

The Impact of Different Soil Tillage Systems on the Physical Characteristics of Soils in the Context of Current Climate Change

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ABSTRACT

Increasing aridity and climate variability are placing significant pressure on agricultural soils in southeastern Romania, where water scarcity and soil degradation increasingly limit crop productivity. In this context, the selection of appropriate soil tillage technologies plays a key role in maintaining soil structure, improving water retention, and supporting sustainable crop development. Therefore, the aim of this study was to evaluate different soil tillage technologies in areas affected by aridity phenomena in Tulcea County (Nalbant) and Constanța County (Cogealac and Râmnicu de Jos). A comparative analysis of two tillage systems was carried out in experimental fields, with soil sampling conducted in spring 2024 and 2025, in order to assess how conservation technologies influence the physical properties of soils within the studied administrative territorial units. Soil samples were collected at depths of 5-10 cm, 25-30 cm, and 45-50 cm, and their physical properties were determined in the laboratory using standardized methodologies. In the conventional tillage field (2024) organized at Cogealac, bulk density values were higher, particularly at 25-30 cm, where a value of 1.31 g/cm³ was recorded, indicating a more pronounced compaction. In contrast, the minimum tillage (no-till) technology resulted in a soil with lower bulk density, which may limit both water infiltration and root development under water stress conditions.

In the conservation tillage field at Nalbant, soil sampling the spring 2024 sampling indicated a loose soil structure; however, by spring 2025, significant compaction was observed. Total porosity (PTwi, % v/v) in the two experimental fields ranged between 43.7% and 58.9%, indicating medium to very high values. At Râmnicu de Jos, both tillage systems produced soil structure favorable to root growth and development. Penetration resistance in the no-till system showed that, in spring 2025, the soil presented surface compaction (partially limiting root development), while conventional tillage exhibited more balanced resistance values. With regard to total porosity (PTwi, % v/v), all values recorded for both applied technologies were good (>48%), indicating a generally high soil capacity for water retention.

Keywords: bulk density, total porosity, water permeability, penetration resistance, climate change.

INTRODUCTION

Agriculture, a fundamental economic sector in the evolution of humanity, has been practiced globally under varying agropedoclimatic and social conditions. Over time, it has evolved through multiple forms, enabling continuous development. Its progress has been evaluated based on production capacity, level of mechanization, use of agrochemicals and integration, as well as its environmental impact. Thus, various systems of agriculture have developed, specific to different places, to various historical stages of socio-economic development, with different characteristics, but having a common goal: to increase the

production and quality of agricultural production, with a greater degree of stability of the level of production, for an ever-growing population (Mărin et al., 2025). Soil health is the cornerstone of sustainable agriculture, serving as the foundation for crop productivity, environmental resilience, and long-term ecosystem stability. Contemporary agricultural methods, characterized by excessive pesticide and fertilizer application, monoculture, and intensive tillage, have resulted in extensive soil degradation, requiring novel strategies to restore and sustain soil functionality (Țopa et al., 2025). Conservative agriculture is scientifically regarded as a holistic concept, which is based on all the components of the technological

system: from reduced tillage and fuel consumption to the complex management of plant residues, crop rotation, protective crops, fertilization, irrigation, crop protection, harvesting and transport (Dumitru et al., 2005; Cociu, 2016). Soil tillage of conservative agriculture define at present extremely varied processes from sowing directly into unworked soil (no-tillage, direct drill) to deep loosening without turning the furrow (Burtan et al., 2016; Cizmaş et al., 2022). Soil conservation practices, have the potential to positively impact important soil structure-mediated ecosystem functions (Wittwer et al., 2021) such as carbon sequestration, climate regulation, water purification, nutrient cycling and erosion risk reduction (Fabrizzi et al., 2005; Giambalvo et al., 2018; Norris and Congreves, 2018; Puerta et al., 2018; Schlüter et al., 2018; Seitz et al., 2018). However, these positive effects are variable and depend on the context and local conditions (Autret et al., 2020; Oliveira et al., 2024).

