IMPACT OF TILLAGE INTENSITY WITH VERTICAL ARABLE LAYER STRATIFICATION ON WATER RETENTION CURVES

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Abstract. Tillage practices affect the hydrological functions of soil in arable layers. Here, we evaluated the physical properties of soils, such as water retention, bulk density, pore-size distribution, and S-index, at different arable layers (0-5, 5-10, 10-20 and 20-30 cm) to determine optimal tillage practices in Lithuanian region. In a long-term experiment with four randomized main plots, we applied five treatments: conventional ploughing, shallow ploughing, deep cultivation, shallow cultivation, and no-tillage. Low plant-available water, S-index, and microporosity were found under shallow cultivation at 5–10 cm (2018) and under deep cultivation at 20–30 cm (2019) depths. No-tillage increased bulk density and decreased water content at 0–10 cm depth. Micropores together with residual micropores dominated in the 0–5, 10–20, and 20–30 cm layers. Macropores together with mesopores were dominant at 5–10 cm depth. In conclusion, low water content decreases S-index values, microporosity, and bulk density.
Keywords: *soil depth, bulk density, pore-size distribution, soil physical quality index, plant-available water*

Introduction

Tillage, as a crop production technology, affects the water and hydrological functions of soil (Fatumah et al., 2020). It also acts on soil properties, nutrient uptake, crop growth, and yield (Zhai et al., 2021). However, intensive tillage can lead to soil degradation (Panettieri et al., 2020). In contrast, zero or reduced tillage, called conservation tillage, improves soil quality (Obia et al., 2020) and water retention (Zhai et al., 2021), increases soil organic matter (Panettieri et al., 2020), and subserves the sustainable intensification of production (Kassam et al., 2012). It further increases soil bulk density. However, deep tillage improves the physical, biological, and hydraulic properties of soil (Zhai et al., 2021). Most studies have compared only two, three, or four tillage intensities. The current study involved five tillage intensities with vertical arable layer stratification.

Drought is a major cause of decreased food production (Han et al., 2020). The phenomenon is aggressively progressing and can be attributed to climate change (Lyons et al., 2021). Soil water limitation leads to crop stress and the inhibition of crop growth; slow crop growth further affects the yield. Therefore, precise determination of the soil's water retention capacity is crucial during the crop growth season (Han et al., 2020). Soil water retention (SWR) also affects the physical properties of the soil. Aggregating SWR for hydrological modelling, and upscaling (Mallet et al., 2020) can help farmers choose the right irrigation strategies and improve the ecological environment conditions (Li et al., 2021).

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The soil water level is determined from measurements of soil water retention and soil water potential, to define the soil water status (Kassaye et al., 2020). Soil water content (SWC) involves the volume of soil water present in a particular volume of soil. In contrast, SWP comprises pressure, gravitational, matric, and osmotic potentials (Campbell and Campbell, 2013). While SWR measurements provide only information about water quantity, SWP results provide information regarding the availability or movement of water (Campbell and Campbell, 2013). Soil properties, such as soil texture, organic matter content, soil structure, and SWC, affect the threshold values of SWP (field capacity (θ_{FC}), depletion level (θ_{Dep}), and permanent wilting point (θ_{PWP})) (Kassaye et al., 2020).

Some researchers use the S-index to represent the soil's physical quality. A higher S-index indicates better physical quality. This index is related to available water capacity (Dexter, 2004a). Soil bulk density can also be used as a soil physical quality parameter to evaluate various soil processes (Topa et al., 2021). Soil compaction increases bulk density and reduces soil porosity and water infiltration (Barbosa et al., 2019). Reduced tillage or no-tillage practices can change soil compaction by maintaining physical quality. Most researchers have determined higher soil bulk density at the upper arable layer under no-tillage compared with conventional or minimum tillage (Obia et al., 2020).

Soil porosity is important for soil and water fluxes between the soil and atmosphere. Aeration and water availability are essential for roots and soil organisms (de Lima et al., 2022). Soil water retention curves (SWRC) assist in determining and obtaining information about pore-size distribution (Dexter, 2004a). Macropores play an important role in water entry and movement, and they are lost when soil is compressed (Kraemer et al., 2022). Temporarily, macropores are formed at the beginning of the season under conventional tillage. Rainfall on the soil is known to temporarily increase the temporary growth of total porosity under conventional tillage treatment by compacting the soil surface. Nevertheless, finer pores and fewer pore spaces can be found under reduced tillage (Osunbitan et al., 2005).

In this study, we aimed to determine the most appropriate tillage practices for evaluating soil physical properties such as water retention, bulk density, pore-size distribution, and S-index at different arable layers. The motivation of this study was to determine the effect of different tillage intensities on soil physical parameters at 0–5, 5–10, 10–20, and 20–30 cm depths. Most studies have investigated only three types of tillage; most often, they choose rotary, mouldboard plough, and no-tillage. We researched deep tillage (ploughing and cultivation) and shallow tillage (ploughing and cultivation), as well as no-tillage. Four levels of layers can also show interesting results.

Materials and methods

Experimental site

The research was carried out during the period 2018-2019 in a long-term experiment, set up in 1999, at the Experimental Station of the Vytautas Magnus University. The Experimental Station is located 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, contains sandy loam soil, classified as Epieutric Endocalcaric Endogleyic Planosol (Endoclayic, Aric, Drainic, Humic, Episiltic) according to the WRB (2015), with a pH of 7.3, available P_2O_5 of

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271.7 mg·kg[-1], available K_2O of 145.7 mg·kg^{-1}, and humus content of 2.07% at 0-30 cm depth. The temperature and precipitation data of the experimental station are shown in *Figure 1*.

