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Contrasting tillage systems and vertical arable layer stratification impacts on soil aggregates and root biomass in Lithuania

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Abstract: Tillage intensity can affect soil quality through soil aggregates, which are strongly associated with organic carbon. In this study, we evaluated the effect of different intensity tillage [conventional ploughing (CP), shallow ploughing (SP), deep cultivation (DC), shallow cultivation (SC), no-tillage (NT)] on soil organic carbon (*SOC*), and soil aggregates at the 0–5, 5–10, 10–20, and 20–30 cm layers and root biomass at the 0–10, 10–20, and 20–30 cm layers. The field experiment on spring barley (*Hordeum vulgare* L.*)* consisted of a split-plot arrangement with four replications. Dry soil aggregates were evaluated using the mean weight diameter (*MWD*) index. Wet aggregates were assessed using a water-stable aggregate (*WSA*) index. We identified that tillage intensity significantly influenced the *MWD* index at four soil levels. Shallow tillage showed greater results at 0–5 and 5–10 cm depths. However, deep tillage increased the *MWD* at 10–20 and 20–30 cm depth. NT was dominated by evaluating the *WSA* at every level of the soil. *SOC* was correlated with *WSA*. The highest *SOC* was found under NT. The different tillage intensities did not significantly affect root biomass.

Keywords: deep tillage; organic carbon; shallow tillage; soil depth; soil quality

Intensive tillage might be the reason for soil erosion, herewith-organic matter decrease, and soil aggregate destruction, resulting in a decline in soil productivity. However, conservation tillage can improve soil quality by increasing aggregate stability and reducing the breakdown of aggregates (Kan et al. 2020). Moreover, every tillage system can be useful or useless, depending on the soil and climate (Scarpare et al. 2019). Therefore, more research is needed on this issue. Soil erosion is a serious agricultural problem, which is the reason for the loss of available water and nutrients, the decline of soil quality, acceding to soil degradation, and can be controlled by the aggregate breakdown system (Saygin and Erpul 2019).

Soil organic carbon (*SOC*) is associated with the physical, chemical and biological properties of soil, and it can be determined by the formation, stabilisation and breakdown processes of soil aggregates (Liu et al. 2019). Microbial activity breaks up the organic matter by increasing the carbon content in the soil. Therefore, an appropriate quantity of straw increases carbon accumulation (Jin et al. 2021). Soil aggregates play a key role in *SOC* turnover. Microaggregates or macroaggregates are formed by soil particles, rich in *SOC* (Wei et al. 2017). Moreover,

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Kushwaha et al. (2001) indicated that *SOC* has been directly correlated with macroaggregates, although *SOC* has been negatively correlated with microaggregates. The stabilisation mechanism is also affected by the aggregate size and aggregate composition (Hu and Kuhn 2016).

Soil particles, pore size, shape and arrangement can be defined as soil structure, which depends on aggregates. The interaction between *SOC* and soil structure can be achieved through aggregate formation (Yin et al. 2018). One of the most important soil structure determinations for describing the efficiency of applied, sustainable management strategies is aggregate size distribution and water-stability aggregates (Saygin and Erpul 2019). Soil aggregate size distribution and stability proceed through physical and biochemical processes (Yin et al. 2018) and are important to assess soil quality (Saygin and Erpul 2019). One of the soil's physical indicators is the mean weight diameter (*MWD*) index of soil aggregates (Valani et al. 2022), which is one of the frequently used indices of soil aggregate size. The greater stability of soil aggregates means larger *MWD* values (Hu et al. 2021). The tillage and *SOC* amount affect the water-stable aggregate (*WSA*) index (Guo et al. 2019). Low soil aggregate stability can give rise to soil erosion of wind or water, as well as losses of soil carbon and nitrogen together with phosphorus and increase the number of macroaggregates (Kasper et al. 2009). Moreover, carbon (C) mineralisation proceeds more slowly. Soil aggregate formation and stabilisation occurred greater under no-tillage compared with reduced and conventional tillage, which decreased the stability of wet aggregates (Jin et al. 2021).

