THE IMPACT OF ORGANIC AND MINERAL FERTILISERS APPLICATION ON COMPACTION AND PHYSICAL PROPERTIES OF PSEUDOGLEY-TYPE SOIL

BARAĆ, S. – BIBERDŽIĆ, M. – ĐIKIĆ, A.* – GARIĆ, M. – VUKOVIĆ, A. – LALEVIĆ, D.

University of Priština – Kosovska Mitrovica, Faculty of Agriculture, Kopaonička bb, 38219 Lešak, Serbia

**Corresponding author*
e-mail: aleksandar.djikic@pr.ac.rs; phone: +381-640-263-825

(Received 26th Feb 2025; accepted 22nd Apr 2025)

Abstract. This paper presents the results of a five-year application of mineral NPK and the ameliorative use of lime and manure on the change in compaction of pseudogley soil, with specific physical properties of the soil serving as indicators of its quality. At each treatment, soil samples were taken, and the most important physical properties were analysed. The work also included field soil compaction measurement with the penetrologer Eijkelkamp hardware version 6.0. Soil properties and soil compaction values were compared, and their correlations were analysed. The research results showed that the multi-year meliorative application of lime, manure and mineral fertilisers reduced soil compaction, on average, by 3.0 times in the 0-50 cm profile or up to 1.7 times in the 25-30 cm profile. The compaction of the studied soil (in MPa), especially in the surface layer (0-5 cm), varied significantly over the years of research, ranging from 1.08 (second year of research) to 3.30 MPa (fifth year of research). Micromorphological characteristics (aggregate composition, water resistance of structural aggregates, volumetric mass, and total porosity) clearly demonstrate a significant indirect influence on soil compaction, as evidenced by a strong correlation with soil compaction. Soil compaction exhibits a similar trend to water retention capacity (WR) and an opposite trend to water filtration rate (WFR). Reduction of compaction due to significant improvements in micromorphological and water characteristics of the soil, particularly in unfavourable climatic conditions, promotes the combined use of organic matter (manure) and limestone ($Ca^{2+)}$ for a faster increase in the productivity of degraded pseudoclass.

Keywords: *ameliorative fertilisation, soil compaction, water retention, manure*

Introduction

According to the FAO (WRB, 2006), the classification of pseudogley falls under the stagnogley soil class, which has limited productive capabilities but is widely utilised in agriculture due to its extensive distribution. Dworschak and Milbert (2015) note in the German soil classification that soil affected by stagnating water belongs to the Pseudogleys. Pseudogleys cover significant areas of Serbia, accounting for approximately 285,000 ha, or 78.73% of the total land area in Western Serbia (Tanasijević et al., 1966). Pseudogleys are relatively poor in alkalis, exhibiting a medium to strongly acidic reaction. The acid reaction of pseudogley, its low humus content, and a low supply of available phosphorus and potassium are limiting factors for higher crop yields (Dugalic et al., 2005). It is believed that agricultural production in Central Serbia occupies over 60% of the soil with an acidic reaction. The production of plants on such soils is significantly reduced. They have a highly unfavourable structure and a low content of organic matter. Pseudogley soils in Serbia are characterized by poor chemical and physical properties that limit yields but are still used on large areas due to favorable topographic location and lack of quality soil (Dugalić et al., 2025). In compacted soils, nutrient absorption is weaker, resulting in less developed plant roots and a decrease in the yield of cultivated plants

DOI: http://dx.doi.org/10.15666/aeer/2304_69937008

(Colombi et al., 2019; Shaheb et al., 2021; Liu et al., 2022; Nassir et al., 2024). The structure of such soils deteriorates, and some of the soil functions are lost (Schjonning et al., 2015, 2016). The structure of agricultural soil, together with its aggregates, which are the basic unit of structure, play an important role in biological and physical processes within the soil (Gupta et al., 2015; Tagar et al., 2020; Bali et al., 2021). The intensification of plant production increases the risk of soil compaction, with a particularly pronounced impact on deeper soil profiles (Vanderhasselt et al., 2024). One of the primary reasons for soil compaction is the use of heavy machinery, as a large number of machines pass over the soil during cultivation. Thus, Yang et al. (2022) point out that reducing the number of passes, i.e. controlled traffic, can lead to an increase in plant yield by 16 to 38% and to a decrease in the volume density of the soil in the upper layers by 4 to 6%. The same authors note that the application of amelioration measures aimed at reducing soil compaction can increase plant yield by 9 to 10% and decrease bulk density by 3%. According to these authors, the omission of soil compaction reduction processing can decrease the yield of cultivated plants and increase the volume density of soil in the upper layers. The soil structure plays a crucial role in creating conditions that support the optimal development of plant and animal life. Also, soil structure is vital to sustainable food production, although its role is often overlooked. Different ways of soil use and management can, to a significant extent, affect the stability of structural aggregates as an index of the state of the structure and quality of the soil (Czyz and Dexter, 2009; Josa et al., 2010; Yuan et al., 2023). The low stability of structural aggregates can significantly impact the soil's sensitivity to degradation processes (Lipiec et al., 2006; Shein et al., 2010; Gregory et al., 2015). Soil compaction has significant ecological importance and plays a crucial role in mechanical processing. The greater the soil compaction, the more excellent the resistance it provides to the working organs of the processing machines. Then, a greater traction force is required when moving the walking mechanisms on the surface due to increased resistance. The optimal conditions for processing are those where the soil compaction is 1-1.5 MPa. For most cultivated grains, the upper limit, above which the conditions of growth and development deteriorate sharply, is soil compaction of 1.5 to 1.9 MPa, and for root and tuber plants, 0.5-1 MPa. The compaction of pseudogley soils is a significant problem that farmers often overlook; it occurs in subsoil horizons and is rarely visible on the soil surface. Soil compaction is a physical form of degradation, and compacted soils typically have an unfavourable and unstable structure, as well as a high volume mass, with an increased risk of erosion and pollution (Tullberg, 2010; Mueller et al., 2010). Increasing soil compaction prevents water infiltration and the flow of sufficient oxygen to the root system, inhibiting growth and reducing plant yields. High soil compaction reduces aggregate stability and decreases macroporosity (Swartz et al., 2003; Nawaz et al., 2013). Therefore, the consequence of the aforementioned soil changes is ecological degradation, which includes the loss of water, biodiversity and other plant resources (Isirimah, 2004; Ezeaku and Alaci, 2008). Soil compaction is significantly influenced by its moisture content. With increasing humidity, compaction decreases significantly. A study by Nyeki et al. (2017) indicates that changes in soil moisture content have the opposite effect on the natural compaction of clay. In addition to the above, soil compaction highly depends on the composition of adsorbed cations. Thus, the compaction of chernozem, whose adsorptive complex is saturated with Ca^{2+} ions, is 10-15 times lower compared to the compactness of solonetz, whose adsorptive complex is saturated with Na^{+} ions (Kauričev et al., 1979). Highly humic soils, saturated with divalent cations, have lower compaction than weakly humic soils. According to

