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Impact of Tillage Intensity on Planosol Bulk Density, Pore Size Distribution, and Water Capacity in Faba Bean Cultivation

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Abstract: Tillage systems affect many properties of soil, such as soil bulk density, porosity, pore distribution, and soil water capacity. However, the effect of reduced tillage (RT) on faba bean cultivation requires wider analysis. We carried out our investigations at Vytautas Magnus University, Agriculture Academy (Lithuania), as part of a long-term field experiment. The aim was to determine the effect of tillage intensity on soil bulk density, pore distribution and soil water capacity in faba bean cultivation. Five tillage systems were used: deep (DP) and shallow (SP) ploughing, deep cultivation (DC) (chiselling), shallow cultivation (SC) (disking), and no tillage (NT). The results showed that the soil bulk density in NT plots was somewhat higher in upper (0–10 cm) and less in deeper (15–20 cm and 30–35 cm) soil layers compared to DP. The distribution of soil pores depended more on the sampling depth than on tillage. In RT and NT plots, the number of meso-pores was often higher, and that of micro-pores was lower than in ploughed plots. In the upper (0–5 cm) soil layer, the highest water capacity was established in NT, and in deeper layers, this was found in RT plots compared to DP. The density of soil mainly affected the volume of micro-and-macro-pores and water capacity.

Keywords: reduced tillage; *Vicia faba* L.; soil density; pore structure; water retention

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1. Introduction

The European Environmental Agency and Environment Research Centre are focused on projecting the impacts of climate change projection, especially emphasizing the importance of research on the water capacity of cultivated soils [1]. Additionally, soil conservation and the prevention of soil moisture resources are some of the most important topics in modern agronomy. Unfortunately, such investigations are still lacking for the soils of the Boreal region [2]. Lithuania belongs to this region, which is the largest bio-geographical region of Europe. The young soils that formed after the glacial period are generally shallow, covering large areas of the Boreal region [3].

Planosol is well represented in Lithuania. This soil is intensively used in agriculture. Planosol has unique characteristics, both in terms of morphology and the chemistry of its clay fraction [4], with a mostly light-coloured horizon that shows signs of periodic water stagnation, which abruptly overlies dense subsoil having significantly more clay than the topsoil layer. One of the most important features of Planosol is that waterlogging often occurs due to its dense subsoil environment. Root development is also hindered due to the low hydraulic conductivity of dense, compacted subsoil [5,6].

Research on the conservation of soil and its moisture resources is a major contemporary agronomic topic [7]. The classical approach to the plant-available water capacity of the soil was developed by Veihmeyer and Hendrickson, defining it as the soil water content between an upper limit, termed field capacity, and a lower limit, or the permanent wilting point. The field capacity is the amount of water trapped in the soil after the saturation and run-off of excess water, reaching a minimum downward pace [8]. In the context of climate change, the efficient use of soil water is becoming one of the most important research areas for ensuring the productivity and stability of agro-ecosystems. The conservation of soil water depends directly on the structure of the soil pores, their size distribution, continuity, shapes, meanders, etc. [9]. The structure of soil pores depends on the amount of organic matter, the size of the soil particles, and crop and soil management practices, as well as and other factors that affect the overall structure of the soil [10]. Thus, soil water retention is influenced not only by the ratio of organic matter, proportion of sand, silt, and clay particles (soil texture), but also by the chosen tillage intensity, farming system and other factors [10]. Many researchers have found that ploughing improves soil structure, and allows plants to retain soil moisture [11–15] and uses it more efficiently [9,16] than when deep ploughing is carried out.

The tillage system and its intensity change with the direct and indirect effects of bulk density, soil temperature, porosity, moisture storage, resistance to penetration and soil structure [17–20]. As for the tillage system, when the soil is not mobilized, its evolution properties are influenced more by the internal properties of the soil, the stratification of the soil profile, weather conditions, management conditions and history [21,22].

Plants have been found to suffer equally from excessive soil looseness and excessive soil density. The effect of different soil layers on the density of plants is also unequal. Soil density has different meanings in different stages of plant development. Soil density decreases with tillage, when colloids swell from the moisture and the water in it expands strongly as it cools. Plant roots and various microorganisms reduce soil density. Soil density determinants tend to overlap and interact within certain limits [23–25]. Still, other research has shown that, in directly sown fields, the soil density is significantly higher than in the fields nearby. No significant differences in soil bulk density have been identified with sustainable tillage technologies [26,27].

The effect of reducing tillage intensity—from conventional reversible deep ploughing to shallow ploughing, non-reversible tillage methods (disking, chiselling, and sub-soiling) or no-tillage—has been well documented worldwide in the last 20 years, but the impacts of various long-term tillage systems on soil bulk density, pore space distribution, pore size and volumetric water content in faba bean cultivation have still not yet been further explored, not only in the Baltic countries, but also on a global scale. Additionally, a long-term tillage experiment has been underway since 1984, and it is one of the longest running experiments in the Baltic countries. Therefore, the aim of this research was to investigate the effects of long-term various-intensity tillage systems on the hydro-physical properties of Planosol in faba bean cultivation, and to evaluate the relations between them.

