Scientific Papers. Series A. Agronomy, Vol. LXV, No. 1, 2022
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

MITIGATION OF SOIL COMPACTION BY APPLYING DIFFERENT TILLAGE SYSTEMS

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Abstract

The objective of our work is to present the results of a short-term study in which four different tillage types were tested in order to mitigate soil compaction. The experiment was conducted on a clay-loam soil located in Draganesti-Vlasca Agricultural Research Station in the year of 2018. The tillage variants tested were mouldboard ploughing, subsoiling and chiseling and the control variant was disking. Within each of the tested variants soil physical and chemical properties were determined in laboratory (e.g. saturated hydraulic conductivity, water stable aggregates, bulk density, penetration resistance, soil organic carbon and pH). The obtained results showed that the bulk density values were lower both in topsoil and subsoil in the variant with subsoiling tillage while in the control variant (2 times disking) the bulk density values were higher. The similar tendency was recorded for penetration resistance values. As for the water stable aggregates and saturated hydraulic conductivity, high values were also obtained in the variant where subsoiling was applied, whereas in the variants with mouldboard ploughing and chiseling similar values were obtained. Again, the control variant had the lowest values for both water stable aggregates and saturated hydraulic conductivity. The soil chemical properties did not vary significantly between the tested variants. The soil organic carbon varied between 2.06 and 2.34%, while the soil pH ranged between 5.99 and 6.63. The experimental study showed promising results for mitigating soil compaction by applying subsoiling. The most sensitive soil property to compaction due to tillage was found to be saturatedhydraulic conductivity. Soil chemical properties were not affected by different soil tillages.

Key words*: soil compaction, subsoiling, bulk density, tillage.*

INTRODUCTION

Soil compaction is a worldwide threat for agriculture and a soil physical degradation process which is due to the destruction of soil micro- and macro-aggregates under a certain stress. Soil compaction may affect various ecosystem services such as water retention and movement in soils (Dexter and Zoebisch, 2002), root growth and crop yields (Lipiec et al., 2003).
Soil compaction not only reduces the production of agricultural and forestry crops, but also has negative effects on the environment. For example, the saturated hydraulic conductivity of the soil decreases, and the risk of leakage of water and pollutants to surface waters and the washing of nitrates and pesticides to groundwater increases. It also reduces the volume of soil that can act as a buffer for pollutants and increases the risk of soil erosion due to the presence of excess water over compacted soil layers. Due to the decrease in soil aeration, the production of greenhouse gases by denitrification can take place in the soil due to anaerobic processes.
Taking into account the negative effects of compaction on the soil, the European Commission's proposal for a Framework Directive for the Soil is to say that compaction is one of the major threats to sustainable soil quality in Europe.
Compaction of the subsoil, defined as "soil material below the normal cultivation depth or pedestrian horizon A", is particularly proble-matic because it is difficult and expensive to improve. The risks of underground compaction increase with the increase in farm size, equipment size, and increased mechanization due to the requirements for higher productivity.
When analysing soil compaction, a distinction should be made between the susceptibility of soils to compaction and their vulnerability (Jones et al., 2003). Susceptibility is the likelihood of compaction occurring if a soil is subject to factors that are known to produce compaction of that soil. Susceptibility to compaction depends on intrinsic characteristics,

such as texture and carbon content, and in the short term depends on variable properties, such as, for example, soil moisture. It ranges from sandy (non-susceptible) soils - sandy-sandy - sandy-clayey - clayey - clay-clayey - loamy-clayey - clayey. Clay soils with medium and fine texture are resistant to external mechanical stresses at low soil moisture but are highly susceptible to severe compaction at high soil moisture.

The vulnerability of the soil to a particular degradation process is determined taking into account the intrinsic susceptibility of the soil and the estimation of exposure to the degradation process (Borrelli et al., 2016), which is based on the assessment of stresses induced by land management and climate.