Aggelides and Londra (2000), when more significant amounts of organic matter are introduced into the soil, there is an increase in the content of retention water in the soil and a decrease in its compaction. According to Puzniak et al. (2022) combined application of organic and mineral fertilizers created optimal conditions for the development of functional groups of microorganisms. The soil texture has a direct influence on soil compaction. Dry clay soils have significantly higher resistance than sandy ones. Applying pedomeliorative measures and fertilisation on soils with a low pH value is an effective method for improving their fertility, increasing the yield and quality of cultivated plants, and enhancing the physical properties of the soil. Compacted soils are difficult to recognise. The application of heavy mechanisation and large machine wheels is drawing increasing attention to the topic of soil compaction and producers' awareness of this issue (Ramazan et al., 2012; Keller et al., 2019). The long-term application of organic and mineral fertilisers can have a positive effect on the change of soil structure as well as on the composition of soil aggregates, which together affect the distribution and availability of nutrients in the soil (Maltas et al., 2018; Wang et al., 2020; Das et al., 2023). Thus Shahgholi et al. (2018) state that the application of organic matter affected the reduction of compaction, whereby with the application of 8% organic matter, soil compaction was reduced by 9.25%. In this paper, we begin with the assumption that applying different ameliorants of mineral and organic origin, in addition to their effect on improving specific chemical and physical properties of the soil, can significantly affect the state of compaction. However, changes in most physical traits are very slow and usually occur over a long period (Puglisi et al., 2006; Pupin et al., 2009). Adding compost to the soil, along with tillage, improved its physical and mechanical properties and reduced compaction, with the first noticeable changes occurring after 24 months (Mohammadshirazi et al., 2017). The study by Dugalic et al. (2024) indicates that a positive effect of calcification and fertilization was observed after a two-year experiment on pseudogley-type soil in maize production.

These studies aimed to determine the effect of the combined application of different doses of mineral, organic, and lime fertilisers on the compaction of pseudogley-type soil and its relationship with the most important physical properties.

Materials and methods

This study was conducted over five years in the Kraljevo region, Western Serbia (43°43'53.7" N, 20°40'11.4" E), on a Pseudogley soil at the Kraljevo location, 215 m above sea level, in a temperate continental climate with an average annual temperature of 8.1°C, typical of western regions in Serbia, and a rainfall amount of about 540 mm. The study was conducted at the experimental field of Dr. Djordje Radic Secondary School of Agriculture and Chemistry in Kraljevo (*Figures 1, 2*).

The experiment was set up in a randomised block system with three replications. The following treatments were included in the experiment: T1 (100 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}); T2 (100 kg N ha^{-1}, 160 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}); T3 (100 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}+5.0 t $CaCO_3$ ha^{-1}); T4 (120 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, 60 kg K2O ha^{-1}+5.0 t $CaCO_3$ ha^{-1}+20 t manure ha^{-1}), while T0 was the control. The forms of fertilisers applied were complex NPK fertiliser (8:24:16), superphosphate (17% P_2O_5), ammonium nitrate (AN = 34.4% N), manure, and powdered limestone. Manure and limestone were applied every third year (in the first, second, and last years) in the fall, during basic tillage, and were introduced with a heavy plate to a depth of 20 cm. The

DOI: http://dx.doi.org/10.15666/aeer/2304_69937008

treatments were carried out on plots of 50 m² (5 x 10 m). The treatments were applied alternately to two fields (A and B) with a wheat-maize crop rotation. Measurements were taken at six depths: 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm, and 25-30 cm. Measurement of soil compaction was performed on the control and all treatments and depths using Penetrologer Eijkelkamp hardware version 6.0, software version 6.03, and Penetroviewer version 6.07, which is intended for measuring soil compaction up to 80 cm deep. The measurement was performed by pressing a cone with a surface area of 1 cm² and a cone tip of 600 µm according to the NEN 5140 standard at a penetration speed of 2 cms^{-1}, with a deviation not exceeding 0.5 cm s^{-1}. The cone is of a standard size, defined according to the ASAE standard (ASAE S313.1). Before starting the measurement, a depth reference plate was placed, and the location of the plot, as determined by GPS, and the soil moisture levels were recorded. When measuring soil compaction, the slope of the penetrologer did not exceed 3.5^0 in relation to the vertical (the level of the penetrologer was used), and the speed of penetration was monitored using the speed indicator on display, which was near the middle position. At all treatments and depths of 10-30 cm, soil samples were taken to analyse physical and chemical soil properties. Soil samples were taken in three replicates using Kopecky cylinders with a volume of 100 cm^3. The mechanical and chemical composition of the soil was determined using standard laboratory methods.

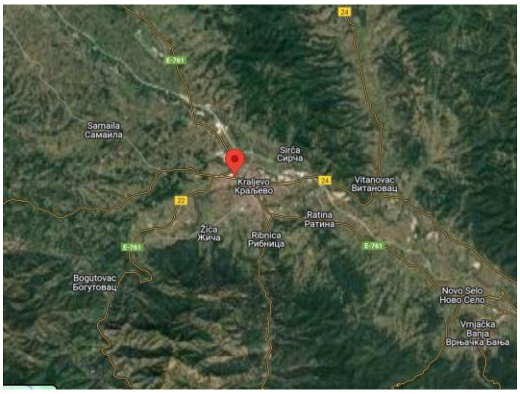

***Figure 1.** Area of research*

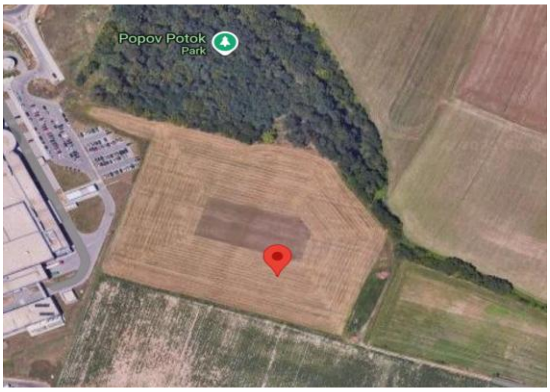

***Figure 2.** Satellite snapshot of the experimental field*

The soil texture was determined by the pipette method, with sample preparation for analysis by the E-variant of the pyrophosphate method (Zivkovic, 1966), aggregate analysis by dry sieving by the Savinov method, macroaggregates stability by the Tyulin-Savinov method, volumetric mass (DM) by Kopecky cylinders of 100 cm^3, total porosity (TP) and air capacity (AC) by calculation, water retention capacity (RW) according to Gračanin (Vucic, 1976) with Kopecky cylinders with a volume of 100 cm^3, filtration rate (DC) with the Darsy-Thiem apparatus (Vucic, 1976), whereby Kopecky cylinders with a volume of 100 cm^3 with samples soil is placed in that device in which water under constant pressure (h) passes through the sample and is collected in vessels for measurement. The calculation procedure is as follows:

$$k = \frac{Q \text{ x } Ldy}{h \text{ x } F \text{ x } t} \qquad \text{(Eq.1)}$$

where, k-speed of water permeability (cm sec^{-1}), Q-amount of filtered water (cm^3) in time t (sec), L- length of the soil sample in the cylinder (cm), h- height (pressure) of the water column (cm), F- the surface of the soil sample in the Kopecky cylinder (cm^2).