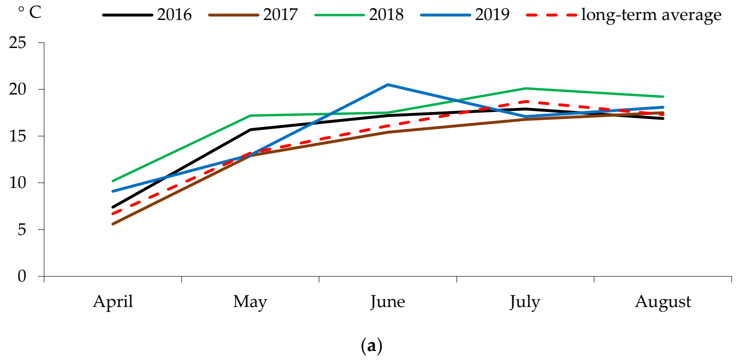
2. Materials and Methods

2.1. Site Description

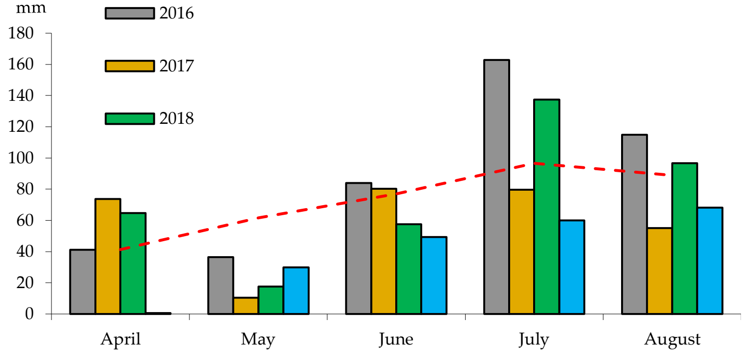
We initiated this long-term stationary field experiment has been performed at the Experimental Station (54°52′ N, 23°49′ E) of Vytautas Magnus University, Agriculture Academy, Lithuania, in 1988. This study analysed the data from 2016 to 2019. Based on the amount of precipitation, we determined that the territory of Lithuania that we examined is in the zone of surplus moisture, with an average annual precipitation of 600–650 mm and evaporation of about 500 mm. The vegetative period lasts about 150–180 days. The soil at the experimental site is a silty loam (45.6% sand, 41.7% silt, 12.7% clay) *Eutric Endogleyic Planosol* (*Drainic*). The topsoil is up to 27–30 cm thick. The topsoil of the experiment (0–15 cm) depended on tillage practice and varied: pH_{KCL}—6.4–7.4; available phosphorus—194.0–384.0 mg kg^{-1}; available potassium—85.0–201.0 mg kg^{-1}; available magnesium—198.0–634.0 mg kg^{-1}; N_{total} g kg^{-1}—1.20–1.73.

2.2. Meteorological Conditions

The vegetative period of 2016 could be described as warmer and more humid than the long-term average (Figure 1). However, in May, the precipitation rate was less than usually. In general, over the four years of the experiment, May experienced 2–6 times lower precipitation rates than the usual amount. These conditions adversely affected crop germination and development.



(**a**)



(**b**)

Figure 1. Average air temperature (**a**) and precipitation rate (**b**) during faba bean growing seasons. Kaunas Meteorological Station, 2016–2019.

During the vegetative period of 2017, the average air temperature was similar to/a little lower than the long-term average (Figure 1). Precipitation rates markedly varied between the months. The beginning of the vegetative period was excessively humid, but during other growth stages the weather was arid, especially in May, July, and August.

The vegetation period of 2018 may be characterised as warmer than usual. May and June were dry, but at the end of the vegetative period, there was excess moisture.

In 2019, the meteorological conditions were very similar to the years studied in previous research; however, at the beginning of the vegetative season, the precipitation rate was quite low (0.6 mm).

In summary, the meteorological conditions of the four growing seasons differed from each other and from the long-term average conditions (since 1974). Meteorological conditions are closely related to the agrophysical and hydro-physical properties of the soil.

2.3. Experimental Treatments and Agronomic Practices

The following five tillage treatments were implemented in the autumn after pre-crop harvesting: (1). deep mouldboard ploughing at 22–25 cm depth (control treatment; DP); (2). shallow mouldboard ploughing at 12–15 cm depth (SP); (3). deep cultivation (DC) (chiselling) at 25–30 cm depth; (4). shallow cultivation (SC) (disking) at 10–12 cm depth; (5). no tillage (direct drilling, NT).

A 4-course crop rotation was used: winter oilseed rape, winter wheat, faba bean, and spring barley. The experiment was performed with four replications for each tillage treatment, and a randomized complete block design (RCBD) was used. The size of each experimental plot was 126 m^2.

In late summer, August, after harvesting of faba bean pre-crop (winter wheat), the experimental plots were disked with a disc harrow, except for NT. Later, in October, the DP and SP plots were ploughed with the same traditional plough, Gamega PP-3-43 (Lithuania), equipped with semi-screw shell boards; deep cultivation (DC) with chisel cultivator was carried out with the KRG-3.6 (Lithuania) ridge (chisel) cultivator. SC plots were additionally disked with a Väderstad Carrier 300 disc harrow (Table 1).