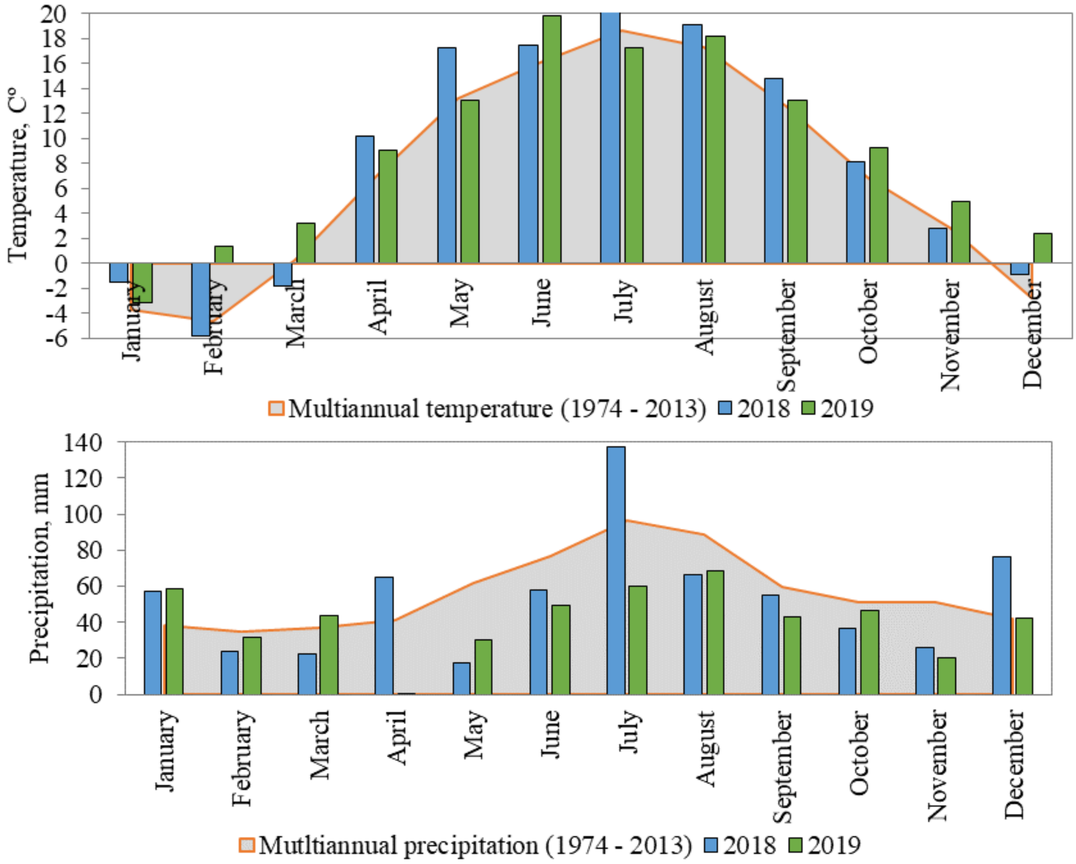

Figure 1. *Monthly temperature and precipitation data of the experimental site during 2018–2019 in Ringaudai (54°52'59.8''N, 23°50'25.1''E), Kaunas district, Lithuania*

Tillage systems

The experimental design (*Figs. 2* and *3*) consisted of four randomized main plots with four replications: spring barley (*Hordeum vulgare* L.), winter rape (*Brassica napus* L.), and faba bean *(Vicia faba* L.) with plant residues and winter wheat *(Triticum aestivum* L.) with plant residues and cover crops. Tillage treatments were applied to five subplots: conventional plowing (CP) at a depth of 23-25 cm (control treatment), shallow plowing (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. There were 16 main plots of 126 m^2 (14 × 9 m) and a protection zone of 1 m. In this study, soil samples were used only from a field of spring barley. The spring barley crop consisted of 20 subplots, each of 70 m^2 (10 × 7 m). The main tillage operation for the treatments was performed during September-October. The pre-sowing operation was conducted during April-May. Spring barley was sown at a rate of 190 kg·ha^{-1} on 24 April (2018) and on 16 April (2019).

Fertilization was the same in all treatments. Fertilizers were applied at a rate of 300 kg ha^{-1} NPK (16:16:16) and 200 kg·ha^{-1} N_{68}. The control of pests, diseases, and

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weeds was the same for all treatments. Karate Zeon 5 CS, Elegant 2FD, and Amistar 250 SC were used for pest control, weed control, and disease control, respectively.

	2018								IV field			
III field	**Spring barley**	NT	Faba bean	SP	Winter rape	CP	Winter wheat	DC	Winter wheat	NT	**Spring barley**	SC
		SC		CP		SP		SC		CP		DC
		DC		SC		NT		NT		SP		NT
		CP		DC		DC		SP		DC		SP
		SP		NT		SC		CP		SC		CP
II field	Winter wheat	SC	Winter rape	NT	Faba bean	CP	**Spring barley**	NT	Faba bean	CP	Winter rape	DC
		DC		CP		SP		SC		SP		SC
		NT		SP		SC		DC		NT		SP
		CP		DC		DC		SP		DC		CP
		SP		SC		NT		CP		SC		NT
I field	Winter wheat	SP	Faba bean	DC	**Spring barley**	NT	Winter rape	SC				
		CP		SC		CP		DC				
		DC		NT		SP		NT				
		SC		SP		DC		CP				
		NT		CP		SC		SP				

***Figure 2.** Experimental design of spring barley (2018) in Ringaudai (54°52'59.8"N, 23°50'25.1"E), Kaunas district, Lithuania. CP – conventional ploughing (control treatment), SP – shallow ploughing, DC – deep cultivation (chiseling), SC – shallow cultivation (discing), NT – no-tillage (direct drilling)*

	2019								IV field			
III field	Winter rape	NT	**Spring barley**	SP	Winter wheat	CP	Faba bean	DC	Faba bean	NT	Winter rape	SC
		SC		CP		SP		SC		CP		DC
		DC		SC		NT		NT		SP		NT
		CP		DC		DC		SP		DC		SP
		SP		NT		SC		CP		SC		CP
II field	Faba bean	SC	Winter wheat	NT	**Spring barley**	CP	Winter rape	NT	**Spring barley**	CP	Winter wheat	DC
		DC		CP		SP		SC		SP		SC
		NT		SP		SC		DC		NT		SP
		CP		DC		DC		SP		DC		CP
		SP		SC		NT		CP		SC		NT
I field	Faba bean	SP	**Spring barley**	DC	Winter rape	NT	Winter wheat	SC				
		CP		SC		CP		DC				
		DC		NT		SP		NT				
		SC		SP		DC		CP				
		NT		CP		SC		SP				

***Figure 3.** Experimental design of spring barley (2019) in Ringaudai (54°52'59.8"N, 23°50'25.1"E), Kaunas district, Lithuania. CP – conventional ploughing (control treatment), SP – shallow ploughing, DC – deep cultivation (chiseling), SC – shallow cultivation (discing), NT – no-tillage (direct drilling)*

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Soil sampling and laboratory analysis

Soil samples for water retention determination were collected from four spring barley crop plots and five subplots at four depth measurements (0-5, 5-10, 10-20 and 20-30 cm) in May (2018 and 2019) and were stored at 4 °C. The total number of samples was 160 (4 × 2 from each depth, 5 × 8 from each subplot and 40 × 4 from each plot). The samples of spring barley were taken during tillering phenological phase.