The roots of the plant perform the basic function of supplying nutrients and water. Tillage impacts aggregates, pore size, soil aeration and root growth (Guan et al. 2014). Root growth depends on the crop variety, the physical, chemical, and biological parameters, and the crop management system (Lovera et al. 2021). Moreover, the depth of tillage can make disagreeable changes, such as decomposing biota, disturbance of soil aggregates and loss of organic matter (Scarpare et al. 2019). Nutrient uptake and water storage depend on root development and distribution (Guan et al. 2014). The *SOC* complex is also maintained through root systems (DuPont et al. 2010). The larger root system better exploits soil ability (Lovera et al. 2021). Moreover, soil density limits root development. Therefore, tillage systems help create changes in soil properties, such as bulk density and aggregate stability (Guan et al. 2014). Root biomass can indirectly affect aggregates stability and formation (Hu et al. 2021). Nevertheless, root biomass is not the decisive factor for a good yield (Lovera et al. 2021). The roots are usually concentrated in the upper soil layer as the quantity of water and nutrients (Guan et al. 2014).

The main aim of this article was to verify the hypothesis that reduced tillage and no-tillage increase *SOC* with reason to increase soil quality.

MATERIAL AND METHODS

Experimental study site description, design and treatments. A long-term stationary field experiment was established at the Research Station of the Agriculture Academy (Vytautas Magnus University) in 2000. The Agricultural Research Station is in Ringaudai (54°52'59.8'N 23°50'25.1'E), Kaunas District, Lithuania. The experimental site is in the temperate zone and sub-region of Atlantic-European continental mixes and broad-leaved forests and contains sandy loam soil, classified as Epieutric Endocalcaric Endogleyic Planosol (Endoclayic, Aric, Drainic, Humic, Episiltic) according to World Reference Base for Soil Resources (2015). The agrochemical conditions of the soil were: pH – 7.3, available phosphorus (P_2O_5) – 271.7 mg·kg^{-1}, available potassium (K_2O) – 145.7 mg·kg^{-1}, and humus – 2.07% at 0–30 cm depth in 2017. The temperature and precipitation data are shown in Figure 1.

The field experiment was designed with four main treatments: spring barley (*Hordeum vulgare* L.) with plant residues, winter rape (*Brassica napus* L.) with plant residues, winter wheat (*Triticum aestivum* L.) with plant residues and cover crops and faba bean (*Vicia faba* L.) with plant residues. The samples were taken only from spring barley plots. The main plot consists of a split-plot arrangement of four-rotation levels replication and splits into five tillage practices: conventional ploughing (CP) at a depth of 23–25 cm, shallow ploughing (SP) at a depth of 12–15 cm, deep cultivation (DC) (chiselling) at a depth of 23–25 cm, shallow cultivation (SC) (discing) at a depth of 12–15 cm and no-tillage (NT) (direct drilling) at a depth of 0–5 cm. The main plots were 126 m^2 (14 × 9) with subplots of 70 m^2 (10 × 7). The protection zone was 1 m, and between replications, it was 9 m.

Under NT treatment, there was no soil cultivation in spring, and the crops were directly planted. More-

