores diverge among authors [13]. The macropores have an important function in the water infiltration and drain of the soil, on the other hand the micropores participate in the retention and availability for the plants. The porosity is one of the aspects that better explain the infiltration capacity of a soil. Continuous and cylindric pores have a high capacity to drive water for the soil profiles [14, 15].

The size of the particles influence in the pores diameter. As bigger the macropores volume, bigger the capacity to lead water to depths of the soil. Granular particles or round ones tend to only touch each other, building empty spaces from where the water find facilities in flow, on the other hand, long and irregular particles tend to fit in a way to create flux trajectories more tortuous for the water [16]. Besides, more irregular structures present greater roughness, resisting the liquid passage [17, 9].

Sandy soils have a particle arrangement bigger and more granular with bigger spaces between particles (not cohesive particles), the water drain in these soils are better. These soils also have bigger composition of macropores in relation to soils with a clay texture, so they have a bigger infiltration [2]. Clay soils tend to present higher values of water storage and inadequate aeration if managed wrongly. The infiltration has a greater dependency for the structure than to the texture of the soil, once it interferes in the geometry of the porous space [12].

Managements applied in the soil which prorogue a discontinuity and alterations in the shape and diameter of the pores, reduce the infiltration of the water being necessary evaluate not only the quantity of pores but also its continuity and shape along the profile [18, 17].

2.2.2 Types of clay and organic matter

The type of clay and the organic matter of the soil have a relevance in the process of infiltration of water in the soil, the oxides of iron (Hematite and goethite) and the aluminum oxides (gibbsite) have an equidimensional shape, different from the silicate clays (plane shape), due to it they work as disorganizing agents of the adjust face to face of the soil particles, promoting greater porosity in more weathered soils [17, 19]. As the soil gets old start forming clays less active, as the kaolinite, oxides and hydroxides of iron and aluminum that develop positive charges in low pH. The negative charges in the surface of more active clays attract positive charges of the clays which favor the flocculation process.

The flocculation is a phenomenon of approximation of clays. In flocculated soils the approximation does not follow an order, creating spaces among particles, increasing the porosity [20, 19]. According to Pedrotti *et al.*, [19] the gibbsite contributes to a formation of macropores in the soil and the kaolinite acts in the opposite way of this formation, soils with 1:1 clay minerals have higher density and lower permeability to water. Tropical soils with predominance of 1:1 clays and iron and aluminum oxides tend to higher aggregation, forming granular structures that easy the water infiltration.

De Moraes [9] states that the relation depends as much in the quantity as in the nature of the soil clays, the clays 2:1 are expansive and this movement of expansion and contraction tend to have facility to compact, discontinuity of pores and superficial sealing.

The organic matter is also important to the water infiltration in the soil because it acts as a cement agent for the formation and stabilization of the aggregates, provide an environment to mesofauna and macrofauna to grow, they produce bio pores, biological mega pores [21]. As more stables the aggregates are bigger will be the space between particles and bigger will be the infiltration. The stability of aggregates represents an important contribution in the maintenance of the soil porosity, as more stable they are, lower are the effects of the impact of the rain drip [2]. The repeated impacts of the rain drop contribute to the reduction in the infiltration rates in two ways: decreasing the surface rugosity, reducing chances of grounds, and a formation of a thin dense layer in the surface, with a low conductivity, denominated superficial sealing, responsible for a reduction of about 90% in the original permeability [10].

The disaggregation allows a dispersion of silt and clay, which when carried block the water passage, decreasing the soil infiltration [4, 22, 10].

The infiltration is also reduced from the clay expansion, that closes the cracks and reduce the pores sizes, whet the soil become wet. Expansive clays, saturate much faster than the non-expansive.