Conservation tillage and cover crops are among the most popular management practices to mitigate soil erosion and degradation (Blanco-Canqui et al., 2015; Townsend et al., 2016; Kaye and Quemada, 2017). They are also recognized as two widely used climate-smart agriculture practices that aim to enhance food security and build resilience to climate change (Lipper et al., 2014; Bai et al., 2019). In general, conservation tillage alleviates soil disturbance and maintains soil surface residue cover, which helps improve soil aggregation and stability (He et al., 2011), conserve soil water (Plaza-Bonilla et al., 2014), and reduce soil erosion (Puget and Lal, 2005). The physical characteristics of soil structure, porosity, bulk density, hydrological regime, the regime of air and heat changes depends on soil tillage systems. Many different researches showed that changes of physical features in a certain direction occurs slowly, after a shorter period when values begin to stabilize (Ferrerias et al., 2000; Reynolds et al., 2002; Guş et al., 2003; Fabrizzi et al., 2005; Osunbitan et al., 2005; Jităreanu et al., 2006). Soil physical

properties have a major influence on how the soil functions within an ecosystem (Dexter, 2004; Hamza and Anderson, 2005; Horn and Smucker, 2005; Pagliai, 2005). Through various technical means, these characteristics can be improved, in a way that they would compete to develop the capacity of the soil, to ensure optimal conditions for plant growth (Țopa et al., 2013).

Recently, some crop (Basche et al., 2016) and soil carbon (Maas et al., 2017; Nash et al., 2018) models have been used to evaluate the individual effects of tillage and cover crops on crop yield and SOC, but few of them addressed the interactive effects of tillage and cover crops. Besides, most ecosystem models that are used to investigate terrestrial biogeochemical cycles have not included detailed representations of tillage practices (Lutz et al., 2019). These limitations might bring large uncertainties to estimating the role of agriculture in the global biogeochemical balance and in assessments to strengthening resilience to climate change.

MATERIAL AND METHODS

Study area

This study was conducted in three areas affected by aridification: Cogealac, Constanța County (Latitude: N 44.57798; Longitude: E 028.48444), Rîmnicu de Jos, Constanța County (Latitude: N 44.3928; Longitude: E 028.2651), and Nalbant, Tulcea County (Latitude: N 45.06139; Longitude: E 028.64716). The investigated soil is classified as a typical Kastanozem (WRB-SR 2014). The Nalbant area, located in the Northern Dobrogea Plateau, is characterized by a temperate-continental climate with semiarid tendencies, reflected in average annual temperatures of approximately 10-11°C and low annual precipitation levels ranging from 330 to 420 mm. The aridity index varies between 17 and 21, while potential evapotranspiration exceeds 700 mm, leading to a strongly negative hydroclimatic balance. The studied typical Kastanozem exhibits a medium humus content (2-3%), slightly alkaline pH, and a fine sandy loam texture. The natural herbaceous vegetation is specific to dry

steppe ecosystems, transitioning toward semi-desert zones, and includes species such as *Stipa capillata*, *Poa bulbosa*, *Agropyron cristatum*, *Artemisia austriaca*, and *Medicago minima*. The prevailing climatic conditions represent a limiting factor for forest vegetation development.

The administrative-territorial unit of Cogealac, located in the northern part of Central Dobrogea, is characterized by a temperate-continental climate with strong semiarid influences. The average annual temperature is around 11-12°C, while precipitation levels are low, ranging between 300 and 400 mm per year, which contributes to a pronounced water deficit during the warm season. Rîmnicu de Jos, located in the southwestern part of Constanța County, is part of the Dobrogean steppe zone, characterized by a temperate-continental climate with semiarid influences, typical of the southern and central regions of Dobrogea. The mean annual temperature is approximately 11-12°C, with very hot and dry summers, and relatively mild winters, occasionally accompanied by episodes of strong winds. The precipitation regime is low, with average annual values ranging between 300 and 420 mm, leading to a pronounced water deficit, particularly during the May-September period. The interaction between the semiarid climate and intensified wind activity generates a high vulnerability to pedological drought and physical soil degradation, which necessitates the implementation of conservation-oriented agricultural practices, such as minimum tillage, appropriate crop rotations, and careful water management.