The soil's hydrolytic acidity was determined by Ca acetate extraction using Kappen's method, and the humus was determined using the Kotzman method.

The paper analysed the compaction of pseudoglay depending on the climatic conditions of the year and the application of various varieties of organic and mineral fertilisers. The dependence between soil compaction and soil aggregate composition was also established through Pearson's correlation coefficient; the dependence between soil compaction and water resistance of structural aggregates and the dependence between soil compaction and some soil characteristics.

The mean values obtained were subjected to analyses of variance using the SAS Institute's PROC ANOVA subroutine (1999) (Correa et al., 2022; Dugalic et al., 2025).

According to the soil texture (*Table 1*) and based on the depth and diameter of the fractions, this soil belongs to the heavy loam category.

Table 1. *Soil texture of the examined pseudogley*

Depth (cm)	**Diameter (mm)**							**Texture class** (Kaczynski)
	2.0-0.25	**0.25-0.05**	**0.05-0.01**	**0.01-0.005**	**0.005-0.001**	**<0.001**	**<0.01**	
0-10	4.67	4.45	42.85	10.74	13.62	23.67	48.03	Heavy Loam
10-20	4.02	5.19	44.63	11.10	14.25	20.81	46.16	Heavy Loam
20-30	4.45	5.26	43.48	11.27	13.24	22.30	46.31	Heavy Loam

According to the depth of the impervious or very poorly permeable horizon, the studied pseudoglay belongs to medium-deep soils because the impervious horizon is located at a depth of 35-45 cm, which is one cause of its poor productive capacity and increased compaction.

As shown by the analysis of the most important chemical properties in *Table 2*, the humus horizon of the studied pseudoglay is characterised by a very low humus content (below 2.18%). In all three investigated depths, the soil shows a pronounced degree of acidification ($pH_{KCl} < 4.5$).

Table 2. *Some chemical characteristics of soils*

Depth (cm)	**Humus (%)**	**pH**		**Y_1 (cm^3)**	**T-S**	**S**	**T**	**V (%)**
		H_2O	**$_nKCl$**		**(mekv/100 g)**			
0-10	2.18	5.24	4.45	15.47	8.63	8.08	16.71	48.35
10-20	1.84	5.50	4.48	14.05	8.12	7.98	16.71	49.04
20-30	0.66	5.46	4.42	13.98	6.90	9.79	16.69	58.66

Also, hydrolytic (Y_1) and total acidity (T - S) are generally relatively high. At the same time, the sum of exchangeable-adsorbed base cations (S) and the degree of soil saturation with exchangeable-adsorbed base cations (V) is low (below 50%).

Based on their chemical composition, pH value, and humus content, these types of soil require meliorative repairs for agricultural production to be successful.

The total amount of precipitation and its distribution throughout the year is of great importance for successful plant production. During the research period, the highest amounts of precipitation (861.4 and 804 mm) were recorded in the second and third years, respectively, while the lowest amounts (511.7 and 597.3 mm) were recorded in the fourth and fifth years of the study. Comparing the total amounts of precipitation by the years of the study with perennial average, it can be concluded that the were significantly varied (*Table 3*).

Table 3. *Amount of precipitation in the examined period and perennial average (Source: Republic Hydrometeorological Service of Serbia)*

Month	Precipitation (mm)				
	Year				
	I	II	III	IV	V
January	32.6	47.0	34.0	28.1	107.1
February	22.1	55.5	81.6	59.1	54.9
March	72.4	72.0	38.6	48.9	24.5
April	62.9	22.8	100.2	37.1	69.1
May	40.1	36.2	84.0	82.9	105.5
June	73.4	194.0	136.4	71.7	17.8
July	153	58.1	38.2	37.3	45.3
August	57.1	59.3	74.0	18.7	0.0
September	72.3	17.8	24.0	32.1	7.7
October	39.8	137.9	93.6	30.4	56.7
November	48.2	63.1	34.1	1.7	11.1
December	41.1	97.7	64.9	63.7	97.6
Total	715.0	861.4	804.0	511.7	597.3
Mean 1981-2010	**740.3**				

The total annual amount of precipitation is significant for the physical properties of the soil. In years with a higher total precipitation, there is better nutrient uptake and improved plant growth. According to Biberdzic et al. (2020), higher soil moisture content reduces the solid phase content, which reduces soil compaction.

Results and discussion

The five-year measurement of soil compaction by year of research is shown in *Table 4*. Soil compaction depended on the year of research. Thus, the highest average soil compaction was recorded in the fourth and fifth years (5.28 and 6.33 MPa), and the lowest in the second and third years (2.43 MPa), corresponding to the periods with the most precipitation. Differences in compaction from year to year are primarily determined by the total precipitation amounts accumulated during those years. In all years of testing, the lowest compaction was observed in the 5-10 cm profile, which was statistically significantly lower than in the deeper soil profiles. Extremely high compaction was measured in all depths of the examined soil profile in the fifth year, ranging from 3.30 MPa (0-5 cm) to 8.25 MPa (25-30 cm). Additionally, during the first and fourth years, high soil compaction was measured in the same test period, specifically at 2.28 and 1.88 MPa at a depth of 0-5 cm, respectively, and at 6.96 and 7.82 MPa at a soil depth of 25-30 cm. The soil's high compaction results from a substantial deficit of moisture and dryness at the depth of the arable horizon, as well as unfavourable physical properties.