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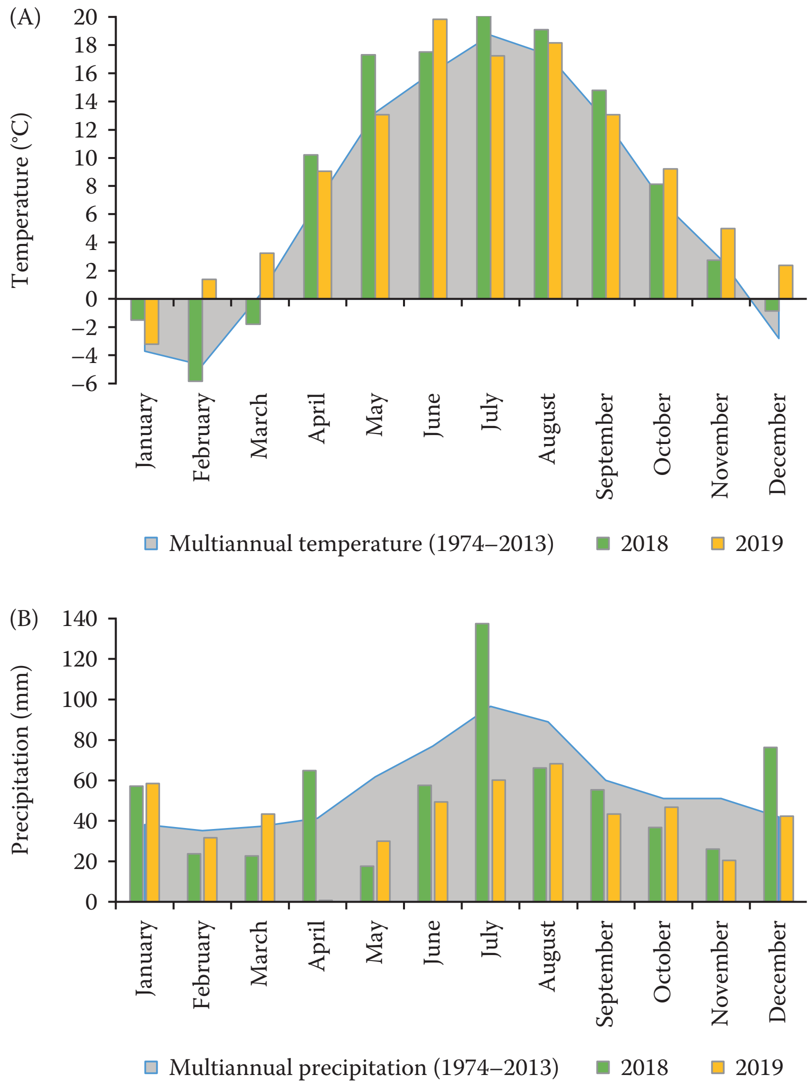

Figure 1. (A) Monthly temperature and (B) precipitation data of the experimental site during 2018–2019 in Ringaudai (54°52'59.8'N 23°50'25.1'E), Kaunas district, Lithuania

over, weeds were chemically controlled with the herbicide Glyphogan 360 SL. The main cultivations were performed in September–October (2018 and 2019). For CP, SP ploughing was used as a plough Gamega PP-3-43 (Gamega Ltd., Lithuania). For DC tillage, a chisel cultivator KRG-3.6 (Laumetris Ltd., Lithuania) was used, and for SC and NT tillage, a disc harrow Väderstad Carrier 300 (Väderstad AB, Sweden) was used. The pre-sowing tillage operation was performed with a complex cultivator KLG-3.6 (Laumetris Ltd., Lithuania), in April–May. Spring barley was sown at a row spacing of 12.5 cm, at a depth of 3 cm and at a rate of 190 kg·ha^{-1} with a drill Väderstad Rapid 300C Super XL (Väderstad AB, Sweden) in April–May. The application of NPK (16 : 16 : 16) and ammonium nitrate (N_{68}) fertilisers was 300 kg·ha^{-1} and 200 kg·ha^{-1}, respectively. There was the same rate for all plots. The crops were sprayed using insecticide Karate Zeon 5 CS, herbicide Elegant 2FD and fungicide Amistar 250 SC. Insecticides and herbicides were applied twice per season.

Soil sampling and methods of analysis. Soil samples for aggregates from spring barley were carefully collected in May (2018–2019) from the four layers (0–5, 5–10, 10–20, and 20–30 cm). The composite samples were air-dried at room temperature in the laboratory.

Dry aggregates were perpetrated to identify size distribution and fix water-stable aggregate using the Kemper and Rosenau method (1986). All samples were dry sieved into particle size fractions: > 10 mm, 10–7.10 mm, 7.10–5 mm, 5–3.15 mm, 3.15–2 mm,

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2–1 mm, 1–0.50 mm, 0.50–025 mm, and < 0,25 mm. Dry sieve analysis was performed in an analytical sieve shaker 'Retsch' (Eijkelkamp, Netherlands). A 2–1 mm size fraction was used to fix the wet aggregates stability. Water-stable aggregate was tested with the wet sieving apparatus 'Eijkelkamp' (Eijkelkamp, Netherlands).

Root biomass samples from spring barley were collected by homemade steel core (length 10 cm × width 10 cm × height 10 cm) from each plot at 0–10, 10–20, and 20–30 cm layers in July (2018–2019). Roots were washed out of the soil through a sieve (0.25 mm^2 mesh), and later dried at 50 °C for 48 h and weighed.