Soil sampling

Agro physical profiles were dug in the soil and samples were taken by 5-10; 25-30; and 45-50 cm depths. The analyses and determinations were performed according to current methodology and standards (Florea and Munteanu, 1987, 2003; Florea, 2012).

Physical determinations: granulometric composition, according to the pipette method

for fractions <0,02 mm, inclusive; wet and dry sieving method for fractions and subfractions included in the range 2 - 0.02 mm; bulk density determined by the drying method at 105°C (Dawi g/cm³); SR EN ISO 11272:2017; determination of water permeability (Ksat mm/h) constant water gradient method; Stas 7184/15:1991; determination of penetration resistance (RP kg f/cm²) Stas 7184/-88; Methods of physical soil analysis (2009); determination of total porosity (PT wi % v/v) methods of physical soil analysis (2009).

RESULTS AND DISCUSSION

The determination of soil physical indicators was carried out under field conditions, using standardized methods for soil sampling and analysis. The study aimed to compare the influence of two tillage systems: a conservation tillage system (minimum tillage, no-tillage, strip-till) and a conventional tillage system, applied at three predefined soil depths: 5-10 cm, 25-30 cm, and 45-50 cm. Soil data were collected during the spring seasons of 2024 and 2025, across three representative locations in the Dobrogea region: Cogealac, Rîmnicu de Jos, and Nalbant.

Bulk density DA_{wi} (g/cm³)

In the experimental field located at Cogealac, under the minimum tillage system (2024), bulk density values ranged between 1.12 g/cm³ and 1.23 g/cm³, indicating low to very low density, which suggests a well-structured, loose to very loose soil. In the spring of 2025, the values remained similar to those recorded in the previous year, with the exception of the 25-30 cm depth, where a slight compaction was observed (Figure 1).

In contrast, under conventional tillage (2024), bulk density values were higher, ranging from 1.11 g/cm³ to 1.31 g/cm³, indicating a more compacted soil structure, particularly at greater depths.

At the 25-30 cm depth, a value of 1.31 g/cm³ was recorded under conventional tillage at Cogealac, indicating a more

pronounced compaction (non-loose soil), typical for areas subjected to intensive mechanical operations. In comparison to the minimum tillage system, the soil exhibited higher bulk density, which may limit both water infiltration and root development, particularly during periods of water stress. At the Nalbant site, under conservation tillage, the results from the spring of 2024 indicated a well-loosened soil structure. However, in the spring of 2025, an increased compaction

was observed, and the soil was classified as slightly compacted.

Under conventional tillage at Nalbant, the situation appeared more balanced, yet with a compaction risk at the 25-30 cm depth, where a bulk density of 1.49 g/cm³ was recorded also classified as slightly compacted. Across treatments, bulk density values ranged between 1.05 and 1.37 g/cm³, indicating moderate variability depending on tillage intensity and sampling depth.