Undisturbed soil samples were collected using stainless steel rings (100 cm^3 in volume) from 0-5, 5-10, 10-20, and 20-30 cm soil depths to identify water retention curves. Soil samples were saturated and measured at different matric potentials (h): 0, -4, -10, -30, and -100 cm H_2O using a sandbox; -300 cm H_2O using a sand-kaolin box; and -15000 cm H_2O using a high-pressure membrane apparatus (Klute, 1986). Finally, the soil samples were oven-dried at 105 °C for 48 h.

The Van Genuchten model was used for determining the water retention parameters (*Eq. 1*):

$$\frac{\theta-\theta_r}{\theta_s-\theta_r} = \frac{1}{[1+(\alpha h)^n]^m} \quad \text{(Eq.1)}$$

where θ_s and θ_r are the saturated and residual water retention ($cm^3 \cdot cm^{-3}$), respectively; θ is the volumetric water retention ($cm^3 \cdot cm^{-3}$); h is the soil matric potential (cm); α indicates the inverse of the air-entry pressure (cm^{-1}) parameter, and n is the pore-size distribution parameter; m = 1-1/n (Guber and Pachepsky, 2010).

Soil bulk density (SBD) was calculated using *Equation 2:*

$$\text{SBD} = \frac{\text{Weight of dry soil}}{\text{volume of core}} \quad \text{(Eq.2)}$$

Total porosity (TP) was calculated using *Equation 3:*

$$TP = 1 - \frac{\rho_B}{\rho_S} \quad \text{(Eq.3)}$$

where ρ_B is the bulk density and ρ_S is the particle density, which was taken as 2.65 $g \cdot cm^{-3}$ (Holthusen et al., 2018).

The pore size distribution was calculated as follows (*Eq. 4*):

$$\text{f(h)} = \frac{d\theta}{d(\log|h|)} \quad \text{(Eq.4)}$$

where θ is the volumetric water retention ($cm^3 \cdot cm^{-3}$) and h is the soil matric potential (cm) (Gao et al., 2019).

The field capacity (θ_{FC}) was determined in the root zone at -10 kPa (100 hPa). The permanent wilting point (θ_{PWP}) was set in the root zone at -1500 kPa (15850 hPa). Available soil water was defined as plant available water (PAW), PAW = $\theta_{FC} - \theta_{PWP}$ (Kassaye et al., 2020). The optimal PAW for crops is PAW ≥ 20% as reported by Kassaye et al. (2020).

Dexter (2004a) determined the approximate limit between good (S ≥ 0.05 very good, 0.05 > S ≥ 0.035 good) and poor (0.035 > S ≥ 0.020 poor, S < 0.020 very poor) soil

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qualities, and this value has been used to characterize various soil types. The soil physical quality was calculated as follows (Dexter, 2004b):

$$S = n(\theta s - \theta r)\left[\frac{2n-1}{n-1}\right]^{\left[\frac{1}{n}-2\right]} \quad \text{(Eq.5)}$$

where n is an adjustable parameter, θ_{sat} is the saturated soil water retention ($cm^3 \cdot cm^3$), and θ_r the residual soil water retention ($cm^3 \cdot cm^3$).

Results

Effect of tillage practices on soil water retention and critical threshold identification

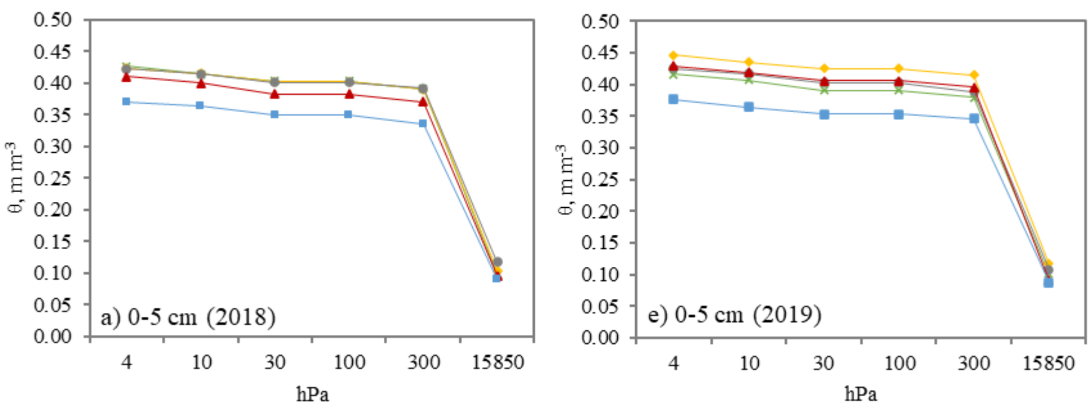
Soil water retention curves (SWRC) were significantly affected by tillage in the upper (0-5 and 5-10 cm) soil layers at 4, 10, and 30 hPa in 2018 (*Fig. 4a, b*) and 2019 (*Fig. 4e, f*). Water content was higher under deep (CP and DC) and shallow (SP and SC) tillage compared with no-tillage at 4, 10, and 30 hPA.