The soil's intrinsic susceptibility to compaction is estimated based on soil properties that are relatively stable, such as texture, clay type, bulk density, organic matter content, structure, saturated hydraulic conductivity (Saffit-Hdadi et al., 2009).

In this context, the paper presents the results of a short-term study in which four different tillage types were tested in order to mitigate soil compaction.

MATERIALS AND METHODS

The study is located at Agricultural Research Station from Drăgănești-Vlașca (TR), in an area characterised by natural subsoil compaction. The soil type is CambicChernozem with a clay loam texture. The experiment consisted of a pilot study established in March 2018, and its aim was to mitigate natural soil compaction by tillage. The experimental design was a split plot (36 plots, 6 m × 33 m) with three blocks and involving four treatments: TR1 - mouldboard ploughing with furrow inversion to 25 cm depth, TR2 - subsoiling to 60 cm by ripping and disking to 12 cm depth, TR3 - a control treatment with 2-times disking, and TR4 - chiselling to 25 cm depth with furrow inversion. The testing of tillage treatments also involved three rotations with deep-rooting leguminous crops. Only the main effect of the tillage treatments on the soil physical properties is reported here.

Soil physical and chemical parameters were measured in all plots. For this, disturbed soil samples were collected in autumn of 2018 after crop harvesting for soil water-stable aggregates (WSA, in % g/g) >250 μm, and undisturbed soil cores (100 cm^3 volume) were sampled at 10–20 cm and 40-50 cm depths for soil physical analyses: saturated hydraulic conductivity (Ks, in m s^{-1}) and bulk density (BD, in g cm^{-3}).

The content of water-stable aggregates was measured by the Henin–Feodoroff method based on wet sieving (SR EN ISO 10930:2012). The Ks was determined according to the steady-state falling head method (Romanian standard: STAS 7184/15–91). The BD was gravimetrically determined by weighing the soil core samples before and after drying for 24 h at 105°C (SR EN ISO 11272:2017).

The results obtained for the measured soil properties were then statistically analysed by one-way repeated measure ANOVA considering the soil tillage as the tested factor. Post-hoc pairwise comparisons of the least-squares means were performed using the Tukey method to adjust for multiple comparisons ($p < 0.05$). All statistical analyses were performed with OriginLab 6.1 software (Origin Lab Corporation, Northampton, MA, USA).

RESULTS AND DISCUSSIONS

The soil from this study was characterized in terms of hydro-physical and chemical properties.

The soil type is a CambicChernozem with clay loam texture, and a clay content varying from 44.2% in topsoil layer to 45.2 % in subsoil layer (Table 1).

Table 1. Physical characterization of the soil profile

Location	Depth (cm)	Clay content (%)	Organic matter (%)	Bulk density (Mg m^{-3})	Texture class
Drăgănești - Vlașca	10-20	44.2	2.25	1.43	clay loam
	40-50	45.2	1.45	1.39	

Soil compaction changes the pore space size, distribution and soil strength. One way to quantify the change is by measuring the bulk density. As the pore space decreases within a soil, the bulk density increases. Such soils with a higher percentage of clay and silt which naturally have more pore space, have a lower bulk density than sandy soils.

For the BD in the topsoil (Table 2), the mean value in the subsoiling treatment (TR2) ranged from 1.27 g cm^{-3} in topsoil to 1.32 g cm^{-3} in subsoil and was always significantly different from the other treatments, which had higher values between 1.44 g cm^{-3} in TR3 to 1.48 g cm^{-3} in TR1 (Figure 1).

For the BD in the subsoil (Table 2), the results follow the same trend as for the topsoil regarding the subsoiling treatment (TR2: 1.27 g cm^{-3}) and had significantly lower values than the other tillage treatments (TR4: 1.39 g cm^{-3}; TR3: 1.51 g cm^{-3}) (Figure 1).