Table 1. Tillage practice in the experiment, 2016–2019.

Tillage System	Stubble Tillage	Primary Tillage	Implement	Depth of Tillage (cm)	Pre-Crop Residue Cover after Bean Sowing (%)
Deep ploughing	yes	inversion	mouldboard plough	22–25	0.5–1.5
Shallow ploughing	yes	inversion	mouldboard plough	12–15	0.3–8.2
Deep cultivation	yes	non-inversion	chisel cultivator	25–30	8.5–36.8
Shallow cultivation	yes, twice	no	disc harrow	10–12	10.5–25.8
No tillage	no	no	no	0	22.0–82.8

Faba bean was grown using a conventional technology, more comprehensively described by Kimbirauskiene et al. [28]. Faba bean was sown on: 25 of April 2016, 8 of May 2017, 24 of April 2018 and 6 of May 2019. Local fertilization (NPK 7:16:32, 300 kg ha^{-1}) was used during sowing operation. The distance between rows was 25 cm, the sowing rate was 200–220 kg grain per ha (40–45 seeds per m^2), the sowing depth was 5–6 cm, and the variety 'Fuego'. Before sowing, the seeds were inoculated with a *Rhizobium leguminosarum* bacterial preparation (approximately 200 mL of preparation per 100 kg of seeds). A single application of the herbicide Fenix 3.0 L ha^{-1} (a.i. *aclonifen* 600 g L^{-1}) shortly after the sowing of faba bean was used only to highlighting the differences between the tillage treatments [29]. Insecticide application (a.i. *lambda-cyhalothrin*, 0.15 L ha^{-1})—10 of May 2016, 7 of June 2017, 15 of May 2018, and 6 of June 2019. Fungicide application (26.7% a.i. *boscalid* and 6.7% a.i. *pyraclostrobin*, 1 L ha^{-1})—13 June 2016, 23 of June 2017, 18 of June 2018, and 22 of June 2019 [27].

2.4. Methods and Analysis

The soil sampling for soil bulk density and water capacity and pore size distributions was performed in 2016–2019 after the sowing of faba bean. For this reason, undisturbed core samples were collected using stainless-steel rings (100 cm^3 volume). Sampling layers—0–5, 5–10, 15–20, and 30–35 cm, 8 samples per each experimental plot.

The characteristics of water capacity were determined at -4, -10, -30, and -100 hPa (in a sandbox) and at -300 hPa (in a 15-bar pressure plate extractor) in 6 replications. Loose soil samples were taken in the same place of each plot and used to determine the water capacity at 15,500 hPa tension by using a high-pressure membrane apparatus [30]. The water content at -100 and $-15{,}500$ hPa were considered as the field capacity (prevailing in Europe) and the permanent wilting point, respectively. Water content between these two suctions was identified as the plant's available moisture content.

The space distribution of soil pores was assessed for micro-pores <0.2 µm, meso-pores 0.2–30 µm, and macro-pores >30 µm as a percentage of total porosity at the depths of 0–5, 5–10 cm, 15–20 cm, and 30–35 cm [31,32]. The diffusivity was measured by a non-steady-state method as suggested by Taylor (1949) using the technique described by Schjønning [31].

Samples of soil bulk density were dried in an oven at 105 °C for 48 h [33].

All experimental data were processed using two-factor analysis of variance (ANOVA) from the statistical software package SYSTAT, version 10 [34]. The significance of differences among the treatments was estimated by the least significant difference (LSD) test. If there was a significant difference between a specific treatment and the control treatment, its probability level is indicated as follows: * when $0.010 < p \leq 0.050$ (significant at 95% probability level), ** when $0.001 < p \leq 0.010$ (significant at 99% probability level), and *** when $p \leq 0.001$ (significant at 99.99% probability level).

A correlation analysis was applied to evaluate the causality of the studied traits. We used the program STAT ENG from the package ANOVA [35–37].

3. Results and Discussion

3.1. Soil Bulk Density

In our experiment, in general, the intensity of tillage mostly had no significant effect on the bulk density of Planosol (Table 2). Despite this, soil density was found to be little lower in shallowly ploughed (SP) plots. In the upper (0–5 cm and 5–10 cm) soil layers, in most cases, reduced-tillage (RT) systems tended to increase soil density compared to deeply ploughed (DP) ones. The opposite tendencies were found in the deeper soil layers (15–20 cm and 30–35 cm).

Table 2. Effect of tillage on soil bulk density (10^6 g m^{-3}) at different sampling depths, 2016–2019.

