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Otpor tla i volumna gustoća tla pri različitim sustavima obrade tla

Stošić, M., Brozović, B., Vinković, T., Ravnjak, B., Kluz, M., Zebec, V.

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Fakultet agrobiotehničkih znanosti Osijek, Poljoprivredni institut Osijek

Faculty of Agrobiotechnical Sciences Osijek, Agricultural Institute Osijek

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Stošić, M.[1], Brozović, B.[1], Vinković, T.[1] Ravnjak, B.[1], Kluz, M.[2], Zebec, V.[1]

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SUMMARY

A stationary field experiment of a reduced soil tillage was implemented at a Hypogley (Hypogleyic soils A–Gso–Gr soil horizon sequence) soil type of Eastern Croatia during three seasons and set up as a split-plot randomized block design in four repetitions. The tillage systems (TS) were as follows: 1) conventional tillage, i.e., plowing at 30 cm (CT), 2) disking up 10-12 cm (DT), 3) soil loosening up to 35 cm (LT), 4) no-tillage (NT). The experiment was designed to compare the penetration resistance (PR), soil moisture (SM), and bulk density (BD) at different TSs and soil depths. A cone penetrometer was used to measure the PR with 10 prods per TS, accompanied with a measurement of SM with a soil auger on every 10 cm, with four samples up to a 40-cm depth. The BD was determined by metal cylinders on every 10 cm up to a 30-cm depth, being weighed and dried thereafter to obtain an absolutely dry sample, and then calculated using absolutely a dry soil sample mass (m_s) and the soil volume (V). The PR and SM were significantly influenced by the TS and soil depth. The CT had the significantly lowest PR at all depths, while the DT has manifested a significantly higher PR at a soil depth amounting to 10 to 20 cm. The PR on NT were significantly diverse from the CT at all soil depths. The BD varied significantly concerning the TS and the soil depth. Subsequent to the three years, the CT had a significantly smaller BD at a depth amounting from 0 to 10 cm, and a significantly higher BD at 20- to 30-cm depth, compared to reduce the TS.

Keywords: soil compaction, bulk density, soil moisture, tillage systems, soil depth

INTRODUCTION

Over the last decades, a soil compaction is becoming increasingly important and puts a modern agricultural production at risk (Stolte et al., 2016). The development of mechanization, heavy field machinery, tillage implements, increased food demands, and an intensive crop production induces the soil's physical degradation (i.e., soil compaction), recognized and identified in the EU as a crucial concern (Virto et al. 2015; Adderley et al., 2018).

Globally, there is a growing body of report literature about hectares struck by compaction (Kuhwald et al., 2018). The crops react to the soil compactness by reducing the number of roots and root lengths, limiting root growth, and generally resulting in the smaller yields (Correa et al. 2019). A soil porosity and water permeability and infiltration by the topsoil or subsoil compacted layer can be reduced, resulting in the aggravation of water and gas exchange (Grzesiak et al., 2013), which can lead to a poor and complicated nutrient uptake (Elfadil and Salih, 2017) and also to the reduction of organic matter mineralization (Silva et al., 2011). Due to the soil compaction, macrofauna is impeded when it comes to the earthworms in their burrowing (Blouin et al., 2013), but Barré et al. (2009) stated that "earthworms may provide an efficient mechanical resilience to soils". Therewith, the European Commission (2013) classifies the loss of soil biodiversity and soil compaction as the

(1) Assoc. Prof. Miro Stošić, Assist. Prof. Bojana Brozović (bojana.brozovic@fazos.hr), Assoc. Prof. Tomislav Vinković, M. Sc. Boris Ravnjak, Assist. Prof. Vladimir Zebec - Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechnical Sciences Osijek, Vladimira Preloga 1, 31000 Osijek, Croatia, (2) Assist. Prof. Maciej Kluz - Uniwersytet Rzeszowski, Aleja Tadeusza Rejtana 16C, 35-310 Rzeszów, Poland

overriding hazards. There is a vast literature about functioning tillage systems on a soil's physical properties, especially concerning the reduced tillage systems, due to its benefits in the organizational, environmental, and economic aspects (Jarvis and Woolford, 2017). Some research has noticed that the penetration resistance values in a soil layer amounting from 0 to 15 cm was significantly higher in the NT than in the CT (Fernandez-Ugalde et al., 2009).