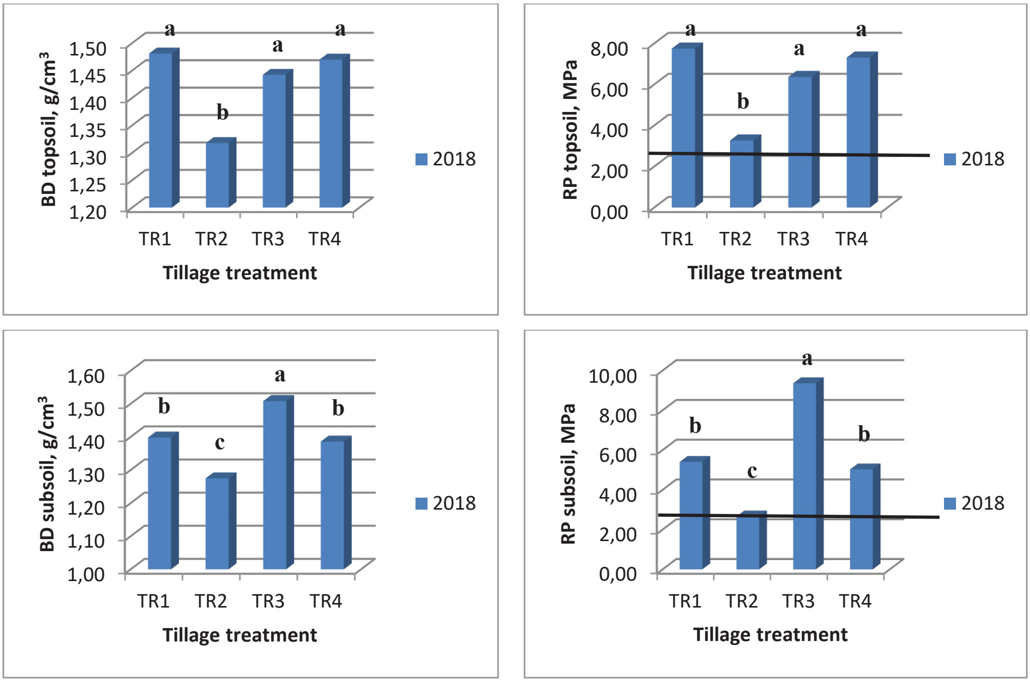

Figure 1. Topsoil (10-20 cm) and subsoil (40-50 cm) bulk density and penetration resistance as affected by different tillages. The black line represents the RP at 2.5 MPa, which is considered as critical limit for root growth

Soil penetration resistance was calculated using a pedotransfer function (Canarache, 1990), its equation being as follows:

$$RPst = 0.55 * 1.047^{C} * BD^{7.53}$$

where: *RPst* is the standard penetration resistance (in $Kgfcm^{-2}$), *C* the clay content (soil particles <0.002 mm, in %, g/g) and *BD* the bulk density (in g cm^{-3}). Then, the resulted penetration resistance values were converted from $Kgfcm^{-2}$ to MPa by using the following conversion factor:

$$1\, kgf/cm^{2} = 9.80665 \cdot 10^{-2} MPa$$

The penetration resistance (RP) was affected by tillages and is correlated with bulk density (Figure 1). For topsoil layer, higher values of BD in TR1, TR3 and TR4 resulted in high values of RP (6.37-7.74 MPa), all of them exceeding the critical limit for root penetration,even in TR2 the RP value exceeded by 0.77 MPa. This can lead to loses of crop yields in time due to formation of a compacted layer below the tillage depth. The tillage variant TR2 (subsoiling) recorded for RP an average value of 3.27 MPa.

Table 2. Bulk density (BD, g cm^{-3}) for different tillage treatments

Soil layer	Treatment	2018	
		Mean	± s.d.
Topsoil	TR1	1.48	0.024
	TR2	1.32	0.039
	TR3	1.44	0.032
	TR4	1.47	0.023
Subsoil	TR1	1.40	0.051
	TR2	1.27	0.035
	TR3	1.51	0.028
	TR4	1.39	0.044

The subsoil layer showed the same tendency of values between the tillage variants. While the RP values in TR1, TR3 and TR4 ranged between 5.02-9.36 MPa, the average RP value in TR 2 was 2.66 MPa.

