

IMPROVEMENT OF SOIL PHYSICAL PROPERTIES THROUGH THE INTEGRATION OF GREEN MANURE CROPS UNDER THE PEDO-CLIMATIC CONDITIONS OF BRĂILA

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Abstract

During the agricultural years 2022-2023 and 2023-2024, a study was carried out at SCDA Brăila, under the specific pedo-climatic conditions of the area, to evaluate the effect of green manures on selected soil physical properties, namely soil penetration resistance and bulk density. The experiment included autumn pea, mustard, rye, rapeseed, and a mustard + rapeseed mixture as green manure crops, compared with a control without green manure. Measurements were performed along the soil profile, assessing depth-dependent changes in penetration resistance and bulk density as indicators of soil structure and compaction. The results obtained over the two years show that green manure use led to an overall improvement in the analyzed soil physical parameters. Soil penetration resistance decreased in the upper soil layers, while bulk density improved compared with the control, indicating more favorable conditions for root growth and for water and air movement. Although the magnitude of the effect varied among species, all green manure treatments contributed to reducing soil compaction and improving soil physical quality, supporting the role of green manures in conservative soil management.

Key words: green manures, soil penetration resistance, bulk density.

INTRODUCTION

The intensification of agricultural systems, characterized by repeated soil tillage and the predominant use of mineral fertilization, has frequently led to soil structure degradation, a reduction in organic matter content, and decreased aggregate stability. Under the pedo-climatic conditions of the Brăila area, where Chernozems soils predominate and the rainfall regime is often limiting, maintaining soil physical properties is a key prerequisite for yield stability and efficient water use.

Green manures represent a viable agronomic alternative for restoring soil fertility and improving soil structure. The incorporation of fresh plant biomass contributes to increased organic matter content, enhanced particle aggregation, and improved water retention capacity. Green manure crops can supply approximately 80-100 kg N/ha within 40-50 days of growth, while leguminous species provide an additional contribution through biological nitrogen fixation. In addition, the input of organic residues promotes an increase in soil organic carbon and improves soil structure through the formation of stable

aggregates. The input of plant biomass promotes the formation and stabilization of structural aggregates, reduces bulk density, and increases soil porosity, with direct effects on air and water movement within the soil profile. The root systems of crops used as green manures also contribute to the natural loosening of the soil and to improved water infiltration and retention, supporting the development of subsequent crops and the functional stability of soil in sustainable agricultural systems. (Sumiahadi et al., 2020; Gulaiya et al., 2024).

These crops contribute to improving the physical, chemical, and biological properties of soil by increasing organic matter content and nutrient availability. They reduce soil compaction, improve soil structure and aggregation, and stimulate microbial activity. Green manure crops also increase soil water retention capacity, reduce bulk density, and limit nutrient losses through leaching. Species such as rye (*Secale cereale* L.), triticale (*Triticosecale rimpaui*), and barley (*Hordeum vulgare* L.) are commonly used to protect soil against erosion, while legumes such as grass pea (*Lathyrus sativus* L.) and clover (*Trifolium* spp.) contribute to

improved nutrient cycling and the maintenance of soil fertility (Topa et al., 2025).

Analyses reported in the scientific literature show that the use of cover crops can reduce soil bulk density by about 4% on average, depending on the species, soil type, and management system. Species such as rye (*Secale cereale*), hairy vetch (*Vicia villosa*), sunn hemp (*Crotalaria juncea*), and pearl millet (*Pennisetum glaucum*) have demonstrated the ability to reduce soil compaction and increase total porosity, thereby improving the physical conditions for root development as well as water and air movement in the soil (Haruna et al., 2020).

It has been demonstrated that annual legumes such as red clover (*Trifolium pratense*) and common vetch (*Vicia sativa*) are frequently associated with increased structural stability and reduced soil bulk density. Species such as yellow lupine (*Lupinus luteus*) contribute to improving soil texture and reducing compaction and are particularly recommended for lighter or degraded soils. In addition, crops such as mustard (*Brassica juncea*) and forage rape, used as green manures, are associated with increased total porosity and improved soil structure (Sumiahadi et al., 2020); they can be easily integrated into crop rotations in Romania due to their low technological requirements and good climatic adaptability.

The use of green manures contributes not only to the improvement of the physical characteristics of the soil but also to the enhancement of its chemical properties by increasing organic carbon content and nutrient availability. Species such as clover, barley, rye, and triticale used as green manure have been shown to increase soil organic carbon, phosphorus, and potassium levels compared with the control treatment (Soleymani & Shahrajabian, 2011).

In an experiment conducted on a clay soil cultivated under an organic system, soil bulk density was higher in the control treatment (approximately 1.30 g cm^{-3}), while the application of green manure reduced this value to about 1.22 g cm^{-3} , with the effect being more pronounced in the surface soil layer (Műjdecı et al., 2020).