Table 4. *Influence of the test period (years) on soil compaction (MPa) (control)*

Depth (cm)	**Years**				
	I	**II**	**III**	**IV**	**V**
0-5	2.28 ± 1.13[1]	1.0 8 ± 0.41	1.28 ± 0.41	1.88 ± 1.29	3.30 ± 0.48
5-10	3.38 ± 1.28	1.48 ± 0.35	1.58 ± 0.49	3.66 ± 1.46	4.64 ± 0.73
10-15	6.33 ± 2.19	2.72 ± 0.61	2.10 ± 0.66	4.85 ± 1.46	6.26 ± 1.21
15-20	4.86 ± 1.83	2.44 ± 0.73	2.52 ± 0.80	6.20 ± 1.36	7.56 ± 1.12
20-25	6.52 ± 1.93	3.10 ± 1.03	3.24 ± 0.99	7.31 ± 1.09	7.98 ± 0.94
25-30	6.96 ± 1 .82	3.78 ± 1.17	3.88 ± 1.14	7.82 ± 1.07	8.25 ± 0.56
Mean	**5.05**	**2.43**	**2.43**	**5.28**	**6.33**

[1] Values of the standard error of the mean are given after ±

Thus, the drying of soil due to intense radiation and evaporation results in the accelerated oxidation of organic matter, leading to its significant reduction and more substantial degradation of soil aggregates, as well as an increase in soil compaction (Abrishamkesh et al., 2011). However, soil compaction was significantly reduced during the years with a significantly more favourable rainfall regime in the examined period (the second and third years of the examination). Thus, it ranged from 1.08 to 1.28 MPa in the 0-5 cm profile to 3.78 or 3.88 MPa (in the second and third years of testing) in the 25-30 cm profile (*Table 4*). The obtained results indicate a significant influence of increased moisture content in the soil, a high proportion of dust particles, and a low content of organic matter (humus) (Abrishamkesh et al., 2011; Halde et al., 2011; Arocena et al., 2012).

Soil compaction is significantly related to the saturation of the adsorptive complex with calcium ions. The results are shown in *Table 5* as proof of the stated claim. Soil compaction increases with the depth of the profile. Thus, with all fertilisation variants, including the control, the lowest compaction was in the 0-10 cm layer, and it was statistically significantly lower compared to deeper soil profiles. In the fertilisation variants, there were no statistically significant differences in soil compaction between the depths of 0 - 5 and 5 - 10, 10 - 15 and 15 - 20, and 20 - 25 and 25 - 30 cm.

Table 5. *Influence of fertilisation variants on soil compaction (MPa)*

Depth (cm)	**Treatment**				
	T0	**T1**	**T2**	**T3**	**T4**
0-5	3.05±1.91	2.82±1.49	2.09±0.98	1.75±0.82	1.01±0.55
5-10	4.01±1.67	3.80±1.77	2.88±1.28	2.08±1.10	1.14±1.35
10-15	4.84±1.68	4.47±2.38	3.94±1.53	3.16±1.64	2.53±1.57
15-20	6.16±2.12	5.24±2.50	5.06±2.18	4.15±2.07	3.28±0.38
20-25	6.92±2.00	6.46±2.34	4.62±2.79	4.48±2.09	4.10±2.02
25-30	7.54±1.71	7.02±2.10	6.44±2.14	5.04±1.74	4.46±2.02
Mean	**5.42**	**4.96**	**4.17**	**3.44**	**2.75**

Values of the standard error of the mean are given after ±

The highest average soil compaction (5.42 MPa, *Table 5*) was recorded in control (T0), where there was extreme acidity (pH < 4.5) and a low degree of soil saturation with exchangeable-adsorbed basic cations (V<50%, *Table 2*). Also, the soil's high average compaction (4.96 and 4.17 MPa) was observed in the application variant of mineral NPK fertiliser (T1 and T2).

However, it was reduced by an average of 18.8% compared to the control. The extremely high average compaction on soil treatments T0, T1 and T2 (4.17-5.42 MPa) is far above the optimal values for the treatment, which range between 1.0 and 1.5 MPa. Such plots of pseudogley are unfavourable for the growth and development of small-grain plants.

The combined use of NPK fertilisers with lime (T3) and NPK with lime and manure (T4) significantly reduced soil compaction in all depths of the studied soil profile. The average reduction in soil compaction for the T4 variant compared to the control (T0) was approximately 97%, nearly double the reduction. The reason for the reduction in soil compaction is the result of the effects of organic and lime fertilisers, which improve the physical and mechanical properties (aggregate composition and porosity) as well as the chemical properties of the soil (the share of base cations, mainly calcium, in the adsorptive complex).

Many studies have found a significant impact of the application of organic fertilisers on the improvement of soil physical properties, especially overall porosity and structure, which leads to the slowing down of surface water runoff and the reduction of erosion processes and soil compaction (Aggelides and Londra, 2000; Hargreaves et al., 2008).

The mutual relationship between soil compaction and different fertilisation variants, as well as soil aggregate composition (up to 30 cm deep), was determined using Pearson's correlation coefficient (*Table 6*). From the presented table, it can be seen that a primarily negative and strong correlation was established between soil compaction and its aggregate composition. Only soil macroaggregates (>10 mm) exhibited a strong positive correlation with soil compaction in all applied treatments, indicating that an increase in the proportion of macroaggregates contributes to an increase in soil compaction.

Table 6. *Dependance between soil compaction and soil aggregate composition (Pearson's correlation coefficient)*

Aggregate size (mm)	**Treatment**				
	T0	**T1**	**T2**	**T3**	**T4**
>10	0.91**	0.92**	0.83**	0.94**	0.69*
10-5	-0.90**	-0.58*	-0.74**	0.95**	-0.89**
5-3	-0.34^{ns}	-0.87**	-0.80**	-0.91**	-0.89**
3-2	-0.75**	-0.90**	-0.12^{ns}	0.92**	-0.88**
2-1	-0.93**	-0.84**	-0.84**	-0.92**	-0.80**
1-0.5	-0.95**	-0.88**	-0.93**	0.93**	-0.89**
0.05-0.25	-0.87**	-0.86**	-0.85**	-0.97**	-0.94**
< 0.25	-0.77**	-0.67*	-0.05^{ns}	-0.95**	-0.87**

ns – there is no statistical significance, ** statistically significant on the probability level of 0.01, * statistically significant on the probability level of 0.05

The share of almost all other macroaggregates (0.25-10 mm) and microaggregates (<0.25 mm) exhibited a strong negative correlation with soil compaction, particularly in the T3 and T4 treatments. Therefore, the tested soil with a smaller proportion of the most favourable structural aggregates, except for treatments T3 and T4, has predispositions for high compaction, as confirmed by our test results.

Our hypothesis was that the combined ameliorative application of lime and manure would reduce soil compaction by changing the distribution of structural aggregates.

The obtained results confirmed this thesis, as well as the findings of numerous authors who, by applying manure, shifted the distribution of structural aggregates from larger (12.7 mm) to medium to smaller (0.47 mm) (Whalen and Chang, 2002; Larney et al., 2006; Miller et al., 2012).

The same researchers report very positive effects of multi-year (22 years) application of large amounts of manure on the change in the distribution of structural aggregates of soil with the characteristics of heavy clay loam.