Soil samples for *SOC* determination were taken after harvesting in August 2019. Samples were taken with a soil auger at different depths: 0–5, 5–10, 10–20, and 20–30 cm, combined samples of 200 g for each depth were prepared and placed in cardboard boxes. The carbon contents were measured using the Tyurin method modified by Nikitin.

Statistical analysis. The aggregates size distribution for each soil sample was calculated using the *MWD* index (mm) (Kemper and Rosenau 1986):

$$MWD = \sum_{i=1}^{n} w_i \times x_i \quad (1)$$

where: n – the number of fractions (–); x_i – the diameter of the size fraction (mm); w_i – the proportion of each size fraction over the total sample weight (g).

The water-stable aggregates for 1–2 mm size fraction were calculated using the *WSA* index (%) (Kemper and Rosenau 1986):

$$WSA = \frac{w_{ds}}{w_{ds} + w_{dw}} \times 100 \quad (2)$$

where: w_{ds} – aggregates dispersed in the dispersing solution (g); w_{dw} – aggregates dispersed in water (g).

The least significant difference (LSD) was used to compare the means for each variable (P < 0.05) and were analysed with ANOVA. Statistical analyses were performed with the statistical software package Systat12 (version 12.02.00).

RESULTS

Effect of different intensity tillage on the *MWD* index. In the present study, the *MWD* index was significantly influenced by different tillage intensities at almost every layer in 2018 (Figure 2A) and 2019 (Figure 2B).

Low values were determined under deep tillage treatments (CP and DC) at 0–5 and 5–10 cm depths

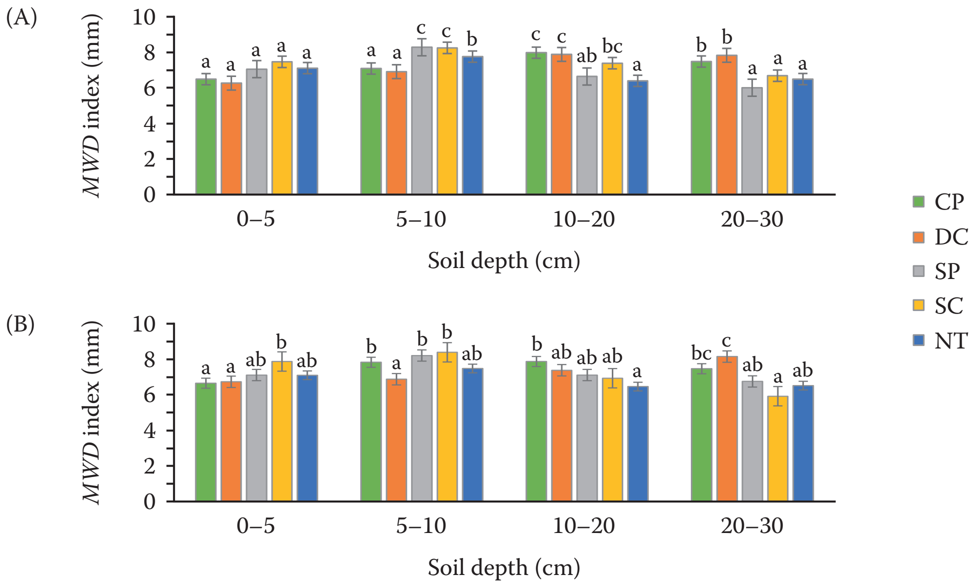

Figure 2. *MWD* index under CP, DC, SP, SC, and NT at the 0–5, 5–10, 10–20, and 20–30 cm layers in (A) 2018 and (B) 2019

Error bars represent the standard error; [a–c] significant differences between treatments P < 0.05, based on Fishers least significant difference (LSD) test; *MWD* – mean weight diameter; CP – conventional ploughing; DC – deep cultivation; SP – shallow ploughing; SC – shallow cultivation; NT – no-tillage

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in 2018. A high *MWD* index was found under shallow (SP and SC) tillage and no-tillage (NT) in the upper layers (0–5 and 5–10 cm). The reverse result was found in the deeper layers (10–20 and 20–30 cm): the deep tillage treatments dominated compared with shallow and no-tillage in 2018.

In 2019, the *MWD* index showed very similar results as in 2018. The low *MWD* was under deep tillage at 0–5 and 5–10 cm depth. High values were found under shallow and no-tillage in the upper layers. At 10–20 and 20–30 cm depth, *MWD* was higher under CP and DC compared with SP, SC, and NT.

