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How the Soil Resistance to Penetration Affects the Development of Agricultural Crops?

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The SPR is an indicator that describes the physical strength that the soil exerts on the root that tries to move through along the profile, being directly influenced by bulk density, porosity and, mainly, by soil moisture at the time of evaluation. The soil resistance to penetration has been one of the most used parameters in the evaluation of its physical structure. The compaction is one of the problems of greatest relevance in different regions of Brazil, characterized by the alteration of the physical properties of the soil, being the direct result of a particular practice of management in which the soil is subjected to a pressure above its capacity to support, by encouraging the reduction of volume and resulting in increased resistance to penetration and in soil bulk density, impairing root growth and reducing the development of aerial part of the plants. To assist the management of these compacted areas, research has attempted to determine critical levels of soil physical properties for the proper development of the plants, using mainly the SPR. The penetrometer stands as the instrument capable of measuring and provide a good estimate of the soil penetration resistance by becoming an alternative to the survey information with respect to the soil physical quality in order to determine the appropriate management in the context of a sustainable conservation agriculture. In

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an attempt to resolve the problems arising from the increase of SPR, various alternatives may be used, such as the use of chisel plows and rippers, cover crop, especially species of aggressive root systems with high phytomass production among other management techniques. Knowing the critical limits of RMP is necessary in order to create a soil management plan that is viable and more sustainable for the agricultural system and that favors the growth of plants for productivity gains.

Keywords: Compaction; bulk density; critical limits; soil compaction; root system.

1. INTRODUCTION

The different systems of soil use and management aim to create conditions favorable to the development and yield of crops [1]. However, management practices that only aim to maximize production may cause changes in relation to morphological and physical properties of the soil - as in the arrangement of particles, resulting in variation of soil penetration resistance (SPR) [2].

The SPR is an indicator that describes the physical strength that the soil exerts on the root that tries to move through along the profile, being directly influenced by bulk density, porosity and, mainly, by soil moisture at the time of evaluation [3]. In a condition of low soil moisture, the water is in a higher state of tension in the pores of the soil. In addition to this tension, the cohesive and adhesion forces already existing between the soil solids are added, resulting in greater resistance to deformation or root penetration in a low soil moisture condition. As a result of the increase in water content, the influence of cohesion forces on soil particles and internal friction decreases, causing a decrease in SPR [4]

The SPR is one of the physical attributes of the soil directly influences the growth and development of the roots of the plants. This parameter usually has a greater relationship with the productivity of crops than with other physical attributes, such as the soil bulk density and total porosity [5].

The soil resistance to penetration is characterized as one of the main indicators for the diagnosis and evaluation of soil compaction. The compaction is currently one of the problems of greatest relevance in different regions of Brazil. It is characterized by the alteration of soil physical properties (bulk density, porosity), that affect the infiltration of water from the rains, absorption of nutrients and gaseous exchanges, it is the result of inadequate management in which the soil is subjected to a pressure which exceeds its resilience, promoting the reduction of soil volume and resulting in increased resistance to penetration and the bulk density of the soil [6,7].

The compaction affect root growth, affecting the development of the plant [8]. [9] and [10] reported that different management practices, such as conventional tillage (using plowing and harrowing) can result in compaction of the deep layers of soil, changing the infiltration and runoff waters, which may cause soil erosion. Moreover, in this case the porosity and permeability are reduced and the resistance is increased, in function of loads or pressures applied. Also, there are losses of nitrogen by denitrification, higher fuel consumption of machines in the preparation of the soil, and reduction in the macroporosity, the retained water in the micropores remains under high tensions, presenting low availability to the plants [11, 12, 13, 14, 15].

The soil penetration resistance has been frequently used to be an attribute directly related to the growth of plants and easy and rapid determination. According to [16], the electronic penetrometer and impact stand as apparatus capable of measuring and provide a good estimate of resistance to penetration by identifying what depth they are the layers with greater resistance. It becomes an alternative for the collection of information regarding the physical quality of the soil in order to determine the appropriate management in the field of a sustainable conservationist agriculture.

To assist the management of these compacted areas, research has attempted to determine critical levels of soil physical properties for the proper development of the plants, using mainly the SPR [17,18,19]. The value of 2.0 MPa, proposed by Taylor et al. [17], there are times is adopted as limiting reference to the development of roots, but many studies show different results, which suggests the need for further studies in this area. Several authors have stated that the SPR values above 2.0 MPa are considered to be harmful to the development of roots [20,21,22].

The critical levels of soil resistance to penetration for the growth of plants vary with the type of soil and with the cultivated species.

In this sense, it is necessary to know more about this subject, in order to obtain more information that can help the scientific community, research and extension companies and especially rural producers on the extent to which this property can compromise and / or limit the development of crops so that more efficient and sustainable techniques of land use and management can be used, which will minimize the adverse effects of compaction and favor the improvement of the soil-plant system, contributing to the increase of the productivity of agricultural crops. The objective of this study was to discuss the effect of soil resistance on root penetration in crop development and what alternatives could be used to reduce the direct impacts caused by soil compaction.

