http://journal.unoeste.br/index.php/ca/index
DOI: 10.5747/ca.2023.v19.h534
ISSN on-line 1809-8215

Colloquium Agrariae

Submetido: 19/09/2022 Revisado: 06/06/2023 Aceito: 04/09/2023

PHYSICAL ATTRIBUTES OF SOIL AND WHEAT PRODUCTIVITY AS A FUNCTION OF COVERING PLANTS AND MECHANICAL CHISELING

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Abstract

Soil compaction is a main physical problem in many growing areas. The use of ground cover crops for soil decompaction has been a subject of many studies. That has promising results both used alone and in association with mechanical chiseling. The objective of this study was to evaluate the influence of cover crops associated or not with mechanical chiseling, for that, on the physical attributes of the soil, and the wheat grain yield, in an Ultisol from the Central Depression of RS. The experimental design used was randomized blocks with 3 replications in each block, in a 2 x 5 factorial scheme. Where the factor A: soil chiseling - chiseled and non-chiseled, and P fator: cover crops – pigeon pea (*Cajanus cajan*), *Crotalaria juncea* (*Crotalaria juncea*), pearl millet (*Pennisetum americanum*) and velvet bean (*Mucuna aterrima*). The chiseling was adjusted to a depth of 0.30m, with 5 rods spaced 0.3m apart. The determinations carried out were: macroporosity, microporosity, total soil porosity, bulk density (BD), penetration resistance (RP), and grain yield. The physical attributes of the soil showed improvements in the second year evaluated, highlighting the treatments with pearl millet and velvet bean that showed higher differences. The maximum RP of the Soil was observed at a depth of 0.25m with 1.64 Mpa. There was a significant difference in the RP of the soil between the treatments of factor A at depths of 0.15 - 0.20 and 0.25m. Mechanical chiseling provided a 15% increase in wheat grain yield compared to non-chiseling treatment, while P factor treatments did not provide any gain.

Keywords: soil physics; turning over; *Triticum aestivum*.

ATRIBUTOS FÍSICOS DO SOLO E PRODUTIVIDADE DO TRIGO EM FUNÇÃO DO USO DE PLANTAS DE COBERTURA E ESCARIFICAÇÃO MECÂNICA

Resumo

A compactação do solo constitui um problema físico importante em muitas áreas de cultivo. A utilização de plantas de cobertura do solo para a descompactação do solo tem sido objeto de muitos estudos, com resultados promissores, tanto usadas isoladamente quanto em associação com a escarificação mecânica. O objetivo deste estudo foi avaliar a influência de plantas de cobertura associadas ou não com escarificação mecânica, nos atributos físicos do solo e no rendimento de grãos de trigo, em um Argissolo da Depressão Central do RS. O delineamento experimental utilizado foi de blocos ao acaso com 3 repetições em cada bloco, no esquema fatorial 2 x 5, onde o fator A: escarificação do solo - escarificado e não escarificado, e o fator P: plantas de cobertura – guandu (*Cajanus cajan*), *Crotalaria juncea* (*Crotalaria juncea*) milheto (*Pennisetum americanum*) e mucuna (*Mucuna aterrima*). A escarificação foi ajustada a 0,3m de profundidade, com 5 hastes espaçadas a 0,30 m entre si. As determinações realizadas foram: macroporosidade, microporosidade, porosidade total do solo, densidade do solo (Ds), resistência a penetração (RP) e rendimento de grãos. Os atributos físicos do solo apresentaram melhorias no segundo ano avaliado, destacando os tratamentos com milheto e mucuna os quais apresentaram maiores diferenças. A RP máxima do solo, foi observada na profundidade de 0,25m com 1,64 Mpa. Houve diferença significativa na RP do solo entre os tratamentos do fator A nas profundidades de 0,15 - 0,20 e 0,25m. A escarificação mecânica proporcionou um incremento de 15% no rendimento de grãos de trigo em comparação ao tratamento não escarificado, enquanto os tratamentos do fator P não proporcionaram nenhum ganho.

Palavras-chave: física do solo; revolvimento; *Triticum aestivum*.

Introduction

The no-tillage system (NTS) is a conservation management technique that comprises minimal soil mobilization, permanent maintenance of soil cover, crop rotation, and diversification of species, as well as a harvest-sowing process aiming to increase the number of crops and the time that the soil remains covered with plants (POSSAMAI *et al.*, 2022). However, these NTS fundamental principles are not used all the time many areas adopt a simplistic model system, which often results in changes in the structural quality of the soil and leads to an increase in the compaction status of soils (DRESCHER, 2015).