Soils whose adsorptive complex is saturated with Ca^{2+} ions (T3 and T4 treatments) with a higher proportion of favourable microstructural aggregates (<0.25 mm) show lower compaction compared to unstructured soils.

The results presented in *Table 7* indicate a significant dependence between soil compaction and the presence of waterproof structural aggregates (up to 30 cm deep) in almost all studied treatments.

Table 7. *Dependence between soil compaction and water resistance of structural aggregates (Pearson's correlation coefficient)*

Aggregate size (mm)	Treatment				
	T0	T1	T2	T3	T4
>3	-0.93**	0.78**	0.59*	0.34^{ns}	-0.72**
3-2	0.79**	-0.78**	-0.63*	-0.79**	-0.84**
2-1	0.87**	0.88**	-0.65*	0.76**	-0.74**
1-0.5	0.79**	0.87**	0.66*	-0.76**	0.82**
0.5-0.25	0,76**	0.87**	0.65*	0.76**	-0.80**
< 0.25	-0.75**	-0.87**	-0.66*	0.76**	-0.18^{ns}

ns – there is no statistical significance, ** statistically significant on the probability level of 0.01, * statistically significant on the probability level of 0.05

A strong positive dependence was observed between soil compaction (T1 and T0) and the portion of macroaggregates that have reduced water resistance (2-0.25 mm). The low biotic activity of plants, animals (such as earthworms), and microorganisms, which is conditioned by the low pH value of the studied soil, results in weak structural aggregate stability, increased drying, and significant soil compaction (White, 2003).

A negative and mostly strong correlation was established between soil compaction and the content of water-resistant micro-aggregates (<0.25 mm) in the control (T0) and variants of mineral NPK fertiliser application (T1 and T2). In the treatments (T3 and T4), where lime and organic fertiliser were used, a strong negative correlation was found, for the most part, between soil compaction and the content of larger macroaggregates (0.25-10 mm) (r = -0.72** to r = -0.84 **).

The increase in the stability of macroaggregates in the T3 and T4 treatments was attributed to a partial increase in organic matter content, accompanied by an increase in Ca^{2+} ion content in the adsorptive complex, as well as a decrease in soil acidity.

Increasing the water resistance of macroaggregates helps reduce soil compaction. Biberdzic et al. (2020) note a negative correlation between soil water content and soil compaction (r = -0.26). However, there are also reports that the binding forces established at the level of macroaggregates have a temporary character and are unstable and dynamic (Gajić et al., 2010).

The relationship between soil compaction and different types of fertilization, as well as specific soil characteristics, is shown in *Table 8*. The results show a significant negative correlation between bulk density (DM) and soil compaction across all applied treatments, indicating a significant decrease in soil compaction with increasing bulk density. Other studied soil characteristics (TP, AC, RW) exhibit a strong positive correlation with compaction.

Table 8. *Dependence between soil compaction and some soil characteristics (Pearson's correlation coefficient)*

Soil characteristics	**Treatment**				
	T0	**T1**	**T2**	**T3**	**T4**
DM	-0.93**	-0.58*	-0.55*	-0.76**	-0.74**
TP	0.80**	0.85**	0.65*	0.76**	0.80**
AC	-0.86**	0.89**	0.70**	0.75**	0.81**
RW	0.66*	0.70**	0.87**	0.54*	0.27^{ns}

ns – there is no statistical significance, ** statistically significant on the probability level of 0.01, * statistically significant on the probability level of 0.05

Thus, the increase of finer micropores in the soil increases total porosity and water retention capacity, contributing to increased compaction. The ameliorative introduction of limestone and manure also contributed to an increase in the soil's total porosity and air capacity, leading to a decrease in its compaction (Fierro et al., 1999; Gardner et al., 2010).

During the ameliorative use of manure, macroporosity and microporosity increase through the elongation of micropores in newly formed aggregates (Pagliai and Vitorri Antisari, 1993) or through indirect influence through soil fauna (earthworms), whose activity (feeding and digging corridors) modifies soil porosity (Peres et al., 1998) and its structure (Scullion and Malik, 2000).

The application of organic fertilisers increases the content and stability of macroaggregates, resulting in a significant positive correlation between the content of organic fertilisers and the amount of aggregates ($p < 0.05$; Niu et al., 2022).

The relationship between soil compaction and different types of fertilization, as well as specific soil characteristics, is shown in *Table 8*.

The results show a significant negative correlation between bulk density (DM) and soil compaction across all applied treatments, indicating a significant decrease in soil compaction with increasing bulk density. Other studied soil characteristics (TP, AC, RW) exhibit a strong positive correlation with compaction. Thus, the increase in finer micropores in the soil leads to an increase in total porosity and water retention capacity, which in turn contributes to an increase in compaction. The ameliorative introduction of limestone and manure contributed to an increase in the soil's total porosity and air capacity, resulting in a decrease in its compaction (Fierro et al., 1999; Gardner et al., 2010).

During the ameliorative use of manure, macroporosity and microporosity increase through the elongation of micropores in newly formed aggregates (Pagliai and Vitorri Antisari, 1993) or through indirect influence of soil fauna (earthworms), whose activity (feeding and forming corridors) modifies soil porosity (Peres et al., 1998) and its structure (Scullion and Malik, 2000).

The application of organic fertilisers increases the content and stability of macroaggregates, resulting in a significant positive correlation between the content of organic fertilisers and the amount of aggregates ($p < 0.05$; Niu et al., 2022).

Data on the filtration rate for the studied soil and pseudogley type (Darcy's coefficient) are shown in *Table 9*. In all treatments, the surface horizons of the studied soil (0-10 cm) exhibit a high filtration rate of 3.0×10^{-3} cm sec^{-1}.

Table 9. *Filtration speed (Darcy's coefficient, DC) on different types of fertilisation (cm sec*$^{-1}$*)*

Depth (cm)	**Treatment**				
	T0	**T1**	**T2**	**T3**	**T4**
0-10	3.1 x 10^{-3}	3.0 x 10^{-3}	3.1 x 10^{-3}	3.0 x 10^{-3}	3.0 x 10^{-3}
10-20	4.4 x 10^{-4}	4.4 x 10^{-4}	3.1 x 10^{-3}	3.0 x 10^{-3}	3.0 x 10^{-3}
20-30	6.3 x 10^{-6}	6.3 x 10^{-6}	4.4 x 10^{-4}	4.4 x 10^{-4}	3.1 x 10^{-3}
30-40	6.3 x 10^{-6}	6.3 x 10^{-6}	6.3 x10^{-6}	4.4 x 10^{-4}	4.4 x 10^{-4}

However, with increasing soil depth, the filtration rate decreases significantly, especially in the control (T0), T1, and T2 fertilisation variants. In the control (T0) and treatments T1 and T2, at depths exceeding 20 cm, the filtration rate is generally very low (6.3×10-6 cm s^{-1}).