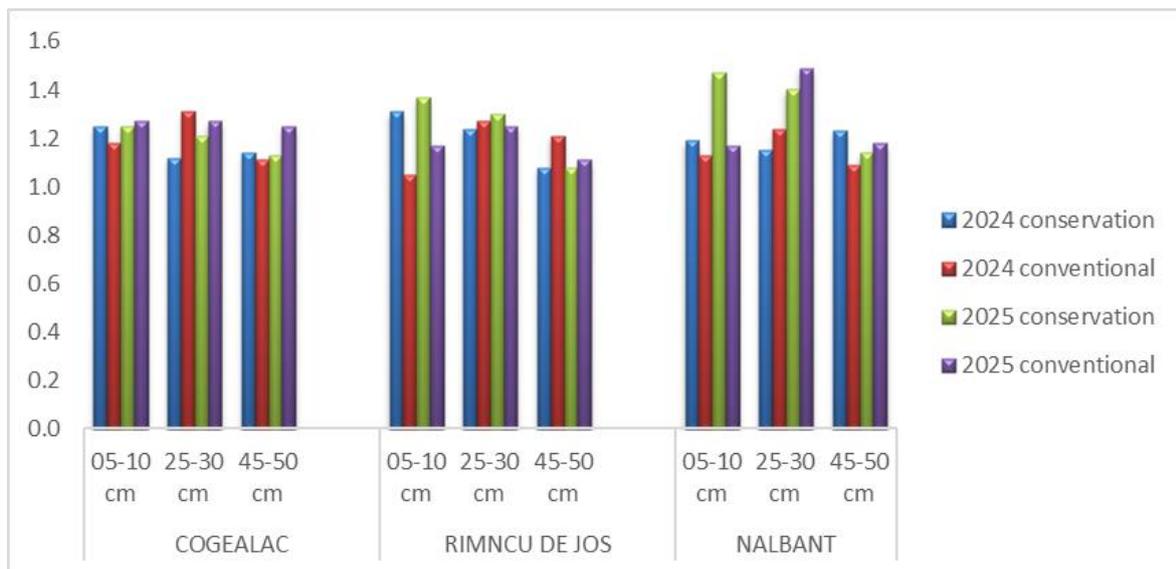


Figure 1. Impact of soil tillage systems on bulk density

In the conservation tillage system (no-till) applied at Rîmnicu de Jos, the bulk density values were slightly higher compared to those under the conventional system (classified as low to very low). In the conventional system, bulk density values remained similar across both sampling periods, indicating a stable bulk density over time. Under both tillage systems, the soil exhibited a structure favorable to plant growth and development.

Total Porosity PTwi % v/v

In the experimental field at Cogeaalac, the application of minimum tillage led to the maintenance of higher and more uniform total porosity values (PTwi, expressed as % v/v) compared to the conventional tillage system (Figure 2). This characteristic supports better water infiltration, soil aeration, and root system development. In the case of conventional tillage, total porosity

values were slightly lower, yet still fell within the interpretation class associated with non-compacted soils, with no signs of excessive compaction.

At the Nalbant site, total soil porosity ranged between 43.7% and 58.9% v/v, corresponding to moderate to very high interpretation classes. No significant differences were observed between the two tillage systems - conventional tillage and conservation tillage using strip-till - indicating a similar soil behavior in terms of pore structure, regardless of the technology applied.

In the third experimental area, Rîmnicu de Jos, total porosity values exceeded 48%, suggesting a generally good capacity of the soil to retain water and allow adequate aeration.

In the case of the no-till system, a slight decrease in total porosity was observed at

the first two depths analyzed (5-10 cm and 25-30 cm), indicating a non-compacted soil, yet with a slightly compacted structure near the surface.

In contrast, under the conventional tillage system, although a similar trend was noted, porosity values were higher, reflecting a more pronounced loosening of the soil structure.