2. LITERATURE REVIEW

2.1 What is Soil Penetration Resistance (SPR)?

According to Pedrotti et al. [23], the soil penetration resistance is the effort of reaction that the soil provides the pressure of penetration of something or a rod of the penetrometer with conical tip to the ground, whose area is known. Simulates the reaction of the soil to root elongation. In the International System of Units, the unit of measurement is given in MPa (Mega Pascal).

The critical levels of SPR, soil for the growth of the roots of plants is dependent on the cultivated species [24], texture, bulk density and, especially, the soil moisture [21], requiring careful in their use and interpretation [25].

The most compacted soils present higher SPR [26] due to the greater proximity between the particles, which confers consequently, lower index of pallets and higher densities of soil, as well as affecting the processes of aeration, conductivity of air, water and heat, infiltration and redistribution of water, in addition to the chemical and biological processes [27]. The soil compaction determines, in some way, the relationship between air, water and temperature, and these influence the germination, sprouting and the emergence of the plants, root growth, and practically all phases of its development [28].

The SPR is an attribute of the soil sensitive and efficient in identifying the structural changes of the soils [29] moreover, this attribute allows us to infer the greater or lesser ease of root penetration [30].

2.2 Forms of Evaluation of the SPR

The identification of the soil compaction is a necessary procedure to evaluate their physical quality [31]. The compaction involves the relationship between the different attributes of the soil, and its diagnosis is performed by specific methods of high reliability, such as bulk density and porosity of the soil [32]. However, these determinations have complexity in their implementation, in addition to being expensive and require highly skilled labor and time for its determination [33].

The use of practical methods, such as the soil resistance to penetration, it presents itself as a quantitative technique widely used, due to the ease and speed of determination, as well as the possibility of carrying out a large number of samples for obtaining reliable data [27,30].

The soil resistance to penetration is determined by means of penetrometers, which indicate the resistance exerted by the soil to the penetration of a conical tip, simulating the resistance that the soil gives the root penetration [34,35,36,37]. Measuring the resistance of the soil is not so simple, being a property highly variable, since the soil can both decrease and increase its resistance to deformation [38].

The penetrometers more used are classified according to the principle of penetration [39], from the simplest, such as the impact penetrometer, which measure the SPR by indirect calculations, even the most practical in the collection and storage of data, such as the electronic penetrometers [40].

However, the variety of penetrometers can bring differences with relation to the number of data obtained, being influenced mainly by area and projection of the end piece, as well as by the speed of penetration [35].

Studies have demonstrated the existence of variation in the information of the equipment, depending on the characteristics of the same. Authors such as [39], found a significant difference of SPR between penetrometers electronics and impact, highlighting that the equipment presented impact reliability of 91% with the bulk density, being superior to the electronic penetrometer (42%) in relation to the same variable. Regardless of the mode of operation, it is important that the determination of the SPR is done accurately and, preferably, that there are reliability and exactness of its results, aiming to optimize the interpretation of data and the management to be adopted [41].

According to Lima et al. [31], although these penetrometers present distinct operating principles, both have the same purpose. In this way, it becomes necessary to know their inherent characteristics and the behavior and performance of these equipment in the evaluation of the SPR, evaluating its relationship with the attributes of the soil physical quality.

Its assessment, together with the determination of bulk density, or the opening of trenches for observations of root growth, it is crucial to better grounding of the results of resistance to penetration [38]. Despite the well-established functional relationship between the SPR and the growth of roots, the values of the SPR measured by use of soil compaction may be 2.6 to 7.5 times higher than the pressure actually exercised by the roots of the plants), due to the unidirectional action of equipment [42] , but even so, this shoe is still the most indicated for evaluation of this property, whose functioning approaching the real behavior of the root system of the plant in the soil.

With the use of the soil, it is possible to identify in the soil profile barriers that impeded the root growth of plants and this finding can assist in reaching a decision which operation of soil preparation will serve to break this layer [43].

2.3 Dry Soil *versus* Compacted Soil

Soil SPR is one of the main indicators of soil compaction status in the Direct Planting System (DPS), but it is strongly influenced by moisture. The dependence of SPR on soil moisture can lead to errors in the diagnosis of soil compaction, that is, under or overestimates it. This may result in the adoption of inappropriate soil management strategies, leading to increased production costs and reduced production performance of several crops component of the grain production system [44]. Thus, the dry soil has a higher resistance to penetration, but it does not mean that it is compacted, and may be only the momentary situation in which it is in the tenacious consistency, that is, the maximum cohesion between the particles.