The low water permeability of the soil at that depth is attributed to its heavy soil texture, characterized by a high content of dust and clay (Vrbek, 2003; Ohu et al., 2009).

With the ameliorative application of lime and manure (T3 and T4) in the arable part of the soil (0 - 20 cm), the rate of water filtration was high, while in the deeper parts of the soil (20-40 cm) there was a decrease in soil permeability (4.4 x 10^{-4} cm sec^{-1}).

However, the filtration rate at the same soil depth was significantly higher compared to the control and variants using mineral fertilisers (T1 and T2). Lime and manure have formed micro-aggregates into macro-aggregates through the action of Ca^{2+} ions, enabling the subsequent formation of macroaggregates via humus and mineral colloids.

This improved the soil's structure, resulting in a higher proportion of non-capillary pores than capillary pores. The improved structure of pseudoglay also contributed to the better stability of structural aggregates against gasification.

Structural aggregates with a diameter of 0.25-10 mm have the most favourable influence on the water-air properties of the soil (Vučić, 1976; quoted by Dragovic, 2000). The resulting structural changes of pseudogley led to an increase in the rate of water conductivity in deeper soil layers (20-40 cm) but also to a more remarkable ability to bind and retain beneficial water for plants (Ohu et al., 2001, 2009).

Conclusion

The compaction of the pseudogley soil varied significantly over the years of the study. The highest compaction, measured across all depths of the tested profile, occurred in the fifth year, with values of 3.30 MPa at a depth of 0-5 cm and 8.25 MPa at a depth of 25-30 cm. During the years with a more favourable rainfall regime (the second and third years of the study), soil compaction was significantly reduced. At a soil depth of 0-5 cm, the compaction was 1.08 MPa in the second year and 1.28 MPa in the third year of testing. In the more deeply examined horizon (25 - 30 cm), values of 3.78 MPa (second year) and 3.88 MPa (third year) were determined.

The combined application of NPK and lime, as well as NPK, lime, and manure, significantly reduced soil compaction in all depths of the studied profile. The average soil compaction was 3.0 times lower in the surface profile (0-5 cm) and 1.7 times lower in the most profound profile (25-30 cm) on variants with multi-year application of ameliorative fertilisation compared to the control.

Applying meliorants of mineral and organic origin, such as limestone and manure, improved the physical quality of the soil, particularly in the upper parts of the pseudogley profile (0-10 cm), which reduced compaction even during dry years with an intense moisture deficit. These results promote combining organic matter (manure) and limestone (Ca^{2+}) to improve micromorphological and water characteristics. This reduces the compaction of the soil, which leads to a faster increase in the productivity of degraded pseudoglay.

Acknowledgements. This research was financially supported by the Ministry of Education, Science, and Technological Development of the Republic of Serbia, Project No. 451-03-65/2024-03/200189.

REFERENCES

[1] Abrishamkesh, S., Gorji, M., Asadi, H. (2011): Long-term effects of land use on soil aggregate stability. – International Agrophysics 25(2): 103-108.

[2] Aggelides, S. M., Londra, P. A. (2000): Effects of compost produced from urban wastes and sewage sludge on the physical properties of loamy and clay soil. – Bioresource Technology 71(3): 253-259. https://doi.org/10.1016/S0960-8524(99)00074-7.

[3] Arocena, J. M., van Mourik, J. M., Cano, A. F. (2012): Granular soil structure indicates reclamation of degraded to productive soils: A case study in southeast Spain. – Canadian Journal of Soil Science 92: 243-251. https://doi.org/10.4141/cjss2011-017.

[4] Bali, R., Pineault, J., Chagnon, P. L., Hijri, M. (2021): Fresh compost tea application does not change rhizosphere soil bacterial community structure and has no effects on soybean growth or yield. – Plants 10(8): 1638. https://doi.org/10.3390/plants10081638.

[5] Biberdzic, M., Barac, S., Lalevic, D., Djikic, A., Prodanovic, D., Rajicic, V. (2020): Influence of soil tillage system on soil compaction and winter wheat yield. – Chilean Journal of Agricultural Research 80(1): 80-89. http://dx.doi.org/10.4067/S0718-58392020000100080.

[6] Colombi, T., Keller, T. (2019): Developing strategies to recover crop productivity after soil compaction - A plant eco-physiological perspective. – Soil and Tillage Research 191: 156-161. https://doi.org/10.1016/j.still.2019.04.008.

[7] Correa, J., Postma, J. A., Wojciechowski, T. (2002): Phenotypic response to soil compaction varies among genotypes and correlates with plant size in sorghum. – Plant and Soil 472(12): 59-76. https://doi.org/10.1007/s11104-021-05160-z.

[8] Czyz, E., Dexter, A. (2009): Soil physical properties as affected by traditional, reduced and no-tillage for winter wheat. – International Agrophysics 23(4): 319-326.

[9] Das, S., Liptzin, D., Maharjan, B. (2023): Long-term manure application improves soil health and stabilizes carbon in continuous maize production system. – Geoderma 430: 116338. https://doi.org/10.1016/j.geoderma.2023.116338.

[10] Dragovic, S. (2000): Irrigation. – Scientific Institute for Agriculture and Vegetables, Novi Sad.

[11] Dugalic, G., Gajic, B., Jelic, M., Jovanovic, Z. (2005): Agrochemical characteristics of pseudogley in the Kraljevo basen. – Proceedings XL Croatian Symposium on Agriculture, Opatija, Croatia, pp. 415-416.

[12] Dugalic, M., Zivotic, Lj., Gajic, B., Latkovic, D. (2024): Small Doses of Lime with Common Fertilizer Practices Improve Soil Characteristics and Foster the Sustainability of Maize Production. – Agronomy 14(46): 2-12. https://doi.org/10.3390/agronomy14010046.

[13] Dugalic, M., Rakocević-Boskovic, Lj., Latkovic, D., Rajicic, V., Terzic, D., Životic, Lj. (2025): Effect of Lime, Mineral Fertilizer and Manure on Soil Characteristics and Yield of Four Maize Hybrids. – Agronomy 15(542): 2-19. https://doi.org/10.3390/agronomy15030542.

[14] Dworschak, M., Milbert, G. (2015): Soil of the Year 2015 Pseudogley. – Imprint, State Geological Survey North Rhine- Westphalia.

[15] Ezeaku, P. I., Alaci, D. (2008): Analytical situations of land degradation and sustainable management strategies in Africa. – Pakistan Journal of Agriculture & Social sciences 4(1): 42-52.

[16] FAO (2006): World Reference Base for Soil Resources. – FAO Soils Portal.

[17] Fierro, A., Angers, D. A., Beauchamp, C. J. (1999): Restoration of ecosystem function in an abandoned sandpit: plant and soil responses to paper de-inking sludge. – Journal of Applied Ecology 36: 244-253.

