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Modification of soil physical attributes as a function of subsoiling operations under different managements[1]

Modificação dos atributos físicos do solo em função da operação de subsolagem sob diferentes manejos

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HIGHLIGHTS:
Areas with different management systems have different soil characteristics.
A mechanized operation can modify soil properties.
Pasture areas are more resistant to root penetration.

ABSTRACT: Subsoiler performance can be influenced by crop residue in the soil through different types of vegetation cover. In any of these cover systems, the use of subsoilers for decompaction changes soil physical properties. The present study aimed to evaluate soil physical properties in different management systems using several subsoiling speeds and soil depths. The experiment was conducted at IF Goiano, Morrinhos Campus, Goiás state, Brazil. A completely randomized design was used in a split-plot scheme with 12 treatments and five replicates, totaling 60 plots. The factors corresponded to two management areas (rainfed and pasture), two subsoiling speeds (2.5 and 4.5 km h^{-1}) and three soil depths (0.00-0.015; 0.15-0.30 and 0.30-0.45 m). The main plot consisted of the two management areas and the subplot the combination of the other two factors. Penetration resistance, bulk density, water content, soil mobilization and soil volumetric expansion were evaluated. The results were then submitted to analysis of variance and Tukey's test ($p \leq 0.05$). Penetration resistance and bulk density differed before and after subsoiling. The subsoiling speeds altered penetration resistance and soil mobilization. Pasture areas showed greater root penetration resistance, provided lower water content and favored greater soil volumetric expansion.

Key words: cultivation system, vegetation cover, shank furrower

RESUMO: O desempenho dos subsoladores pode ser influenciado pelos restos culturais no solo através dos diferentes tipos de cobertura vegetal. Em qualquer um desses sistemas de cobertura, o uso de subsoladores para descompactação altera as propriedades físicas do solo. O presente estudo teve como objetivo avaliar os atributos físicos do solo em tipos de manejo sob diferentes velocidades de deslocamento e profundidades na operação de subsolagem. O experimento foi conduzido no IF Goiano, Campus Morrinhos, Goiás, Brasil. O delineamento inteiramente casualizado foi usado em esquema de parcelas subdivididas com 12 tratamentos e cinco repetições, totalizando 60 plarcelas. Os fatores corresponderam a duas áreas de manejo (sequeiro e pastagem), duas velocidades de operação de subsolagem (2,5 e 4,5 km h^{-1}) e três profundidades do solo (0,00-0,015; 0,15-0,30 e 0,30-0,45 m). A parcela principal foi constituída pelas duas áreas de manejo e a subparcela a combinação dos outros dois fatores. Foram avaliados a resistência à penetração, densidade do solo, teor de água, mobilização do solo e expansão volumétrica do solo. Posteriormente, os valores encontrados foram submetidos à análise de variância e teste de Tukey $p \leq 0,05$. A resistência à penetração e a densidade aparente foram diferentes antes e após a subsolagem. As velocidades de subsolagem alteraram os valores de resistência à penetração e mobilização do solo. As áreas de pastagem apresentaram maior resistência à penetração das raízes e proporcionaram menor teor de água e favoreceram maior expansão volumétrica do solo.

Palavras-chave: sistema de cultivo, cobertura vegetal, hastes sulcadoras

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Introduction

Farmers face problems such as soil penetration resistance (PR), making them more dependent on soil tillage implements (Aydin et al., 2020; Silva et al., 2020). However, these practices incur high operating costs and their effects on the soil may be short-lived (Nunes et al., 2019).

Soil physical quality is the ability to provide adequate physical conditions for root development in cultivated plants (Paiva et al., 2020). Thus, some quality indicators have a closer relationship with root development, such as porosity, which is related to aeration and water retention (Reis et al., 2022).

Knowledge of soil PR makes it possible to observe the state of soil compaction across the evaluated profile and determine management alternatives with the lowest possible impact on soil properties, particularly with regard to increased bulk density and lower soil porosity (Suzuki et al., 2021).