In this way the Embrapa soybean, in partnership with other institutions, development mathematical models for the correction of the SPR for a reference moisture value, which are valid for clay soils managed under SPD, these being simple models, using as input variables only SPR and soil moisture in gravimetric basis, which makes the methodology of great practical applicability [44].

2.4 Resistance to Penetration in Accordance with the Texture and Water Content in the Soil

The management of the area is an important factor contributing to the worsening or not of the processes of compaction, the soil may have a higher propensity to increase the SPR by their training process pedogênico, related mainly to the size and arrangement of their particles [45]. The physical properties of the soil presents different susceptibility to compaction, for example, the texture influences the behavior of the soil when suffers external pressures as trades of machinery or erosion processes, since the same interferes with the friction and connection type of soil particles [46].

In a study aiming to evaluate the effect of different textures in the resistance to penetration, [47] evaluated 4 classes of soils with different contents of sand, silt and clay. The authors concluded that the textural class of the soil was significantly influential in the results of penetration resistance, and, the more clayey soils presented higher values of soil resistance to penetration than the most sandy soils.

Therefore, soils with high content of sand consider critical values of SPR between 6.0 and 7.0 MPa, while those with high clay contents have restrictive values around 2.5 MPa [48]. Thus demonstrating the importance of the processes of soil formation and texture to determine the greater or lesser propensity of the processes of soil compaction. According to Silveira et al. [30] when there is a predominance of the sand fraction in the soil layers results in rapid permeability and the consequent decrease in water content. And the soils with higher clay content have in general better distribution of micro and macropores, soon greater structuring, thus allowing greater water retention capacity.

The increases in the penetration resistance values are related to the dependence of soil water content, as these two factors are inversely proportional, i.e., the higher the water content of the lower resistance to penetration due to factors of accession and cohesion of the soil, [47,30,49].

When the soil is dry or with low water content of the particles are more forthcoming and difficult to be separated by external forces [30]. Already with the increase in the water content, this has acted as a lubricant between the particles of soil, decreasing the activity of the cohesion forces between the particles of soil, allowing the slip and the packaging of particles when it is subjected to some type of pressure, thus experiencing the reduction of soil penetration resistance [47,50].

This fact was confirmed by [51], who worked with different amounts of straw and manures of this material in Direct Planting System (DPS). The characters determined in this study were the penetration resistance (MPa) and gravimetric moisture (g g-1) which were evaluated in the layers 0.0-0.1; 0.1-0.2 and 0.2-0.3 m on the 1st, 6th and 8th days after the tractor has passed. In this sense, Fig. 1 shows the correlation between resistance to penetration and soil moisture in the treatments, one day after the tractor moved in the plots, at which point the soil moisture was close to the field capacity.

Surface straw significantly modified soil moisture values over time, especially in the 0.0-0.2 m layer, the effect of treatments on soil compaction may have been obscured because there is a negative correlation (r =-0.5758) between SPR and soil moisture attributes. Thus, if the straw helps to maintain soil moisture, it is expected that in the straw treatments, whose moisture is higher, the SPR values are smaller, since these properties are inversely proportional (Fig. 3).

According to Ferreira et al. [52], the vegetal cover of the soil reduces the direct incidence of the solar rays, contributing for the decrease of the temperature of the soil, and consequently of the evaporation, thus promoting the increase of water in the soil and the development of the cultures. In addition, the cultural residues left on the soil surface have a direct and effective action in the reduction of water erosion, as it promotes the dissipation of the kinetic energy of the rain droplets, reducing soil disintegration and surface sealing, favoring the increase of infiltration of water.

The absence or minimum soil rotation in the DPS provides higher water content than traditional cropping systems, due to the maintenance of cultural residues, which reduce evaporation rates and maintain a smoother soil temperature [53].

2.5 Main Consequences of SPR High for the Plants

In an arable soil in addition to care with the inputs to be applied, it became essential to the care with the physical attributes, such as porosity, aggregation, bulk density and resistance to penetration, since these attributes will influence the development of the plant, and consequently in production.

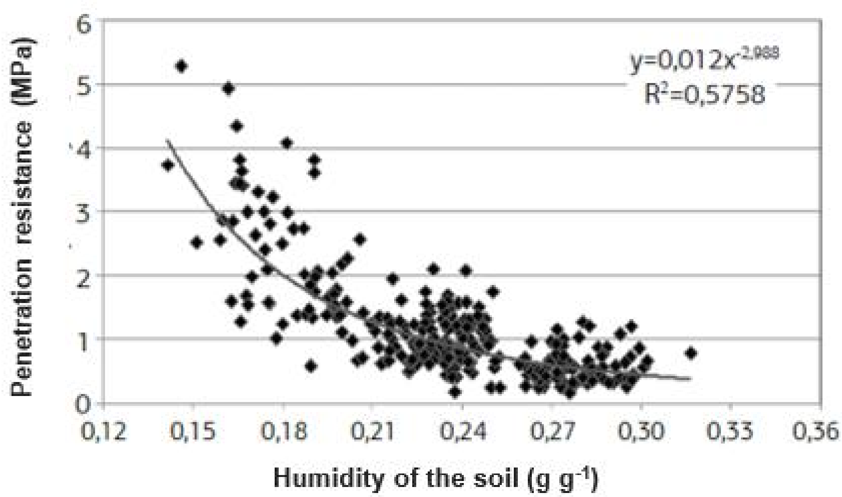

Fig. 1. Correlation between resistance and soil moisture in the layer 0.0-0.3 m [51]