In case of both topsoil and subsoil RP values, the statistical analysis showed that there are significant differences between tillage variants.

Continuous mouldboard ploughing or disking at the same depth will cause serious tillage pans (compacted layers) just below the depth of tillage in some soils (Parvin et al., 2014). This tillage pan is generally relatively thin (3 to 5 cm thick), may not have a significant effect on crop production, and can be alleviated by varying depth of tillage over time or by special tillage operations, such as subsoiling (Piccoli et al., 2022).

The studied soil is susceptible to degradation by natural subsoil compaction. Compaction is a worldwide problem, and the problems caused by this may be: a decreased root length, retarded root penetration and shallower rooting depth (Nawaz et al., 2013). The soil compaction can result in greater concentration of roots in upper soil layer and reduced root growth in deeper soil layer, mostly due to excessive mechanical impedance such as hard pan which is formed below the tillage depth.

Water stable aggregates (WSA) were significantly affected by soil tillage (Figure 2).

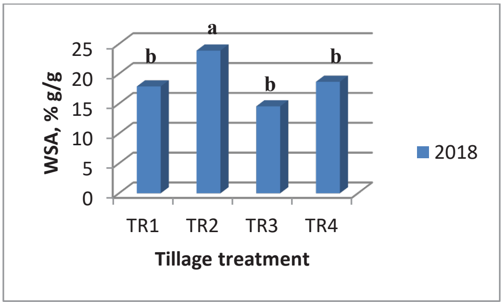

Figure 2. Water stable aggregates in topsoil layer as affected by different tillages

The most pronounced negative effect was observed in the control variant where the soil tillage by disking was two times done (TR3) and the WSA content was the smallest (15% g/g). The less disturbed the soil, as is the case for subsoiling variant (TR2), the higher the content of water stable aggregates (24% g/g).

When statistical analysis was done for comparison of WSA within tillage treatments, the content of water stable aggregates was statistically significantly influenced.

Saturated hydraulic conductivity (Ks) is the soil physical property that was most affected by soil tillage (Figure 3). The more intense the soil is tilled, the more the porous system and its continuity is destroyed and the Ks values are lower. The Ks values in control variant (TR3), when compared with subsoiling variant (TR2), decreased 10 times, while when compared with ploughing (TR1) and chisel tillage (TR4) were only 3 times smaller.

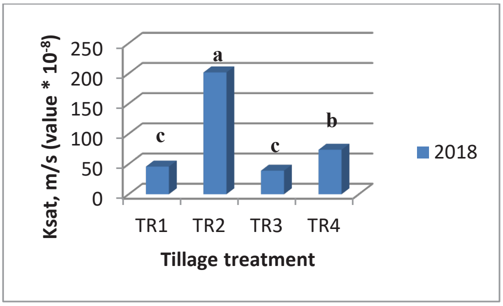

Figure 3. Saturated hydraulic conductivity in topsoil layer as affected by different tillages

The saturated hydraulic conductivity values were highly variable between treatments. The highest values of saturated hydraulic conductivity were determined in variants where subsoiling tillage was done (202×10^{-8} m s^{-1}). Moreover in these plots with subsoiling tillage, the high saturated hydraulic conductivity values means that the soil porous system continuity was not further disturbed by tillage and the water pathways in soil were not interrupted.

When statistical analysis was done for comparison of Ks within tillage treatments, the values were statistically significantly influenced.

Soil structure represents one of the major attributes of soil quality and it affects the soil pore system and through it the water movement processes in soil, which is measured by saturated hydraulic conductivity (Dexter, 2004). The saturated hydraulic conductivity of such fine-textured soil shows high variability and records low values, the most significant decrease being encountered in the control variant where disking tillage was done.