In anthropized areas, soil compaction can be defined as the decrease in soil volume caused by compression, which results in a reduction in porosity due to the rearrangement of particles and causes changes in the relationships between aeration, nutrients, heat, and water with the mass of the soil (COLOMBI; KELLER, 2019). In conclusion, compacted layer areas present reduced macroporosity and increased microporosity, bulk density, and soil resistance to penetration (DRESCHER, 2015). As a consequence, there is a reduction in water infiltration and gas exchange in the soil (VALICHESKI *et al.*, 2012), an increase in water retention in the soil (REICHERT *et al.*, 2007), as well as a reduction in the growth of the root system and aerial part of the plants (SHAHEB, 2020).

The presence of compacted soil layers in NTS areas has led many producers to adopt measures to mitigate them. Mechanical chiseling is a practice widely used by producers to reduce soil compaction (DRESCHER, 2015), as it brings immediate benefits, which result in the reduction of soil resistance to penetration (HASKEL, 2020), and bulk density (BECKER *et al.*, 2022), in addition to increasing the surface roughness of the soil, total porosity and water infiltration (DRESCHER, 2015).

However, many studies have pointed out that these effects are ephemeral (REICHERT *et al.*, 2017), lasting less than one year (ÁLVAREZ *et al.*, 2009; HASKEL, 2020). That may be associated with the resilience of the soil (DRESCHER, 2015), that is, the intrinsic ability of the soil to recover from degradation or applied stress and return to a new balance, similar to the previous state (BLANCO; LAL, 2010).

Furthermore, the benefits of mechanical chiseling on crop grain yield are not always verified (GUBIANI *et al.*, 2013; NUNES *et al.*, 2014; HASKEL, 2020). That, combined with the high cost of carrying out this practice (CHAMEN, 2015), suggests that it should be used, in specific compaction situations, such as when there is a limitation in plant development or when you want to prevent the occurrence of limiting levels (DRESCHER, 2015).

Another practice that can be used to reduce compaction or prevent it from occurring is the adoption of Crop Rotation Systems, which include species with a vigorous and diversified root system capable of growing in soils with the compacted layers. The implementation of this practice brings improvements to the soil, such as increased macroporosity and water infiltration rate, reduced soil resistance to penetration (MORAES *et al.*, 2016; SULZBACH, *et al.*, 2017; RUFFATO, *et al.*, 2019), formation of stable bio pores that will contribute to the water flow, air, and root growth of successor crops (HASKEL, 2020). In addition to the accumulation of organic matter, that increases the moisture critical for compaction and makes soils more resistant to this effect (BRAIDA *et al.*, 2006).

It is also noteworthy, the effect of straw on the dissipation of compaction energy (BRAIDA *et al.*, 2006) that results in the reduction of pressures that reach the soil. According to Moraes *et al.* (2016), the presence of 8 Mg ha^{-1} of straw on the soil surface has the potential to dissipate 16% of the compacting energy, reaching 30% of dissipation with 12 Mg ha^{-1} of straw (BRAIDA *et al.*, 2006). Furthermore, specifically related to crop productivity, the understanding is consolidated that production units that advocate the use of appropriate crop rotation systems have increased production rates in the medium and long term, making them more economically and environmentally balanced.

In many areas of RS, the succession of soybean cultivation in summer and wheat or ryegrass associated with crop-livestock integration in winter predominates (DENARDIN *et al.*, 2008). In this production model, there is a waste generation in quantity, quality, and frequency below the biological demand of the soil (DENARDIN *et al.*, 2008), motivating concern with the sustainability of the soil structural quality (DRESCHER, 2015). In this sense, the implementation of plant species with high potential for phytomass production of shoots and roots in the production system becomes necessary.

Some species of spring-summer cover crops such as pigeon pea, crotalaria juncea, pearl millet and velvet bean because they have characteristics such as vigorous root system, tall. Phytomass production and nutrient cycling (LIMA FILHO *et al.*, 2014; REDIN *et al.*, 2016; BOLZAN *et al.*, 2019) are highly desirable for insertion in crop rotation systems. Thus, the objective of this study was to evaluate the influence of cover crops associated or not with mechanical chiseling, on soil physical attributes and wheat grain yield, in an Ultisol in the Central Depression of RS.