The presence of coverage by plant residues on the soil surface is a key factor to the infiltration because, besides protecting the superficial horizons of the soil by dissipating the energy of the rain drop impact, it also reduces the speed and volume of the flash flood and causes deposition or filtration of sediments [22]. The mixture of the organic matter to the soil exercise direct effect against a formation of a crust in the soil surface, after the beginning of its decomposition, by the liberation of polysaccharides and linking aromatic compounds, that aggregate the soil particles [17]. To adequate maintenance of the soil organic matter in the south region of Brazil, the contents of vegetal dry matter must be between 7 and 8 ton/ha on each crop [21].

The loss of water is more affected by the management of waste than by the percentage of mulch. Research mentioned by Troeh and Thompson [17] show that crushed corn stalks left over the soil

surface reduce the loss of water to less than half when compared to areas where the stalks were left standing after harvest.

The green plants are also important to the water infiltration in the soil, the characteristics of the vegetal species, as the kind of root and leaf, the angle of leaf disposition in relation to the trunks, the quantity and diameter of the trunks, the growth habit of the plants have an influence in the water dynamic in the soils. The roots, as an example, rot forming channels which will help in the guiding of the water in depth [3, 7]. Correa *et al.*, [23] demonstrated the important paper of the roots in the water movement in the soil that as they grow they form preferential ways for the water and also to the quantity of water available in the soil for recharge, besides making it easy the drainage of the superficial horizons of the soil. For De Moraes [9], Pinheiro, Teixeira and Kaufmann [10] the infiltration in the soil with different densities of roots is directly related to the infiltration rates because it elevates the macroporosity as the number of roots increase. Most of the annual crops have its radicular system working in the most superficial layers of the soil, so that relation is more noticeable in the horizon A [24].

2.2.3 Humidity, Precipitation, changes in seasons and temperatures

In the initial phase of water infiltration in the soil, primarily occur the pores saturation, the greater are the pores volume, greater will be the absorption capacity. Soils constantly irrigated have a smaller absorption capacity due to its initial humidity [2]. The greater is the capacity of the soil to absorb water, smaller the intensity of superficial flow.

The weather interferes in the humidity content of the soil (antecedent humidity) which directly influences in the infiltration and conductivity [17], because as the humidity content increases, occur a reduction in the water conductive area.

The wind is another climate factor intervener in the infiltration because the percolated water is influenced by the evapotranspiration [25]. The quantity and intensity of insolation received by the soil also influence in the evaporation, therefore, in the infiltration [9].

Thus, when there is a seasonal fall in precipitation rates, the evaporation/evapotranspiration, which are conditioned by both the intensity and the relative humidity of the wind and the saturation of the pores, reduces. For Wagner-Junior *et al.*, [26] managements that reduce the temperature inside the soil favor the maintenance of the water in it and reduce the evaporation increasing the infiltration in the soil. The mulch from previous crops protects the soil surface, reducing the drying and runoff process. The mulch reduces the wind speed over the field in up to 99% and so, the loss of water by evaporation is reduced. Moreover, cover crops and spontaneous plants can improve the water infiltration and reduce from two to six times flow losses [27].

Naked soils have its temperature changing a lot, reaching 48°C or more according to the time of the year, so the evaporation rates are elevated, soils with significant clay contents as the smectites easily cracks when dry what allows the water evaporation from the deeper layers, this movement of contraction and expansion reduces the pores size and the rates of infiltration and storage of water in the soil [17, 7].

Wind break walls can protect the soil from the evaporation and reduce the transpiration by the plants which can favor the crops yield, as the case of the soy that was 20 to 26% more productive in protected areas than in areas unprotected by wind break walls [17].

2.2.4 Terrain relief and slope

The relief can also influence in the water infiltration once that flat areas tend to absorb mostly of the water whereas more inclined areas tend to have a higher superficial flow and lower infiltration rates [2].

According to Klein, Klein [3] the shape of the slope establishes areas of divergence and convergence of water flows, marking spots of high or low infiltration. The low parts of concavities, besides the convergence, can generate the presence of sub superficial flows that contribute to the decrease in the capacity of the soil to absorb water, characterizing these spots as a discharge area. The shape of the

slopes together with the declivity regulates the speed of the superficial flow of pluvial waters and therefore, controls the quantity of water that infiltrates in the horizons, thus defining preferred recharge zones [9].