Soil porosity plays a significant role in evaluation of the impact of management practices on the quality of soil structure (Pagliai et al., 2004). By adopting alternative tillage systems, such as subsoiling tillage treatment, the soil macro-porosity can increase and is more-homogeneously distributed through the profile when compared with a disking tillage variant, and the resulting soil structure has a better quality, as confirmed by the higher hydraulic conductivity measured in the soil tilled by subsoiling. This is confirmed also by the values measured for water stable aggregates, which were higher in the treatment with subsoiling tillage.

Although subsoiling improved the soil indicators such as infiltration rate and bulk density, by applying subsoiling every year, it is time and energy consuming leading to an
The soil organic carbon content did not vary between the applied treatments (2.06-2.34%), the content being moderate between all tillage treatments. The investigated soil was highly supplied with available phosphorus (37-52 ppm), while for the exchangeable potassium content the soil was low to moderately supplied (8-20 ppm).

Soil compaction is one of the most important anthropogenic factors that influence the physical properties of the soil, with immediate effect on the management of agricultural farms and the environment (Nawaz et al., 2013). Soil compaction influences soil water dynamics, erosion, nitrogen and carbon cycle in the soil, agricultural yield, soil biology, and crop productivity (Piccoli et al., 2022).

Compaction affects agricultural and forestry crops and results from the traffic of heavy machinery and equipment on soils susceptible, mainly during the harvesting and harvesting operations (Nawaz et al., 2013). The negative effects of soil compaction on crop production have been shown in many research studies (Shaheb et al., 2021). Compaction causes a decrease in porosity and an increase in soil resistance that can restrict root development and affect the density and diversity of meso-fauna and bacterial communities in the soil (Glab, 2013).

In addition, the exchange of gases slows down in compacted soils, causing an increase in the likelihood of aeration-related problems. increase of workload, and the financial benefits for farmers are not significant. In addition, if the farmers are using high levels of chemical inputs there may increase the health risk due to nutrients leaching and infiltration in groundwater table. For example, in dry years, there is a potential risk of crop failure because of the water stress for crops during the growing season.

Based on these, it is recommended that the subsoiling tillage type should be done periodically at 3-4 years in combination with annually application of mouldboard ploughing.

Regarding the chemical characterization of the studied soil, there were no statistically significant variations between the applied treatments. The soil reaction values in case of all treatments varied between 5.99-6.63, which highlighted a lightly acid soil.

Finally, while soil compaction increases soil strength (the ability of soil to resist being moved by an applied force) a compacted soil also means roots must exert greater force to penetrate the compacted layer.

CONCLUSIONS

Saturated hydraulic conductivity is the soil physical property that was most affected by soil tillage. The highest values were recorded in the subsoiling variant.

The penetration resistance was affected by different tillage treatments and is correlated with bulk density. Significant effects were recorded both in topsoil and subsoil layers.

Soil chemical properties were not significantly affected by different tillage treatments applied to soil. The soil is lightly acid, highly supplied with available phosphorus and low to moderately supply with exchangeable potassium.

In order to mitigate the natural subsoil compaction of the studied soil, the best solution with positive effects on soil quality is to use a combination of the two tillage treatments which were investigated, namely the application of the mouldboardploughing annually and of the subsoiling periodically at 3-4 years. In this way is prevented the formation of the hard pan layer at the base of tillage depth.

The tillage treatment involving subsoiling was found to be efficient for improving soil compaction. However, it was also found that applying subsoiling every year is time and energy consuming, and the financial benefit for farmers is questionable. There is a need for further evaluating if the subsoiling could be done only periodically, once at every 3-4 years.

ACKNOWLEDGEMNTS

This work was supported by a grant of the Romanian Ministry of Research, Innovation and Digitization, project number 44 PFE /2021, Programme 1 – Development of national research-development system, Subprogramme 1.2 – Institutional performance – RDI Excellence Financing Projects.

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