Materials and Methods

The experiment was in the Central Region of Rio Grande do Sul state, specifically in the Central Depression (latitude 29º41'30" and longitude 54º40'46"). The local soil is an Ultisol (Argissolo Bruno-Acizentado), with a sandy surface texture and clay increase in depth, characterizing a type B textural subsurface horizon (Table 1).

Tabela 1. Clay contents expressed in percentage for the different depths evaluated.

Depth (m)	**0.0 – 0.05**	**0.05 – 0.10**	**0.10 – 0.20**	**0.20 – 0.40**
Clay (%)	14	17	19	35

Source: The author.

The experimental design used was randomized blocks, with subdivided plots and three replications in a 2x4 factorial scheme, where factor A was the soil chiseling, and factor P was the cover crops.

The factor A treatments were distributed in the main plots, which consisted of chiseled soil and non-chiseled soil. Each main plot was divided into subplots, where the P factor treatments were distributed, consisted of 4 species of cover crops: pigeon pea (*Cajanus cajan*), *Crotalaria juncea* (*C. juncea*), pearl millet (*Pennisetum americanum*) and velvet bean (*Mucuna aterrima*).

The practice of chiseling of the soil was carried out before the sowing of the cover crops, using a chisel with 5 stems spaced 0.30 m apart and the depth adjusted to 0.30 m. Sowing was in a row, after chiseling at a spacing of 0.50 m between rows for *C. juncea*, pigeon pea, and velvet bean, and 0.25 m between rows for pearl millet. The cover crops were implanted on 12/06/2018 and conducted until the beginning of the reproductive phase when they were desiccated and felled for later sowing of the wheat crop.

The determinations performed were macroporosity (Ma), microporosity (Mi), total soil porosity (Pt), bulk density (BD), resistance to penetration (RP), wheat grain yield. Soil samples for determination of Ma, Mi, and BD were collected in the layers of 0-0.05 m; 0.05-0.1 m; 0.1-0.2 m; 0.2-0.4 m, at depths corresponding to the median portion of each layer.

To determine Ma and Mi, the tension table method was used (TEIXEIRA *et al.*, 2017). This method uses undisturbed soil samples collected using metal cylinders of known volume. The soil samples were saturated with water, weighed, and taken to the tension table where the tension of 0.006 Mpa was applied, which removes the water present in the macropores (>0.05 mm). After 48 hours, samples were removed and weighed. The water content drained in this period at this tension corresponded to the volume of macropores and, the water content retained in that period at this tension corresponded to the volume of micropores in the soil. Pt was obtained by the sum of the Ma and Mi of the Soil.

The BD was determined by the volumetric ring method (TEIXEIRA *et al.*, 2017). For this purpose, soil samples with the preserved structure were collected with the aid of a metal cylinder, dried in an oven at 105 °C for 48 hours, and weighed after cooling. The BD was obtained from the relationship between the dry soil mass and the ring volume.

The determination of resistance to penetration was carried out only in the second year of the experiment and was evaluated using a penetrometer (Falker PLG1020), which measures the resistance to penetration of a metal rod into the soil. The device was configured to collect resistance every 0.05m of depth up to a maximum 0.4 m depth.

The grain yield of the wheat crop was evaluated only in year 2 and was obtained by harvesting all plants in each plot, threshing the cobs, and weighing the grains adjusted to 13% moisture. The data were subjected to analysis of variance, and when significant, compared by the Scott Knott test at 5% probability, using the SISVAR statistical package (FERREIRA, 2011).

Results and Discussion

In this study, there was no interaction between the factors assessed in the two years of work. In the same year of evaluation, there was no significant difference for the variables BD, Pt, and Mi in the 0.0 to 0.05 m layer (Table 2). The other layers had some alterations in Pt and Mi, but the emphasis was on the pearl millet crop and velvet bean crop. That proved to be efficient in mainly changing the BD of the soil, even in depth from 0.20 to 0.40 m, a layer of soil that can hardly be turned over mechanically.