Sampling Layer, cm	**Year**	**Treatments**				
		DP	**SP**	**DC**	**SC**	**NT**
0–5	2016	1.50 b	1.45 a	1.50 b	1.56 c	1.53 bc
	2017	1.40 a	1.42 a	1.47 a	1.44 a	1.42 a
	2018	1.37 b	1.43 c	1.36 b	1.26 a	1.29 a
	2019	1.34 b	1.33 b	1.27 a	1.35 b	1.33 b
5–10	2016	1.47 a	1.58 c	1.45 a	1.53 b	1.52 b
	2017	1.61 b	1.57 a	1.66 c	1.67 c	1.66 c
	2018	1.59 b	1.52 a	1.60 b	1.49 a	1.59 b
	2019	1.43 a	1.47 b	1.47 b	1.56 c	1.60 d *
15–20	2016	1.62 b	1.59 b	1.61 b	1.59 b	1.51 a **
	2017	1.59 ab	1.56 a	1.64 c	1.61 bc	1.61 bc
	2018	1.63 c	1.60 bc	1.61 c	1.53 a	1.56 a
	2019	1.54 b	1.56 b	1.49 a	1.49 a	1.54 b
30–35	2016	1.60 b	1.53 a	1.63 b	1.60 b	1.53 a
	2017	1.65 b	1.59 a	1.67 b	1.59 a	1.61 a
	2018	1.63 b	1.59 a	1.60 ab	1.61 ab	1.60 ab
	2019	1.54 b	1.59 b	1.46 a	1.55 b	1.56 b

Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). *—significant difference from control treatment (DP) at $0.01 < p \leq 0.05$; **—at $0.001 < p \leq 0.01$. Different lowercase letters indicate significant differences between all treatments at $0.01 < p \leq 0.05$. The significance of data was determined by Fisher's least significant difference (LSD) test.

In our earlier investigations in 2001–2006, in sugar beet cultivation, the meteorological conditions during winter had a stronger influence on the soil bulk density in springtime before pre-sowing soil tillage than soil tillage intensity. Mostly, the highest soil bulk density before pre-sowing soil tillage was observed after shallow loosening and zero tillage [38]. The influence of unploughed soil tillage on soil bulk density in the upper layer (0–10 cm) was higher than in the deeper layer (10–20 cm) [38]. Similarly, Feiza et al. [39] found that reduced tillage (RT) increased soil bulk density. Similar results have been presented by plenty of other scientists. It has been found that RT and direct sowing (NT) into stubble also increased density [40–43]. However, there are also contradictory research results, similar to our findings. These have shown that continuous shallow ploughing and RT tended to reduce soil density in the upper (0–10 cm) and middle (10–20 cm) arable layers, but the soil density increases in the 20–30 cm layer [44].

In our experiment, a negative medium-strength significant relation was found between the bulk density of the topsoil (0–15 cm) and amount of available phosphorus ($r = -0.673$; $p < 0.01$) and available potassium ($r = -0.492$; $p < 0.01$). We also found a relationship between density of the 0–15 cm soil layer and saccharase ($r = -0.556$; $p < 0.05$) and urease ($r = -0.578$; $p < 0.01$) levels. In Heuscher et al.'s [45] investigations, soil bulk density was found to have the strongest relation with organic C content in the soil. Similarly, Chaudhari et al. [46] found the reverse correlation between organic matter and the bulk density of soil.

However, soil bulk density also negatively correlated with soil's total macro- (N, P, K, Ca, and Mg) and total micro-nutrient (Fe, Mn, Zn, and Cu) contents.

3.2. Soil Pore Size Distribution

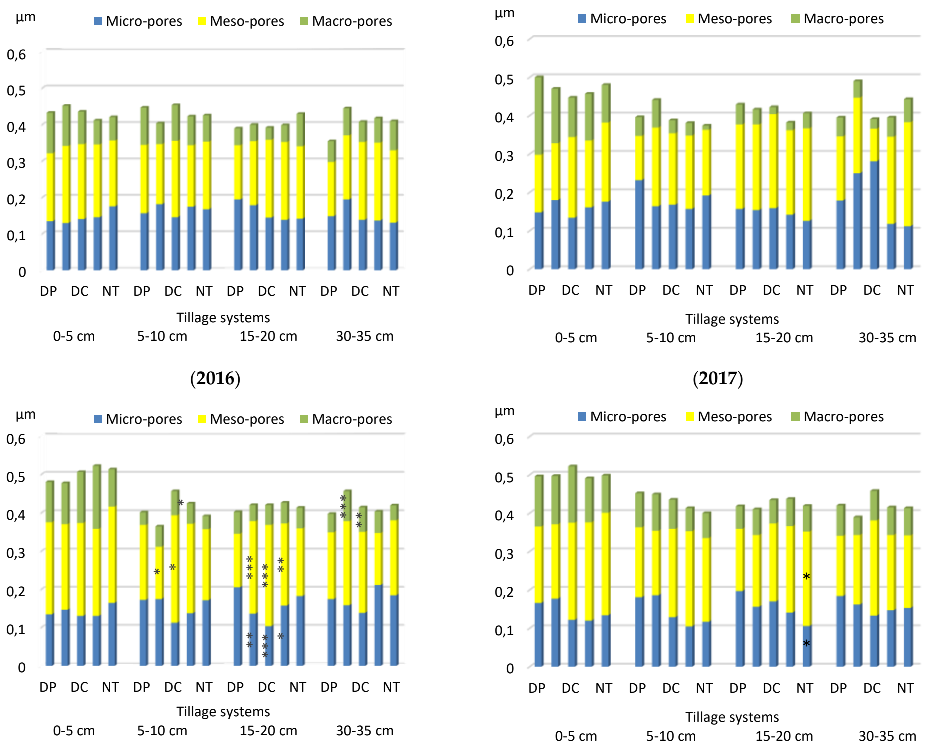
A soil's porosity and pore size distribution characterize its pore space. The basic character of the pore space affects and is affected by the movement of water, air, and other fluids, as well as the transport and reaction of chemicals and the position of roots and other biota [47]. According to their equivalent radius, soil pores are divided into three classes: micro-pores, meso-pores, and macro-pores. The micro-pores represent the pore space of the permanent wilting point and the meso-pores the pore space of the available field capacity. The macro-pores correspond to the remaining pore space [48,49]. Pore size distribution controls the water infiltration and retention [50,51]. Pores with equivalent cylindrical diameters > 50 µm are classified as transmission pores and <0.50 µm as residual + bonding pores. While the former are responsible for air movement and the drainage of excess water, the latter allow the retention and diffusion of ions in solutions. The intermediate pore size between 0.50 and 50 µm is responsible for the retention of water against gravity and release [52].