A continuous disking or a continuous plowing (for some crops) leads to the formation of a plowpan or of a diskpan with a greater compactness. E.g., Maity et al. (2013) noticed that, subsequent to the plowing, a penetration resistance at a layer amounting from 15 to 30 cm still remained high, ranging from 1.8 MPa to 2.7 MPa and indicating the presence of a plowpan. Cortez et al. (2016) recorded an increase in the penetration resistance under a disking tillage in a layer amounting from 10 to 20 cm for 0.98 MPa, compared to a layer amounting to 0-10 cm (1.35 MPa), i.e., an increase of 0.37 MPa when compared to the same layer under plowing (1.86 MPa). Subsoiling, in order to alleviate the compactness zones, can significantly reduce a penetration resistance within a layer amounting from 10 to 50 cm (Medeiros et al., 2013). Hakansson (1994) emphasized that a subsoil compaction is more difficult to be noticed and to be rebuilt than a surface compaction.

Some authors cite the limit values and state that a slower root growth can be expected at 1.41 MPa (Graham et al., 1986), while Angebag and Maree (1988) raise that limit even above 3.75 MPa. A recent study by Bengough et al. (2011) has showcased that a root growth is struck in the soils with the values amounting to 0.8-2.0 MPa. A bulk density is also affected by the tillage systems. He et al. (2019) have noticed a diminution in the tilled layers (30 cm), but below that an increase in the bulk density occurs. The similar results were obtained by Barut and Celik (2017). They have substantially observed an increase of bulk density on the disking and no-tillage variants, compared to the plowing. Likewise, a magnification of the bulk density with a depth increasement was detected. Ussiri and Lal (2009) have recorded a lower bulk density under the NT compared to the tilled systems and have emphasized that the changes depend on the duration of the study, soil type, and residue retention. Thereby, a basic intention of this research was to explore the effect of different tillage systems' intensity and frequency on a bulk density and penetration resistance on a Hypogley soil type.

MATERIAL AND METHODS

Experimental design

The research was carried out in the eastern part of Croatia, with the site location being 45°37'48''N/18°42'0''N, i.e., near Darda (Osijek-Baranya County), on a Hypogley soil type (Hypogleyic soils A–Gso–Gr soil horizon sequence). Thereby, a national classification of soil was used (Škorić et al., 1985), being genetic and also serving as a basis for the soil production and an ecological assessment, based on the properties of soils that are morphologically visible or easily measurable. A comparison of the national soil classification with the World Reference Base (FAO, 2015) classification system was also conducted, according to which the classified soil matches the Gleysols. The soil texture was that of a silt loam, with an organic matter content of 2.13% (arable horizon 0-30 cm). The Soil pH amounted to 4.52, phosphorus content amounted to 70.0 g kg^{-1}, while potassium content amounted to 247.0 g kg^{-1}. The investigated area had an average temperature of 11.0°C and 650 mm of precipitation per year. The stationary field experiment was conducted during three seasons and set as a completely randomized block design in four repetitions, with the TS as the main factor in the winter wheat/soybean crop rotation. All data presented in this paper were collected in the period of winter wheat vegetation. The size of a basic tillage plot was 540 m^2. Four tillage systems (TSs) were applied: CT – conventional tillage (autumnal plowing up to a 30 cm depth, with the two disk passes up to 12 cm), DT – disking (12 cm depth, performed twice), LT – soil loosening with one disking (35 cm depth), and NT – without soil tillage. All tillage treatments, except the NT, were accompanied by a seedbed preparation (seedbed cultivator) and sowed by a no-till cereal seeder at a depth of 2 to 3 cm.

Field measurements

Soil penetration resistance (PR) was determined for each TS by measuring the soil penetration resistance using a soil cone penetrometer. Soil penetration resistance (PR) was measured by a soil cone penetrometer (SN from Eijkelkamp, with a cone diameter amounting to 2.00 cm^{-2}, 60° cone angle, and a penetration speed amounting to 2.00 cm s^{-1}). The PR measurement was performed observing a 10 cm distance up to a 40 cm depth at 10 places per TS in three repetitions. Simultaneously, the soil samples for soil moisture (SM) were collected using an auger, observing a 10 cm distance, up to a 40 cm depth (four samples per depth) from the TS in three repetitions (n=192). The SM content was measured by the gravimetric method (Pernar et al., 2013). All field measurements were conducted in a tillering stage (ZGS 26) of winter wheat in all seasons.