Similar data were obtained by Torres *et al.* (2022) working with different species of cover crops. The authors observed lower bulk density and resistance to penetration in the millet treatment. This result was attributed to effect of the Poaceae root system, which has voluminous and well-developed roots. Also, Silva *et al.* (2017), that compared the effect of plants, such as, velvet bean, pearl millet, and sunn hemp on the soil observed that the treatment with pearl millet showed greater capacity to decrease bulk density and increase soil porosity, even at a depth of 0.30 m. In this study, BD above that considered critical by Reinert *et al.* (2008) that states that up to a density of 1.75 g cm^{-3} the growth of the root system of cover crops would be normal, the same was observed in a visual evaluation of the root system of the plants, which had normal growth and no deformations.

Table 2. Bulk density (BD), total porosity (Pt), macroporosity (Ma), and microporosity (Mi) of the soil were conducted under different cover crops and submitted or not to chiseling in two years of the study.

Treatment	BD (Mg m^{-3})		Pt (m^3 m^{-3})		Ma (m^3 m^{-3})		Mi (m^3 m^{-3})	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Depth from 0.0 to 0.05 m								
Pigeon pea	1.36 Ba	1.22 Aa	0.44 Aa	0.57 Ba	0.12 Aa	0.22 Ba	0.33 Aa	0.35 Aa
C. juncea	1.42 Ba	1.18 Aa	0.45 Aa	0.58 Ba	0.09 Aa	0.19 Ba	0.36 Aa	0.39 Aa
Pearl millet	1.34 Ba	1.20 Aa	0.49 Aa	0.56 Aa	0.10 Aa	0.16 Ba	0.38 Aa	0.40 Aa
Velvet bean	1.37 Ba	1.22 Aa	0.49 Aa	0.57 Ba	0.12 Aa	0.15 Aa	0.37 Aa	0.41 Aa
Depth from 0.05 to 0.1 m								
Pigeon pea	1.73 Bb	1.43 Aa	0.33 Ab	0.48 Ba	0.07 Aa	0.12 Ba	0.26 Ab	0.35 Ba
C. juncea	1.66 Aa	1.57 Aa	0.39 Aa	0.38 Ab	0.07 Aa	0.05 Ab	0.32 Aa	0.33 Aa
Pearl millet	1.67 Aa	1.57 Aa	0.39 Aa	0.48 Ba	0.08 Aa	0.17 Ba	0.31 Aa	0.31 Aa
Velvet bean	1.65 Aa	1.60 Aa	0.38 Aa	0.42 Ab	0.06 Aa	0.07 Ab	0.32 Aa	0.34 Aa
Depth from 0.10 to 0.20 m								
Pigeon pea	1.73 Ab	1.63 Ab	0.31 Ab	0.42 Ba	0.07 Aa	0.05 Ab	0.24 Ab	0.37 Ba
C. juncea	1.65 Aa	1.71 Ab	0.38 Aa	0.38 Aa	0.07 Aa	0.07 Ab	0.31 Aa	0.31 Aa
Pearl millet	1.69 Ba	1.54 Aa	0.38 Aa	0.45 Aa	0.07 Aa	0.09 Aa	0.31 Aa	0.36 Aa
Velvet bean	1.66 Aa	1.70 Ab	0.38 Aa	0.40 Aa	0.07 Aa	0.09 Aa	0.31 Aa	0.31 Aa
Depth from 0.20 to 0.40 m								
Pigeon pea	1.60 Ab	1.57 Aa	0.35 Ab	0.42 Aa	0.08 Aa	0.11 Aa	0.28 Ab	0.31 Aa
C. juncea	1.60 Ab	1.60 Aa	0.38 Ab	0.41 Aa	0.06 Aa	0.06 Aa	0.32 Aa	0.35 Aa
Pearl millet	1.53 Aa	1.60 Aa	0.41 Aa	0.43 Aa	0.07 Aa	0.11 Aa	0.34 Aa	0.32 Aa
Velvet bean	1.61 Ba	1.48 Aa	0.41 Aa	0.43 Aa	0.07 Aa	0.09 Aa	0.34 Aa	0.33 Aa

Averages followed by the same uppercase letter in the row and lowercase in the column do not differ statistically by the Scott Knott test at a 5% error probability. *C. juncea* = *Crotalaria juncea*. Source: the author.

In general, there was an improvement in all physical attributes of the soil evaluated using the cover crops in the second year of the study compared to the first (Table 2). Borges *et al.* (2016) found similar results using the same species in biological chiseling. According to Fernandes *et al.* (2023), the improvement of physical properties observed in production systems that use crop rotation, with the insertion of different plant species tends to be slower. However, it is more stable and lasting.