In our experiment, in 2016–2017, different tillage methods did not affect soil pore distribution significantly (Figure 2). The distribution of pores mainly depended on the sampling depth. In SP plots, fewer micro-pores were detected in the 15–20 cm soil layer compared to DP in all study years. Decreases in micro-pores were observed in DC plots in the 15–20 cm and 30–35 cm soil layers. In all the years studied, only the 15–20 cm layer in SC and NT plots showed fewer of these pores. In SC plots, fewer micro-pores were found in the 15–20 cm soil layer than in DP plots. In NT plots, in the upper (0–5 cm, 5–10 cm) and deepest (30–35 cm) soil layers, these pores were found less frequently than in the DP plots. In SP and DC plots, the number of macro-pores was unevenly distributed. In Scandinavian investigations, the volume of micro-pores (<0.2 µm) was affected little by tillage systems [53]. Similarly, Dal Ferrlo et al. [54] concluded that different tillage methods mainly affected the soil macro-porosity (54–750 mm), while the impact on micro-pores did not significantly differ.

In all the studied years, more meso-pores were found in the deeply cultivated (DC) plots in 5–10 cm and 15–20 cm soil layers. In shallowly cultivated (SC) plots, these trends were observed only in the 15–20 cm soil layer. In NT plots, in the 15–20 cm and 30–35 cm layers, more meso-pores were found. Pagliai et al. [55] found that, over a long period, NT improved the storage of meso-pores. In our experiment, in SP plots, similar trends were found for all experimental years, as in the case of direct sowing (NT), except for 2016. Similarly, Rasmussen [53] found, that ploughless tillage increases the density of the soil. A higher density leads to a decrease in the volume of macro-pores (>30–60 µm) and increase in the volume of meso-pores (30–0.2 µm). This has also been confirmed by other authors [56,57].

A significant impact of tillage systems on the volume of macro-pores was found in 2018 only. In SP and DC plots, the volume of these pores was significantly higher compared to DP. Intensive soil tillage and compaction generally decrease soil macroporosity and affect the pore size distribution [58,59].

We found some relations between of volume of soil pores and other soil properties of soil (Table 3).



(2016) **(2017)**

(2018) **(2019)**

Figure 2. Impact of tillage intensity on soil pore size distribution at different layers, 2016–2019. Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). *—significant difference at $0.01 < p \leq 0.05$; **—at $0.001 < p \leq 0.01$; ***—at $p \leq 0.001$. The significance of data was determined by Fisher's least significant difference (LSD) test.

Table 3. Correlation (r) between soil enzymatic activity and bulk density (x) and volume of soil pores (Y).

Soil Enzymatic Activity and Bulk Density, x Soil Layer	**Soil Pores m^3 m^{-3}, Y**				
	Micro-Pores	**Meso-Pores**			**Macro-Pores**
	15–20 cm	**0–5 cm**	**5–10 cm**	**15–20 cm**	**0–5 cm**
Saccharase (mg glucoses 1 g of soil 48 h)	−0.372	0.550 *	0.363	0.370	n
Urease (mg NH_3 1 g of soil per 24 h)	−0.426	0.519 *	0.347	0.416	n
Bulk density of 0–5 cm layer, $\cdot 10^6$ g m^{-3}	n	−0.536 *	−0.373	n	−0.542 *
Bulk density of 15–20 cm layers, $\cdot 10^6$ g m^{-3}	−0.729 **	n	n	n	n

Note: n—weak correlation; *—correlation significant at $p \leq 0.05$; **—at $p \leq 0.01$. Based on Fisher's test.

Therefore, the density of soil is the most important factor for pores distribution and volume. We also found a strong relation between the volume of macro-pores in the 30–35 cm soil layer and soil bulk density ($r = -0.748$; $p < 0.01$).

3.3. Soil Water Retention Capacity

As the soil dries, water drains from the largest pores of the soil. Its place is filled by air. As the suction force increases, the moisture content of the soil decreases. Thus, as the potential of the moisture matrix decreases, so does the moisture content of the soil. These parameters were determined under both field and laboratory conditions, and a graphical (curve) representation method was used to assess their interdependence. The plotted curve (the pressure is delayed on the Y axis and the moisture content on the x axis) is called the water retention curve (pF curve) [60]. The water retention of in the soil and the supply of moisture to plants during the growing season are relevant issues in both dry and temperate climates [61].

