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SOIL RESISTANCE TO PENETRATION IN INTEGRATED CROP-LIVESTOCK WITH GRAZING INTENSITIES AND FERTILIZATION

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ABSTRACT - Soil compaction periodic monitoring through soil penetration resistance (PR) has been a rapid, easy, and economic way to evaluate the different management systems on soil physical attributes effect. The aim was to evaluate the grazing intensities and nitrogen fertilization effect in two winter/summer seasons (black oat/corn/black oat/soybean) on soil PR in an integrated crop-livestock system. The experimental design was in randomized blocks, in a factorial 2×3 [2 black oat pasture residual heights (15 and 7 cm), under rotational grazing × 3 nitrogen rates applied to pasture (0, 75 and 150 kg N ha^{-1})], with 4 repetitions. Soil PR was measured using an electronic penetrograph to an 80 cm depth. Soil samples were collected to determine gravimetric moisture. In the first year, 75 kg N ha^{-1} resulted in the highest depth compaction while intensive grazing (7 cm) resulted in the highest PR. In the second year, plots without N resulted in lower PR levels, mainly in the superficial layers. However, the rate of 150 kg N ha^{-1} presented greater compaction in the 15-20 cm layer after grazing. The high moisture levels in depth reduced PR in all evaluated periods, highlighting the close relationship between both variables. General grazing heights did not affect PR, but the use of systems that increase residues production, as moderate grazing and nitrogen fertilization might be an alternative to mitigate the soil compaction in surface layers effects.
Keywords: Black oat, rotational grazing, soil compaction, integrated systems.

RESISTÊNCIA DO SOLO À PENETRAÇÃO EM INTEGRAÇÃO LAVOURA-PECUÁRIA COM INTENSIDADES DE PASTEJO E ADUBAÇÃO

RESUMO - O monitoramento periódico da compactação do solo por meio da resistência do solo à penetração (RP) tem sido uma forma rápida, prática e econômica de avaliar o efeito de sistemas de manejo nos atributos físicos do solo. O objetivo foi avaliar o efeito de intensidades de pastejo e adubação nitrogenada em duas safras de inverno/verão (aveia/milho/aveia/soja), na RP em um sistema de integração lavoura-pecuária. O delineamento foi blocos ao acaso, em fatorial 2×3 [2 alturas residuais da pastagem de aveia preta (15 e 7 cm), sob pastejo rotacional × 3 doses de nitrogênio aplicadas na pastagem (0, 75 e 150 kg N ha^{-1})], contendo 4 repetições. A RP foi mensurada utilizando um penetrógrafo eletrônico, até 80 cm de profundidade. Foram coletadas amostras para determinação da umidade gravimétrica. No primeiro ano, a dose 75 kg N ha^{-1} foi responsável pela maior compactação em profundidade enquanto o pastejo intensivo (7 cm) apresentou a maior RP. No segundo ano, a ausência da adubação nitrogenada resultou em menor RP, principalmente nas camadas superficiais. Contudo a dose 150 kg N ha^{-1} apresentou maior compactação na camada de 15-20 cm, após o pastejo. A maior umidade em profundidade reduziu RP em todos os períodos avaliados, destacando a relação estreita entre ambas as variáveis. De forma geral não houve efeito da altura de pastejo na RP, contudo o uso de um sistema que aumenta a produção de resíduos, como pastejo moderado e adubação nitrogenada, podem ser uma alternativa para mitigar os efeitos da compactação à longo prazo.
Palavras-chave: Aveia preta, pastejo rotativo, compactação do solo, sistemas integrados.

INTRODUCTION

The agricultural systems intensification during the last decades has been a promising alternative for farmers who seek to diversify their incomes in a safe and sustainable way, maximizing the resources available on the farm (BALBINOT JUNIOR et al., 2009; CARVALHO et al., 2018). In this sense, an expressive increase has been observed in the conversion of traditional agricultural areas, which were previously characterized by the conventional planting system, monoculture, or crop succession, to areas with conservationist bases, such as the no-tillage system (NTS), crop rotation, green manure, and more recently, the crop-livestock integration system (ICLS) (CARVALHO et al., 2014; COSTA et al., 2015).

The areas managed growth under the ICLS system, especially in the southern region of Brazil are responsible

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for the benefits this system can offer; increased grain productivity, pastures greater development and establishment, providing greater animal weight gain, income diversification, and contributing directly to reducing the pest’s incidence, diseases, and weeds (BALBINOT JUNIOR et al., 2009; PELISSARI et al., 2011; VILELA et al., 2011). In this system, the plant species diversity, associated with the nitrogen fertilizers addition, and the animal waste deposition provides a series of benefits to the physical, chemical and biological soil compartments, mainly through the nutrients cycling (SANTOS et al., 2011; COSTA et al., 2015; CARVALHO et al., 2018).