[18] Gajic, B., Djurovic, N., Dugalic, G. (2010): Composition and stability of soil aggregates in Fluvisols under forest, meadows, and 100 years on conventional tillage. – Journal of Plant Nutrition and Soil Science 173(4): 502-509. https://doi.org/10.1002/jpln.200700368.

[19] Gardner, W. C., Broersma, K., Naeth, A., Chanasyk, D., Jobson, A. (2010): Influence of biosolids and fertilizer amendments on physical, chemical and microbiological properties of copper mine tailings. – Canadian Journal of Soil Science 90(4): 571-583. https://doi.org/10.4141/cjss09067.

[20] Gregory, A. S., Ritz, K., Mcgrath, S. P., Quinton, J. N., Goulding, K. W. T., Jones, R. J. A., Harris, R. B., Wallace, P., Pilgrim, E. S., Whitmore, A. P. (2015): A review of the impacts of degradation threats on soil properties in the UK. – Soil Use and Management 31(1): 1-15. https://doi.org/10.1111/sum.12212.

[21] Gupta, V. V. S. R., Germida, J. J. (2015): Soil aggregation: Influence on microbial biomass and implications for biological processes. – Soil Biology and Biochemistry 80: A3-A9. https://doi.org/10.1016/j.soilbio.2014.09.002.

[22] Halde, C., Hammermeister, A. M., McLean, N. L., Webb, K. T., Martin, R. C. (2011): Soil compaction under varying rest periods and levels of mechanical disturbance in a rotational grazing system. – Canadian Journal of Soil Science 91: 957-964. https://doi.org/10.4141/cjss2011-026.

[23] Hargreaves, J. C., Adl, M. S., Warman, P. R. (2008): A review of the use of composted municipal solid waste in agriculture. – Agriculture, Ecosystems & Environment 123(1-3): 1-14. https://doi.org/10.1016/j.agee.2007.07.004.

[24] Isirimah, N. O. (2004): Soils and Environmental pollution management. – Nuton publishers Oweji 76.

[25] Josa, R., Ginovart, M., Sole, A. (2010): Effect of two tillage techniques on soil macroporosity in sub-humid environment. – International Agrophysics 24(2): 139-147.

[26] Kauričev, I. S., Lykov, A. M. (1979): Problems of humic soil erosion in the context of independent land use. – Research 12: 5-14.

[27] Keller, T., Sandin, M., Colombi, T., Horn, R., Or, D. (2019): Historical increase in agricultural machinery weights enhanced soil stress levels and adversely affected soil functioning. – Soil and Tillage Research 194: 104293. https://doi.org/10.1016/j.still.2019.104293.

[28] Larney, F. J., Sullivan, D. M., Buckley, K. E., Eghball, B. (2006): The role of composting in recycling manure nutrients. – Canadian Journal of Soil Science 86: 597-611. https://doi.org/10.4141/S05-116.

[29] Lipiec, J., Kuoe, J., Nosalewicz, A., Turski, M. (2006): Tillage system effects on stability and sorptivity of soil aggregates. – International Agrophysics 20(3): 189-193.

[30] Liu, H., Colombi, T., Jäck, O., Keller, T., Weih, M. (2022): Effects of soil compaction on grain yield of wheat depend on weather conditions. – Science of The Total Environment 807(1): 150763. https://doi.org/10.1016/j.scitotenv.2021.150763.

[31] Maltas, A., Kebli, H., Oberholzer, H. R., Weisskopf, P., Sinaj, S. (2018): The effects of organic and mineral fertilizers on carbon sequestration, soil properties, and crop yields from a long-term field experiment under a Swiss conventional farming system. – Land Degradation Develeopment 29(4): 926-938. https://doi.org/10.1002/ldr.2913.

[32] Miller, J. J., Bremer, E., Beasley, B. W., Drury, C. F., Zebarth, B. J., Larney, F. J. (2012): Long-term effect of fresh and composted cattle manure on the size and nutrient composition of dry-sieved soil aggregates. – Canadian Journal of Soil Science 92(4): 673-683. https://doi.org/10.4141/cjss2011-056.

[33] Mohammadshirazi, F., McLaughlin, R. A., Heitman, J. L., Brown, V. K. (2017): A multi-year study of tillage and amendment effects on compacted soils. – Journal of Environmental Management 203(1): 533-541. https://doi.org/10.1016/j.jenvman.2017.07.031.

[34] Mueller, L., Schindler, U., Mirschel, W., Shepherd, T. G., Ball, B. C., Helming, K., Rogasik, J., Eulenstein, F., Wiggering, H. (2010): Assessing the Productivity Function of Soils. – Agronomy Sustainable Development 30(3): 601-614. https://doi.org/10.1051/agro/2009057.

[35] Nassir, A., Mishall, A., Mohammed, A. (2024): Soil Compaction Induced by Different Tillage Systems and its Impact on Growth and Yield of Maize (*Zea Mays L.*): A Review. – University of Thi-Qar Journal of Agricultural Research 13(1): 185-200. https://doi.org/10.54174/utjagr.v13i1.302.

[36] Nawaz, M. F., Bourrié, G., Trolard, F. (2013): Soil compaction impact and modelling. A review. – Agronomy for Sustainable Development 33(2): 291-309. https://doi.org /10.1007/s13593-011-0071-8.

[37] Niu, Z. R., An, F. J., Su, Y. Z., Liu, T. N., Yang, R., Du, Z. Y., Chen, S. Y. (2022): Effect of Long-Term Fertilization on Aggregate Size Distribution and Nutrient Accumulation in Aeolian Sandy Soil. – Plants 11(7): 909. https://doi.org/10.3390/plants11070909.

[38] Nyéki, A., Milics, G., Kovács, A. J., Nemény, I. M. (2017): Effects of soil compaction on cereal yield. – Cereal Research Communications 45(1): 1-22. https://doi.org /10.1556/0806.44.2016.056.

[39] Ohu, J. O., Arku, A. Y., Mamman, E. (2001): Modelling the effect of organic materials incorporated into soils before load applications from tractor traffic. – Ife Journal of Technology 10(1): 9-18.

[40] Ohu, J. O., Mamman, E. O. J., Mustapha, A. A. (2009): Impact of organic material incorporation with soil in relation to their shear strength and water properties. – International Agrophysics 23(2): 155-162.

[41] Pagliai, M., Vittori, A. L. (1993): Influence of waste organic matter on soil micro- and macrostructure. – Bioresource Technology 43(3): 205-213. https://doi.org/10.1016/0960-8524(93)90032-7.