In our experiment, in most cases, soil moisture soil moisture was found to be higher compared to DP in SC plots for all soil layers and all years of the study, at different pressures. Similar trends were found in NT plots in 2016, 2017 and 2018 (Figures 3–6).

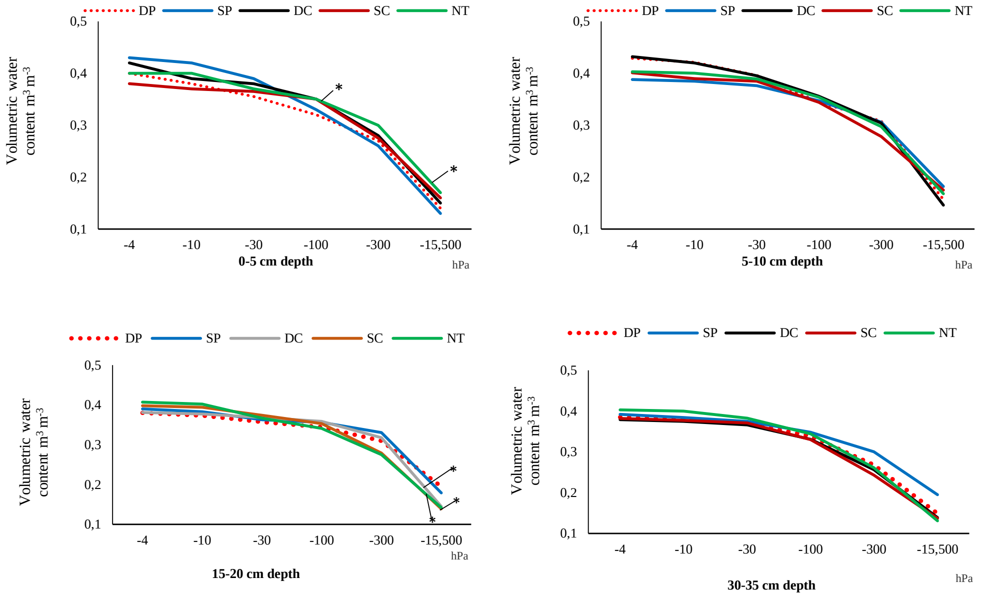


Figure 3. Effect of tillage intensity on soil water retention capacity in different soil layers, 2016. Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). *—significant difference at $0.01 < p \leq 0.05$. The significance of data was determined by Fisher's least significant difference (LSD) test.

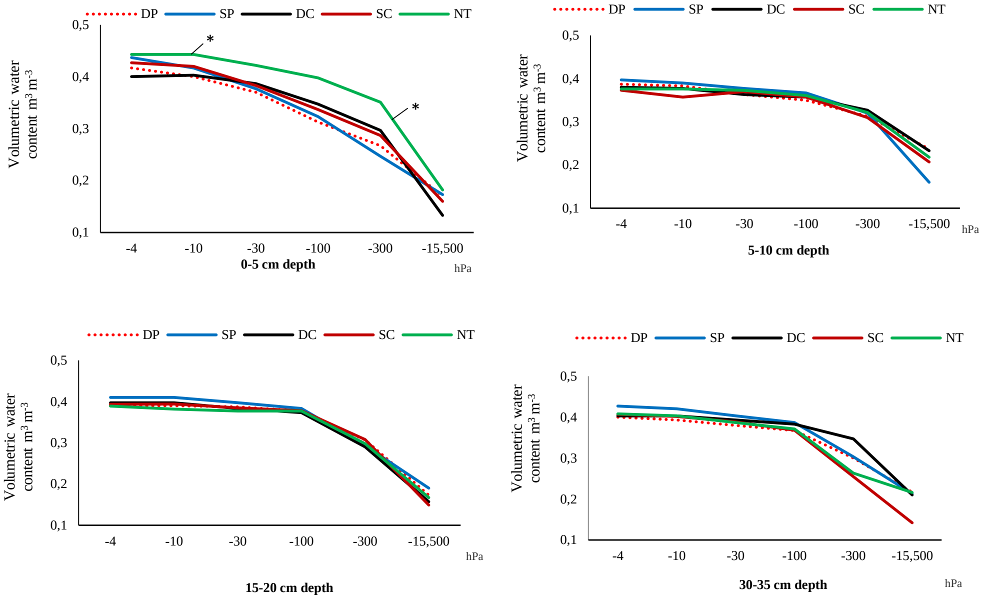


Figure 4. Effect of tillage intensity on soil water retention capacity in different soil layers, 2017. Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). *—significant difference at $0.01 < p \leq 0.05$. The significance of data was determined by Fisher's least significant difference (LSD) test.