Despite the advantages, there are still questions about the possible impacts created by the animal’s presence in ICLS areas, mainly related to the soil’s physical degradation (CECAGNO et al., 2016). Collares et al. (2011) attributed the soil surface compaction to the higher animal load and lower residual grazing height. These works reinforce the idea that intensive grazing with high animal stocking rates is primarily responsible for soil physical degradation in ICLS systems. On the other hand, moderate grazing contributes to a greater addition of biomass (remaining residue), which plays a key role in maintaining soil carbon contents (POEPLAU et al., 2018), and consequently, soil structure and stability (SOUZA et al., 2010), which reduces soil susceptibility to compaction (CONTE et al., 2011). This demonstrates that when properly conducted, grazing may be an alternative to mitigate the effects of animal trampling by promoting soil aggregation through root effect (GOULD et al., 2016).

In farming systems, compaction is conditioned to stocking animal rates on the soil (PARENTE; MAIA, 2011); soil granulometry (CORREA; REICHARDT, 1995), grazing system, pasture management height, soil moisture (BENGOUGH et al., 2006), and the plant residues amount on the soil surface. In general, the animal trampling effects are more substantial in the surface layers, while compaction caused by machine traffic is generally observed at depth (DEBIASI; FRANCHINI, 2012).

Soil compaction is a limiting factor for agricultural production. The main consequences are related to the reduction of infiltration rates and the consequent increase in superficial runoff (EKWUE; HARRILAL, 2010), which makes the soil susceptible to erosive processes. In addition, soil compaction imposes limitations on root development, which directly affects the natural ability of roots to explore the soil profile, compromising nutrient uptake and restricting access to water (FRANZLUEBBERS et al., 2011).

Recent studies have reported improvement in physical and chemical soil attributes in ICLS systems (SANTOS et al., 2011; ANGHINONI et al., 2013), due to crop rotation, vegetation cover maintenance, adjustments in stocking rates and rotational grazing system. In addition to grazing intensity management, pasture fertilization can increase biomass production (CASSOL et al., 2011) and consequently soil organic matter (POEPLAU et al., 2018), promoting greater stability to soil aggregates. However, there is a lack of information about the effects of different grazing intensities and fertilization levels, especially related to nitrogen fertilizer, due to the interactions and changes that these factors can cause in the soil. Thus, this study aimed to evaluate the grazing intensities and nitrogen fertilization effects in two agricultural seasons (black oats/corn/black oats/soybean) on soil PR (resistance to penetration) in an ICLS system in southern Brazil.

MATERIAL AND METHODS

The research was conducted in Federal University of Santa Catarina (UFSC) experimental farm, located in the Curitibanos municipality - SC (27º16'25.55" S, 50º30'14.41" W, 1000 m elevation), during two agricultural seasons (2016 to 2018). The climate, according to the Köppen classification, is subtropical (ALVARES et al., 2013), with an average temperature of 12°C in the coldest month (July) and 21°C in the hottest month (January), with average annual precipitation of 1500 mm (WREGE et al., 2012).

The soil was classified as “Cambissolo Háplico Tb Distrofico”, with a clay content of 660 g kg^{-1} (based on the Brazilian classification) (SANTOS et al., 2018). The chemical characteristics of the soil in the 0-20 cm layer are described as: pH ($CaCl_2$) 4.6; 0.3 cmolc dm^{-3} of Al (KCl, 0 M); 7.9 cmolc dm^{-3} of H + Al; 2.4 cmolc dm^{-3} of Ca (KCl, 0 M); 2.0 cmolc dm^{-3} of Mg (KCl, 0 M); 0.1 cmolc dm^{-3} of K (Melich^{-1}); 3.8 mg dm^{-3} of P (Melich^{-1}); 30.4 g dm^{-3} of C.

No-tillage system has been practiced in the area since 2013, and in the previous period, the area was a pine reforestation area. After the pine harvest, the soil in the area was prepared with a plowing and cultivated with brachiaria and corn in the 2013/14 harvest, and brachiaria and soybeans in the 2014/15 harvest. In 2015, the area had begun to be managed in an ICLS system with the cultivation of triticale for winter grazing. In subsequent years, the crops were composed of the following crops: beans (2015/16), black oats (2016), corn (2016/17), black oats (2017), and soybeans (2017/18). The experimental design used was a randomized block design, in a 2 × 3 factorial scheme, containing 4 repetitions. The first factor consisted of the black oat pasture (15 and 7 cm) residual heights and the second factor was nitrogen doses applied in the black oat cover (0, 75 and 150 kg N ha^{-1}).