Another harmful effect of high PR and increased bulk density in agricultural systems is reduced water infiltration into the soil, altered physical properties and consequent declining crop yields, which can range from 6 to 34% (Obour & Ugarte, 2021).

To remedy this problem in long-term monocultures, the use of implements such as subsoilers is essential to reduce soil compaction caused by different machines used in each crop cycle (Esteban et al., 2019).

Thus, the present study aimed to evaluate soil physical properties using different management systems, subsoiling speeds and soil depths.

Material and Methods

The experiment was conducted at the Federal Institute of Goiás, Morrinhos Campus, Goiás state, Brazil, with coordinates from 17º 30’ 20” to 18º 05’ 40” South and 48º 41’ 08” to 49º 27’ 34” West, average altitude of 771 m and a mild climate (humid tropical). The topography is flat and the relief undulating, with an average annual temperature of 20 °C (EMBRAPA, 2008).

According to EMBRAPA (2018), the soil at the site is classified as Oxisol (United States, 2014), which corresponds to red-yellow latosol in the Brazilian Soil Classification System (EMBRAPA, 2018) with a clayey texture. The two experimental areas were characterized as rainfed agricultural with no crop for four years, and pasture cultivated with *Brachiaria brizantha* cv. *marandu* for approximately eight years. A completely randomized design was used in a split-plot scheme with 12 treatments and five replicates, totaling 60 plots. The factors corresponded to two different management areas (rainfed and pasture), two subsoiling speeds (2.5 and 4.5 km h^{-1}), and three soil depths (0.00-0.015; 0.15-0.30 and 0.30-0.45 m). The main plot consisted of the two management areas and the subplot the combination of the other two factors. The experimental units in each treatment had an area of 10 m^2.

Before and after subsoiler passage, physical analyses of soil PR, bulk density and water content were performed to compare the characteristics between the different levels of each factor and their interaction.

Subsoiling was performed using a 4 × 2 FWD tractor (Valtra® BH174), with nominal power of 131.65 kW (179 hp) and a TATU AST subsoiler with five shanks.

The subsoiling speeds were determined after choosing the tractor gear and engine speed. A speed of 4.5 km h^{-1} was adopted for the operation and 2.5 km h^{-1} as a variation. These were used in both areas with four replicates, measuring the time taken to cover 50 m.

The working soil depths were determined according to shank size and subsoiler capacity to penetrate the soil. The working soil depth was determined by piston displacement, whose rod was limited to maintain the depth in each plot. After the implement was regulated, the soil depths were 0.00-0.15, 0.15-0.30 and 0.30-0.45 m.

Collections were performed in the two areas under different uses and at three working soil depths. There was no mechanized intervention in this phase of the study.

Samples were collected three days after mechanized subsoiling to analyze soil characteristics for the following variables: soil mobilization, soil density, soil water content, penetration resistance (PR) and volumetric expansion (calculated as the amount of expanded soil after implement passage).

PR was measured with a digital penetrometer (Eijkelkamp M10615SA Penetrologger) in three measurements per point and subsequently using the average of the values. Soil density was determined using volumetric rings to collect soil at different depths (EMBRAPA, 2017). Soil water content was obtained by the gravimetric method in disturbed samples (EMBRAPA, 2017).

Before the subsoiler passage, the rainfed and pasture areas had a microrelief of 25.83 and 54.39 cm^2, respectively. After its passage, the mobilized area was obtained with a demountable profilometer, consisting of 50 hollow aluminum sticks, 0.02 m apart, with reading capacity of up to 0.35 m. Reading was performed immediately after passage of the mechanized implement.

The mobilized area lies between the original and the bottom profile of the furrows, while the elevation area is located between the surface and bottom profile of the soil after mobilization, as described by Carvalho Filho et al. (2007). Once the mobilized layer data were obtained, the average thickness was calculated using Eq. 1.

$$T_L = \frac{A_m}{L_p} \quad (1)$$

where:

T_L - average thickness of the mobilized layer (m);
A_m - mobilized area of the soil (m^2); and,
L_p - length of profilometer (m).