In this sense, at a depth of 0.0 to 0.5 m, there was a significant difference between BD, Pt, and Ma data for all cover crops studied in the second year of the study compared to the first. At a depth of 0.5 to 0.10 m, the plants pigeon pea and pearl millet stood out, providing significant differences besides the BD, Pt, and Ma. The same occurred in the layer from 0.10 to 0.20 m in these treatments. However, with differences only in Pt and BD when comparing the years. Similar results were observed by Ferreira *et al.* (2023) with millet. The authors point out that the vigorous root system of millet contributes to the improvement of the soil's physical environment. Accordind to Calonego *et al.* (2017), that the crop root systems inserted in production systems are important strategies in soil physical improvement. In this sense, there is also the pigeon pea culture that has a pivoting root system capable of providing physical improvements in the deeper layers of the soil.

Regarding the soil chiseling factor (Table 3), in the first year of evaluation, there was a significant difference between treatments especially, in the variable BD for layers up to 0.20m. Similar results were observed by Suzuki *et al.* (2022a). However, this effect is ephemeral and the soil reconsolidates naturally (REICHERT *et al.*, 2017). For the other variables, the treatments did not show significant differences.

Table 3. Bulk density (BD), Total porosity (Pt), Macroporosity (Ma), and Microporosity (Mi) of the soil for four depths submitted or not to chiseling in two years of the study.

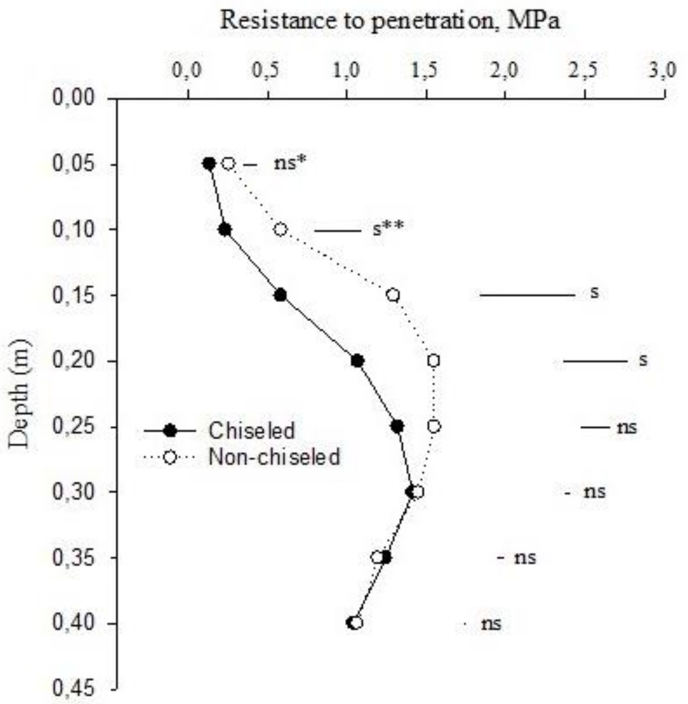
Treatment	**BD (Mg m^{-3})**		**Pt (m^3 m^{-3})**		**Ma (m^3 m^{-3})**		**Mi (m^3 m^{-3})**	
	Year 1	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**	**Year 1**	**Year 2**
	Depth from 0.0 to 0.05 m							
Chiseled	1.30 a	1.11 a	0.48 a	0.56a	0.11 a	0.19 a	0.37 a	0.37 a
Non-chiseled	1.44 b	1.15 a	0.43 a	0.55 a	0.09 a	0.16 a	0.34 a	0.39 a
	Depth from 0.05 to 0.1 m							
Chiseled	1.63 a	1.50 a	0.35 a	0.41 a	0.06 a	0.09 a	0.29 a	0.32 a
Non-chiseled	1.71 b	1.57 a	0.37 a	0.45 a	0.07 b	0.11 a	0.30 a	0.34 a
	Depth from 0.10 to 0.20 m							
Chiseled	1.64 a	1.61 a	0.33 a	0.43 a	0.06 a	0.07 a	0.27 a	0.36 a
Non-chiseled	1.72 b	1.67 a	0.38 b	0.38 a	0.07 b	0.07 a	0.31 a	0.31 a
	Depth from 0.20 to 0.40 m 0.37							
Chiseled	1.57 a	1.62 a	0.36 a	0.37 a	0.06 a	0.06 a	0.30 a	0.31 a
Non-chiseled	1.53 a	1.56 a	0.39 a	0.45 b	0.06 a	0.11 a	0.33 a	0.34 a

Averages for each depth followed by the same lowercase letter do not differ statistically by the Scott-Knott test at a 5% error probability. Source: the author.