Details on plant conduction and management were described by Ribeiro et al. (2020). In May of each year, black oat cultivar IAPAR 61 was sown at a rate of 80 kg ha^{-1}, at 17 cm spacing between rows. The base fertilization was 300 kg ha^{-1} of the formula 0-18-18 (NPK), and the cover fertilization was performed during the tillering stage, using urea (45% N). Grazing was performed by calf heifers with a 300 kg average weight, allocated in plots with dimensions of 14 × 16 m (224 m^2). Grazing was conducted in a rotational system, with the first grazing cycle beginning 25 days after cover crop nitrogen fertilization, when the oat plants reached approximately 30 cm height. Each grazing cycle lasted 1-day average in treatments maintained under moderate grazing (15 cm residual) and 1.5 days under intensive grazing (7 cm residual), with 5 animals per plot. A new grazing cycle began when the plants reached 30 cm again. To identify the moments of animals' entry and exit in the plots, the average plant height was monitored with a "sward stick" ruler, at 40 random points per area unit.

Summer crops were sown on the residual straw of the oat crop, in NTS, performed 30 days after the area desiccation. In October 2016 hybrid corn 30F53YHR was grown at a spacing of 0.7 m among rows with a density of 85,000 seeds ha^{-1}. The base fertilization was 300 kg ha^{-1} of the 0-18-18 formulate. In October 2017, soybean cultivar NS6909 was grown at a spacing of 0.45 m among rows and a density of 355,000 seeds ha^{-1}, inoculated with *Bradyrhizobium* bacteria genus. The base fertilization was 300 kg ha^{-1} of the formulated 02-20-20. Pest and disease management were performed according to the technical recommendations for each crop.

The PR evaluations began at oat post-harvest (2016) and were conducted after the end of each crop, with the last evaluation at soybean post-harvest in 2018. To determine the PR evaluations, soil gravimetric moisture was monitored. The evaluations were avoided during prolonged drought or constant rainfall periods, to reduce errors associated with the environmental conditions. The sampling grid used in each plot was composed of regularly spaced 2 × 3 m points, georeferenced using a GPS receiver (model BHC Nava - F30). The grid of the area and its respective sampling points were distributed in 12 points in the plot, in each of the 24 blocks, totaling 288 sampled points. To determine gravimetric moisture, samples were collected at depths 0-5; 5-10; 10-15; 15-20; 20-30; 30-40; 40-60 and 60-80 cm, using a Dutch auger-type. After the collecting, soil samples were weighed to determine the wet mass and taken to a constant air circulation oven at 65 ºC until they reached constant mass. After one week, the samples were weighed again and the moisture content was calculated (Equation 1).

$$\mathrm{Gw} = \frac{\mathrm{Wm - Dm}}{\mathrm{Dm\ Bs}} \times 100\mathrm{g} \qquad \text{(Equation 1)}$$

Which:
Gw = gravimetric water content (%),
Wm = wet soil mass (g)
Dm = dry soil mass (g).

The soil PR was performed using an electronic penetrometer (model Eijkelkamp®), with 80 cm shaft, and integrated GPS. The readings were recorded in the equipment's memory base and processed in the Eijkelkamp® computer program, supplied by the equipment manufacturer. The resulted files were interpolated directly by the software and were exported in .txt format, with intervals fixed at 1 cm depth. The data set was rearranged in 5 cm intervals, respecting the layer where the samples for gravimetric moisture were collected (mainly 0-30 cm).

The soil PR data were submitted to the normality (Shapiro-Wilk) and homogeneity (O'Neill-Mathews) tests, followed by variance analysis (ANOVA) using the R statistical program, ExpDes.pt package (FERREIRA et al., 2013) in order to verify each treatment effects on soil compaction levels. The Tukey's test ($p<0.05$) was used for differences between the two grazing heights and nitrogen doses. The scatter plots results in the soil profile were made on Excel program.

RESULTS AND DISCUSSION

No interactions among grazing levels and nitrogen doses were observed for soil PR in any of the evaluations made. Still, the maximum values 2.4 MPa verified in the post-harvest of soybean are below 2.5 MPa, a value considered critical to the main annual crops and pastures development (IMHOFF et al., 2000). Even though, plant roots can develop under values close to or above this limit, under the argument that in no-till systems root growth is benefited by the continuous macropores presence, resulting from biological activity (mesofauna and roots). Furthermore, in environments with greater compaction, the presence of structures that allow the diffusion of oxygen, associated with ideal chemical and humidity conditions, what allows the roots to develop at points of least resistance, without restrictions to their growth, although they suffer deformations in their morphology (TAVARES FILHO et al., 2001).