In the 10-20 cm soil layer, the SWRC was significantly affected by tillage at 4, 10, and 30 hPa in 2018 (*Fig. 4c*) and 2019 (*Fig. 4g)*. Conventional ploughing, no-tillage, shallow ploughing, and shallow cultivation had higher water contents than deep cultivation in 2018. Furthermore, we determined different results in 2019. Shallow cultivation had a lower water content compared with CP, DC, SP, and no-tillage.

In the 20-30 cm soil layer, intensity tillage had a significant effect on water content at 4, 10, and 30 hPa in 2019 (*Fig. 4h)*. Low water content values were measured under shallow cultivation. There was no significant effect at 20-30 cm depth in 2018 (*Fig. 4d)*.

In 2018 and 2019, significant differences between tillage systems were indicated when the θ_{FC} threshold was considered (*Fig. 4*), except at 20-30 cm depth. No-tillage treatment was significantly lowest than deep (CP and DC) and shallow (SP and SC) tillage in the upper (0-5 and 5-10 cm) soil layers. In the 10-20 cm layer, the lowest values of water contain were determined under cultivation tillage: deep cultivation in 2018 and shallow cultivation in 2019.

Our results showed that tillage significantly affected the SWRC at the θ_{PWP} threshold, with the exception of 0-5 cm depth in 2019. The highest values were determined under shallow ploughing at 5-10 cm depth. Shallow cultivation had low water content at 10-20 cm depth.



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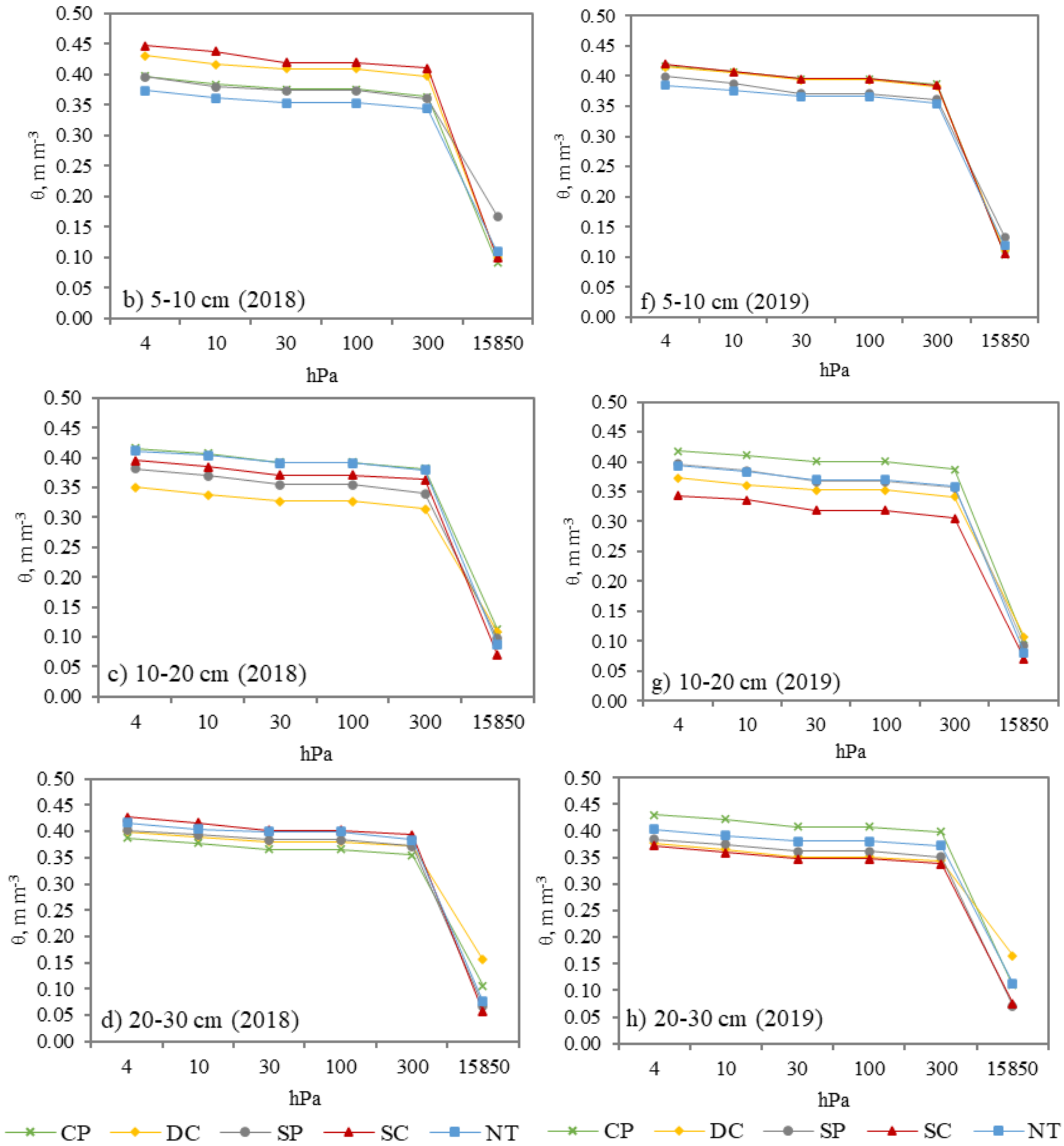

Figure 4. *Soil water retention curves under CP, DC, SP, SC and NT at 0-5, 5-10, 10-20, 20-30 cm depth in 2018 (a, b, c, d) and 2019 (a, b, c, d). CP – conventional ploughing (control treatment), SP – shallow ploughing, DC – deep cultivation (chiseling), SC – shallow cultivation (discing), NT – no-tillage (direct drilling)*

PAW is optimal for crop production when it is PAW ≥ 20%, as previously reported by (Kassaye et al., 2020) Low water-holding capacity (lower than 20%) was observed under SP (19.2%) at 5-10 cm in 2018 (*Fig. 5a*) and under DC (17.9%) at 20-30 cm depth in 2019 (*Fig. 5b*).

Effect of tillage practices on soil bulk density

Tillage intensity significantly affected soil bulk density at 0-5, 5-10, 10-20, and 20-30 cm depths in 2018 (*Fig. 6a*) and 2019 (*Fig. 6b*). The most compressed soil was found under no-tillage compared with conventional and shallow ploughing and with

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deep and shallow cultivation at 0-5 and 5-10 cm depths. Low bulk density was found under deep (0–5 cm) and shallow (5-10 cm) cultivation.