A compacted soil hinders root growth and subsequent development of the shoots as a result of decreased absorption of water and nutrients essential for the growth and development of these [50]. According to Girardello et al. [54], in the initial period of development of cultures, which comprises the emergency phase and establishment of plants, crops are extremely susceptible to compacted layers, since the establishment of the roots and the development of aerial part are related to the occurrence or not of physical restrictions on the ground.

Table 1 shows the critical values of soil resistance classes at the penetration and degree of root growth restriction adapted by Canarache [55]. These values were references for the understanding of the limitation of the vegetal development of areas in recovery. Although penetration resistance is affected by texture, bulk density and water content, [55] suggests that values above 2.5 MPa begin to restrict the full growth of plant roots (Table 1).

In view of this, it is noticeable that these values vary throughout the analyzed works, being this variation mainly dependent on factors such as the soil type and the agricultural culture worked, where in this way the development of more current studies that prove or update these are impreensible found by Canarache [55].

The values in this table approaches the established by Filho et al. [56] who studied the soil resistance to penetration, georeferenced , in areas under cultivation of sugar cane, to locate regions of the field with different levels of compaction associated with the values of SPR as can be observed in Fig. 2.

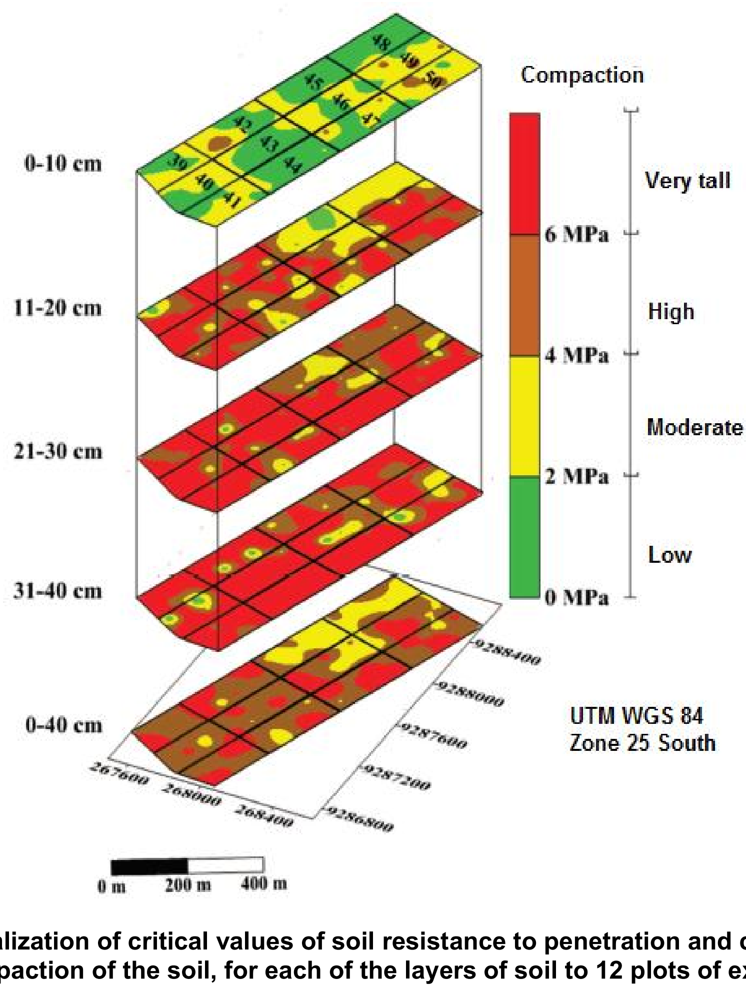

Fig. 2. Spatialization of critical values of soil resistance to penetration and classification of levels of compaction of the soil, for each of the layers of soil to 12 plots of experimental area [56]

Table 1. Limits of classes of soil resistance to penetration and degrees of limitation to growth of roots [55]

Classes	Limits (MPa)	Limiting the growth of roots
Too low	<1.1	Without limitation
Low	1.1-2.5	Little limitation
Media	2.6-5.0	Some limitations
High	5,1-10,0	Serious Limitations
Too High	10,1-15.0	Virtually no roots grow
Extremely High	>15.0	Roots do not grow

The analysis of the SPR per layer (Fig. 2) shows that the most superficial layer (0-10 cm) shows a predominance of low SPR (up to 2 MPa), followed by moderate (from 2 to 4 MPa). As you analyze the deeper layers, it is observed that higher intensities of compaction pass to predominate, as moderate and very high (from 6 MPa), the layer of 11 to 20 cm high and very high (4 to 6 MPa), 21 to 30 cm, and very high, 31 to 40 cm [56].