After black oat grazing (2016) there was no significant nitrogen fertilization effect on soil PR in the first 55 cm depth (Figure 1A), but there was an effect at depth (60-65 and 70-80 cm) in the treatment with 75 kg N ha^{-1}. The PR in this treatment cannot be justified by the presence or absence of nitrogen, as the dose of 0 kg N ha^{-1} was similar to the dose of 150 kg N ha^{-1}. The higher PR in this first year of evaluation may be related to the high cohesion among depth aggregates, caused by the area preparation before the ICLS system installation, which was restricted to the layer of ±45 cm.

According to Cintra and Mielniczuk (1983), the smaller macropores number and the increase in soil density at depth caused by not disturbing the deeper layers may increase soil PR, and the roots' capacity to develop in these deeper layers depends on the cultivated species and the humidity and aeration conditions. Ribeiro et al. (2020) verified a root biomass increase in water deficit periods, where the availability of nitrogen compensated the lack of rainfall to root production, demonstrating that even in adverse conditions the roots develop at points of weakness in searching for water and nutrients.

For grazing heights, there was a significant effect in the 5-10 cm (1.61 MPa) and 30-45 cm layers (1.65 ± 1.70 MPa) (Figure 1B). The higher PR value on the surface can be attributed in the first moment to animal trampling, which was intensified by the low contribution of remaining residues on the soil surface. In addition, the lower soil cover rate and the gravimetric humidity below 32% (Figure 3A) intensified compaction and the penetrometer rod driving in the soil profile.

According to Collares et al. (2008), PR is directly related to soil moisture, and its values increase proportionally as soil water content decreases. Conte et al. (2011) concluded that the animal's presence in grazing areas might be the main contributing factor to the increase in PR after the end of the grazing cycle, mainly in the superficial layers, while the increase in PR in depth is attributed to lower soil organic matter contents, or to the eventual grazing with high moisture contents (BONINI et al., 2016). Despite the increase in PR in-depth, the layers' average values with higher PR were close to those verified by Spera et al. (2010), with 1.51 MPa and below 2.5 MPa, proposed by the literature as a limiting value for the growth of greater commercial interest crops (IMHOFF et al., 2000; MARCHÃO et al., 2007)

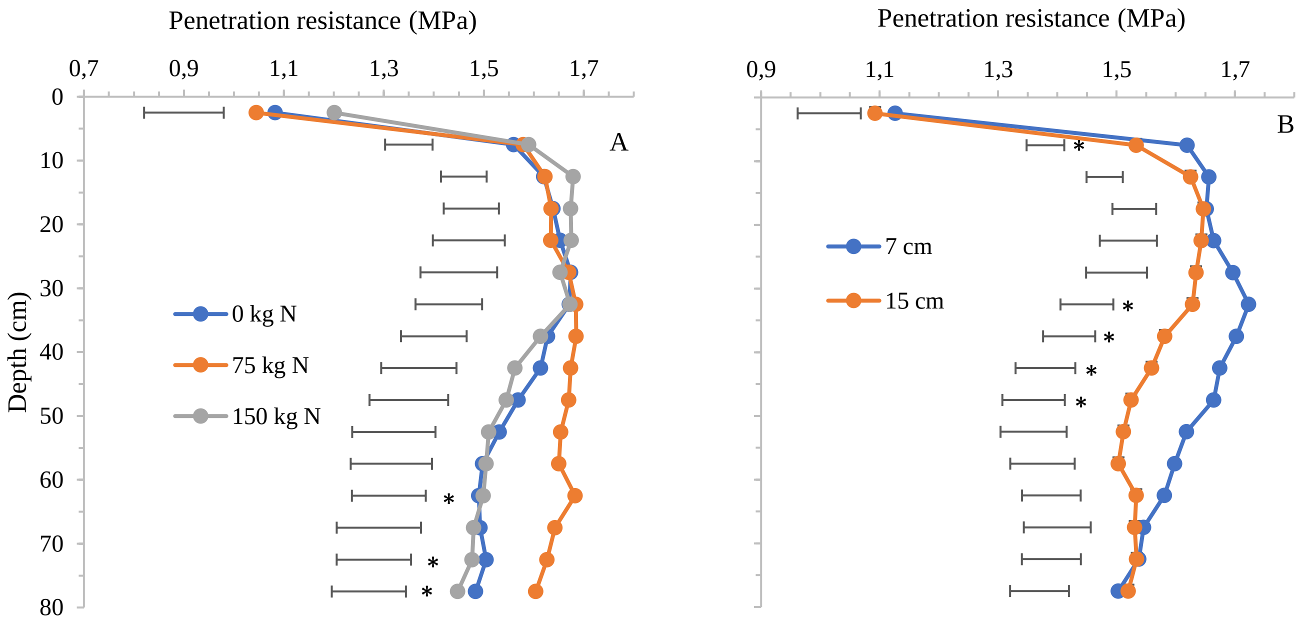

FIGURE 1 - Soil resistance to penetration in the post-grazing period of black oat (2016) under three nitrogen doses (A) (0, 75 and 150 kg N ha^{-1} applied in cover and two grazing heights (B) (7 and 15 cm). Horizontal bars indicate the minimum significant difference. *It represents the significant effect occurrence using Tukey test ($p<0.05$).