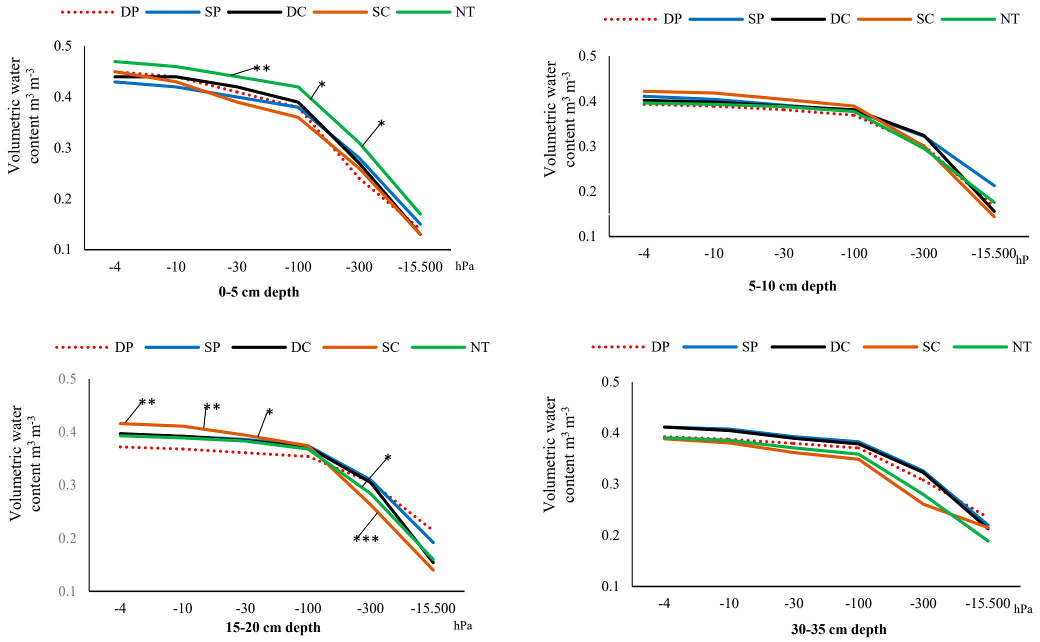


Figure 5. Effect of tillage intensity on soil water retention capacity in different soil layers, 2018. Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). *—significant difference at $0.01 < p \leq 0.05$; **—at $0.001 < p \leq 0.01$; ***—at $p \leq 0.001$; $p > 0.05$—no significant difference compared to the DP. The significance of data was determined by Fisher's least significant difference (LSD) test.

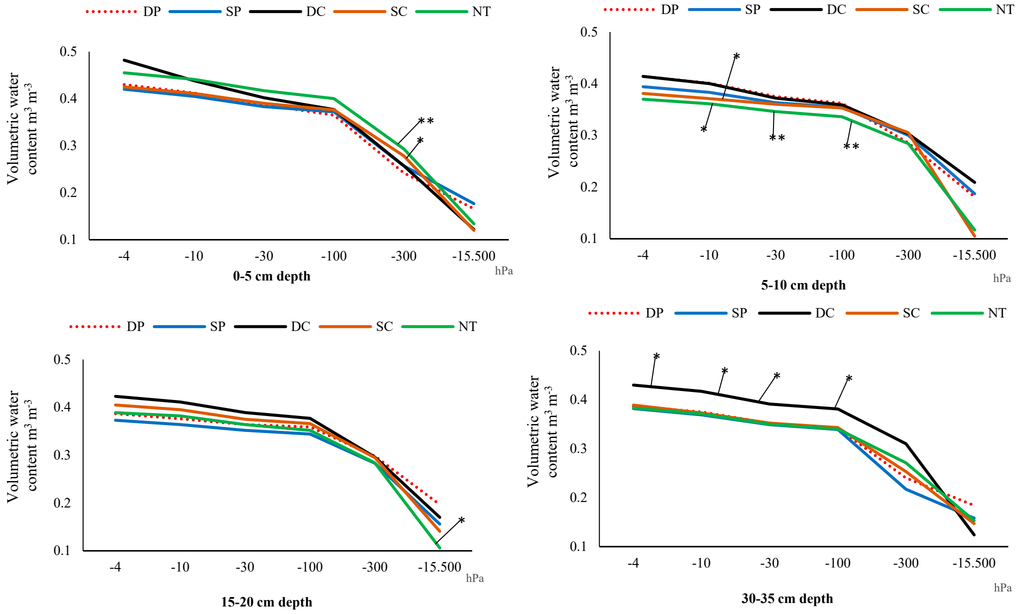


Figure 6. Effect of tillage intensity on soil water retention capacity in different soil layers, 2019. Notes: DP—deep ploughing (control treatment); SP—shallow ploughing; DC—deep cultivation; SC—shallow cultivation; NT—no tillage (direct drilling). *—significant difference at $0.01 < p \leq 0.05$; **—at $0.001 < p \leq 0.01$. The significance of data was determined by Fisher's least significant difference (LSD) test.

In the topsoil (0–5 cm), in most cases all RT systems in most cases increased soil moisture at different pressures compared to the DP. In the 5–10 cm soil layer, in most cases the soil moisture was found to be higher at different pressures in SP plots. In the 15–20 cm soil layer, at different pressures, in most cases the soil moisture was found to be higher in SP, DC and SC plots compared to DP. In the 30–35 cm soil layer, in most cases, the soil moisture was found to be higher at different pressures, only in SP and SC plots, while in NT plots the opposite tendencies were observed.