Effect of different intensity tillage on the *WSA* index. Different intensity tillage significantly affected the *WSA* index at the upper (0–5 and 5–10 cm) and deeper (10–20 and 20–30 cm) soil layers in 2018 (Figure 3A) and 2019 (Figure 3B).

The *WSA* index was the highest under NT, and the lowest amount of water-stable aggregates was made under CP at upper soil layers in 2018. Shallow tillage and NT positive affected the *WSA* index at a depth of 10–20 cm. At the 20–30 cm layer, NT showed the highest *MWD* value in 2018.

A very similar tillage intensity effect on *WSA* was found in 2019 compared with 2018. At the upper layers, the highest *WSA* values were found under NT and the lowest values of *WSA* were found under CP. Shallow tillage and NT showed higher results compared with deep tillage at 10–20 cm depths. The highest *WSA* values were under NT at 20–30 cm in 2019.

Effect of different intensity tillage on root biomass. Different intensity tillage did not significantly affect root biomass at 0–10, 10–20, and 20–30 cm depth in 2018 (Figure 4A) and 2019 (Figure 4B). A higher amount of root biomass was at the upper layers compared with the deeper layers in 2018 and 2019.

The high values of root biomass were determined under CP in 2018 and 2019. Low root biomass was found under DC in almost every layer of soil.

Effect of different intensity tillage on *SOC*. Tillage intensity significantly affected by *SOC* contained at 0–5, 5–10, and 10–20 cm depths in 2019 (Figure 5). The highest values of *SOC* were found under NT at 0–5, 5–10, and 10–20 cm depth. The lowest values of *SOC* were under CP at 0–5, 5–10, and 10–20 cm depths.

Relationship between *SOC* and *WSA*. In the present study, the relation between *SOC* and *WSA* was determined using line regression. *SOC* was significantly positively correlated with *WSA* (Figure 6).

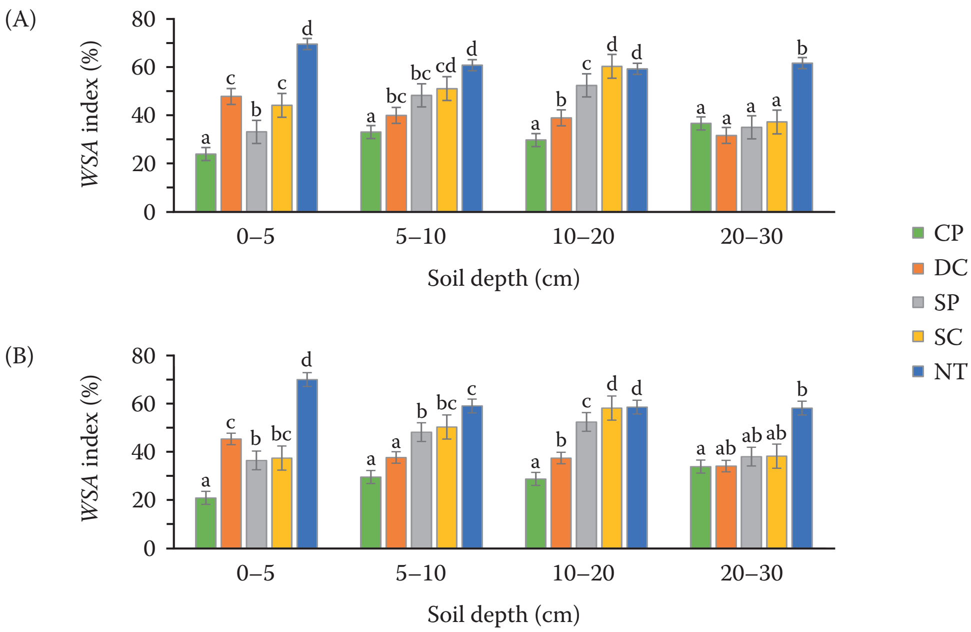

Figure 3. *WSA* index under CP, DC, SP, SC, and NT at the 0–5, 5–10, 10–20, and 20–30 cm layers in (A) 2018 and (B) 2019

Error bars represent the standard error; [a–d] significant differences between treatments $P < 0.05$, based on Fishers least significant difference (LSD) test; *WSA* – water-stable aggregate; CP – conventional ploughing; DC – deep cultivation; SP – shallow ploughing; SC – shallow cultivation; NT – no-tillage