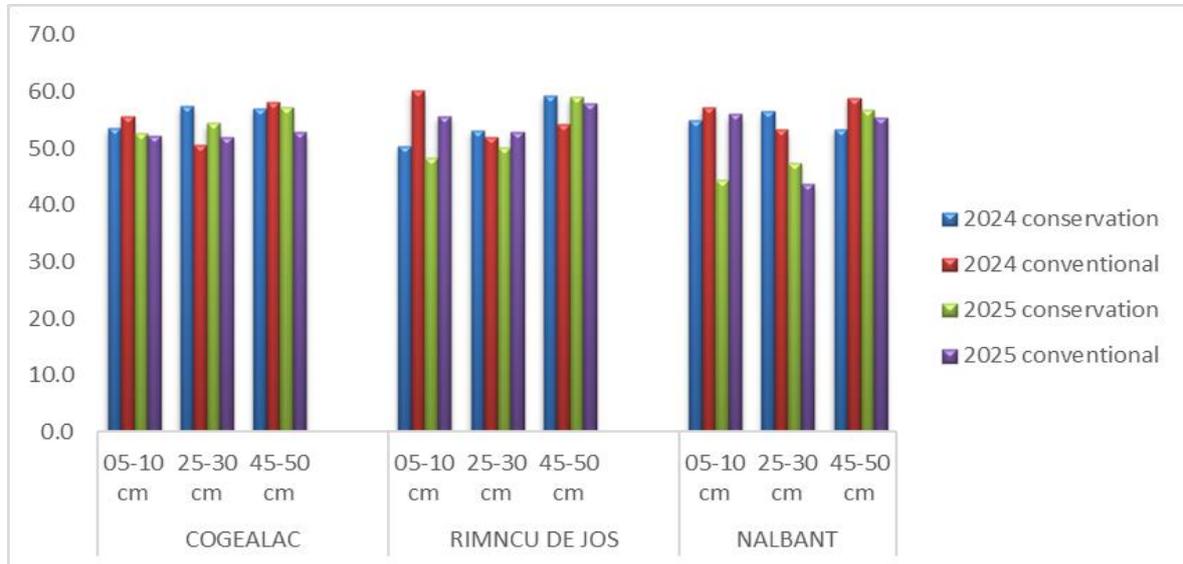


Figure 2. Impact of soil tillage systems on total porosity

Water permeability K_{sat} (mm/h)

Water permeability K_{sat} (mm/h) at the Cogevalac site, under the minimum tillage system, high water permeability values were recorded in 2024 at the second and third sampling depths: 25-30 cm (69.82 mm/h) and 45-50 cm (83.10 mm/h). In contrast, the first depth (5-10 cm) showed a low infiltration rate of 9.33 mm/h. These results suggest that porosity is better developed at greater depths. Under conventional tillage, water permeability values were more balanced across the profile, but generally lower. In 2025, under conservation tillage, high values were again observed at 25-30 cm (56.51 mm/h) and 45-50 cm (85.46 mm/h), confirming a trend of active porosity accumulation in the lower soil layers. Although the 5-10 cm layer still presented reduced permeability (19.03 mm/h), the value represented a 100% increase compared to 2024, indicating a notable improvement in water infiltration near the surface. Conversely, in the conventional tillage system, a marked decrease in water permeability was observed in 2025 compared to the previous year. The highest value was

recorded at 45-50 cm (35.14 mm/h), but overall, permeability remained lower than in the conservation system.

Conservation tillage contributes to improved water infiltration and helps reduce the risk of surface water ponding. In contrast, conventional tillage shows lower permeability, especially at the 45-50 cm depth. Over the long term, conservation practices demonstrate a better potential for adaptation to climate change, particularly under conditions of intense rainfall events. Under the strip-till system applied at Nalbant, the measured values were relatively similar across the profile, with the exception of 25-30 cm (73.23 mm/h) and 45-50 cm (112.79 mm/h), where very high infiltration rates were recorded. In the conventional tillage system, the values were more constant and uniform, indicating a more stable infiltration rate.

In the experimental field located in Rîmnicu de Jos, water permeability values exceeded 35.1 mm/h, which indicates a very high infiltration rate, characteristic of soils with a medium loam texture.

In the case of the conservation tillage system (no-till), an increase in water infiltration rate was observed with soil depth, as well as an improvement in permeability between the two sampling periods (spring 2024 and spring 2025).

This behavior reflects the stabilization of soil structure and the accumulation of organic matter at depth, both of which are typical features of conservation agriculture practices (Figure 3).