After corn harvest, nitrogen fertilizer rates did not influence surface PR (Figure 2A). However, the 150 kg N ha^{-1} dose reduced the PR in the 60-65 cm layer, from 1.45 MPa in the treatment with 75 kg N ha^{-1} to 1.39 MPa in the treatment with 150 kg N ha^{-1} rate. These PR values in depth are less limiting to corn root development, but compacted layers with soil PR around 1.4 MPa can hinder the root system development, especially in superficial (0-20 cm) and intermediate (20-40 cm) layers.

In soils with high cover crop residues addition (e.g., corn) and continuous macropores, the soil compaction status may be reduced (RASSE; SMUCKER, 1998). In addition, the greater nitrogen availability applied as a cover crop in corn, combined with the residual pasture effect and the moisture presence above 36% (Figure 3B), may have contributed to the corn roots' development in-depth, which induced a lower soil PR in these layers. A similar situation was verified by Qin et al. (2005), who have found a greater proportion of corn roots in-depth in searching for phosphorus, reaching up to 1.0 m depth.

The winter grazing heights did not affect the soil PR in the superficial layers after corn harvest, however, intensive grazing increased the PR in-depth (50-70 cm), varying from 1.53 to 1.59 MPa, while the treatments under moderate grazing varied from 1.40 to 1.45 MPa (Figure 2B). The highest PR values (1.65 MPa) were verified after corn cultivation and are below those considered limiting for its development, twice lower than the values found by Tavares Filho et al. (2001), who has evaluated the soil PR and the corn root system development in management systems, finding PR values >3.5 MPa.

Despite not compromising the productivity, higher PR values negatively affected maize root morphology and initial crop development, leading to long-term soil degradation. Bergamin et al. (2010) observed that in compacted soils, the corn root anatomy is highly impaired, and soil PR may be a damage degree significant evidence caused by soil compaction.

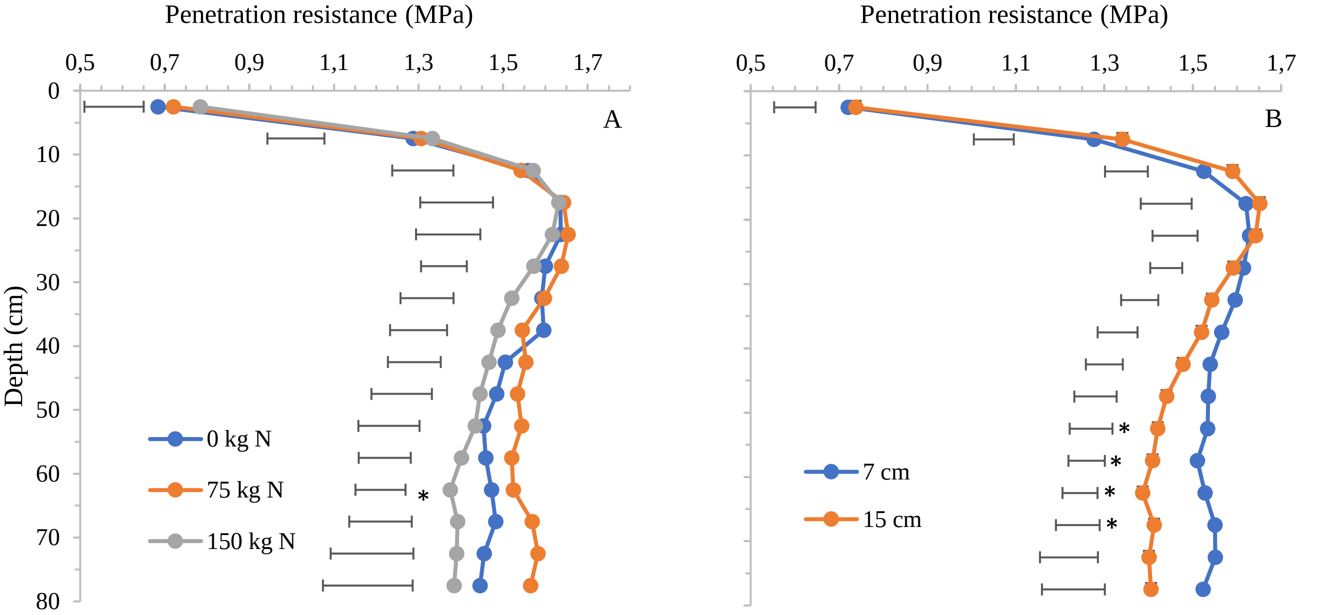

FIGURE 2 - Soil resistance to penetration, in the corn post-harvest period (2016/17), grown under black oat pasture, under three nitrogen doses (A) (0, 75 and 150 kg N ha^{-1}) applied in coverage and two grazing heights (A) (7 and 15 cm). Horizontal bars indicate the minimum significant difference. * It represents the significant effect occurrence using Tukey test ($p<0.05$).