In the deeper (10-20 and 20-30 cm) soil layers, high soil bulk density was determined under shallow ploughing and no-tillage. Intensive tillage (CP and DC) practices decreased soil bulk density in deeper layers.

The lowest average bulk density was measured at 0-5 cm depth. In the deeper soil layers (5-10 and 10-20 cm), the average bulk density increased compared with that 0-5 cm deep.

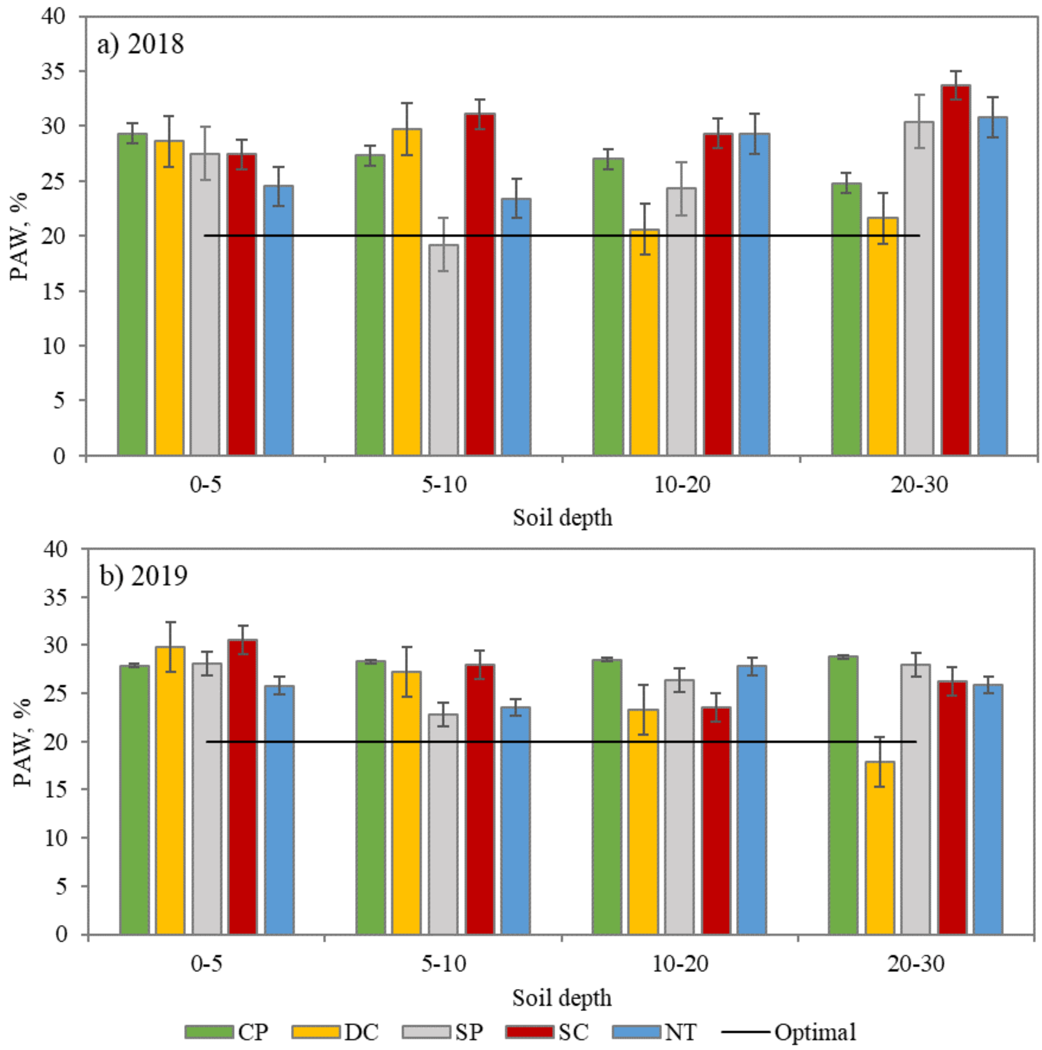

Figure 5. *Plant available water under CP, DC, SP, SC and NT at 0 – 5, 5 – 10, 10 – 20, 20 – 30 cm depth in 2018 (a) and 2019 (b). Error bars indicate 1 standard error. CP – conventional ploughing (control treatment), SP – shallow ploughing, DC – deep cultivation (chiseling), SC – shallow cultivation (discing), NT – no-tillage (direct drilling)*

Effect of tillage practices on pore-size distribution

Conventional and shallow ploughing, deep and shallow cultivation, and no-tillage significantly affected the pore-size distribution in 2018 (*Fig. 7a*) and 2019 (*Fig. 7b*).

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Shallow (SC (2018) and SP (2019)) tillage made the highest number of residual micropores at 0-5 and 5-10 cm depths. In the 10-20 and 20-30 cm layers, a high number of residual micropores was observed under deep (CP and DC) tillage.