In NT plots, in the upper 0–5 cm layer, soil moisture was found to be higher compared to deep ploughing at different pressures in 2016–2018. In 2019, the soil moisture in this tillage system (NT) was found to be higher at a pressure of −4 hPa to −300 hPa. It can be stated that the applied tillage system in the top layer of (0–5 cm) was the most effective at retaining moisture. Similarly, Çelik et al. [62] pointed out that the NT system supported the formation of a well-developed pore system with a higher water retention capacity. Blevins and Frye [63] highlighted that NT maintained the soil surface, conserving natural soil structure and biopores (from earthworms and dead roots).

The relations between soil bulk density, volume of soil pores and water capacity are presented in Table 4.

Table 4. Correlation (r) between soil bulk density and volume of pores (x) and water capacity (Y).

Soil Bulk Density and Pores Volume, x Tension, hPa	**Water Capacity m^3 m^{-3} at 0–5 cm Soil Layers, Y**					
	4	**10**	**30**	**100**	**300**	**15,500**
Bulk density of 0–5 cm layer, 10^6 g m^{-3}	−0.672 **	−0.641 **	−0.562 **	−0.440	n	n
Micro-pores of 0–5 cm layers m^3 m^{-3}	n	n	n	n	n	0.586 **
Meso-pores of 0–5 cm layers m^3 m^{-3}	n	n	0.408	0.474 *	n	n
Macro-pores of 0–5 cm layers m^3 m^{-3}	n	n	n	n	−0.402	n
	Water Capacity at 5–10 cm Soil Layers, Y					
Bulk density of 5–10 cm layer, 10^6 g m^{-3}	−0.637 **	−0.566 **	−0.604 **	−0.604 **	−0.637 **	−0.604 **
Macro-pores of 5–10 cm layers m^3 m^{-3}	0.781 **	0.710 **	0.682 **	−0.629 **	0.781 **	0.629 **
	Water Capacity at 15–20 cm Soil Layers, Y					
Micro-pores of 0–5 cm layers m^3 m^{-3}	−0.451 *	−0.454 *	n	n	0.499 *	0.487 *
Meso-pores of 0–5 cm layers m^3 m^{-3}	n	0.532 *	0.508 *	0.416	−0.455 *	−0.433

Note: n—weak correlation; *—correlation significant at $p \leq 0.05$; **—at $p \leq 0.01$. Based on Fisher's test.

Therefore, the soil bulk density and the volume of pores are important for Planosol water capacity. An increase in bulk density in the 0–10 cm layer initiates a decrease in soil water capacity. Additionally, the upper soil layers are sensitive to heavy agricultural techniques.

To summarize, in our tested faba bean cultivation, the most important (key) parameter, which influences many of soil's physical, biological, and chemical properties, was the topsoil coverage with pre-crop (winter wheat) straw and stubble. The coverage varied each year. In non-reversibly tilled plots, residues layer could rich 26–37%; in non-tilled, this value was 82% (Table 1). We found average and strong correlations between the topsoil coverage and amount of soil macro-nutrients, volume and biomass of earthworms, soil enzymatic activity, CO_2 concentration, temperature, moisture content, and structural stability. In most cases, faba bean productivity was strongly related to the amounts of nitrogen, phosphorus, potassium, and magnesium in the top-soil layer (0–15 cm). The effect of soil's physical properties on faba bean productivity was weaker. Schlüter et al. [64] stated, that the differences in structural, physical, and ecological properties of soil under different tillage treatments had less of an impact on crop yield than climatic conditions.

In our study, soil sampling was performed just after sowing faba beans, so the relation with crop productivity was not strong. However, we found a positive relation between the crop seed yield and bulk density of topsoil after sowing beans (r = 0.582, $p \leq 0.01$). A slightly higher bulk density increased the contact of seed-soil and improved germination and crop density. Crop density was the most influential parameter on faba bean seed yield in our experiment. It should be mentioned that this conclusion is supported by the fact that, as the sampling depth increased, the correlations (r) between seed productivity and soil density decreased consistently, from 0.437 at the depth of 5–10 cm depth to 0.286 at 30–35 cm.

4. Conclusions

In the top layers of Planosol (0–5 cm, 5–10 cm), reduced-tillage systems tended to increase soil density in most cases, unlike deeply ploughed system. In the deeper soil layers (15–20 cm and 30–35 cm), the opposite trends were observed.

The effect of different tillage methods of on the volume of micro-pores was not consistent; however, in non-reversibly tilled and non-tilled plots, these pores were found to be less in terms of volume than deeply ploughed plots. A higher number of meso-pores, compare to deep ploughing, was found in deeply cultivated plots in the 5–10 cm and 15–20 cm soil layers; in shallowly cultivated plots, this was in the 15–20 cm layer, and in not tilled plots, this was in the 15–20 cm and 30–35 cm layers. The volume of soil macro-pores mainly decreased with the reduction in tillage intensity; however, this effect varied between soil layers.

In most cases, the no tillage system led to the highest water retention capacity in the top (0–5 cm) soil layer, while the reduced-tillage systems resulted in lower-placed ones.

The increase in the bulk density of topsoil negatively affected the volume of soil pores and water capacity in the 0–5 and 5–10 cm layers.

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