Laboratory analysis

The undisturbed soil samples in metal cylinders were taken from a different soil layer (with a depth amounting to 0-10, 10-20, and 20-30 cm) at TS in three repetitions for the determination of a soil bulk density (ISO 11272, (2004). Three metal cylinders (100 cm^3) were used for soil sampling per the TS and depth and weighed (n=108). Subsequently, the soil samples were dried at 105°C to obtain a constant mass, cooled in a vacuum desiccator, and weighed. A cylinder and mesh mass was deducted from the weight mass of the dried sample to obtain the mass of an absolutely dry soil sample (m_s), which was then divided by the volume of the same soil (V). The following equation was used to calculate soil bulk density:

$$\rho_V \ (g\ cm^{-3}) = \frac{m_s}{V}$$

Data analysis

The obtained results were statistically analyzed using the SAS 9.3 software for Windows (SAS Institute Inc., Cary, NC, USA) and Microsoft Office Excel 2016. The significant differences were tested by the ANOVA using the Fisher tests ($p<0.05$).

RESULTS AND DISCUSSION

A comparison of bulk density (BD), penetration resistance (PR), and soil moisture (SM) on the reduced tillage systems was performed according to the CT (Table 1).

Table 1. Bulk density (BD, g cm^{-3}) on a different TS and soil depths during three seasons

Tablica 1. Volumna gustoća tla (g cm^{-3}) na različitim sustavima obrade tla i dubinama tijekom triju sezona

Soil depth - *Dubina tla*, cm	CT	DT	LT	NT
Season 1 – *Sezona 1*				
0-10	1.50 A	1.51 A	1.51 A	1.51 A
10-20	1.55 B	1.57 A	1.54 B	1.57 A
20-30	1.60 A	1.57 B	1.57 B	1.58 B
Season 2 – *Sezona 2*				
0-10	1.43 B	1.47 A	1.43 B	1.50 A
10-20	1.49 C	1.51 B	1.51 B	1.55 A
20-30	1.52 B	1.51 B	1.50 B	1.56 A
Season 3 – *Sezona 3*				
0-10	1.42 C	1.48 A	1.45 B	1.47 A
10-20	1.49 B	1.51 A	1.49 B	1.50 AB
20-30	1.56 A	1.54 B	1.53 B	1.53 B

TS: CT – plowing – *oranje*; DT – disking – *tanjuranje*; LT - soil loosening – *rahljenje*; NT – no-tillage

Notes: The means in the rows followed by different letters are statistically significantly different ($p<0.05$) - *Srednje vrijednosti u redu koje sadrže različitu slovnu oznaku statistički su značajno različite (p<0,05)*

The bulk density (BD) was significantly affected by the TS and the soil depth. Subsequent to the three seasons, the CT has recorded the significantly lowest BD at a depth amounting from 0 to 10 cm, compared to reduce the TS. At a depth amounting from 10 to 20 cm, the DT and the NT were significantly diverse from the CT. At a soil depth amounting from 20 to 30 cm, all three reduced TSs have recorded a significantly lower BD, in comparison to the CT.

The PR values in Season 1 (Fig. 1) were significantly influenced by the tillage systems at all depths. The significantly lowest PR was recorded on the CT in all soil layers. A significantly higher PR was on the NT at all soil depths and also on the DT and the LT at a depth amounting to 20 and 30 cm. The SM data varied significantly through the depths, with the differences in respect to the CT in all soil layers. The highest SM was recorded on the DT and the LT at all four depths.

