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SOIL PENETRATION RESISTANCE AFTER DEEP SUBSOILING IN A NO-TILL SOYBEAN FIELD

RESISTÊNCIA DO SOLO À PENETRAÇÃO APÓS SUBSOLAGEM PROFUNDA EM ÁREA DE SOJA SOB PLANTIO DIRETO

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ABSTRACT

The objective of this study was to evaluate the residual effect of deep subsoiling on soil penetration resistance in a commercial soybean field under a no-till system. The study was conducted at Fazenda Recanto, Agropecuaria Trevo, Sidrolandia, Mato Grosso do Sul, Brazil, over an area of 4,086.90 ha. Subsoiling was performed during the 2021/2022 crop season using a 517 hp Fendt 1050 Vario tractor coupled to a 10-shank Terrus subsoiler, operating to a depth of 60 cm. Soil penetration resistance was evaluated three crop seasons after the operation at depths of 10, 20, 30, 40, 50, and 60 cm. The highest resistance values occurred at 10 and 20 cm, with means of 3.9 and 3.7 MPa, respectively, indicating surface recompaction. At 30, 40, 50, and 60 cm, mean values were 2.9, 2.5, 2.2, and 1.9 MPa, respectively, showing a progressive decrease with depth. Complementary chemical characterization of the 20-40 cm layer (n = 47) showed a mean pH (CaCl2) of 5.99, base saturation of 75.3%, and no exchangeable Al, indicating that the observed mechanical restriction persisted under generally favorable subsurface acidity conditions. Deep subsoiling preserved a lower-resistance zone from 30 to 60 cm, but the surface layer requires preventive management, continuous monitoring, and integration of

keywords: soil compaction; penetration resistance; subsoiling; no-till system; root growth; soil fertility; agricultural mechanization.

RESUMO

O objetivo deste estudo foi avaliar o efeito residual da subsolagem profunda na resistência do solo à penetração em uma lavoura comercial de soja sob sistema de plantio direto. O estudo foi conduzido na Fazenda Recanto, da Agropecuária Trevo, em Sidrolândia, Mato Grosso do Sul, Brasil, em uma área de 4.086,90 ha. A subsolagem foi realizada durante a safra 2021/2022, utilizando um

trator Fendt 1050 Vario de 517 cv acoplado a um subsolador Terrus de 10 hastes, operando a uma profundidade de 60 cm. A resistência do solo à penetração foi avaliada três safras após a operação, nas profundidades de 10, 20, 30, 40, 50 e 60 cm. Os maiores valores de resistência ocorreram nas profundidades de 10 e 20 cm, com médias de 3,9 e 3,7 MPa, respectivamente, indicando a ocorrência de recompactação superficial. Nas profundidades de 30, 40, 50 e 60 cm, os valores médios foram de 2,9, 2,5, 2,2 e 1,9 MPa, respectivamente, demonstrando uma redução progressiva com o aumento da profundidade. A caracterização química complementar da camada de 20 a 40 cm (n = 47) revelou pH (CaCl2) médio de 5,99, saturação por bases de 75,3% e ausência de alumínio trocável, indicando que a restrição mecânica observada persistiu mesmo sob condições de acidez subsuperficial geralmente favoráveis. A subsolagem profunda preservou uma zona de menor resistência entre 30 e 60 cm; no entanto, a camada superficial demanda manejo preventivo, monitoramento contínuo e a integração de práticas de manejo físico e químico do solo.
Palavras-chave: compactação do solo; resistência à penetração; subsolagem; sistema de plantio direto; crescimento radicular; fertilidade do solo; mecanização agrícola.

INTRODUCTION

Soil compaction is one of the primary processes of physical degradation in mechanized agricultural areas, especially in grain production systems subjected to recurring traffic by tractors, sprayers, combines, grain carts, and agricultural implements. This process increases soil bulk density and mechanical resistance, reduces total porosity and macroporosity, alters pore continuity, and impairs water infiltration, internal drainage, and aeration.

Consequently, root growth is restricted, exploration of the soil profile is reduced, and crop water- and nutrient-use efficiency declines (SOANE; VAN OUWERKERK, 1994; HAMZA; ANDERSON, 2005; REICHERT et al., 2007).