The two-dimensional maps of isovalores allow you to view the spatial behavior of the values of soil resistance to penetration in different layers and in average terms, in addition to that the referênciamento of regions of interest allows your spot check. The importance of these maps lies in the possibility of hiring them to plan management actions located, as the variation in the depth of the soil along the area, according to the intensity of compaction in each region of the country, as was studied by Filho et al. [56].

The evaluation of soil penetration resistance has been a good indicator to check the condition of compactation that is, because it simulates the difficulty that the roots will grow and development [30,57,58]. As the resistance to penetration of the soil is a dependent variable of numerous factors such as water content, texture and structure of the soil, it becomes difficult to obtain critical values the plants [59]. Silveira et al. [30] reported in their study that values of SPR have been considered limiting factors for the majority of plants when they are between 2 and 2.5 MPa. However, [26] In a study carried out on a dystrophic Red Latosol in consolidated SPR found average values of SPR ranging between 2.90 and 4.28 MPa, at depths of 0 to 30 cm. These values are considered restrictive to most crops, although in this study showed no restriction on the productivity of soybean crop, being tied primarily to the fact that there was no water restriction.

Several studies have been conducted showing the changes in the development of agricultural crops with the increase of the SPR. [60] working with the culture of maize (*Zea mays*) subjected to different management systems, verified the effect that these managements and compaction provided to the root system of culture, as can be observed in Fig. 3.

The system minimum no-tillage in compacted soil (CMc-picture c) presented higher soil density (1,63 Mg m^{-1}) and higher SPR (2,30 MPa) in the 0.25-0.35 m layer. Thus, through the Fig. 3, it is possible to observe the root distribution of maize in the soil profile, where in this treatment with compacted soil, root system growth was directly compromised, reaching only 0.15 m depth [60]. In this sense, the functions of the roots can be compromised, since the soil presents less aeration and availability of water and nutrient, which can directly interfere in the growth and root development.

It is known that the physical quality of soils is a paramount factor to promote the proper growth and development of plants, since it determines the ability of the roots to development and exploit the soils to absorb water and nutrients. For better elongation of the roots, it is necessary to a physical environment in the soil porous space enough for movement of water and gases and which, when subjected to tests of SPR, does not reach values impediments to its development.

Sinnett et al. [61] reported that a soil with a cone strength greater than 3 MPa caused a major impediment to root penetration of four tree species (Japanese larch, Italian alder, birch and Corsican pine) on the sandy-loam soils as shown in Fig. 4; almost all the roots (90.7%) were present in the soil with a class of resistance to the cone smaller than 3 MPa. All species had between 63 and 74% of their roots in soils with penetration resistance values lower than 2 MPa and between 84 and 96% in soils with less than 3 MPa.

The data presented here show that tree root numbers are significantly reduced as the resistance to penetration increases. It also suggests that the development of tree roots is significantly impeded in values of resistance to penetration between 2 and 3 MPa.