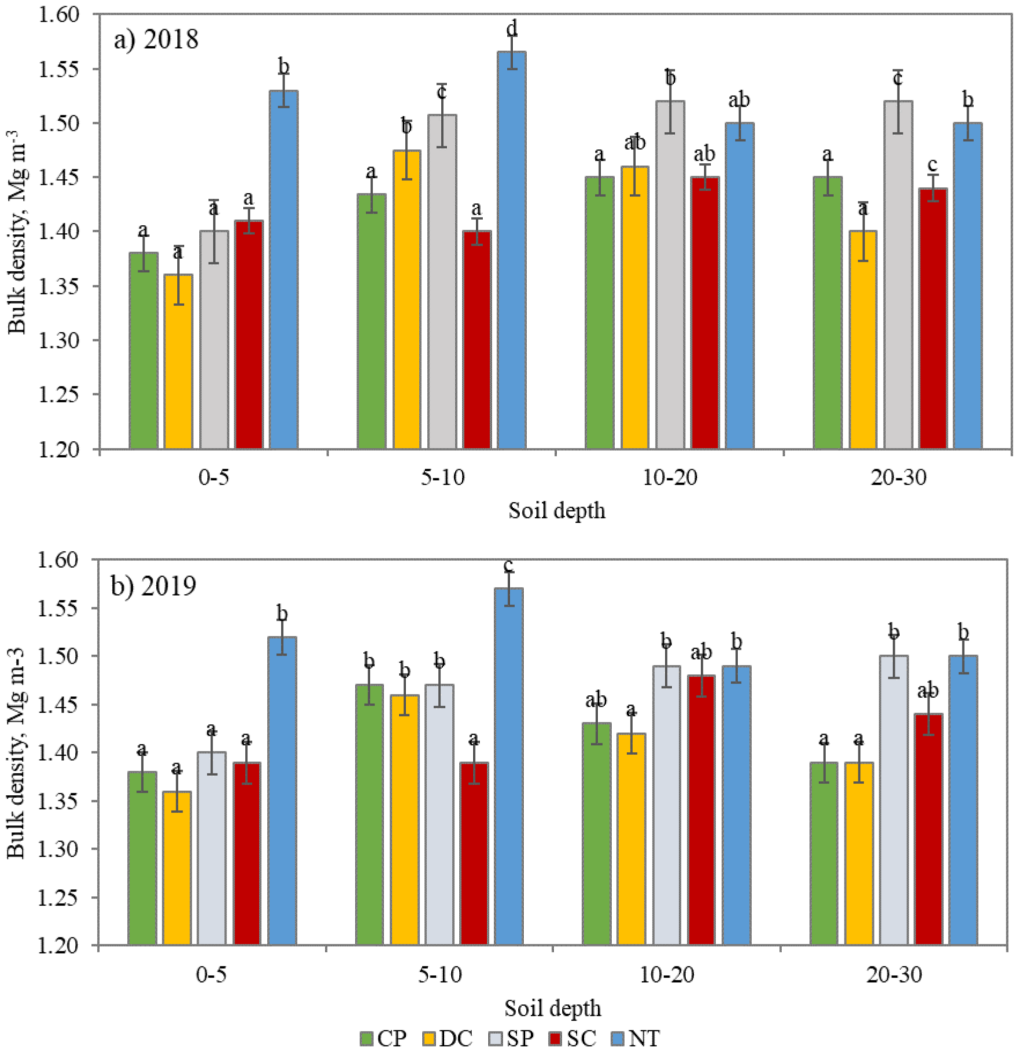

Figure 6. *Soil bulk density under CP, DC, SP, SC and NT at 0-5, 5-10, 10-20 and 20-30 cm depth in 2018 (a) and 2019 (b). Values with different letters represented significant difference (P < 0.05) according to ANOVA. Error bars indicate 1 standard error. CP – conventional ploughing (control treatment), SP – shallow ploughing, DC – deep cultivation (chiseling), SC – shallow cultivation (discing), NT – no-tillage (direct drilling)*

Tillage intensity significantly affected micropores in the majority of layers. In the 0-5 and 5-10 cm layers, deep (CP and DC) tillage made a higher number of micropores compared with shallow (SP and SC) tillage and no-tillage. In the 10-20 cm layer, a high number of micropores was made under no-tillage.

No-tillage and shallow ploughing increased the number of mesopores at 0-5 and 5-10 cm depths. Cultivation (deep and shallow) decreased the number of mesopores at 20-30 cm depth.

In the 0-5, 10-20, and 20-30 cm layers, micropores together with residual micropores dominated. Macropores together with mesopores dominated at 5-10 cm depth.

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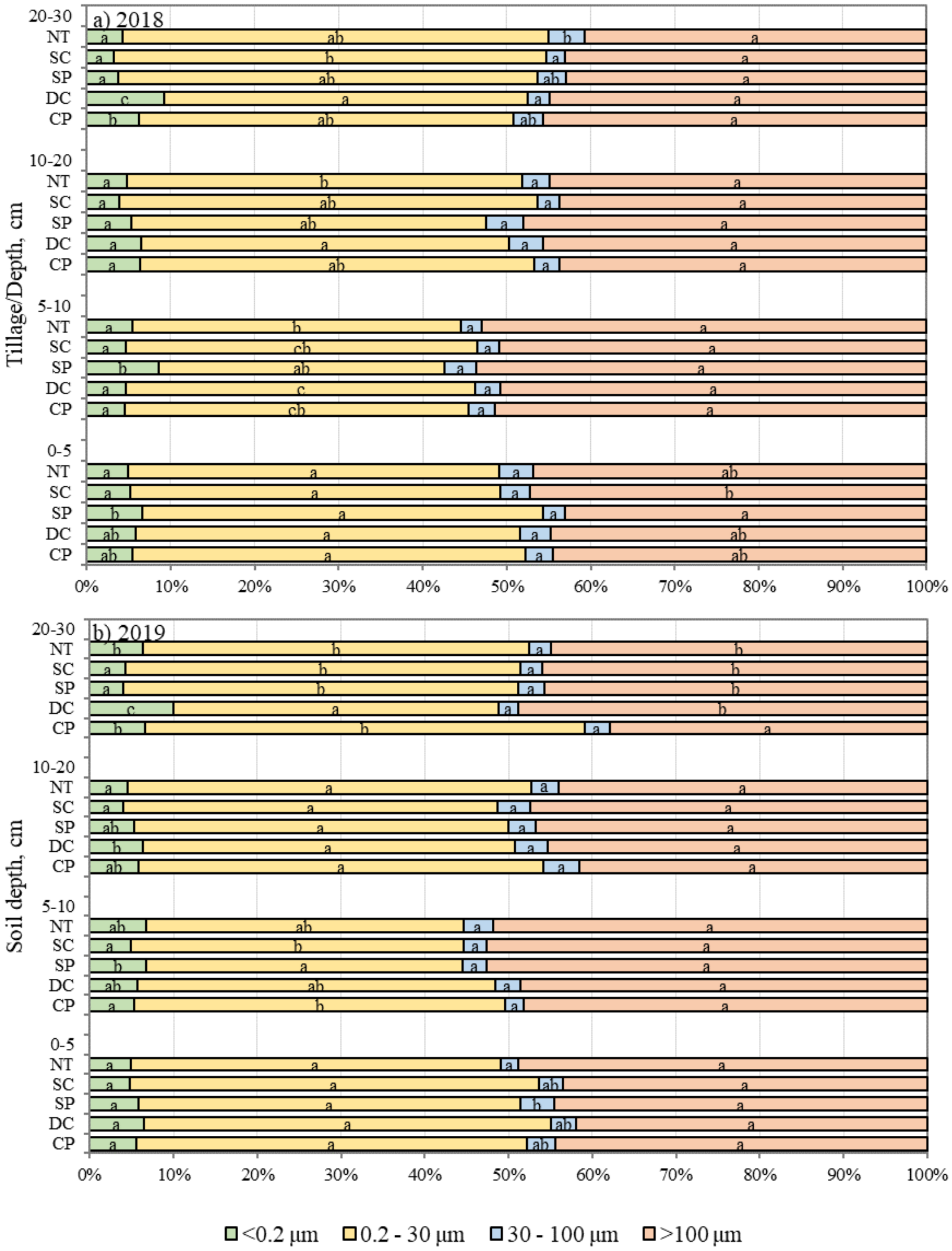