Surface-bound factors interfere with the movement of water through the air-soil interface so that the applied soil management can interfere with water infiltration as it interferes with the physical properties of the soil, the characteristics of its surface and the natural conditions of a temperature and a temperature [10].

The rugosity of a soil is a vital component that increases the infiltration of water in the soil, forming a physical barrier to the flow, rough surfaces formed by the use of farm equipment usually form small depressions that can store water until it infiltrates [2]. However, a bigger rugosity caused by soil repair implements can constitute a disadvantage because it makes harder the operations. The seeding operation (especially the direction) influences the rugosity of the soil surface [28].

The planting system, when managed correctly, promotes an improvement in the soil structure, increasing the infiltration and water storage, preventing the formation of superficial crusts and increasing the retention time of water in the area optimizing the infiltration, due to the rugosity in the surface [3]. According to Franchini *et al.*, [29] the system also favors the ascendant flux of water from the deeper layers to the superficial ones where is most of the plants root system. The infiltration rates in the no-tillage system are higher.

The only obstacle to the infiltration in the no-tillage method is when there is soil compaction due to the intense traffic of machines and for the inadequate management of the process of crop rotation, thereby, occurs a decrease in the basic infiltration rate [10, 3, 12].

Some works performed by Klein *et al.*, [30], Castro; Vieira, Siqueira [31], Angelotti Netto and Fernandes [4] indicate that the soil tillage increases the entrance of water in the soil profile due to the higher rugosity in the surface, increase of the soil porosity, however, work performed by Drescher *et al.*, [32], with mechanic scarification in soils with no-tillage showed greater infiltration in the soil for a period of 24 months, this being a recommended practice in some cases of soil compaction, to increase the infiltration rates, not being adopted as frequent practice because it promotes a long term degradation and losses for erosion. Panachuki *et al.*, [22] indicate that managements under no-tillage without mulch and under tillage had shown higher soil and water losses and lower rates of water infiltration.

The terrace is a mechanic conservationist practice which implantation involves the dirt movement by cuts and landfills [3]. This practice decreases the size of the ramp, allowing the control of the flood favoring the infiltration. The increased infiltration greatly depends on the slope of the terrain, flat terrains have greater water absorption. On sloping terrain, terraces have proved useful in reducing runoff and soil loss. Terraces with closed edges and smaller spacings are more efficient at retaining water than larger terraces [17].

2.3 Water retention in the soil

To the growth of a plant there is a dependency to the amount of water in the soil. The retention is the capacity of the soil on keeping the water provided from the rain or irrigation. The retained water varies from soil to soil according to its characteristics and it can be expressed in medium values considered optimum: sandy soils 0,25 to 0,10 mm.cm⁻¹, silty soils 0,10 to 0,175 mm.cm⁻¹ and clayey of 0,175 to 0,25 mm.cm⁻¹, it depends on the joint action of some factors: content and mineralogy of the clay fraction, organic matter content, of the differences of the microstructure and compaction [3, 7].

The water availability is defined as the volume between the field capacity and the permanent wilting point [3, 5]. To Klein, Libardi [33] the retention is interconnected to the soil structure (particles arrangement); the texture, the kind and quantity of clay and the organic matter content.

The texture is one of the properties which influences the most the retention of water in the soil, being modified only in the long term by the weathering. The clay content, which defines the distribution and diameter of the pores in the soil, determining by that the contact area between the solid particles and the water, creating a retention strength (low potential) as the permanent wilting point, the contents of

clay and silt affect significantly the water content in the permanent wilting point. As the soil texture becomes thinner, there is an increase in the water storage, Klein *et al.*, [34] found better correlation between the water content and the clay content in the potential of -1,5 MPa to soils with high chemical activity of the clay ($>27\text{cmol}_c\text{ dm}^{-3}$), the availability of water increases as the soil texture decreases.

Differences in the soil texture, mulch, vegetable species, quantity of received (precipitation/irrigation) influence in the dynamic of the water in the soil and consequently in the availability for the plants.