In highly weathered tropical soils, such as Oxisols, compaction is particularly relevant because of agricultural intensification, increases in machine power and mass, and the need to conduct field operations within increasingly narrow time windows. Although mechanization has increased the operational capacity of farms, traffic under unsuitable soil-moisture conditions can reduce soil load-bearing capacity, increase penetration resistance, and disrupt essential physical relationships among water, air, and temperature (REICHERT et al., 2007; TORMENA et al., 1998).

Under no-till systems, maintaining crop residues and avoiding continuous soil disturbance are fundamental principles of soil conservation. However, no-till does not automatically eliminate the risk of compaction when crop diversification is limited, deep root production is insufficient, and machinery traffic is frequent. Tormena et al. (1998) noted that, in no-till areas, compaction may become concentrated in surface and subsurface layers, requiring diagnosis and integrated management.

Soil penetration resistance is a practical indicator of mechanical impedance to root growth. Values near 2 MPa are often used as a critical reference; however, this threshold should not be interpreted rigidly because it varies with soil texture, structure, moisture, crop, and management history (TAYLOR; BRAR, 1991; MORAES et al., 2014; BENGOUGH et al., 2011). Under conditions of lower water availability, the same level of resistance may have a more severe effect on root growth because of the interaction between mechanical impedance and water stress.

In soybean, soil compaction can alter root distribution and affect yield. Beutler and Centurion (2004), in a study conducted on an Oxisol, observed that compaction interferes with soybean root development and yield, reinforcing the agronomic importance of penetration resistance as an indicator of soil physical quality. In Spanish-language studies on no-till systems, Alvarez et al. (2009) also reported that mechanical loosening can reduce penetration resistance and modify water infiltration, although its residual effects depend on subsequent management.

In addition to its direct physical effects, compaction affects soil-water dynamics and root health. Reduced macroporosity and internal drainage may increase water residence time in the soil profile and reduce oxygen availability in the rhizosphere. These conditions may predispose plants to biotic and abiotic stresses, particularly in areas where soil- and root-associated microorganisms are present. Therefore, compaction assessment should integrate the physical, chemical, and biological properties of the soil, consistent with the conservation-oriented approach of no-till systems.

Physical and chemical restrictions should be interpreted separately but jointly. A soil profile may present adequate pH, base saturation, and low exchangeable aluminum while still imposing substantial mechanical impedance to root elongation. Field studies in Oxisols show that compaction modifies soybean root distribution, morphology, and access to water even when nutrient management is not the primary limiting factor (MORAES et al., 2020). Likewise, the effect of soil amendments should not be confused with mechanical loosening: gypsum can improve subsurface chemical conditions and root growth, but it does not necessarily reduce soil penetration resistance (SANTOS et al., 2019).

Deep subsoiling is a corrective practice used when compacted subsurface layers are present. The effectiveness of this operation depends on correctly identifying the restrictive layer, soil moisture at the time of intervention, operating depth, number and spacing of shanks, available power, and the field capacity of the mechanized unit. In large areas, physical soil correction requires high-horsepower tractors and robust implements capable of meeting draft requirements while maintaining operational performance compatible with the scale of the farm (BELLÉ et al., 2014; TAVARES et al., 2020).

In this context, the use of a 517 hp Fendt 1050 Vario tractor coupled to a 10-shank Terrus subsoiler made it possible to conduct deep soil loosening at a commercial scale over an area exceeding 4,000 ha. The objective of this study was to evaluate the residual effect of deep subsoiling performed during the 2021/2022 crop season on soil penetration resistance to a depth of 60 cm, three crop seasons after the operation, in a commercial soybean field under a no-till system.

Materials and Methods

The study was conducted at Fazenda Recanto, owned by Agropecuária Trevo, in the municipality of Sidrolândia, Mato Grosso do Sul, Brazil, in a commercial area of 4,086.90 ha. Field reports characterized the soil as a Rhodic Hapludox (Latossolo Vermelho Distroférrico), with 58% clay content, an approximate elevation of 476 m, and an average slope of 1.67%.

Mechanical soil loosening was performed during the 2021/2022 crop season using a Fendt 1050 Vario tractor with a rated power of 517 hp, coupled to a 10-shank Terrus subsoiler. The mechanized unit operated to a depth of up to 60 cm with the objective of breaking compacted layers and reducing soil mechanical resistance at depth (Figure 1).