In experiments conducted on eroded soils in north-western Romania, organic fertilization

with green manure crops led to a reduction in soil bulk density by approximately 2.1-4.7% compared with the control treatment. Lower values were recorded in plant mixtures (for example vetch + oat + ryegrass or lupine + oat + rape) compared with single crops. At the same time, the use of these crops reduced soil penetration resistance from 26.8 kgf/cm^2 in the control treatment to values ranging from about 19.9 to 21.5 kgf/cm^2 in the green manure treatments, indicating improved loosening of the arable layer and more favorable conditions for plant root development (Pantiş, 2016). In a similar experiment conducted under the same conditions on an eroded soil, the use of green manure crops led to a decrease in soil bulk density from 1.53 g/cm^3 in the control treatment to values between 1.38 and 1.43 g/cm^3 , depending on the species or mixture used. At the same time, penetration resistance values decreased from 25.6 kgf/cm^2 in the control treatment to approximately $19\text{-}21 \text{ kgf/cm}^2$ in the treatments with green manure crops (Domuţa et al., 2010).

In a study conducted on a cambic chernozems, the incorporation of vetch (*Vicia sativa*) biomass as green manure led to an improvement in the structure of the arable layer and an increase in organic matter content. Experimental data showed that in the surface layer (0-10 cm), soil bulk density decreased from 1.24 g/cm^3 in the control treatment to 1.16 g/cm^3 after the incorporation of two green biomass harvests, while penetration resistance decreased from 13 to 9 kgf/cm^2 , indicating better soil loosening and increased porosity (Leah, 2017).

Soils in south-eastern Romania frequently face pedoclimatic constraints that limit soil fertility and agricultural productivity. The more arid climate of this region favors water deficit and a lower organic matter content in the soil, which negatively affects soil structure and water-holding capacity. These characteristics can limit root system development, restrict the movement of water and air in the soil, and contribute to the degradation of soil physical properties (Păltineanu et al., 2025)

To address these constraints and evaluate the role of green manure crops in improving soil physical properties, an experiment was conducted at ARDS Brăila, a representative area for south-eastern Romania. The experiment

included autumn pea, mustard, rye, rapeseed, and a mustard + rapeseed mixture as green manure crops, compared with a control treatment without green manure. Measurements were performed along the soil profile, analyzing depth-dependent variations in penetration resistance and bulk density as indicators of soil structure and compaction.

MATERIALS AND METHODS

The study was conducted during the 2022-2023 and 2023-2024 agricultural years at SCDA Brăila, under the local pedoclimatic conditions. The experiment was set up at the Chiscani Experimental Center on a Calcaric Alluvial Chernozem (SRTS, 2012).

For the implementation of the experiment, green manure crops were sown under the following treatments:

- a1 - unfertilized with green manure (control);
- a2 - autumn pea green manure;
- a3 - mustard green manure;
- a4 - rye green manure;
- a5 - mustard + rapeseed green manure;
- a6 - rapeseed green manure.

The green manure crops were sown in the last decade of August during both experimental years. The chopping and incorporation of the green manure were carried out in the first decade of April in all three years of the experiment, at the budding-flowering stage, respectively at the stem elongation-booting stage in rye, using disk tillage. The mustard green manure treatment entered the winter at the budding–flowering stage and, depending on annual conditions, was partially or completely affected by frost.

Measurements of soil bulk density and penetration resistance were performed 30 days after the incorporation of the green manure crops.

Bulk density was determined in undisturbed soil samples taken by steel cylinders (Blake and Hartge, 1986).

In the experimental research presented in this study, a digital electronic cone penetrometer, FieldScout SC 900 (Figure 1), was used to measure the resistance force to cone penetration and the penetration depth in the soil. Penetration resistance was determined at each of the three points at 2.5 cm intervals, down to a depth of 45 cm, using the FieldScout SC 900 penetrometer.



Figure 1. FieldScout SC 900 penetrometer

RESULTS AND DISCUSSIONS

Green manure influence on bulk density

In 2023, soil bulk density recorded lower values in all treatments following the incorporation of green manures compared with the control (1.37 g/cm³), indicating an improvement in soil physical condition. The measured values ranged between 1.27 and 1.32 g/cm³, corresponding to 92.8-96.2% of the control.

The greatest reduction in bulk density was observed in the mustard treatment (1.27 g/cm³; -0.10), followed by the mustard + rapeseed and rye treatments (1.29 g/cm³; -0.08). Rapeseed and autumn pea showed more moderate decreases of -0.06 and -0.05 g/cm³, respectively (Table 1).