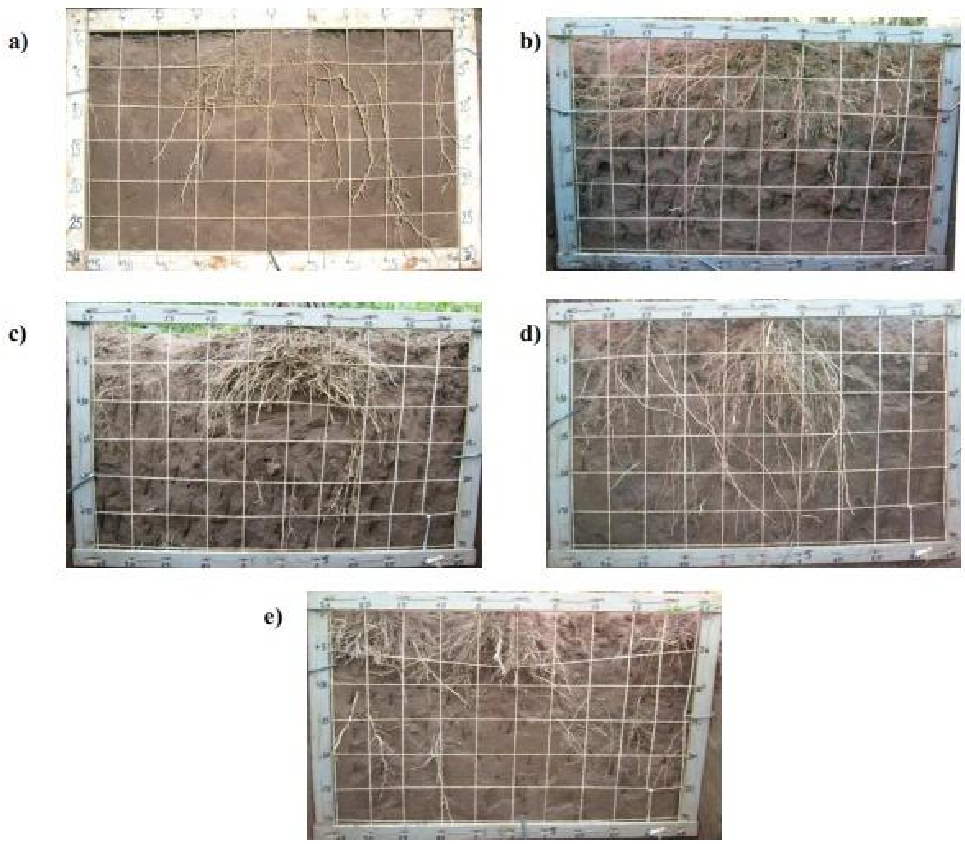

Fig. 3. Distribution of the root system of maize plants under: a) direct seeding (SD) b) direct seeding with 4 passed (SDc4) c) direct seeding with 8 passed (SDc8) d) minimum tillage (CM) and) Minimum Cultivation in compacted soil (CMc) [60]

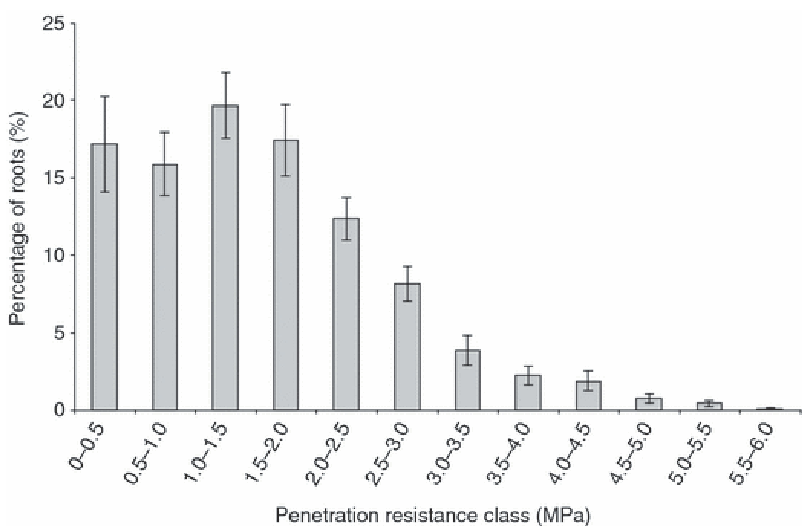

Fig. 4. Mean percentage of roots in each penetration resistance class using the penetrometer [61]

Another study that demonstrates the effect of increasing the SPR at root system of the plants was development by [19] that evaluated different doses and forms of application of phosphorus fertilization and the effect of the soil compaction by the traffic of machines in physical attributes and in the root system of soybean and maize in the conditions of the Chapada dos Parecis, Mato Grosso/Brazil.

The traffic of tractor changed the area of the root system of soybeans, as well as the distribution in the soil profile (Fig. 5). In PT8 (bulk density = 1.30 kg dm-3 and SPR of 0.80 MPa), there was a 23% reduction of root area in the 0.00-0.05 m layer compared to PT0 (bulk density = 1.09 kg dm-3 and RSP = 0.35 MPa).The compaction increased the diameter of the roots of soybean, being 122.59% higher in the system PT8, in relation to PT0. The analysis of the soil profile at the time of the opening of the trench, it was possible to observe deformation of the radicular system with characteristic thickening of the secondary roots to the point of not being able to identify the main root, changing significantly the average diameter. Probably, the mechanical impediment caused by the increase in compaction affected the root development because of the reduction of the meristematic cell division, making the roots less spiky and, consequently, causing greater thickening of these, which in turn ends enovelando and focusing on a specific part of the soil profile, thus compromising their growth and the use of its maximum potential for exploitation and absorption [19].

Through the results of the different papers presented in the present review, it was possible to verify that the root systemic of the plant species was seriously compromised as the SPR increased along the soil profile, preventing the roots from developing in depth, not allowing the exploitation of water and nutrients that are the basis for the development and sustainability of any plant species, and can influence the production and productivity of crops.

Besides the impairment of the root system of the plants, the increase of the SPR can influence directly on the productivity of agricultural crops. [62] evaluated the effects of the soil compaction, provided by the traffic of tractors, and the variation of its water content on certain physical properties of an Oxisol of loamy texture and associate them to the root system and the productivity of maize, established the linear regression equation between the SPR and grain yield of corn crop in what is presented in Fig. 5.