Figure 1. Equipment used: 517 hp Fendt 1050 Vario + 10-shank Terrus subsoiler, operating to a depth of 60 cm.

Soil loosening was performed in 2022 after the second-crop corn harvest (July/August 2022). In the 2022/23 crop season, soybean was grown in the summer and corn intercropped with Urochloa ruziziensis in the winter. In the 2023/24 crop season, soybean was again grown in the summer and corn with Urochloa in the winter; and in the 2024/25 crop season, soybean was grown in the summer and corn with Urochloa ruziziensis in the winter. The residual effect was evaluated during the 2025/2026 crop season, three crop seasons after the operation, that is, in February 2025. Soil penetration resistance was measured in MPa at depths of 10, 20, 30, 40, 50, and 60 cm. Measurements were organized by soil layer, allowing comparison of the surface condition with deeper layers of the profile.

The mean penetration resistance values used in the analysis were obtained from PenetroView/DataFarm reports for Fazenda Recanto/Agropecuária Trevo. Mean values were 3.9 MPa at 10 cm, 3.7 MPa at 20 cm, 2.9 MPa at 30 cm, 2.5 MPa at 40 cm, 2.2 MPa at 50 cm, and 1.9 MPa at 60 cm.

As complementary information for agronomic interpretation, a soybean soil and root pathology report was considered, in which soil- and root-associated microorganisms were detected. This report was used solely to support discussion of the integration of physical, chemical, and biological soil management, without establishing a direct causal relationship between compaction and disease occurrence (Figure 03).

A complementary subsurface fertility dataset was compiled from 47 SGIS sampling points corresponding to the 20-40 cm layer. The laboratory dataset included pH in CaCl2 and water, organic matter, Mehlich-1 P, exchangeable K, Ca, Mg, and Al, potential acidity (H+Al), sum of bases, cation-exchange capacity at pH 7, base saturation, and cation ratios. Descriptive statistics (mean, standard deviation, minimum, maximum, and coefficient of variation) were calculated from the 47 analytical points. The SGIS fertility maps were used to evaluate the spatial pattern of selected chemical attributes and to provide complementary context for interpretation of penetration resistance in the 20-40 cm interval.

Application-rate maps generated on April 12, 2026 were also reviewed as indicators of the farm's fertility-management prescriptions. The maps specified agricultural gypsum at 700 kg ha-1, KCl from 64 to 100 kg ha-1 (mean 81 kg ha-1), and monoammonium phosphate (MAP) from 52 to 392 kg ha-1 (mean 72 kg ha-1). Because the supplied documents are prescription maps rather than treatment records, these rates were used only to characterize management planning and were not treated as experimental factors or as evidence of application before the penetration-resistance measurements.

Table 1. Mean soil penetration resistance at the depths evaluated at Fazenda Recanto, Agropecuária Trevo, Sidrolândia, Mato Grosso do Sul, 2025/2026 crop season.

Depth (cm)	Mean resistance (MPa)
10	3.9
20	3.7
30	2.9
40	2.5
50	2.2
60	1.9

Source: PenetroView/DataFarm reports, Fazenda Recanto - Agropecuária Trevo, 2025/2026 crop season.

RESULTS AND DISCUSSION

Soil penetration resistance showed a distinct pattern between the surface layers and the deeper layers of the profile (Table 1; Figures 2 and 6). The highest mean values were observed at 10 and 20 cm, at 3.9 and 3.7 MPa, respectively. These values indicate surface recompaction three crop seasons after subsoiling, possibly associated with machinery traffic, natural rearrangement of soil structure, wetting and drying cycles, and greater mechanical stress in layers near the soil surface.

The values observed at 10 and 20 cm were above ranges frequently used as critical references for root-growth restriction. Although the 2 MPa threshold is widely cited, the literature demonstrates that this reference depends on soil moisture, texture, structure, and the crop evaluated (TAYLOR; BRAR, 1991; MORAES et al., 2014). Bengough et al. (2011) emphasized that the interaction between mechanical impedance and water stress can intensify limitations to root growth, especially as the soil dries and resistance increases.