Figure 7. *Pore-size distribution under CP, DC, SP, SC and NT at 0-5, 5-10, 10-20 and 20-30 cm depth in 2018 (a) and 2019 (b). Values with different letters represented significant difference (P < 0.05) according to ANOVA. CP – conventional ploughing (control treatment), SP – shallow ploughing, DC – deep cultivation (chiseling), SC – shallow cultivation (discing), NT – no-tillage (direct drilling)*

Effect of tillage practices on S index

In this study, the S-index was not lower than 0.035; consequently, the physical quality of the soils was good or very good. Shallow ploughing at 5-10 cm depth (2018)

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(*Fig. 8a*) and deep cultivation at 20-30 cm depth (2019) (*Fig. 8b*) nearly reached the 0.035 limit. The S-index was lower than 0.05 under SP (2018), DC, NT (2019) at 0-5 and 5-10 cm depth, and under DC at 20-30 cm depth, which indicated that the soil's physical quality was "very good".

Tillage intensity did not affect the S-index at 0-5 cm depth. In the 5-10 cm layer, the S-index was very low under shallow cultivation tillage in 2018. The highest S-index was under shallow cultivation at 10-20 cm depth. A very low S-index was observed under deep cultivation tillage at 20-30 cm depth.

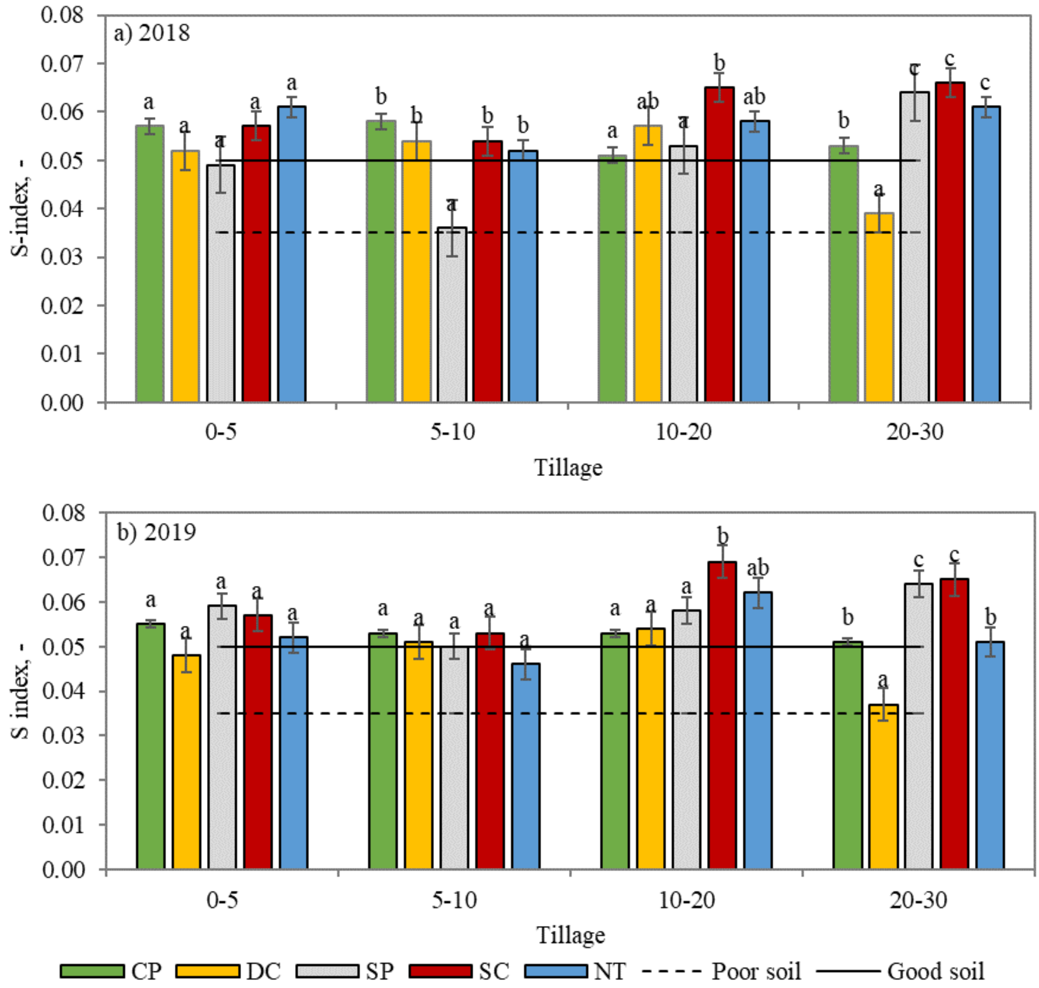

Figure 8. *The S-index of soil physical quality under CP, DC, SP, SC and NT at 0-5, 5-10, 10-20 and 20-30 cm depth in 2018 (a) and 2019 (b). Values with different letters represented significant difference (P < 0.05) according to ANOVA. Error bars indicate 1 standard error. CP – conventional ploughing (control treatment), SP – shallow ploughing, DC – deep cultivation (chiselling), SC – shallow cultivation (discing), NT – no-tillage (direct drilling)*