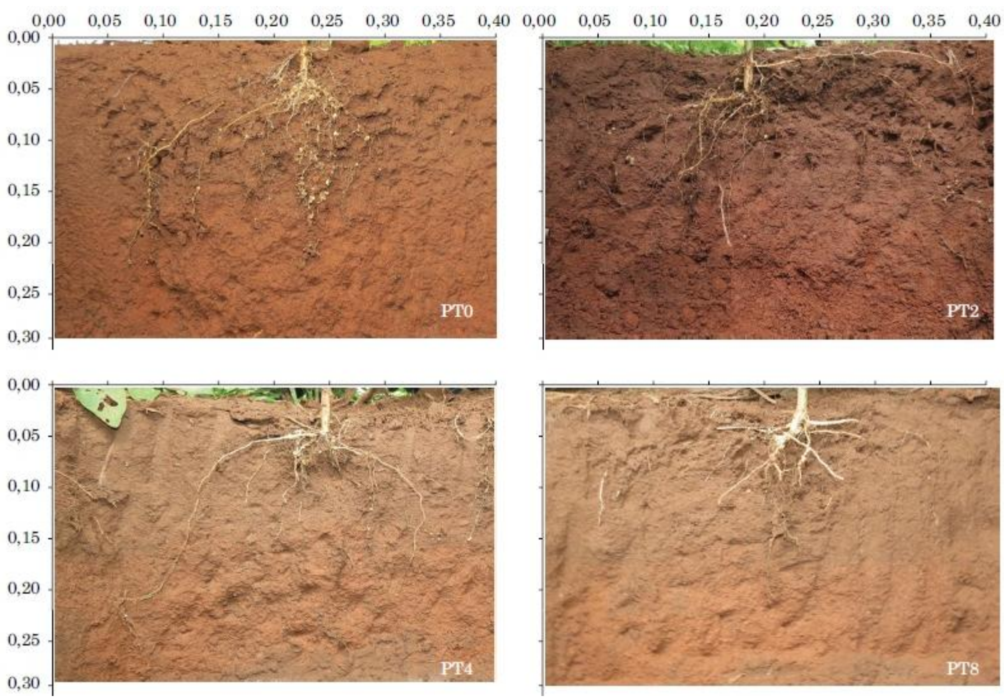

Fig. 5. Distribution of soybean roots of up to 0.30 m of soil depth, due to zero (PT0), two (PT2), four (PT4) and eight (PT8) passed from tractor [19]

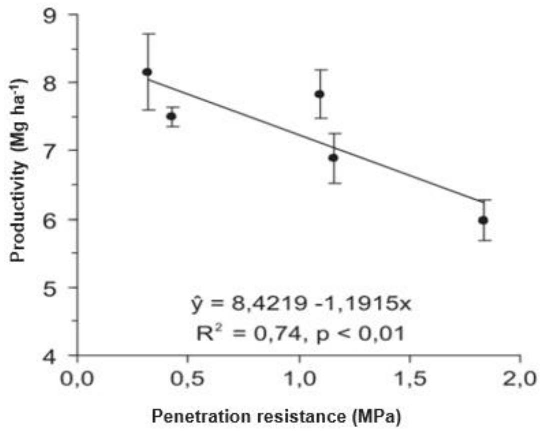

Fig. 6. Maize productivity as a variable of penetration resistance in a eutrophic Red Latosol [62]

It is observed that with the increase of the SPR, since the treatment T0 (0.32 MPa) until the T4 (1.83 MPa), there was a reduction of 27% in the productivity of corn. Therefore, verifies that the increase of the soil compaction resulted in changes in the root system, causing reduced productivity [62].

These values are close to those found by [63], in which verified that the increase of the values of SPR, from 1.53 MPa, linearly reduced productivity of maize crop in 15%; 20% and 22%, when compared the treatments analyzed. However, [64], in the Argissolo Vermelho-Amarelo arênico (sandy loam Typic Paleudalf), could observe that, from the SPR of 0.91 MPa, there was a reduction in grain yield of maize, and [62], from even smaller value, i.e., 0.87 MPa. Therefore, in soils of the sandy texture, the critical level of SPR that affects the productivity of grains is higher than in clayey soil [65,66].

High levels of productivity and increased profitability depend fundamentally on the productive capacity of soils, which in turn is dependent on its use and management. In this sense, the association of more sustainable farming practices, which provide improvements in chemical and physical quality of soil can contribute to an environment more conducive to root growth and consequently with higher yields [25].

Thus, the search for values that indicate restrictions on growth of roots and decreased productivity becomes essential for the success of the agricultural holding [67] and, in accordance with [68] and [64], the soil penetration resistance can restrict root development of corn, and several studies are development with the Intuited to determine critical limits to the development of culture.