Figure 2. Maps by depth show greater mechanical impedance in the surface layers and a gradual decrease with depth.

From a practical standpoint, resistance values of 3.9 MPa at 10 cm and 3.7 MPa at 20 cm represent a warning condition for soybean development. These values may restrict root initiation and penetration, concentrate the root system in surface layers, and reduce the plant's capacity to explore water and nutrients at depth. This behavior is consistent with Beutler and Centurion (2004), who observed changes in soybean root development and yield in a compacted Oxisol.

The complementary 20-40 cm fertility survey helps separate chemical and mechanical constraints within the same subsurface interval. Across the 47 analytical points, mean pH ($CaCl_2$) was 5.99, organic matter was 36.1 g dm^{-3}, cation-exchange capacity was 164.0 mmolc dm^{-3}, and base saturation was 75.3%. Exchangeable Al was 0 mmolc dm^{-3} at all sampling points. Therefore, the high penetration resistance measured at 20 cm (3.7 MPa), together with values of 2.9 and 2.5 MPa at 30 and 40 cm, respectively, occurred in a layer that did not show strong acidity or exchangeable-Al constraints in the complementary survey. This strengthens the interpretation that mechanical impedance was an independent and agronomically relevant limitation, rather than a response that can be attributed solely to chemical soil conditions.

Table 2. Descriptive statistics for complementary soil chemical attributes in the 20-40 cm layer at Fazenda Recanto (n = 47).

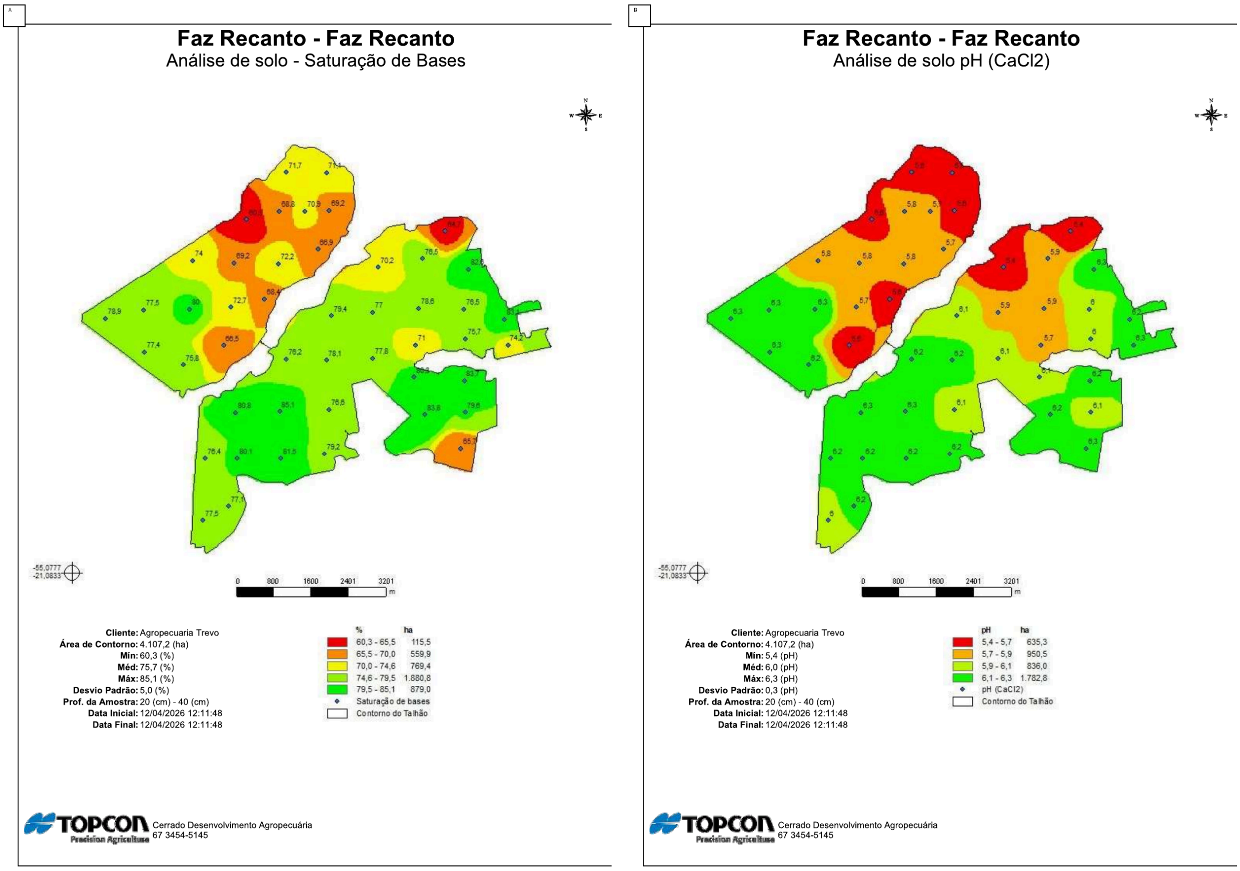
Soil attribute	Mean	SD	Minimum	Maximum	CV (
pH (CaCl2)	5.99	0.28	5.40	6.30	4.7
Organic matter (g dm-3)	36.1	5.4	17.0	49.0	14.9
P, Mehlich-1 (mg dm-3)	39.6	15.6	4.4	62.8	39.4