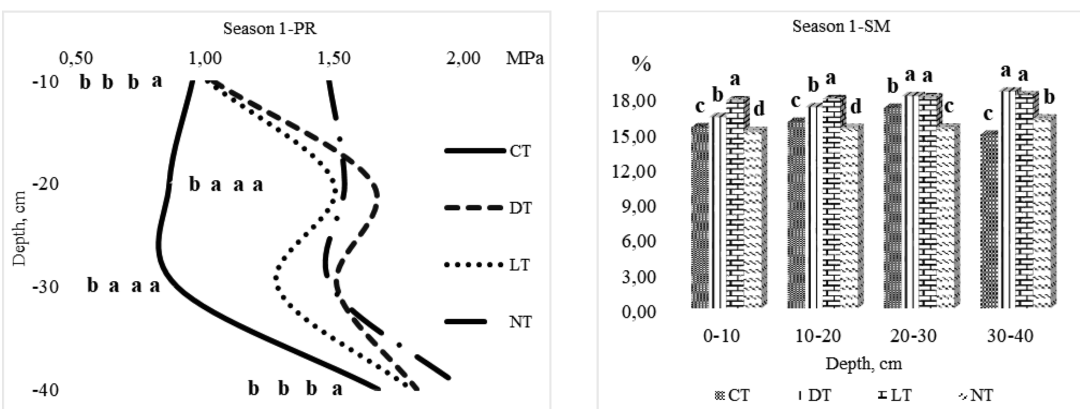


Figure 1. Penetration resistance (PR, MPa) and soil moisture (SM, %) on different TSs and soil depths. in season 1 (TS: CT - ploughing; DT - disking; LT – soil loosening; NT - no-tillage)

Slika 1. Otpor tla (MPa) i trenutačna vlaga tla (%) na sustavima obrade tla i dubinama u 1. sezoni (TS: CT – oranje; DT – tanjuranje; LT – rahljenje; NT – no-tillage)

Notes: The means in the rows followed by different letters are statistically significantly different (p<0.05) - Srednje vrijednosti u redu koje sadrže različitu slovnu oznaku statistički su značajno različite (p<0,05)

The TS has significantly implicated the PR values at all depths in Season 2 (Fig. 2). The lowest PR values were recorded on the CT at a 10, 20, and 30 cm depth, whilst at 40 cm the LT had a lower PR but without a significant difference. The significantly highest SM at all depths was on the CT, whereas the DT, LT, and NT were significantly lower.

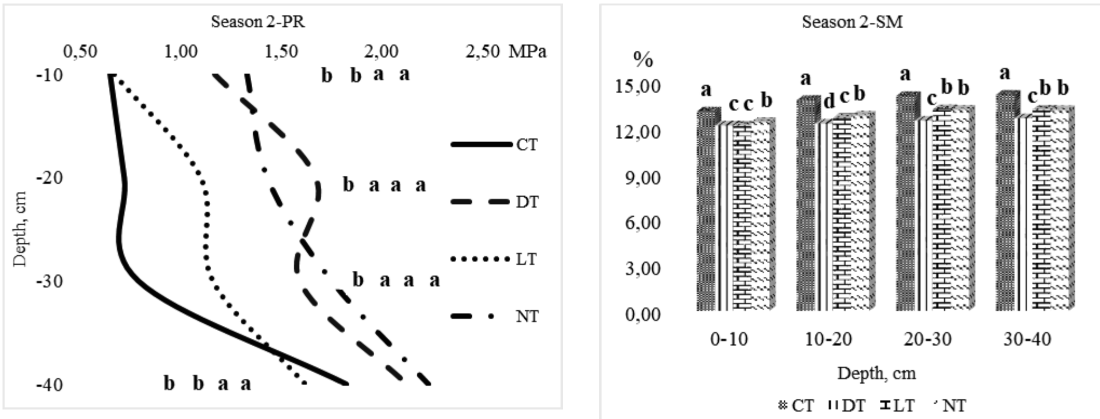


Figure 2. Penetration resistance (PR, MPa) and soil moisture (SM, %) on the different TSs and soil depths in Season 2 (TS: CT – plowing; DT – disking; LT – soil loosening; NT – no-tillage)

Slika 2. Otpor tla (MPa) i trenutačna vlaga tla (%) na sustavima obrade tla i dubinama u 2. sezoni (TS: CT – oranje; DT – tanjuranje; LT – rahljenje; NT – no-tillage)

Notes: The means in the rows followed by different letters are statistically significantly different ($p<0.05$) - *Srednje vrijednosti u redu koje sadrže različitu slovnu oznaku statistički su značajno različite ($p<0,05$)*

Likewise, in Season 3, the PR values were significantly affected by the TS at all depths. A significantly lowest PR at all four depths was recorded on the CT (Fig. 3).