2.4 Management to favor water retention in the soil and the provision of water to the plants

2.4.1 Addition of organic matter to the soil and techniques of soil preparation

The organic matter contributes directly to the water retention in the soils, because it has electrical charges dependent of the pH which adsorb and keep water, and due to it largest area, in average it retains up to twenty times the dry matter in water being part of it removed from the internal structure, the maintenance of the organic matter on the soil reduces the evaporation and contributes to the hydric availability in the initial phases of crops [35, 36].

The soil texture is related to the organic matter to retain water, the retaining in sandy soils is more sensible to the quantity of organic matter than the clayey texture [24].

Managements that increase the supply of organic matter associated to a small revolving of the soil (minimal cultivation or no-tillage), allows it to develop an adequate physical structure due to the higher cohesion and aggregation among particles, with this occur an increase in the porosity, water retention, root development, increasing the area of root growth in the soils leading to an indirect effect in the water availability to the plants due to the bigger root exploration [36, 29, 24, 7]. Works performed by Vasconcelos *et al.*, [37], Sampaio *et al.*, [38], in soils with different textures prove the changes in the physical properties that favor directly the infiltration, storage and availability of water, associated with managements of low soil revolving and addition of vegetal or animal organic matter.

Bhattacharyya *et al.* [39] evaluated the effect of mineral and organic fertilization (manure) and found low soil density, increase in the macroaggregates percentage, decrease of the microaggregates, increase in the medium diameter of pores in all depths and an increase in the rates of water infiltration with the addition of manure.

The use of swine liquid manure in different periods was not favorable to the improvement of the physical conditions of pasture areas along the time [40], this effect can be justified by the fact that was used the conventional cultivation in the area which destabilizes the soil aggregates, which makes it difficult the recover even with the addition of organic matter.

The planting systems also influence in the storage and retention of water, Bayer *et al.*, [41] observed that the soil revolving in conventional system increase the rates of organic matter loss by the fractioning and incorporation of the wastes in the soil, increase in the oxygen and temperatures, low physical protection intraaggregates, reducing the storage of organic carbon consequently influence negatively the stock and the availability of water for the plants in the medium and long term.

Normally the revolving of the soil promotes a temporary increase of the macroporosity when compared to the guaranteed aeration of the root system whose critical limit is 10% of the total volume of pores. The revolving also cause a temporary increase in the macroporosity, this effect, however, is eliminated by the natural reconsolidation or densification of the soil compaction caused by agricultural use and may in many cases have a higher volume of micropores, which would increase the water storage capacity in deeper layers of the soil [36].

Dalmago *et al.* [42] observed that in the no-tillage system, near the surface (2.5 cm) the density was 7% lower and the total porosity was about 15% higher than in conventional tillage systems, for this reason the water storage was 80% higher in no-tillage. They also found that in the 0-15 cm depth layer 70% of available water was retained above -80 kPa, compared to 50%, for conventional planting, the force for water withdrawal is lower in no-tillage.

The integration of tree components into the production system, agroforestry system, also brings benefits to the retention and availability of water for plants, trees have a deep root system, which open channels for water infiltration, modify the microclimate, reduce wind speed and shade part of the area and reduce soil temperature [43, 44].

Many are the benefits of performing a good management of the soil organic matter as a better stability and formation of aggregates, reduction in the soil density, low levels of resistance to penetration [45].

According to Matias *et al.* [46] soil textures along with the organic matter content have a high influence on total porosity and microporosity and, inversely to soil density, it is revealed that macroporosity and compaction rates are directly related to soil densification, such results corroborate with Souza Neto *et al.* [47].

The reduction of the water infiltration rate, the macropores volume densification and the reduction of the aggregate diameter are the main physical alterations that occur in the soil, in this way the density increases and consequently the capacity of the roots of penetration [48, 49, 50].

Sampaio *et al.*, [38] found a good potential of sludge to form aggregates when applied at doses of 15 to 20 t ha⁻¹ until twelve months after application and also found an increase in porosity in doses of 20 t ha⁻¹ six months after application and the microporosity had an increase after twelve months of application, other factors were not improved after one year.