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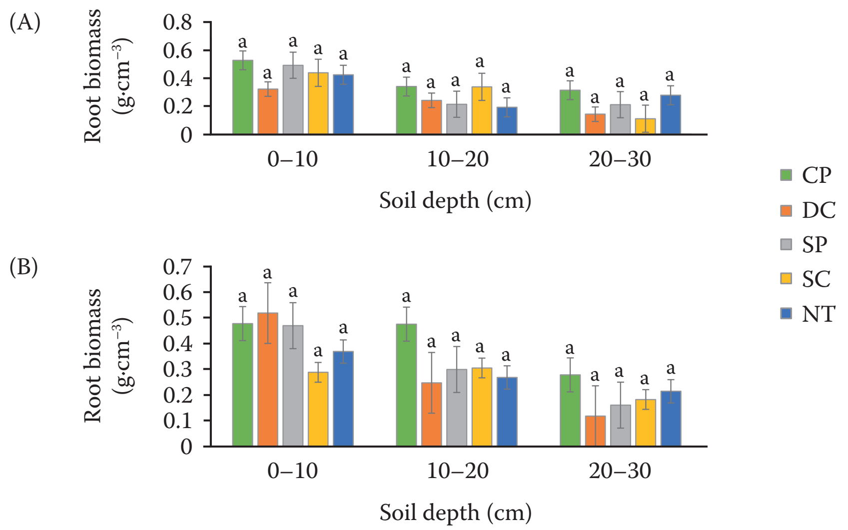

Figure 4. Root biomass under CP, DC, SP, SC, and NT at the 0–10, 10–20, and 20–30 cm layers in (A) 2018 and (B) 2019

Error bars represent the standard error; [a] significant differences between treatments $P < 0.05$, based on Fishers least significant difference (LSD) test; CP – conventional ploughing; DC – deep cultivation; SP – shallow ploughing; SC – shallow cultivation; NT – no-tillage

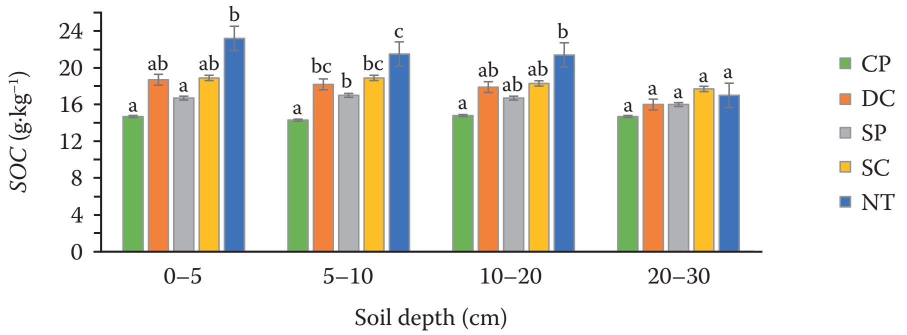

Figure 5. *SOC* under CP, DC, SP, SC, and NT at the 0–5, 5–10, 10–20, and 20–30 cm layers in 2019

Error bars represent the standard error; [a–c] significant differences between treatments $P < 0.05$, based on Fishers least significant difference (LSD) test; *SOC* – soil organic carbon; CP – conventional ploughing; DC – deep cultivation; SP – shallow ploughing; SC – shallow cultivation; NT – no-tillage

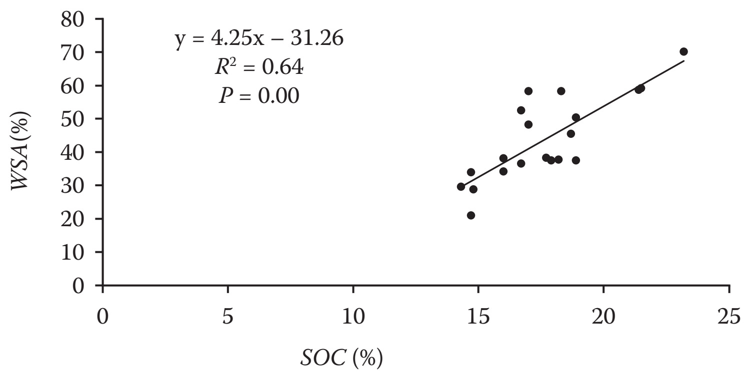

Figure 6. Line regression of *SOC* and *WSA*

The data represent the mean values of plots (n = 40); *SOC* – soil organic carbon; *WSA* – water-stable aggregate