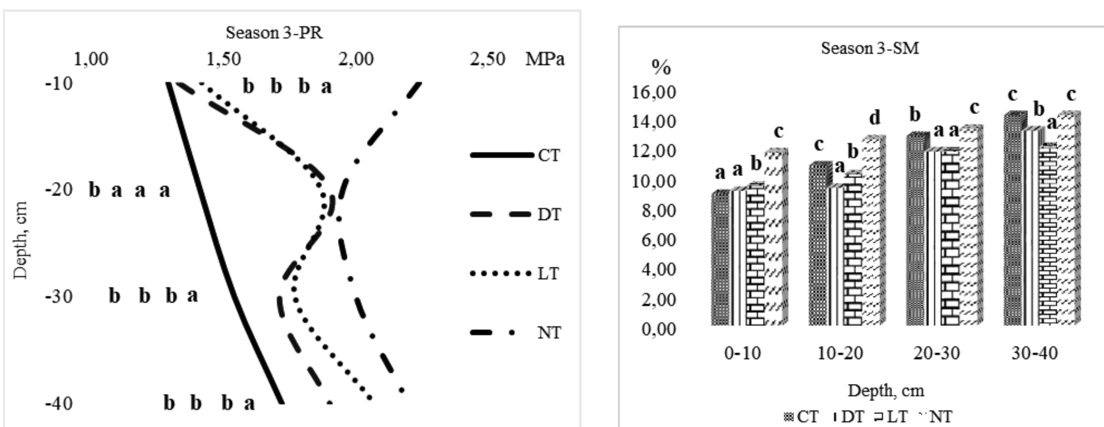


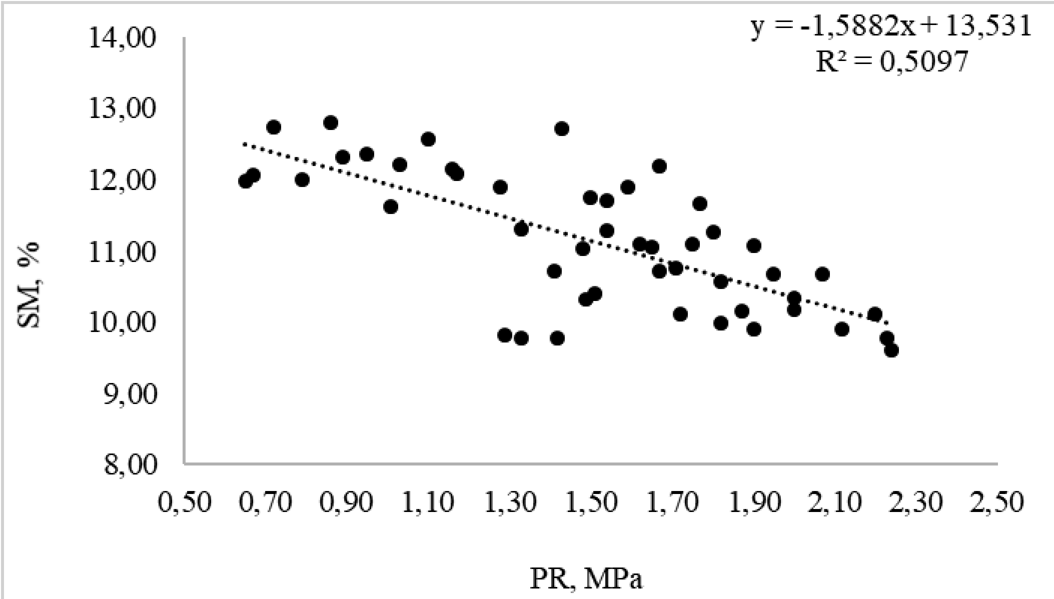
Figure 3. Penetration resistance (PR, MPa) and soil moisture (SM, %) on the different TSs and soil depths in Season 3 (TS: CT – plowing; DT – disking; LT – soil loosening; NT – no-tillage)

Slika 3. Otpor tla (MPa) i trenutačna vlaga tla (%) na sustavima obrade tla i dubinama u 3. sezoni (TS: CT -oranje; DT – tanjuranje; LT – rahljenje; NT – no-tillage)

Notes: The means in the rows followed by different letters are statistically significantly different ($p<0.05$) - *Srednje vrijednosti u redu koje sadrže različitu slovnu oznaku statistički su značajno različite ($p<0.05$)*

The NT had a significantly higher PR at all four depths, while the DT and the LT have manifested a significant difference only at a 20 cm soil depth. The SM was significantly the highest on the NT in all depths, except at a depth amounting to 30.40 cm, after three years of continuous practice.