These results show that the ICLS management system according to its principles, which include light or moderate grazing system maintenance, combined with adjustment in stocking rates and the rotational system adoption among pastures, allows crop production without jeopardizing physical and fertility conditions, being superior to systems managed only by a single component (BALBINOT JUNIOR et al., 2009). According to Nicoloso et al. (2006), corn yields can be compromised when there is a high frequency and pressure grazing.

In the second-year evaluation, after black oat grazing (2017), the treatment without nitrogen showed a lower PR, with 0.92 MPa in the 0-5 cm layer, compared to the treatments with the nitrogen fertilizer presence, in which PR was above 1.0 MPa (Figure 4A). On the other hand, the treatment with 150 kg N ha^{-1} showed higher PR in the 20-25 cm layer. The lower PR value without the nitrogen addition may be attributed to the short period of time that the animals remain in this location, considering that the fertilizer absence compromised the pasture's quality and quantity supply.

In general, a PR increase was observed in relation to the previous year (2016) post-grazing (Figure 1A), possibly due to the soil moisture variation in the profile. Considering that in the first year it was higher as the soil depth increased, while in the post-grazing (2017) the moisture was lower in the first 20 cm of the profile, showing no variation below 40 cm. The increase in PR from one crop to the subsequent one was also observed by Debiasi and Franchini (2012), who has found an increase from 1.72 to 3.48 MPa in an ICLS system under intensive grazing. Despite this, we found no grazing heights effect in the pasture second-year evaluation (Figure 4B).