2.4.2 Crop rotation and mulch

Different cover plants with different spacings may not modify the soil organic matter content [51]. Almeida *et al.* [52] did not find improvements in the organic matter content of the soil when using crotalaria and millet, in an experiment conducted in a Red Dystroferic Latosol for three years. This shows that even crotalaria is not very adequate when it is necessary to improve the physical characteristics of the soil.

In order to test the efficiency of Tifton 85 on different levels of soil compaction, Magalhães *et al.* [53] found that it increased efficiently the macroporosity of a dystrophic red-yellow clay soil with 100% compaction in 4333% when it had 93% of compaction the increment of the macropores of this soil was 1400%. The same treatments were not very effective in improving the micropore content of this soil. When a lower soil compaction at 64% was tested, there was an increase in soil density, which probably occurred due to the strength of the roots which, when penetrating the soil, caused an increase in soil aggregation.

Nicoloso *et al.*, [54] tested the decomposition of the soil via scarification and the use of forage turnip and black oats, both mechanically and biologically, and found that these two techniques, when associated with one another, promoted an improvement in the physical quality of the soil for a longer period, and in this case mechanical scarification was only efficient for up to nine months and biological scarification proved to be efficient in itself to maintain the physical qualities of the soil for longer. This may have occurred due to the higher production of organic matter remaining in the soil and, with its slower decomposition, maintained soil quality for longer, improving soil infiltration and water storage.

The *Brachiaria ruziziensis* + castor bean consortium is a favorable alternative to the improvement of soil physical conditions compared to the soil scarification system, also provoking a better infiltration of the soil. The effects of consorting can be prolonged while the effects of scarification only last for a year [55].

The addition of different organic residues together with different sugar cane managements caused an increase effect on the weighted average diameter of the soil aggregates in humid way [37]. They also observed that there was a correlation between the total organic carbon content of the soil and the percentage of stable aggregates with diameter greater than 2.0 mm in water, proving the importance of O.M. in soil physics.

The organic matter presented good results in a study carried out by Souza [56], who tested the effect of the systems of harvesting of sugarcane under burned or raw cane and found that the bedding

damaged the physical characteristics of the soil once which is removed from the surface, while in the system of raw cane with incorporated straw, in addition to higher values of stem production, there were also improvements in the soil as increase in macroporosity and water retention, more stable aggregates and a lower density of soils sampled.

2.4.3 Macrofauna

Silva *et al.* [57] showed that the invertebrate macrofauna of the soil was re-stabilized with the use of different crops such as mucuna, sorghum and millet residues under cover of pre-cultivation of cassava under no-tillage system. Such information is important because, since macrofauna assists in the stabilization and formation of aggregates, this prevents the organic matter from being rapidly degraded, which will reduce the stability of soil aggregates, rate of infiltration and retention of water in the soil.

The humidification characteristic of the organic matter is fundamental in the microaggregation processes, helping to the stability of them, acting together with the clay particles, Fe and Al oxides and with polyvalent cations of tropical and subtropical soils of Brazil. The macroaggregates of small size are stabilized by polysaccharides synthesized by bacteria and fungi. Macroaggregates with larger diameter are stabilized by other organic agents through a network that interweaves and stabilizes them, this is usually produced by fungal hyphae and fine roots [58].

The greatest activity of the soil biota is found in the surface horizons of the soil, with the first horizon being the most suitable for the cycling of nutrients and organic matter, its thickness has been identified as one of the best indicators of soil quality [59].

3. CONCLUSION

All managements that favor the improvement of soil physical conditions are recommended to optimize the processes of infiltration, retention and availability of water for the plants, recharge of the aquifers and maintenance of the fountains, in sufficient quantity and quality to ensure that the crops develop satisfactorily under various climatic conditions. However, the managements that use increments of organic matter allied to the smallest soil movement, presented as more efficient alternatives for these processes.

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