The results obtained in the research have demonstrated that, between the PR and the SM, a moderate negative and significant ($P<0.01$; $n=48$) correlation was identified and backed by the correlation coefficient r= - 0.71 (Graph 1).



Graph 1. Correlation between the soil moisture (SM, %) and a penetration resistance (PR, MPa)
Grafikon 1. Korelacija između vlage tla (SM, %) i otpora tla (PR, MPa)

The correlation coefficient and regression equation certify that the penetration resistance increases with the decrease of soil moisture.

Some agricultural practices can be used to avoid or reduce the negative impact of climatic change (FAO, 2018) on the crop yield potential and production and also to evolve certain positive effects. The short-term solutions could be a new agricultural production management (conservation agriculture, organic farming, etc.), the introduction of new crops in crop rotation, the alternations in tillage or tillage implements, the discovery of the new crop protecting methods, etc. (Patil et al., 2014; Thaler et al., 2015). According to Nunes et al. (2015), soil compaction is a concern that usually implicates an agricultural effectivity on the NT. The obtained results for the 0-40 cm depth over the whole research period designate that the PR at the NT was differentiated ($P<0.05$) from the CT. The interpretation could be that the NT demands ten or more years for reconstruction of soilborne physical properties.

Also, a long-term NT is suitable for a topsoil compaction due to the gravity and rainfall's kinetic energy, leading to the settling and compaction sensibility. De Moraes et al. (2016) stated that the compaction of surface layer on the NT is actually an agglomerated effect of a previous machinery traffic and tillage default. The highest PR at a 0-10 cm soil depth (2.20 MPa NT) could be an effect of re-compaction caused by the rainfall and percolation of water, generating soil settling. Pittelkow et al. (2015) stated that the NT needs three to ten years for matching the CT yields. Disking system, the DT, had a higher PR ($P<0.05$) that the one obtained from the CT at 10-20 cm in the entire three-year period.

The PR at 10-20 cm was probably such due to disking at same depth, resulting in a compacted layer or diskpan (Dekemati et al., 2019).

A continuous disking at the same depth leads to the formation of a compacted layer, which is much more hazardous than a plowpan because of the root depth reduction and water flooding, infiltration and capillarity difficulties, etc. It could be alleviated by plowing or subsoiling for the following crop, which requires a deep tillage. Contrary to the disking, subsoiling and LT lead to the preferable root development, expansion, and water infiltration (Weil, 2015).

The PR at the LT was higher than the CT ($P<0.05$) at a 20- and 30-cm depth. The LT has manifested the smallest deviations when compared to the CT, which can be explained by the usage of a subsoiler with the leg spacing amounting to 50 cm and a brittle soil state creating favorable soil structure and an improved water infiltration.

Bogunović et al. (2015) noticed that subsoiling has achieved even better results than the CT in some years and at some depths. In a summary, the penetration of roots is being incapable or reduced in the pores narrower than their diameters are, and depending on the crop species the roots can adapt to the PR values on a scale fluctuating from 0.7 to 2.5 MPa (Kahlon and Kurana, 2017). Kolb et al. (2017.) reported that the PR measured by a penetrometer was two to eight times higher than that perceived by roots.

In our study, the highest PR amounted to 2.20 MPa, and according to those limitations, it was in a range in which the roots can overcome the given PR. Nawaz et al. (2013) have named that soil a compaction, being an interaction of soil moisture, texture, and structure, soil bulk density, porosity and strength, soil fauna (biodiversity), etc. The results for the BD figured the differences ($P<0.05$) between the TS, with the more pronounced differences.

Subsequent to the three years of continuous practice, the effect of TS on the BD at different depths has demonstrated that the CT had the lowest (1.42) and the highest (1.60) BD at a 10-cm and at a 30-cm soil depth. Due to the looseness and hollowness of the soil density by tillage equipment (Heidarpur et al., 2011), a BD decrement following the application of TS can be expected, especially in the tilled horizons.