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DISCUSSION

The present study showed that the *MWD* index was lower under deep tillage (CP and DP) than in shallow (SP and SC) tillage and no-tillage at the upper soil layers (0–5 and 5–10 cm) in 2018 and 2019. At the deeper soil layers (10–20 and 20–30 cm), tillage had a reverse result on *MWD* values. The higher *MWD* was under deep tillage than in shallow and no-tillage in 2018 and 2019. Yin et al. (2018) found that *MWD* was higher under no-tillage than under conventional tillage. However, the residues were used only under no-tillage, and the conventional tillage was made without residues, which could be the reason for obtaining a different result at the deeper layers. Deep tillage could also improve straw incorporation, aeration, and infiltration in deeper soil layers (Gao et al. 2019). Pinheiro et al. (2004) also found *MWD* lower under conventional tillage compared with no-tillage. Mondal and Chakraborty (2022) found that in the 0–10 cm layer, *MWD* was 30.2% higher after no-tillage compared with conventional tillage. Obalum et al. (2019) found that tillage (CP and NT) had no impact on *MWD* and argued that this tillage system might not likely affect wind erosion in soil.

In the present study, the *WSA* index was the highest under NT at almost every depth researched. Similar results were found by Hati et al. (2021), who found that *WSA* was higher under reduced tillage compared with conventional. Madarász et al. (2021) found that *WSA* was higher in reduced tillage compared with conventional. Jin et al. (2021) also determined a higher percentage of *WSA* under lower intensity tillage. In another research, the aggregate stability was twice as low as under conventional and reduced tillage, compared with minimum tillage (Kasper et al. 2009).

SOC also plays an essential role in soil quality (Valani et al. 2022). The straw on the soil surface increases porosity, soil oxygen and permeability. Suitable soil aeration and porosity enlarge the activity of microorganisms. Numerous microorganisms break up more quantities of straw, increasing the organic carbon content of the soil. Organic carbon is impotent for stabilising soil aggregates (Hu et al. 2021). In the present study, *SOC* amount was the highest under NT at 0–5, 5–10, and 10–20 cm depth in 2019. The high *SOC* value could be the reason for increasing the *WSA* index under NT, since organic carbon is necessary for the formation of water-stable aggregates. The correlation between *SOC* and *WSA* showed that organic carbon plays an important role in water-stable aggregates. Babur et al. (2021) and Alagöz and Yilmaz (2009) found the same correlation result.

In the present study, tillage did not significantly affect root biomass. However, deep tillage by plough was most useful for root biomass. Conventional tillage reduces bulk density, increases soil moisture and oxygen values, and causes changes in root biomass extension at the deeper layer of soil. Guan et al. (2014) found significantly higher root biomass under rotary tillage and plough tillage compared with no-tillage across a 0–40 cm soil profile. DuPont et al. (2010) found that root biomass under perennial grass was significantly higher compared with no-tillage across a 0–40 cm soil profile. Lampurlanés et al. (2002) found the reverse result: a greater result of root length density was found under no-tillage compared with minimum tillage (by cultivator at 15 cm depth) and subsoil tillage (by cultivar at 15 cm and tilling at 40 cm depth). Moreover, in this study, soil structure did not play a direct role in root biomass.

CONCLUSION

This study focused on different intensity tillage at the 0–5, 5–10, 10–20, and 20–30 cm layers, researching the effect on soil aggregates, root biomass, and *SOC* with reason to increase soil quality. Shallow tillage and NT increased the *MWD* index only in the upper soil layers. However, deep tillage was more appropriate for deeper soil layers, because the *MWD* index was higher than shallow tillage and no-tillage. The *WSA* index was the highest under no-tillage at all levels of the soil layers. *SOC* plays a major role in the stability of aggregates. Therefore, the *WSA* index correlated with the *SOC* values. Organic carbon amounts were the highest under NT. Different intensity tillage had no significant effect on root biomass. The appropriate tillage for the root biomass was under CT.

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