Table 1. Green manure influence on bulk density, 2023

Green manure	Bulk density		Difference	Signif..
	(g/cm ³)	%		
Autumn pea	1.32	96.2	-0.05	o
Mustard	1.27	92.8	-0.10	ooo
Rapeseed	1.31	95.9	-0.06	o
Mustard + rapeseed	1.29	94.4	-0.08	oo
Rye	1.29	94.4	-0.08	oo
Control	1.37	100	-	Control
LSD 5% = 0.04; LSD 1% = 0.06; LSD 0.1% = 0.09				

The results highlight the beneficial effect of green manures, particularly mustard grown as a sole crop as well as in mixture with rapeseed, on reducing soil compaction and improving soil physical properties.

In 2024, soil bulk density was lower in all green manure treatments compared with the control (1.34 g/cm³), confirming their beneficial effect on soil physical condition. The recorded values ranged from 1.26 to 1.33 g/cm³, corresponding to 94.0-99.5% of the control.

The greatest reductions in bulk density were observed in the rye treatment (1.26 g/cm³; -0.08) and in the mustard + rapeseed mixture (1.27 g/cm³; -0.07), followed by mustard (1.29 g/cm³; -0.05). Rapeseed and autumn pea showed smaller decreases of -0.03 and -0.01 g/cm³, respectively (Table 2).

Statistical analysis indicates that the rye and mustard + rapeseed treatments showed distinctly significant differences compared with the control (LSD 5% = 0.05), whereas mustard had a weaker effect and the other treatments did not exceed the significance threshold.

Table 2. Green manure influence on bulk density, 2024

Green manure	Bulk density		Difference	Signif..
	(g/cm ³)	%		
Autumn pea	1.33	99.5	-0.1	-
Mustard	1.29	96.3	-0.05	o
Rapeseed	1.31	97.5	-0.03	-
Mustard + rapeseed	1.27	94.6	-0.07	oo
Rye	1.26	94.0	-0.08	oo
Control	1.34	100	-	Control
LSD 5%= 0.05; LSD 1%= 0.07; LSD 0.1%= 0.10				

The results confirm that green manures, particularly rye and the rapeseed–mustard mixture, contribute to reducing soil compaction; however, the magnitude of the effect was lower compared with the previous year, suggesting an influence of climatic conditions on the intensity of the soil response.

Green manure influence on penetration resistance

In 2023, soil penetration resistance (Tabel.3) varied depending on the type of green manure applied, compared with the control (31.56 daN/cm²). Most treatments led to a reduction in this parameter, indicating a decrease in soil compaction.

The greatest reduction in penetration resistance was recorded in the mustard treatment (26.11 daN/cm²; 82.7% of the control), with a difference of -5.45, exceeding the LSD 0.1% threshold (2.91), which indicates a highly significant difference. Rye also showed a substantial decrease (28.92 daN/cm²; -2.64), with a distinctly significant difference (p < 0.01). The autumn pea (30.14 daN/cm²; -1.43)

and mustard + rapeseed (30.13 daN/cm²; -1.44) treatments showed moderate reductions, close to the LSD 5% threshold (1.42), and were considered statistically significant.

In contrast, rapeseed showed a slight increase in penetration resistance (31.82 daN/cm²; +0.25), which was not statistically significant, indicating a limited effect on soil loosening.

Table 3. Green manure influence on penetration resistance, 2023

Green manure	Penetration resistance		Difference	Signif..
	(daN/cm ²)	%		
Autumn pea	30.14	95.6	-1.43	o
Mustard	26.11	82.7	-5.45	ooo
Rapeseed	31.82	100.8	0.25	-
Mustard + rapeseed	30.13	95.4	-1.44	o
Rye	28.92	91.6	-2.64	oo
Control	31.56	100	-	Control
LSD 5%= 1.42; LSD 1%= 2.01; LSD 0.1%= 2.91				

The results indicate that green manures contribute to reducing soil compaction, with the strongest effect observed for mustard and rye, which significantly improve soil physical properties.

Soil penetration resistance increased progressively along the 0-45 cm profile in all analyzed treatments (Figure 2), with minimum values in the surface layer (0-10 cm) and maximum values in the 25-35 cm zone. The control consistently showed the highest values, indicating a higher degree of compaction.

The application of green manures reduced penetration resistance throughout the soil profile, with the effect being more pronounced in the 20-35 cm interval, where the differences compared with the control were greatest. This zone corresponds to a compacted layer whose intensity was diminished in the presence of green manure crops. The lowest penetration resistance values were recorded in the mustard, rye, and mustard + rapeseed treatments, which showed a higher capacity to loosen the soil. In contrast, the differences among treatments decreased slightly in the deeper layer (35-45 cm), where the influence of the root system is more limited.