⚠ Esta tabela possui muitas colunas e foi cortada para impressão. Para visualizá-la completa, acesse o artigo original em: https://revistatopicos.com.br/artigos/soil-penetration-resistance-after-deep-subsoiling-in-a-no-till-soybean-field?noblockage

Source: Solo Fertil laboratory dataset and TOPCON/SGIS fertility mapping, 2026. Values are arithmetic summaries of 47 analytical points; interpolated map statistics may differ slightly from sample statistics.

The chemical attributes showed different degrees of spatial variability. pH and base saturation were comparatively uniform (CV = 4.7% and 7.5%), whereas P, K, Mg, and especially sulfur showed greater variability (Table 2). This pattern is important because a chemically heterogeneous profile can coexist with mechanical restriction. Even when nutrients are present in adequate zones, high penetration resistance can reduce the volume of soil explored by roots and limit effective access to water and nutrients. Moraes et al. (2020) demonstrated under field conditions that soil compaction changes the vertical distribution and anatomy of soybean roots and that the interaction between mechanical and hydric stresses is more informative than a single static threshold.

Figure 3. Spatial distribution of selected subsurface chemical attributes in the 20-40 cm layer: (A) base saturation and (B) pH (CaCl2). Source: TOPCON/SGIS fertility mapping, Fazenda Recanto, 2026.



The 2026 fertility-management prescriptions further indicate that the farm uses chemical correction and variable-rate nutrient management as complementary practices (Table 3). However, these data should not be interpreted as direct evidence of physical soil loosening. In a clayey Oxisol, Santos et al. (2019) found that chiseling reduced penetration resistance and increased water infiltration, whereas gypsum application did not significantly alter penetration resistance; gypsum nevertheless promoted greater soybean root growth in the 20-40 cm layer under continuous no-till. This distinction supports treating gypsum and nutrient management as complementary to, rather than substitutes for, physical management of compacted layers.

Table 3. Fertilizer and soil-amendment application-rate prescriptions supplied for Fazenda Recanto in 2026.

Input	Minimum (kg ha-1)	Mean (kg ha-1)	Maximum (kg ha-1)	Estimated total (kg)
Agricultural gypsum	700	700	700	2,949,398
Potassium chloride (KCl)	64	81	100	341,664
Monoammonium phosphate (MAP)	52	72	392	302,364

Source: TOPCON/SGIS application-rate maps generated April 12, 2026. These values represent prescriptions supplied in the supporting documents and were not analyzed as experimental treatments.

At depths of 30, 40, 50, and 60 cm, mean resistance values were 2.9, 2.5, 2.2, and 1.9 MPa, respectively, showing a progressive decrease with depth. This result is the principal indication of the residual effect of deep subsoiling. The 30- to 60-cm zone showed lower mechanical impedance than the surface layers, suggesting that the

10-shank Terrus subsoiler reached the intended depth and maintained better physical soil conditions in the subsoil after three crop seasons.