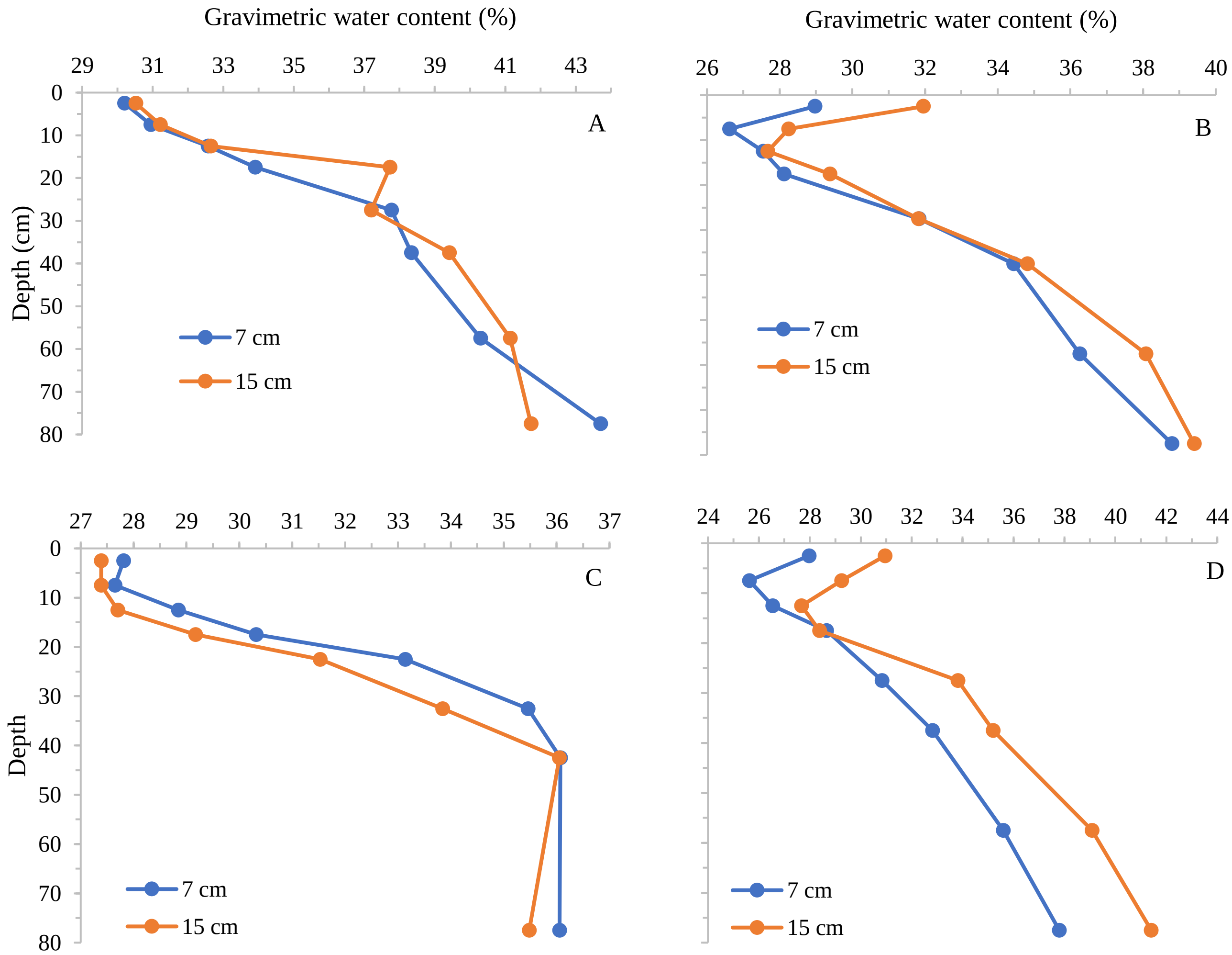

FIGURE 3 - Gravimetric soil moisture, in crop-livestock integration system, conducted with two residual heights (7 and 15 cm), of black oat pasture management in the three N average doses (0, 75 and 150 kg N ha^{-1}). A = post-grazing black oat (2016), B = post-harvest corn (2016/17), C = post-grazing black oat (2017), D = post-harvest soybean (2017/18). There was any significant effect from the treatments for soil moisture indicated by Tukey's test (p<0.05).

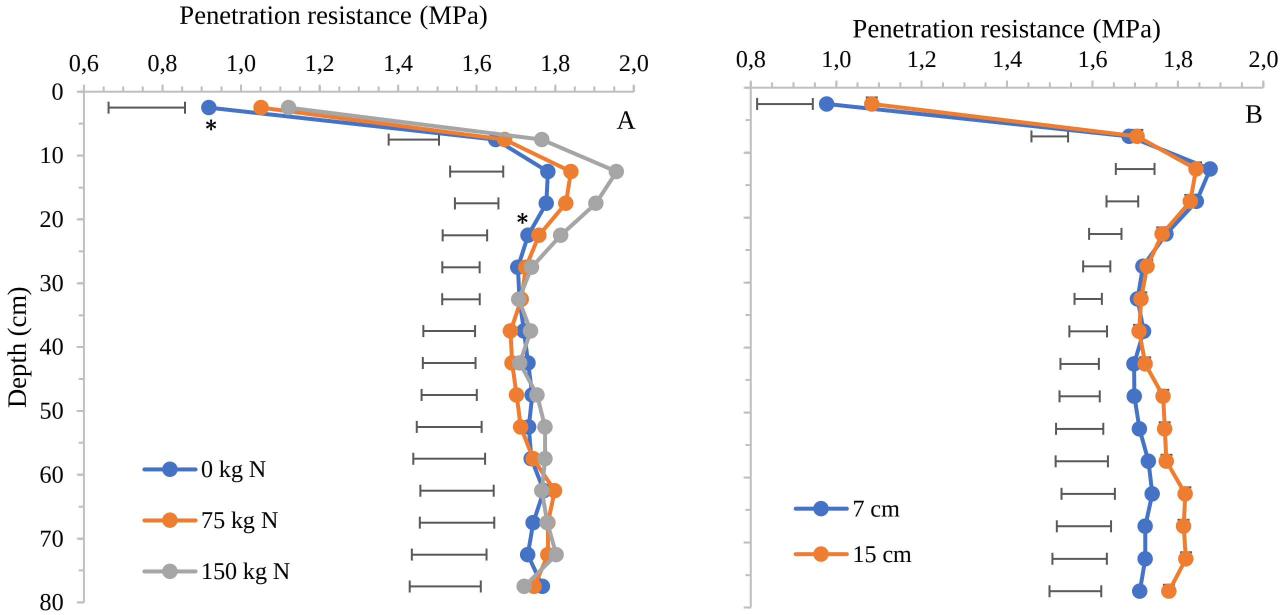

FIGURE 4 - Soil resistance to penetration in the post-grazing period of black oat (2017) under three nitrogen doses (A) (0, 75 and 150 kg N ha^{-1}) applied in cover and two grazing heights (B) (7 and 15 cm). Horizontal bars indicate the minimum significant difference. *It represents the significant effect occurrence using Tukey test (p<0.05).