Soil volumetric expansion (Eq. 2) was determined by the ratio between the soil elevation area and the area mobilized by the active organs of the equipment, according to Carvalho Filho et al. (2007).

$$V_{exp} = \left(\frac{A_e}{A_m}\right) \times 100 \quad (2)$$

where:

V_{exp} - volumetric expansion (%);
A_e - elevation area (m^2); and,
A_m - mobilized area (m^2).

Analysis of variance before and after subsoiler passage was performed using the F test at $p \leq 0.05$ and, when significant, the average values of the variables were compared by Tukey`s test at $p \leq 0.05$. Data were analyzed using the ASSISTAT program, beta version 7.7 (Silva & Azevedo, 2016).

Results and Discussion

According to analysis of variance results (Table 1), the management areas and soil depths evaluated for soil water content before subsoiling, were significant between the levels of the single factors and in the interaction between these factors, demonstrating that this variable changes under all the conditions assessed.

For bulk density, only the rainfed and pasture areas caused significant differences in the results. For penetration resistance (PR), the significant source of variation was the interaction between areas and depth. Table 2 shows the average bulk density for the different management areas and average PR and soil water content in the interaction between management areas and soil depths evaluated before subsoiling

Table 1. Analysis of variance of the effect of management areas and soil depth assessment and their interaction in terms of average of penetration resistance (PR), bulk density and soil water content before subsoiling

	DF	DFR	PR	Bulk density	Soil water content
			p-value		
Area	1	24	0.0001*	0.0001*	0.0001*
Depth	2	24	0.3452ns	0.2974ns	0.0001*
Area × Depth	2	24	0.0133*	0.1522ns	0.0001*
CV (%)			12.02	2.91	2.75

DF – Degrees of freedom; CV – Coefficient of variation; DFR – Degrees of freedom of the residue; *, ns - Significant at $p \leq 0.05$ and not significant ($p > 0.05$), according to the F test, respectively

Table 2. Average bulk density for the different management areas (rainfed and pasture) and average penetration resistance (PR) and soil water content in the interaction between management areas (rainfed and pasture) and soil depths (0.00-0.15, 0.15-0.30, 0.30-0.45 m) assessed before subsoiling

	Bulk density (kg dm^{-3})		
Rainfed	1.36 a		
Pasture	1.25 b		
	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m
	PR (MPa)		
Rainfed	2.38 aA	2.36 bA	2.14 bA
Pasture	2.68 aB	2.96 aAB	3.34 aA
	Water content (%)		
Rainfed	25.01 aA	24.23 aA	24.70 aA
Pasture	16.52 bC	17.91 bB	20.05 bA

Means followed by the same lowercase letter in the columns and uppercase letter in the rows do not differ statistically according to Tukey`s test at $p > 0.05$

The highest bulk density values were obtained in the rainfed area and the lowest in its pasture counterpart. Grass rooting in the pasture, implemented over a longer period, may have contributed to the lower bulk density. Neves Júnior et al. (2013) found that an increase in bulk density is influenced by pasture management via reduced macroporosity. Caetano et al. (2013) reported that high bulk density indicates pastures with high degradation, without correction or fertilization, kept under grazing.

For the rainfed area, these values are below the critical level of 1.40 kg dm^{-3} for most grain crops (Reichert et al., 2009). Above this value, the growth and development of the root system is restricted because of less water infiltration and transport in the soil and gas exchange between the soil and the atmosphere (Fonseca et al., 2007).

This PR behavior was reflected in the soil water content, since the lowest values were found in the pasture. This variable also changed with depth, obtaining a value of 22.38% at 0.30-0.45 m.

PR values declined at a soil depth of 0.00-0.15 m in the rainfed area. This is justified by the absence of machines or animals at the site, thereby creating an initial compacted layer and maintaining lower compaction levels in the deeper layers. With respect to soil depth, the rainfed area remained constant. However, in the pasture, PR was higher in the 0.30-0.45 m layer. The 0.00-0.15 m layer exhibited lower values and despite animal trampling, it is assumed that the roots helped maintain the lower compaction (Costa et al., 2015).