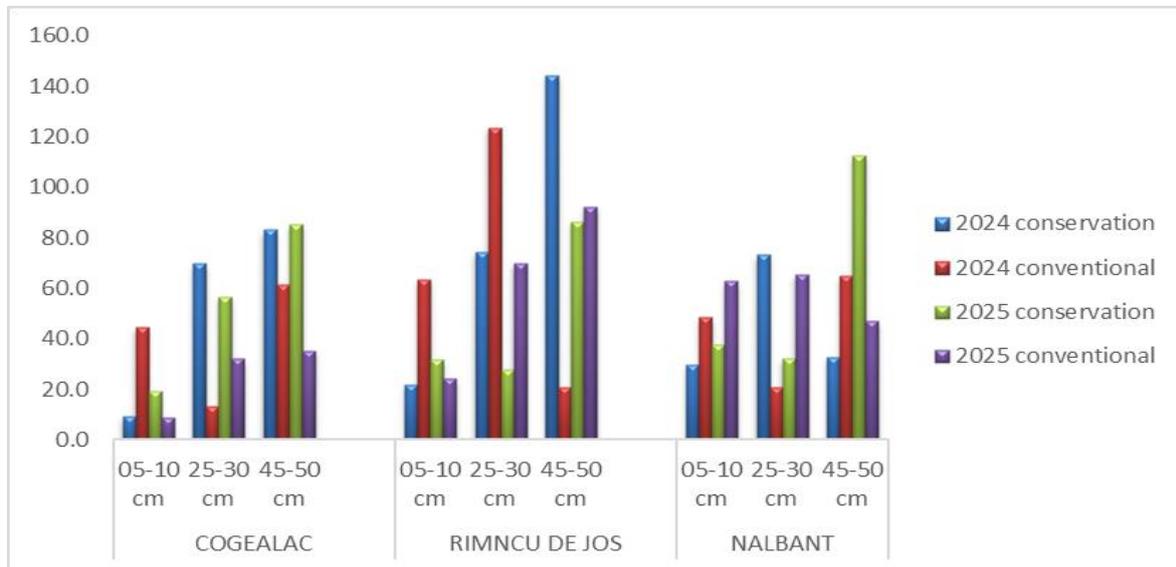


Figure 3. Mean phenotypic data values

In contrast, under the conventional tillage system, water permeability values were good during the first sampling period (2024); however, during the second sampling (2025), a significant decrease of approximately 50% was observed compared to the initial values. Nevertheless, the permeability level remained within the range considered favorable for water infiltration.

This reduction may be associated with the progressive compaction of the soil caused by repeated mechanical operations, which negatively affect soil porosity and the continuity

of macropores.

Penetration resistance Kgf/cm²

Soil penetration resistance (RP), expressed in Kgf/cm² (Figure 4), is an essential indicator for evaluating the degree of soil compaction and its impact on root system development. At the Cogeaalac experimental field, the application of the conservation tillage system (minimum tillage) resulted in moderate RP values in 2024, with a minimum of 11 Kgf/cm² at the 25-30 cm depth and a maximum of 27 Kgf/cm² at 5-10 cm depth.