After soybean harvest, there was any winter treatments effect (nitrogen fertilizer doses x grazing intensity) on soil PR (Figures 5A and 5B). Conte et al. (2011), evaluating the physical attributes development in an ICLS system also has observed that grazing heights did not have significant effect on soil physical attributes after soybean harvest over seven and ten years, respectively. Furthermore, Lunardi et al. (2008) have found that the soybeans crop after winter grazing showed a higher grain yield than soybeans grown in an area without grazing, reinforcing the hypothesis that the animal's presence does not indicate an impediment to obtaining high grain yields.

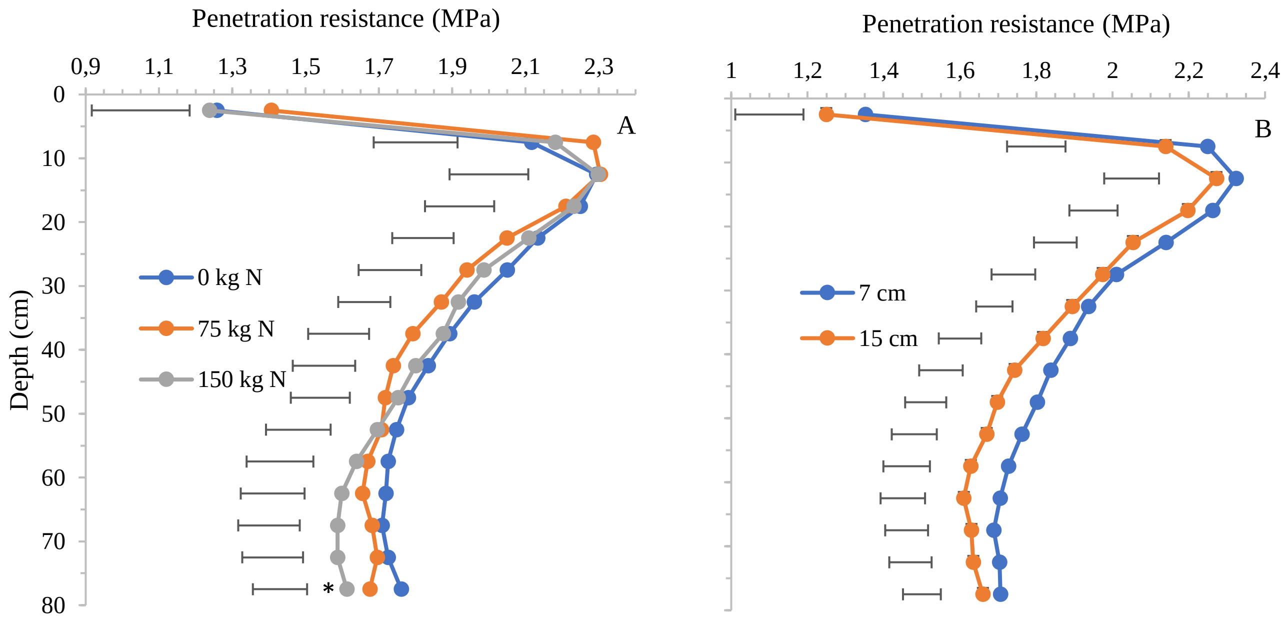

FIGURE 5 - Soil resistance to penetration, in the soybean ost-harvest period (2017/18), under three nitrogen doses (A) (0, 75 and 150 kg N ha^{-1}) applied in cover and two grazing heights (B) (7 and 15 cm). Horizontal bars indicate the minimum significant difference. * It represents the significant effect occurrence using Tukey test (p<0.05).

In a joint crops analysis, it is concluded that the animal's presence, regardless the grazing intensity, did not affect significantly the soil PR. The water content in the soil was the main variable responsible for soil PR increasing in the superficial layers, due to the lower gravimetric humidity. However, soil water content contributed to reducing the PR in the deeper layers. Another relevant aspect for the absence of more significant impacts can be attributed to the rotational grazing system, since the soil PR values found after the grazing periods were below 2.0 MPa, where is not enough to compromise the agricultural crops development, even in long-term experiments (CONTE et al., 2011).

This research aimed to evaluate the residual grazing height effects combined with nitrogen fertilization on soil PR, immediately after the grazing season and subsequently after grain crop harvest in the ICLS system. However, the results showed that the effects of animal trampling, even after a three-year period under rotational grazing, were not sufficient to cause soil compaction. Future research on this topic may focus on other soil physical quality aspects, such as aggregate stability, porosity and soil structure visual assessment. Similarly, these variables can lead to a quick diagnosis of soil physical quality and help in planning grazing intensity management in these areas.

CONCLUSION

Black oat grazing at the different intensities did not affect soil PR, and the increase in the nitrogen dose to 150 kg N ha^{-1} reduced soil PR, especially at depth.

In an ICLS system (2 years) short time development, soil cover by grass residues in moderate grazing systems (15 cm) can be an alternative to mitigate the possible effects of compaction in the surface soil layers.

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