Sartor et al. (2020) observed that one of the main forms of compaction, in addition to the use of machinery and the constant grazing of animals on agricultural properties, is the deposition of particles in the soil profile that are displaced by rainfall, increasing PR at different depths. Cortez et al. (2019) studied the spatial variability of soil penetration resistance in a no-tillage system in the municipality of Dourados, Mato Grosso do Sul state, Brazil, in a dystrophic red latosol, and their maps showed that higher PR was also found in more superficial layers, at a depth of 0.00-0.25 m.

After the subsoiler passage, analysis of variance (Table 3) was conducted for management areas, subsoiling speeds, and soil depths. PR, bulk density, soil water content, soil mobilization and soil volumetric expansion were also assessed.

When assessed individually, all the factors altered PR, soil water content and soil volumetric expansion. Significant differences in bulk density were found only between management areas, while soil mobilization was significantly affected by the different subsoiling speeds and working soil depths of the shanks.

The interaction between management areas and subsoiling speeds was significant for bulk density and soil volumetric expansion. For the interaction between management areas and soil depths, only bulk density and soil volumetric expansion values were not significant. For the interaction between subsoiling speeds and soil depths, bulk density and soil water content were significantly different.

Table 4 shows average soil mobilization and soil volumetric expansion after subsoiling for the factors evaluated and soil mobilization for the interaction between management areas and soil depths after subsoiling.

Table 3. Analysis of variance of the effect of management areas (Ta), subsoiling speeds (Tb) and soil depths (Tc) and their interactions in terms of average penetration resistance (PR), bulk density, soil water content, soil mobilization and soil volumetric expansion after subsoiling

Sources of variation	DF	DFR	PR	Bulk density	Soil water content	Soil mobilization	Soil volumetric expansion
			p-value				
Ta	1	48	0.0001*	0.0001*	0.0001*	0.2871ns	0.0001*
Tb	1	48	0.0001*	0.5298ns	0.0031*	0.0001*	0.0160*
Tc	2	48	0.0001*	0.0985ns	0.0020*	0.0001*	0.0001*
Ta x Tb	1	48	0.4455ns	0.0061*	0.6510ns	0.5930ns	0.1517ns
Ta x Tc	2	48	0.0001*	0.8087ns	0.0001*	0.0001*	0.0943ns
Tb x Tc	2	48	0.2622ns	0.0023*	0.0027*	0.0794ns	0.7952ns
Ta x Tb x Tc	2	48	0.0005*	0.0001*	0.0136*	0.2742ns	0.5575ns
CV (%)			8.68	2.47	2.49	27.15	60.11

DF – Degrees of freedom; CV – Coefficient of variation; DFR – Degrees of freedom of the residue; *, ns - Significant at p ≤ 0.05 and not significant (p > 0.05), according to the F test, respectively

Table 4. Average soil mobilization and soil volumetric expansion after subsoiling for the factors evaluated and soil mobilization for the interaction between management areas and soil depths after subsoiling speeds

	Soil mobilization (cm^2)	Soil volumetric expansion (%)
Rainfed	-	27.46 b
Pasture	-	65.08 a
2.5 km h^{-1}	100.86 b	55.23 a
4.5 km h^{-1}	139.99 a	37.30 b
0.00-0.15 m	-	69.00 a
0.15-0.30 m	-	34.47 b
0.30-0.45 m	-	35.33 b

	Soil mobilization (cm^2)		
	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m
Rainfed	63.73 aC	104.05 bB	207.12 aA
Pasture	63.93 aB	149.04 aA	134.68 bA

Means followed by the same lowercase letter in the columns and uppercase letter in the rows do not differ statistically according to Tukey´s test at p > 0.05

Soil volumetric expansion is higher because breaking the compacted layer increases soil porosity, thereby raising its pasture values.

The subsoiling speeds changed soil mobilization and soil volumetric expansion properties. Comparison between these factors showed greater soil mobilization at a subsoiling speed of 4.5 km h^{-1}. Higher subsoiling speeds in a more compacted soil tend to displace it more forcefully, reducing the likelihood of its returning to its natural state.