This contrast between surface recompaction and the residual effect at depth is agronomically relevant. During periods of irregular rainfall, layers with lower resistance at 40, 50, and 60 cm may allow greater root exploration and access to water stored below the surface. Hamza and Anderson (2005) emphasized that compaction reduces water and nutrient supply to plants, whereas Bengough et al. (2011) indicated that mechanical limitation of root growth increases crop vulnerability to water stress.

Figure 4. Compaction reduces macroporosity and water infiltration, resulting in lower oxygen availability and longer water residence time in the soil. These conditions may impair root growth and increase plant predisposition to soilborne diseases.

The results are also consistent with observations by Alvarez et al. (2009), who evaluated soil loosening under no-till and reported reduced penetration resistance and changes in soil physical properties, although the residual effect depended on subsequent management. In the present stud, subsoiling preserved better conditions at depth, but recompaction at 10 to 20 cm confirms that mechanical intervention does not replace permanent preventive practices.

Mechanization should be interpreted from two perspectives. On one hand, repeated agricultural traffic is a major cause of compaction in agricultural systems, as discussed by Reichert et al. (2007) and Hamza and Anderson (2005). On the other hand, properly sized mechanization makes it possible to perform physical soil correction on a large scale. Deep subsoiling requires high draft force and power, especially when performed with multiple shanks and at depths approaching 60 cm (BELLÉ et al., 2014; TAVARES et al., 2020).

In this regard, the 517 hp Fendt 1050 Vario + 10-shank Terrus subsoiler combination was essential to make the operation feasible over an area exceeding 4,000 ha. The use of a high-horsepower tractor and robust implement made it possible to combine working depth, operating width, and field performance compatible with the conditions of a large-scale farm. Therefore, mechanization should not be viewed solely as a risk factor for compaction, but also as a corrective tool when the tractor-implement combination is technically appropriate.

The complementary analysis of soil- and root-associated microorganisms reinforces the need to integrate physical and biological soil management.

Figure 5. Soil- and root-associated microorganisms, including Fusarium sp., Macrophomina sp., Penicillium sp., Trichoderma sp., Rhizopus sp., and Clonostachys sp.

The report indicated the presence of Fusarium sp. in both soil and roots, as well as Macrophomina sp., Penicillium sp., Trichoderma sp., Rhizopus sp., and Clonostachys sp. in the soil (Table 4). These data do not allow a causal relationship between compaction and disease to be established, but they support discussion of plant predisposition to root stresses in environments with reduced aeration, prolonged soil moisture, and restricted root growth.

Reduced macroporosity and internal drainage can increase water residence time in surface layers and reduce oxygen availability in the rhizosphere. This condition may promote root stress and greater susceptibility to phytosanitary problems, particularly when soil-associated microorganisms are present. Thus, improving soil physical conditions indirectly contributes to better root architecture and to an environment less conducive to biotic and abiotic stresses.

An important limitation is that soil water content was not available for the same time and locations as the penetration-resistance measurements. Penetration resistance is strongly dependent on water content, texture, and structural condition; therefore, fixed critical values should not be interpreted rigidly. Beutler, Centurion, and Silva (2005) showed that soybean yield response to penetration resistance can vary markedly with soil-water conditions, and Moraes et al. (2020) emphasized the dynamic interaction among mechanical impedance, aeration, and water stress. In addition, the fertility and penetration-resistance datasets were generated from different measurement procedures; accordingly, the present analysis uses the chemical data as complementary profile-level evidence and does not claim a point-to-point causal correlation between fertility and penetration resistance.