Discussion

Our study shows that tillage intensity affects water content and thresholds. Water retention at 0-5 and 5-10 cm depths was higher under CP, DC, SP, and SC tillages than NT at 4, 10, and 30 hPa (2018 and 2019). Tian et al. (2022) found a similar water retention effect at 5-10 cm depth; the effect in soils under rotary tillage (RT) and

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mouldboard plough (MP) treatments was higher than in NT (no-tillage) at −1 kPa. We determined that in the 10-20 cm layer, water retention was higher under CP tillages than under NT, DC, SP, and SC in 2018 and 2019. Tian et al. (2022) found a similar effect: water retention was higher under RT and MP than under NT in the 15-20 cm layer. Osunbitan et al. (2005) showed contradictory results at 50, 100, and 150 kPa and reported that soil moisture was significantly higher under NT conditions. Azooz and Arshad (2001) reported significantly higher results at 5 to 160 kPa matric potentials under CP than under NT, especially during the first 34 days at 0-30 cm depth.

Fritton (2006) found that higher soil bulk density decreased water content at higher matric potential. In our study, we found a similar effect: higher bulk density decreased water content. We determined that soil bulk density was higher under NT than under CP, DC, SP, and SC in the 0-5 and 5-10 cm layers (2018 and 2019). The higher bulk density under NT could be attributed to low tillage practices. The lower bulk density under CP, DC, SP, and SC could be a reason for the light soil structure observed after tillage. Kan et al. (2020) reported a similar effect and determined the highest bulk density under NT rather than under CP and rotary tillage in the upper layers of soil. Osunbitan et al. (2005) and Alskaf et al. (2021) mentioned that the highest soil bulk density was seen under the NT treatment. Our study observed a lower bulk density at the 0-5 cm soil depth, which is consistent with the findings of Bescansa et al. (2006) and Kan et al. (2020). Our results showed that higher soil bulk density decreased water retention at 0-5 and 5-10 cm depth. Rainfall and particle resettlement increase soil bulk density, as mentioned by Osunbitan et al. (2005). Conservative tillage improves soil structure by reducing soil disturbance; however, no-tillage can increase or decrease soil bulk density, depending on the period under the no-tillage system (Topa et al., 2021). Li et al. (2020) determined that no-tillage increased soil bulk density in general.

Soil quality involves several physical, chemical, and biological aspects. Determining soil quality is important because it helps in assessing soil degradation and selecting an appropriate management system for sustainability. Poor soil physical quality is directly related to poor water infiltration, poor aeration, and a hard setting. The runoff of water from the surface can also be a reason for poor soil structure (Dexter, 2004a). Soil porosity and the S-index are soil physical quality indicators that depend on tillage intensity. Soil water retention properties and the S-index are affected by soil porosity. However, particle size distribution is more informative than porosity data and provides a detailed report of soil structure (Soltani et al., 2019).

Macropores are like containers for soil air and water (Gao et al., 2019). Cultivation (deep and shallow) tillage made more macropores compared with ploughing (conventional and shallow) and no-tillage in 0-5 cm soil layers. In the 5-10 cm layer, tillage intensity did not affect macroporosity. Tian et al. (2022) determined no significant differences between NT, RT, and MP tillage for microporosity at 5-10 cm. In the current study, shallow ploughing produced a higher number of macropores than conventional ploughing, cultivation (deep and shallow), and no-tillage at 10-20 and 20-30 cm depths. Osunbitan et al. (2005) found that pores are smaller under conventional tillage than under conservation tillage. Additionally, Guo et al. (2020) determined more macropores under CT and more micropores under NT.

As suggested in previous studies, pore sizes were analyzed as macropores (>100 μm), mesopores (30-100 μm), micropores (0.2-30 μm), and residual micropores (<0.2) (Soltani et al., 2019). We found that the particle size distribution affected the soil water capacity and S-index. Critically low water-holding capacity (lower than 20%) was

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observed under SP (19.2%) at 5-10 cm in 2018 and under DC (17.9%) at 20-30 cm depths in 2019. The lowest microporosity was also found under SP at 5-10 cm depth in 2018 and under DC at 20-30 cm depth. The lowest S-index was found under SP at 5-10 cm depth in 2018 and under DC at 20-30 cm depth. On the other hand, the lowest bulk density was under SP at 5-10 cm depth in 2018 and under DC at 20-30 cm depth Thus, our results showed that low bulk density reduced microporosity but increased residual mesoporosity and macroporosity. Plants can more easily absorb water from soil pores with diameters of 0.5-50 μm. A higher number of pores with a diameter > 50 μm allows water to drainage out of pores quickly (Huang et al., 2021). In our study, no-tillage produced the necessary number of micropores; for that reason, water availability was sufficient, although soil bulk density was high. Bescansa et al. (2006), Jemai et al. (2013), and Çelik et al. (2019) reported similar results. In this study, the treatments with low plant-available water produced more macropores, which decreased water retention capacity. Water content and pore-size distribution affect the S-index (Soltani et al., 2019); therefore, the low water-holding capacity reduced the S-index. In the 5-10 cm layer, S-index average values were lower than in the 0-5, 10-20, and 20-30 cm layers. In the 0-5, 10-20, and 20-30 cm layers, micropores and residual micropores dominated. Macropores together with dominated at 5-10 cm depth.

Conclusion

We investigated five tillage practices (conventional ploughing, shallow ploughing, deep cultivation, shallow cultivation, and no-tillage) with a vertical layer stratification effect on some selected soil physical parameters. We determined that no-tillage increased bulk density and decreased water content at 0-10 cm depth. Low PAW was observed under shallow cultivation at 5-10 cm depth (2018) and under deep cultivation at 20-30 cm depth (2019). A low number of micropores decreased PAW, the S-index, and bulk density. Micropores together with residual micropores dominated in the 0-5, 10-20, and 20-30 cm layers. Macropores together with mesopores were dominant at 5-10 cm depth.

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