In this context, Kees (2008) found that very high displacement speed during soil decompression may cause excessive surface disturbances, leading to organic matter incorporation. On the other hand, very low displacement speed may not lift and break up the soil properly.

Soil mobilization increased with soil depth, corroborating the results reported by Seki et al. (2015), who found that subsoiling and chiseling result in greater soil mobilization.

For soil volumetric expansion, the pasture and a subsoiling speed of 2.5 km h^{-1} produced higher values, showing that soil expansion is greater in more compacted soils and at a lower displacement speed.

Bellé et al. (2014) studied different seeder-fertilizer displacement speeds, concluding that this variable does not alter the mobilized soil area, elevation area or soil volumetric expansion.

Table 5 shows the PR values for the triple interaction between management areas, subsoiling speeds and soil depths after subsoiling. These values were higher in the rainfed than in the pasture area, even after subsoiler passage.

Penetration resistance was higher in the rainfed area at a soil depth of 0.00-0.15 m. However, at 0.30-0.45 m, its values were lower than those found in the pasture. It can therefore be deduced that there could be a compacted soil layer below the roots, thus forming a “plow pan”. This explains the higher soil mobilization at greater depths even with lower bulk density.

At the different soil depths and management areas, PR was above 2.0 MPa, compromising root development and water infiltration into the soil (Moraes et al., 2014). The highest

Table 5. Average penetration resistance (PR) for the triple interaction between management areas, subsoiling speeds and soil depths after subsoiling

	PR (MPa)					
	2.5 km h^{-1}			4.5 km h^{-1}		
	0.00-0.15 m	0.30-0.15 m	0.30-0.45 m	0.00-0.15 m	0.30-0.15 m	0.30-0.45 m
Rainfed	2.30 aB	1.84 aCD	1.69 bD	2.68 aA	2.09 aBC	1.77 bCD
Pasture	2.38 aB	1.91 aC	2.25 aBC	2.21 bBC	2.05 aBC	2.78 aA
	Rainfed			Pasture		
	0.00-0.15 m	0.30-0.15 m	0.30-0.45 m	0.00-0.15 m	0.30-0.15 m	0.30-0.45 m
2.5 km h^{-1}	2.30 bA	1.84 bC	1.69 aC	2.38 aA	1.91 aBC	2.25 bAB
4.5 km h^{-1}	2.68 aA	2.09 aBC	1.77 aC	2.21 aB	2.05 aBC	2.78 aA

	Rainfed		Pasture	
	2.5 km h^{-1}	4.5 km h^{-1}	2.5 km h^{-1}	4.5 km h^{-1}
0.00-0.15 m	2.30 aB	2.68 aA	2.38 aAB	2.21 bB
0.30-0.15 m	1.84 bA	2.09 bA	1.91 bA	2.05 bA
0.30-0.45 m	1.69 bC	1.77 cC	2.25 aB	2.78 aA

Means followed by the same lowercase letter in the columns and uppercase letter in the rows do not differ statistically according to Tukey`s test at p > 0.05

Table 6. Average bulk density for the triple interaction between management areas, subsoiling speeds and soil depths after subsoiling

	Bulk density (kg dm^{-3})					
	2.5 km h^{-1}			4.5 km h^{-1}		
	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m
Rainfed	1.23 aBC	1.29 aAB	1.22 aC	1.30 aA	1.22 aC	1.30 aA
Pasture	1.24 aA	1.20 bA	1.22 aA	1.21 bA	1.20 aA	1.19 bA
	Rainfed			Pasture		
	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m
2.5 km h^{-1}	1.23 bAB	1.29 aA	1.22 bB	1.24 aAB	1.20 aB	1.22 aB
4.5 km h^{-1}	1.30 aA	1.22 bB	1.30 aA	1.21 aB	1.20 aB	1.19 aB