The high BD in such layers, where a continuous plowing or disking is applied to the same soil depth, can be explained by an increase in the mechanical soil loading intensity (Gronle et al., 2015), especially for the CT, due to its secondary tillage and operations. Subsequent to the three years, all the reduced TSs have manifested a decrease in the BD compared to the initial state, and similar findings were reported by Ordoñez-Morales et al. (2019), who noticed a BD reduction of 0.5% to 8.8%. Hamza and Anderson (2005) have devised the guidelines to prevent, avoid, or delay a soil compaction, soil pressure decrease using a lighter machinery, a reduced number of passes and frequency, a controlled traffic, an increase in the soil organic matter, the alleviation of hard pans by subsoiling, etc. Likewise, Zebec et al. (2017) have warned that the optimal soil moisture is an important factor in the performance of tillage and machinery operations. Hazelton and Murphy (2007) emphasize that, at a BD amounting from 1.75 to 1.80 g cm^{-3} in the sandy loam soils and from 1.60 to 1.70 g cm^{-3} in the loam soils, the root and plant growth can experience problems. In our study on a silt loam texture, the recorded BD values were below these limitations. Moreover, Lomeling and Lasu (2015) have noted that the BD is a favorable tool type in evaluating its variety effects on the SM and the PR. Furthermore, a better interpretation and explanation of the impact and significance of the BD and of the SM on the PR feedback may be obtained.

CONCLUSION

Concerning the PR and the BD in a tilled horizon, the CT has manifested its benefits in these indicators' lower values, except at a soil depth amounting to 30 cm due to a continuous repetition, which can be alleviated by subsoiling. The DT has a potential for some crops, but it needs to be accompanied or replaced with a deep tillage or chiseling after few years of application due to a disk pan breakdown. The LT has manifested small differences compared to the CT and could represent a possible solution for the crops that require deeper tillage (maize, sunflower). The NT had the highest PR through all soil profiles, which could be a residual effect of previous continuous plowing. The application of NT necessitates more time to express its potential (>5 years) than it occurred in this research (three years). Further longer-range investigations on different soil types are necessary to better understanding and gage the lasting effects of the TS soil properties.

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OTPOR TLA I VOLUMNA GUSTOĆA TLA PRI RAZLIČITIM SUSTAVIMA OBRADE TLA

SAŽETAK

Stacionarni poljski pokus reducirane obrade tla proveden je u istočnoj Hrvatskoj na hipogleju tijekom triju sezona. Pokus je postavljen kao randomizirani blok-sustav u četiri ponavljanja. Sustavi obrade tla (TS) bili su sljedeći: 1) konvencionalna obrada tla oranjem na 30 cm (CT); 2) tanjuranje na 10–12 cm (DT); 3) rahljenje tla na 35 cm (LT); 4) **no-tillage** ***(NT). U eksperimentu su praćeni otpori tla (PR), vlaga tla (SM) i volumna gustoća tla (BD) na različitim TS-ovima i dubinama tla. Konusni penetrometar korišten je za mjerenje PR-a s 10 uboda po TS-u, praćeno sondiranjem za SM na svakih 10 cm, s četirima uzorcima do 40 cm dubine. BD je određen metalnim cilindrima na svakih 10 cm do 30 cm dubine. Izvagani uzorak je osušen do apsolutno suhoga uzorka, a zatim izračunan BD koristeći se apsolutno suhom masom uzorka tla (m_s) i volumena tla (V). PR i SM su bili pod značajnim utjecajem TS-a i dubine tla. CT je imao najniži PR na svim dubinama, DT je pokazao značajno veći PR na dubini tla od 10 do 20 cm u odnosu na CT. PR na NT bio je značajno različit od CT-a na svim dubinama tla. BD se znatno razlikovao po TS-u i dubini tla. Nakon tri godine CT je imao signifikantno manji BD na dubini 0-10 cm te signifikantno veći BD na dubini 20-30 cm u odnosu prema reduciranim sustavima obrade tla.***

Ključne riječi: otpor tla, volumna gustoća tla, vlažnost tla, sustavi obrade tla, dubina tla

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