[42] Peres, G., Cluzeau, D., Curmi, P., Hallaire, V. (1998): Earthworm activity and soil structure changes due to organic enrichments in vineyard systems. – Biology and Fertility of Soils 27: 417-424. https://doi.org/10.1007/s003740050452.

[43] Puglisi, E., Del Re, A. A. M., Rao, M. A., Gianfreda, L. (2006): Development and validation of numerical indexes integrating enzyme activities of soils. – Soil Biology and Biochemistry 38(7): 1673-1681. https://doi.org/10.1016/j.soilbio.2005.11.021.

[44] Pupin, B., Silva, F., Nahas, E. (2009): Microbial alterations of the soil influenced by induced compaction. – Revista Brasileira de Ciência do Solo 33(5): 1207-1213. https://doi.org/10.1590/S0100-06832009000500014.

[45] Puzniak, O., Hrynchyshyn, N., Datsko, T., Andruszczak, S., Hulko, B. (2022): Consequences of the Long-Term Fertilization System Use on Physical and Microbiological

Soil Status in the Western Polissia of Ukraine. – Agriculture 12(11): 1955. DOI:10.3390/agriculture12111955.

[46] Ramazan, M., Daraz, G. K., Hanif, M., Shahid, A. (2012): Impact of Soil Compaction on Root Length and Yieldof Corn (*Zea mays*) under Irrigated Condition. – Middle-East Journal of Scientific Research 11(3): 382-385.

[47] Schjønning, P., Akker, J. J. H., Keller, T., Greve, M. H., Lamandé, M., Simojoki, A., Stettler, M., Arvidsson, J., Madsen, H. B. (2015): Driver-Pressure-State-Impact-Response (DPSIR) Analysis and Risk Assessment for Soil Compaction-A European Perspective. – Advances in Agronomy 133: 183-237. https://doi.org/10.1016/bs.agron.2015.06.001.

[48] Schjønning, P., Akker, J. J. H., Keller, T., Greve, M. H., Lamandé, M., Simojoki, A., Stettler, M., Arvidsson, J., Madsen, H. B. (2016): Soil compaction. – In: Soil Threats in Europe-Status, Methods, Drivers and Effects on Ecosystem Services. EU Joint Research Centre: Petten, The Netherlands, Chapter 6. https://doi.org/10.2788/828742.

[49] Scullion, J., Malik, A. (2000): Earthworm activity affecting organic matter, aggregation and microbial activity in soils restored after opencast mining for coal. – Soil Biology and Biochemistry 32(1): 119-126. https://doi.org/10.1016/S0038-0717(99)00142-X.

[50] Shaheb, M. R. (2020): A study on the effect of tyre inflation pressure on soil properties, growth and yield of maize and soybean in Central Illinois. – Ph.D. thesis. Harper Adams University, Newport, Shropshire, United Kingdom.

[51] Shaheb, M. R., Venkatesh, R., Shearer, S. A. (2021): A Review on the Effect of Soil Compaction and its Management for Sustainable Crop Production. – Journal of Biosystems Engineering 46(3): 417-439. https://doi.org/10.1007/s42853-021-00117-7.

[52] Shahgholi, G., Jnatkhan, J. (2018): Investigation of The Effects of Organic Matter Application on Soil Compaction. – Tarım Bilimleri Dergisi 28(2): 175-185. https://doi.org/10.29133/yyutbd.348036.

[53] Shein, E. V., Umarova, A. B., Milanovskiy, E. Y., Sokolova, I. V. (2010): Preferential water flow, local soil biota and structure degradation in chernozem 20 years after land-reclamation. – International Agrophysics 24(1): 75-80.

[54] Swartz, R. C, Unger, P. W., Evelt, S. R. (2003): Land use effects on soil hydraulic properties. – Conservation and Production Research Laboratory, USDA-ARS.

[55] Tagar, A. A., Adamowski, J., Memon, M. S., Minh, C. D., Mashori, A. S., Soomro, A. S., Bhayo, W. A. (2020): Soil fragmentation and aggregate stability as affected by conventional tillage implements and relations with fractal dimensions. – Soil and Tillage Research 197: 404494. https://doi.org/10.1016/j.still.2019.104494.

[56] Tanasijevic, Dj., Antonovic, G., Aleksic, Z., Pavicevic, N., Filipovic, Dj., Spasojevic, M. (1966): Pedologic composition of the western and northwestern Serbia. – Nolit Publishing House, Serbia.

[57] Tullberg, J. (2010): Tillage, traffic and sustainability-A challenge for ISTRO. – Soil and Tillage Research 111(1): 26-32. https://doi.org/10.1016/j.still.2010.08.008.

[58] Vanderhasselt, A., Steinwidder, L., Hose, D. T., Cornelis, W. (2024): Opening up the subsoil: Subsoiling and bio-subsoilers to remediate subsoil compaction in three fodder crop rotations on a sandy loam soil. – Soil and Tillage Research 237: 105956. https://doi.org/10.1016/j.still.2023.105956.

[59] Vrbek, B. (2003): Soil characteristics in peduncled oak and common hornbeam forest (Carpino betuli-Quercetum roboris Ht. 1938) of the Pokupsko basin, Cesma and Repas. – Coatian Forest Research Institute 38(2): 177-194.

[60] Vucic, N. (1976): Irrigation of agricultural crops. – University of Novi Sad, Faculty of Agriculture, Serbia.

[61] Wang, S., Zhang, Z., Ye, S. (2020): Response of soil fertility characteristics in water-stable aggregates to tea cultivation age in hilly region of southern Guangxi, China. – Catena 191: 104578. https://doi.org/10.1016/j.catena.2020.104578.

[62] Whalen, J. K., Chang, C. (2002): Macroaggregate characteristics in cultivated soils after 25 annual manure applications. – Soil Science Society of America Journal 66(5): 1637-1647. https://doi.org/10.2136/sssaj2002.1637.

[63] White, R. (2003): Soils for fine wines. – Oxford, University Press, New York. https://doi.org/10.1093/oso/9780195141023.001.0001.

[64] Yang, P., Dong, W., Heinen, M., Qin, W., Oenema, O. (2022): Soil Compaction Prevention, Amelioration and Alleviation Measures Are Effective in Mechanized and Smallholder Agriculture: A Meta-Analysis. – Land 11(5): 645. https://doi.org/ 10.3390/land11050645.

[65] Yuan, J., Sadiq, M., Rahim, N., Tahir, M. M., Liang, Y., Zhuo, M., Yan, L., Shaheen, A., Mahmood, B., Li, G. (2023): Changes in soil properties and crop yield under sustainable conservation tillage systems in spring wheat agroecosystems. – Land 12(6): 1253. https://doi.org/10.3390/land12061253.

[66] Zivkovic, M. (1966): Comparative tests of various preparation methods of carbonate-free soils for mechanical analysis. – Soil and Plant 15(3): 381-407.