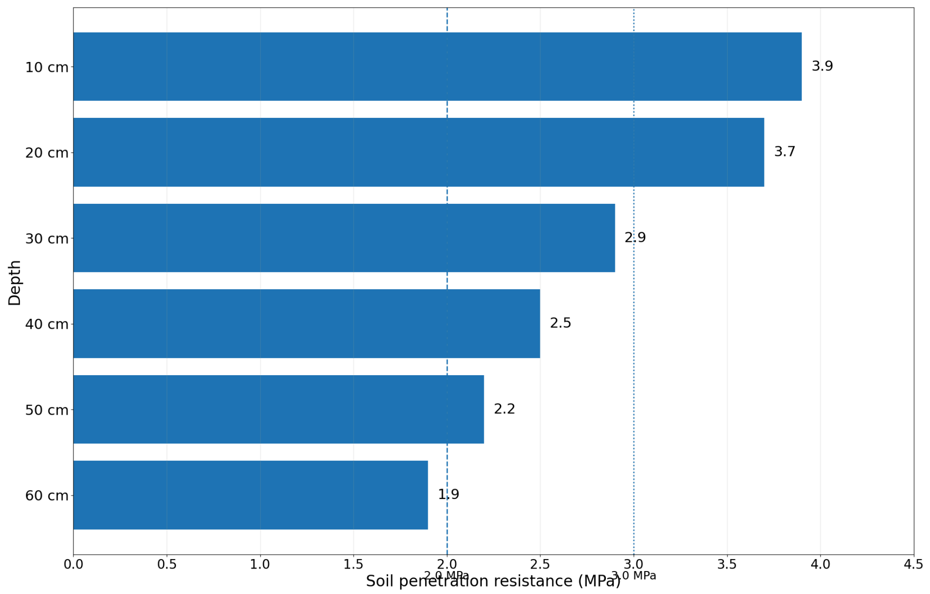
The central finding of this study is that deep subsoiling was effective in preserving lower resistance in the subsoil, especially between 30 and 60 cm, but did not prevent surface recompaction. Therefore, future management should include periodic monitoring of penetration resistance, controlled traffic, fewer operations under wet-soil conditions, maintenance of plant cover, crop rotation, and the use of cover crops with aggressive root systems.

Table 4. Soil- and root-associated microorganisms identified in the supplementary pathology report.

Microorganism	CFU/g soil	CFU/g root
Fusarium sp.	100	1500
Macrophomina sp.	2	ND
Penicillium sp.	1800	ND
Trichoderma sp.	800	ND
Rhizopus sp.	300	ND
Clonostachys sp.	600	ND

ND: not detected.
Source: supplementary soil and root pathology report.

Figure 6. Mean soil penetration resistance at depths of 10, 20, 30, 40, 50, and 60 cm at Fazenda Recanto, Agropecuária Trevo, Sidrolândia, Mato Grosso do Sul, 2025/2026 crop season.



FINAL CONSIDERATIONS

The implementation of subsoiling at a commercial scale over an area exceeding 4,000 ha demonstrates the importance of proper mechanization sizing. Deep subsoiling has high draft requirements, particularly when performed with a multi-shank implement at working depths of up to 60 cm. In this context, the use of the 517 hp Fendt 1050 Vario coupled to the 10-shank Terrus subsoiler was essential to make the large-scale operation feasible, with the capacity to break deep compacted layers while maintaining operational performance compatible with large agricultural areas. Thus, mechanization should not be viewed solely as a potential cause of compaction, but also as a tool for physical soil correction when the tractor-implement combination is properly sized.

From a practical standpoint, the study indicates that mechanical intervention should be incorporated into an ongoing soil physical management program. The residual effect at depth represents an important agronomic gain, but surface recompaction demonstrates that system sustainability depends on permanent soil cover, crop diversification, deep rooting, controlled traffic, and attention to soil water conditions during field operations. The complementary 20-40 cm fertility dataset also shows that a favorable acidity status does not eliminate mechanical impedance; physical and chemical management should therefore be monitored as distinct but interacting dimensions of soil quality.

CONCLUSIONS

1. Deep subsoiling with a 517 hp Fendt 1050 Vario coupled to a 10-shank Terrus subsoiler preserves lower soil penetration resistance between 30 and 60 cm three crop seasons after the operation.

2. The 10- and 20-cm layers show surface recompaction, with mean resistance values of 3.9 and 3.7 MPa, respectively.

3. Soil penetration resistance decreases progressively with depth, reaching 1.9 MPa at 60 cm.

4. Physical correction of compacted layers in large areas depends on proper mechanization sizing and should be integrated with preventive management of machinery traffic and soil cover.

5. Compaction assessment should consider its effects on water dynamics, aeration, root growth, and predisposition to biological problems in the soil.

6. Complementary 20-40 cm soil analyses (n = 47) showed mean pH ($CaCl_2$) of 5.99, base saturation of 75.3%, and no exchangeable Al, indicating that mechanical restriction persisted despite generally favorable subsurface acidity conditions; fertility correction and soil physical management should therefore be treated as complementary strategies.

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