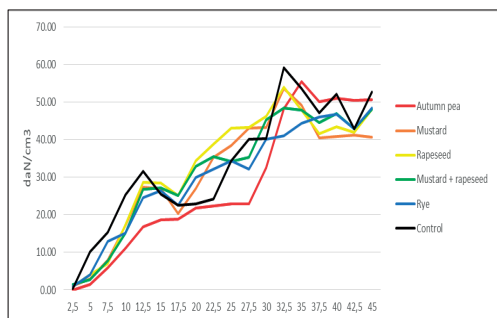


Figure 2. Soil penetration resistance along the 0-45 cm profile under the influence of green manures, 2023

In 2024, soil penetration resistance (Tabel 4) was reduced in all green manure treatments compared with the control (32.32 daN/cm²), indicating a clear improvement in soil physical condition and a decrease in compaction.

Table 4. Green manure influence on penetration resistance, 2024

Green manure	Penetration resistance		Difference	Signif..
	(daN/cm ³)	%		
Autumn pea	28.93	89.5	-3.39	ooo
Mustard	25.01	77.4	-7.31	ooo
Rapeseed	27.93	86.4	-4.39	ooo
Mustard + rapeseed	25.69	79.5	-6.63	ooo
Rye	25.30	78.3	-7.02	ooo
Control	32.32	100	-	Control
LSD 5%= 0.66; LSD 1%= 0.94; LSD 0.1%= 1.36				

The recorded values ranged from 25.01 to 28.93 daN/cm², corresponding to 77.4-89.5% of the control. The greatest reductions were observed in mustard (25.01 daN/cm²; -7.31), rye (25.30 daN/cm²; -7.02), and the mustard + rapeseed mixture (25.69 daN/cm²; -6.63). These differences significantly exceed the LSD 0.1% threshold (1.36) and are therefore considered highly significant.

Rapeseed (27.93 daN/cm²; -4.39) and autumn pea (28.93 daN/cm²; -3.39) also resulted in notable reductions, although of lower magnitude compared with the other treatments, yet still exceeding the statistical significance threshold. Statistical analysis shows that all green manure treatments had a highly significant effect on

reducing penetration resistance, confirming their effectiveness in improving soil structure.

The results demonstrate that green manures consistently contribute to reducing soil compaction, with a more pronounced effect in 2024 compared with the previous year, suggesting a favorable interaction between crop type and climatic conditions on the soil's physical response.

In 2024, soil penetration resistance increased gradually along the 0-45 cm profile in all analyzed treatments (Figure 3), with low values in the surface layer (0-10 cm) and maximum values in the 30-35 cm interval. The control consistently recorded the highest values, reaching a maximum of approximately 58-60 daN/cm², indicating a high degree of compaction.

The application of green manures led to a reduction in penetration resistance throughout the soil profile, with the differences compared with the control being most evident in the 20-40 cm layer. This zone corresponds to a compacted layer whose intensity was reduced in all treated variants.

The lowest penetration resistance values were observed in the mustard, rye, and mustard + rapeseed treatments, which limited the excessive increase in resistance in the critical zone of the profile. Rapeseed and autumn pea showed intermediate values, while still remaining below the control.

In the deeper layer (35-45 cm), resistance values remained high, but the differences among treatments decreased, suggesting a weaker influence of the root system at these depths.

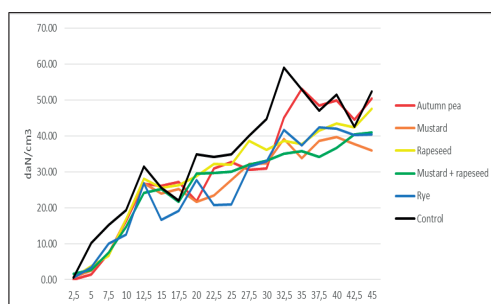


Figure 3. Soil penetration resistance along the 0-45 cm profile under the influence of green manures, 2024

The results highlight the effectiveness of green manures in reducing soil compaction across the entire analyzed profile, with a more pronounced effect in 2024, particularly in the zone of maximum compaction.

CONCLUSIONS

The results obtained over the two experimental years demonstrate that the incorporation of green manure crops led to a consistent improvement in soil physical properties under the pedo-climatic conditions of Brăila.

All green manure treatments contributed to a reduction in soil bulk density compared with the control, indicating improved soil structure and increased porosity. The most pronounced effects were observed for mustard, rye, and the mustard + rapeseed mixture, which showed a higher capacity to reduce soil compaction.

Soil penetration resistance was also significantly reduced in the presence of green manures, particularly in the 20-40 cm soil layer, where compaction was most evident. The strongest effects were recorded for mustard and rye, which consistently showed the lowest resistance values and the highest efficiency in loosening the soil.

The magnitude of the improvements varied between years, with more pronounced effects observed in 2024, suggesting that climatic conditions play an important role in modulating the response of soil physical properties to green manure application.

Overall, the results confirm that green manures represent an effective agronomic practice for reducing soil compaction and improving soil physical quality, with positive implications for root development, water infiltration, and the sustainability of cropping systems.

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