There was no significant difference between the mechanical resistance to soil penetration (RP) and the treatments of the cover crops factor. Soil chiseling resulted in a decrease in RP, down to a depth of 0.2 m (Figure 1), due to the depth that the chisel manages to break down the compacted soil, reducing its RP. Similar results were obtained by Rampin *et al.* (2020) that using the same treatments in a Oxisol obtained a significant difference up to a depth of 0.30 m. Similarly, Moraes *et al.* (2020), observed that soil chiseling resulted in lower RP up to a depth of 0.23 m, when compared to other soil managements. In the upper layers, the RP remained similar due to the re-accommodation of soil particles. In the layers evaluated below 0.3 m, the RP values were similar between treatments since the chiseling was not able to mobilize the soil below this layer.

There was no statistical difference in wheat grain yield between the cover crop species used. In a study with cover crops for six years, Boselli et al (2020) only found differences in wheat grain yield after the fourth year of evaluation. Therefore, the evaluation period used in our study may not have been sufficient to show such differences.

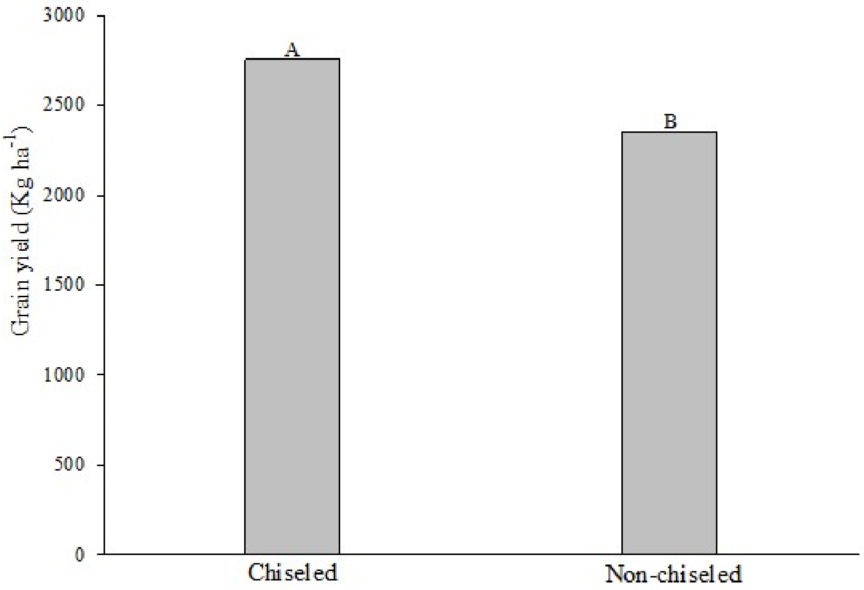
Figure 1. Mechanical resistance to soil penetration at depths from 0.0 to 0.40 m in chiseled and non-chiseled soil. DMS for Scott Knott test at a 5% error probability. *Ns: not significant; **S: significant. Source: the author.



Wheat grain yield was 15% higher in the chiseled compared to non-chiseled tratment (Figure 2). Differing results werw found by Suzuki *et al.* (2022b) that did not observe significant productivity gains for wheat crop. Similarly, Inagaki *et al.* (2021), evaluating the effects of mechanical and biological chiseling in a long-term no-tillage area, observed that mechanical soil chiseling resulted in lower accumulated productivity of soybeans and wheat in a four-year period, when compared to biological chiseling from soil.

Under the conditions of this research, mechanical chiseling was efficient in increasing grain yield, different from cover crops that did not significantly interfere in productive performance. Therefore, the effects of mechanical chiseling alone or associated with the use of biological chiseling need to be further studied to consolidate similar or divergent results.

Figure 2. Wheat grain yield in soil subjected to different soil management. Averages followed by the same letter do not differ from each other by the Scott Knott test at a 5% error probability. Source: the author.



Conclusions

The pearl millet and Velvet bean crops showed the best results in improving the physical attributes of the soil.

Mechanical chiseling was able to change only the penetration resistance in the layer from 0.10 m to 0.20 m.

There was an increase in wheat grain yield by 15% with the practice of chiseling.

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