	Rainfed		Pasture	
	2.5 km h^{-1}	4.5 km h^{-1}	2.5 km h^{-1}	4.5 km h^{-1}
0.00-0.15 m	1.23 bB	1.30 aA	1.24 aB	1.21 aB
0.15-0.30 m	1.29 aA	1.22 bB	1.20 aB	1.20 aB
0.30-0.45 m	1.22 bB	1.30 aA	1.22 aB	1.19 aB

Means followed by the same lowercase letter in the columns and same uppercase letter in the rows do not differ statistically according to Tukey`s test at p > 0.05

Table 7. Average soil water content for the triple interaction between management areas, subsoiling speeds and soil depths after subsoiling

	Water content (%)					
	2.5 km h^{-1}			4.5 km h^{-1}		
	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m
Rainfed	25.58 aA	24.31 aBC	24.78 aABC	24.06 aC	25.09 aAB	24.41 aBC
Pasture	18.22 bBC	19.49 bA	19.21 bAB	17.58 bC	19.05 bAB	18.81 bAB
	Rainfed			Pasture		
	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m	0.00-0.15 m	0.15-0.30 m	0.30-0.45 m
2.5 km h^{-1}	25.58 aA	24.31 bB	24.78 aAB	18.22 aD	19.49 aC	19.21 aCD
4.5 km h^{-1}	24.06 bB	25.09 aA	24.41 aAB	17.58 aD	19.05 aC	18.81 aC

	Rainfed		Pasture	
	2.5 km h^{-1}	4.5 km h^{-1}	2.5 km h^{-1}	4.5 km h^{-1}
0.00-0.15 m	25.58 aA	24.06 bB	18.22 bC	17.58 bC
0.15-0.30 m	24.31 bA	25.09 aA	19.49 aB	19.05 aB
0.30-0.45 m	24.78 abA	24.41 abA	19.21 aB	18.81 aB

Means followed by the same lowercase letter in the columns and uppercase letter in the rows do not differ statistically according to Tukey`s test at p > 0.05

values were obtained in the pasture, due to longer time without maintenance and exposure to animal trampling.

According to Sá et al. (2016), since the effect of subsoiling is temporary, the operation needs to be repeated, which favors rapid soil organic matter mineralization and an increase in greenhouse gases.

Corroborating the present study, Cardoso et al. (2022) considered the existing soil coverage and the different depths evaluated, concluding that PR varied according to the soil depths assessed.

Table 6 shows the bulk density values for the triple interaction between management areas, subsoiling speeds and soil depths after subsoiling.

Bulk density was higher in the rainfed area. In the pasture, operating speed did not influence the values regardless of the working soil depth. Higher values were found in the rainfed area at a soil depth of 0.15-0.30 m and speed of 2.5 km h^{-1} and, for pasture, at a soil depth of 0.00-0.15 m and 4.5 km h^{-1}.

According to Carvalho et al. (2020), bulk density tends to increase in the subsurface layer (0.05-0.10 m) in no-tillage systems, given that these authors also observed increased density in different species of cover crops in the 0.05-0.10 m layer.

Table 7 shows the soil water content for the triple interaction between management areas, subsoiling speeds and soil depths after subsoiling.

The highest soil water content was found in the surface layer of the rainfed area, and the lowest in the 0.00-0.15 m layer of the pasture. This soil water loss was also significant in this layer when subsoiling was carried out at 4.5 km h^{-1}.

The soil water content in all layers assessed in the pasture was lower than those of its rainfed counterpart. These findings are explained by the PR values, which are higher in the pasture, thereby reducing soil water content. In relation to soil depths, only the pasture showed modifications, with a rise in soil water content as soil depth increased (Lima et al., 2008).

Regardless of management area, soil physical properties change after subsoiling (Ralisch et al., 2017). However, it is essential to know the soil usage history of the area in order to better understand the results obtained.

Conclusions

1. Penetration resistance (PR) and bulk density change after subsoiling.

2. Subsoiling speeds reduce PR and soil mobilization. Higher subsoiling speeds caused greater soil mobilization, altering factors such as PR and bulk density.

3. In rainfed areas, increasing the working soil depth of the subsoiler increased soil mobilization, reaching 207.12 cm^2 at 0.30-0.45 m.

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