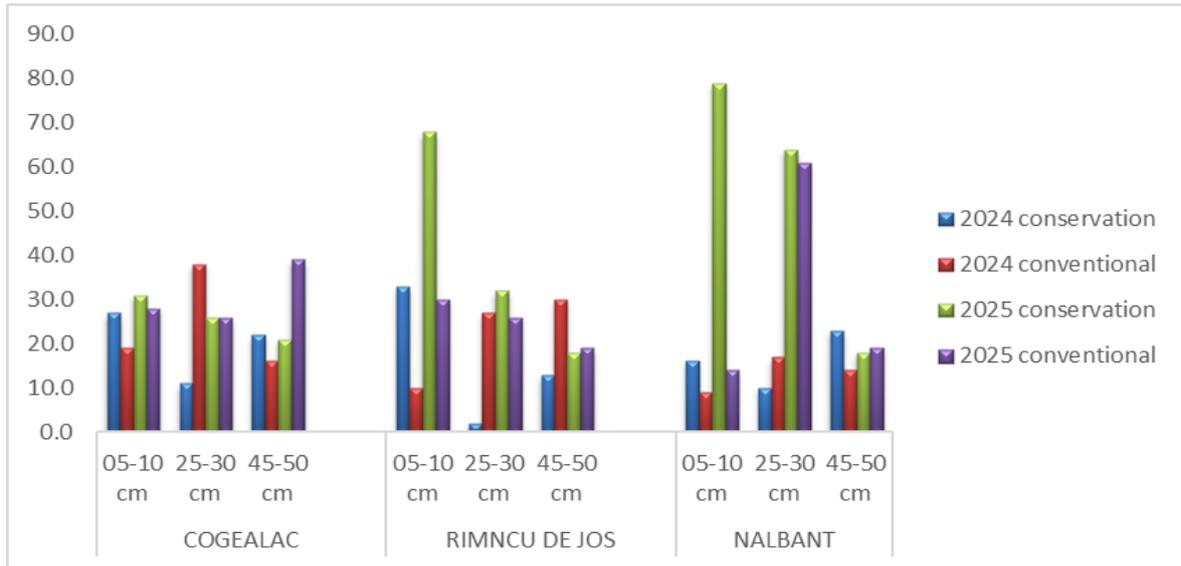


Figure 4. Impact of soil tillage systems on penetration resistance

In spring 2025, under the same tillage system, an increase in RP values was recorded, reaching 31 Kg/cm² at 5-10 cm, indicating a partial limitation of root growth, most likely due to natural soil consolidation and the absence of deep mechanical interventions. In contrast, the conventional tillage system recorded a maximum RP value of 38 Kg/cm² at the 25-30 cm depth in 2024, suggesting pronounced compaction at this level, likely caused by intensive machinery traffic and the disruption of soil structure. In 2025, an additional increase in penetration resistance was observed at the deepest layer (45-50 cm), reaching 39 Kg/cm², highlighting a clear tendency of deep compaction, which may negatively affect water infiltration and root development.

At the Nalbant experimental field, the analysis of soil penetration resistance (RP) reveals significant differences between the two tillage systems evaluated.

Under the conservation tillage system, the results obtained in spring 2024 indicate a well-structured soil, with RP values within the range considered favorable for root development. However, in spring 2025, a significant increase in penetration resistance was recorded under conservation tillage at the Nalbant site, reaching 79 Kg/cm², which indicates excessive soil compaction with potential negative effects on water infiltration and air circulation.

In the conventional tillage system, the situation was relatively more balanced, with moderate RP values overall, although a compacted layer was observed at 25-30 cm, likely due to machinery traffic and structural disruption of the soil.

At the Rîmnicu de Jos experimental site, the application of conservation tillage in spring 2025 showed notable surface compaction, with RP values at 5-10 cm indicating a partial limitation of root system development. This condition can be attributed to the absence of mechanical loosening of the upper layer, which is typical of conservation practices.

By comparison, under conventional tillage, penetration resistance values were more balanced throughout the soil profile, without significant variations between depths, indicating a more uniform compaction pattern across the profile.

CONCLUSIONS

Considering the pedoclimatic characteristics of southeastern Romania, characterized by predominately Kastanozem soils a semi-arid climate, low annual rainfall (300-420 mm), high average temperatures, and an increased risk of pedological drought and physical soil degradation, the results of this study support the adoption of conservation tillage technologies (no-till, minimum tillage, strip-till).

Conservation systems have demonstrated superior effectiveness compared to conventional tillage by: maintaining a favorable soil structure (active porosity, structural stability), reducing soil compaction, especially in critical layers at 25-50 cm depth, improving the infiltration capacity of water, preserving soil moisture and minimizing water loss through evaporation and surface runoff, and enhancing soil resilience under climate stress conditions (drought, heavy rainfall).

In the context of climate change, these systems support sustainable and resilient agriculture, offering an effective alternative for the protection of soil resources.

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