The presence of more dense layers are directly associated with the restriction on the ground, but the time in which the plants are subjected to this kind of stress is what determines the presence of damaged or not cultures [67]. It is important to highlight that the presence of hydric stress coupled to compaction has effects that are both in the presence of water deficit and excess water, because with the increase of the SPR occurs less infiltration and accumulation of water in the soil, causing the lack of water, already in the presence of waterlogging, occurs the decrease of gases like oxygen [68,69].

This stress caused in plants by the presence of compacted layers can contribute to the incidence of many pathogens, and these may hamper the development of the plants and consequently reduce the productivity per area. According to [70], the diseases favored by the compactioin in the soybean are: white mold (*Sclerotinia sclerotiorum*), death *by Fusarium* (*Fusarium* spp.), gray rot of the stem (*Macrophomina phaseolina*), *damping* and sclerotium wilt (*Sclerotium rolfsii*).

2.6 What can be done to Minimize the Increase of the SPR

2.6.1 Management, use of conventional tillage and no-tillage and crop-livestock integration system

In an attempt to resolve the problems arising from the increase of the SPR soil, a possibility has been the use of chisel plows and subsoiler (it is important to remember that the scarification and subsoiling does not eliminate the causes of compaction, only they soften the symptoms). Cover crop, sobretudo espécies de sistemas radiculares agressivos, com elevada produção de fitomassa (como forage radish), também são uma possibilidade para amenizar os sintomas do aumento da SPR [71].

The benefits of cover crops are many, such as the protection of the soil surface by the presence of vegetable waste, training of biopores since, the roots of these species when decomposed leaves channels that provide increased water movement and the diffusion of gases [72], as well as to constitute in ways by means of which the roots of cultures, can grow and increase the organic matter content of the soil, which decreased the compaction of the same.

According to Debiasi et al. [73], the use of cover crops in winter is a viable alternative to mitigate the effects of the soil compaction in areas under DPS, considering the development and productivity of crops of maize and soybean, in comparison to scarification and the use greater depths of furrowing shank.

Among the species that can be used in the crop rotation system, the pigeon pea, the crotalarias, black oat, forage radish, the consortium oat + forage radish, pearl millet and tropical forages, as the *brachiarias*. The use of machines lighter and with a larger contact area turned-soil (Wider wheels, duals), traveling only when the soil is dry, friable or more help in the prevention of compaction [74].

Soil management strategies (vegetative practices, and soil mechanical) to improve or recover the soil structure, highlighting-if the type of coverage on the ground and incorporation of organic matter, allow the increase in porosity and reduction of bulk density and SPR, which results in direct benefits to the soil, improving their physical properties [75].

Another possibility is the use of the Crop-Livestock Integration System (CLIS) which aims at the sustainability and diversification of production in an area being in rotation, consortium or succession of crops, perennial or annual pastures, for animal feed and crops intended for production of grains [76]. It advocates the use and maximum valorization of natural resources and processes that occur among the components of the system, in addition to economic and social viability [77]. However, the management of this system is fundamental to its quality, because if there is trampling and excessive removal of the aerial part, soil compaction will occur, which can decrease the rate of infiltration, increase erosion and reduce plant growth [78].

It is important to emphasize that this compaction depends mainly on the type of soil, its moisture content of animal stocking rate and grazing of forage mass [79], and also of the forage species used in the system [80]. Thus the CLIS, at moderate intensities of grazing, is considered one of the most efficient management systems to improve the soil structure by maintaining the levels of organic matter at appropriate levels and also by providing higher quality and sustainability of agricultural soils [81].

To Moreira et al. [82], in the area of CLIS, the physical characteristics of the soil will vary according to the type of harvester, deployment time of pasture, animal stocking, soil moisture during the cattle trampling and soil texture.

According to Flores et al. [83], in pasture of oats intercropped with ryegrass, the presence of cattle caused a small increase in the bulk density of the soil in the surface layer, compared to the area not grazed, but this did not result in reduction of yield of soybean sown in succession, proving that the cattle trampling did not cause compaction on harmful levels.

The understanding of the interaction between the factors is fundamental for guiding the anthropic activities that aim to use more rational use of the ecosystem, in particular those associated with the management of soils. In CLIS, it seeks to reconcile the best response of animal per unit of area, with high grain yield in summer, evaluating the stocking practiced, the doses of fertilization, the influence of grazing and the time of withdrawal of grazing animals [84].

3. CONCLUSION

By means of this review, you can realize the great limitation that the SPR exercises in agricultural areas, being a factor that directly affects the root development and other phytotechnical aspects, which may compromise the production of crops. Therefore, knowing the critical limits of SPR as well as the factors that can influence the increase of this property becomes necessary so that you can create a plan for the management of soil that is viable and more sustainable for the agricultural system, and that favors the growth of plants, in order to maximize the production and thus obtain gains in productivity of crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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