Impact of sustainable tillage on biophysical properties of Planosol and on faba bean yield

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Decreased tillage intensity can contribute to a reduced agro-technological footprint and stabilise the negative impact of climate change, especially in leguminous crop cultivation. For this reason, a long-term (since 1988) stationary field experiment has been performed on silty loam Planosol (in Lithuania). The main objective of this study was to establish the influence of sustainable tillage and no-tillage systems on soil aggregate stability to water, penetration resistance, enzymatic activity, abundance of earthworm and faba bean grain yield. Five different tillage systems were investigated: conventional deep and shallow mouldboard ploughing, deep chiselling, shallow disking and no-tillage. No-tillage in faba bean cultivation significantly increased soil structural stability by 40–97%, saccharase content by 0.7–2.0 times, urease activity by 3–4 times, the average quantity of earthworm by 55% and the biomass by 3.6 times. The impact of other ploughless tillage systems on soil properties was positive but not as significant. Faba bean grain yield was more influenced by growing seasons than by different tillage methods.

Key words: cold climate, tillage systems, soil properties, grain yield, *Vicia faba*

Introduction

During the last 20–30 years, ploughless tillage technologies have become prevalent inculcated. In some European countries, this practise has reached more than 70% (Alvarez and Steinbach 2009). According to Cannell (1985), shallow tillage can be a good practise as mouldboard ploughing in most countries on a wide range of soil types. No-tillage (NT) or zero tillage technology is the marginal technology, which uses new machinery, higher amounts of pesticides and so on. Despite that, it is currently used on more than one million hectares in Europe (Lopez et al. 2012). Ploughless or no-tillage systems may reduce technological costs, prevent soil moisture and fertility losses due to erosions, promote CO_2 sequestration, stabilise crop productivity and energy use (Morris et al. 2010, Rusu et al. 2011, Soane et al. 2012, Arvidsson et al. 2013, Lozano-García and Parras-Alcántara 2014, Šarauskis et al. 2014, Kazemi et al. 2015). Kertész and Madarász (2014) points out that risk of soil erosion varies according to the different ecological regions in Europe. In the Northern countries, in cold climate conditions, risks of soil erosion are lower compared to the semi-arid Mediterranean regions are lower. However, the Lithuanian climate is quite unstable and has scattered distribution of precipitation. Precipitation rates are sometimes surplus, therefore, on the average 70% of the total soil and 17% of agricultural soil erodes (43–58% in the hilly regions) (Jankauskas et al. 2008). The best way to mitigate the process of erosion is to increase the stability of soil structure through sustainable tillage practises (Rasmussen 1999).

The activity of soil enzymes is one of the most important soil biological activities (mainly reflecting the amount of microorganisms) and fertility indicators (Mikhailovskaya and Tarasčuk 2008). The production of enzymes during the vegetation period depends on temperature, soil moisture, availability of nutrients and abundance of earthworms (Tao et al. 2009, Guenet et al. 2012), all of which highly depend on the applied tillage systems (Lukošiūnas and Germanas 2006, Bogužas et al. 2010).

Faba bean maintains the sustainability of agricultural systems due to efficient symbiotic fixation of atmospheric nitrogen (Karkanis et al. 2018). According to the Ntatsi et al. (2018) investigations, the total amount of biologically fixed N in faba bean crop varied from 118.5 to 193.9 kg ha^{-1} depending on the various cropping systems and cultivars. The amount of CO_2 respiration from the root systems is higher than CO_2 generation during N-fertilizer production. Besides, faba bean crop emits approximately 4–5 times less N_2O per growing season than alfalfa or soybean, 5 times less than fertilized wheat or maize crop, and 10 times less than fertilised pasture. Therefore, developing faba bean cultivation areas may decrease greenhouse gas (GHE) emissions (Jensen et al. 2012).

Sustainable tillage technologies have been widely investigated, but there are very few studies on faba bean crop. The results from over 18 years of investigations in the Mediterranean climate conditions showed that no-tillage (NT)

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system decreased the costs and prevented the negative impacts of tillage on the physical, chemical and biological properties of the soil. The success of NT depends on the effectiveness of weed control (Giambalvo et al. 2012).

The EU Greening program requested increasing the area of leguminous crops. The Lithuanian conditions are the most favourable for pea and faba bean growing, and the area of these crops have increased about 20 times. Sustainable tillage technologies have been used in approximately 40% of Lithuanian agricultural land. Our previous investigations showed that, long-term sustainable soil tillage systems were effective for winter wheat, barley, oilseed rape, maize, and sugar beet (Romaneckas et al. 2006, Romaneckas et al. 2009, Romaneckas et al. 2019). Thus, as with other crops, changing tillage intensity from conventional reversible deep ploughing to chiselling, disking or no-tillage (direct drilling) can be expected to reduce the risk of soil degradation and conserve faba bean productivity in unstable boreal semi humid climate conditions.

Material and methods

Site description

The long-term stationary field experiment was performed at the Experimental Station of Vytautas Magnus University Agriculture Academy (former Aleksandras Stulginskis University) (54°52′ N, 23°49′ E). It was initiated in 1988 and modified in 2001, when a direct sowing treatment was added. The research data, presented in this article, is from 2016–2018. The soil in the experimental field was silty loam (45.6% sand, 41.7% silt, 12.7% clay) Planosol (WRB 2014). The depth of the arable layer was 25–27 cm. The pH_{KCL} of the soil surface was 6.4–7.7, the amount of available phosphorus varied from 194 to 384 mg kg^{-1} and potassium from 85 to 206 mg kg^{-1}. The variation and location of elements depended on long-term soil tillage practices.

The climate of the experimental site is identified as boreal (subarctic). During the last 100 years, the average annual temperature increased from 6.3 to 6.7 °C, precipitation rate from 590 to 625 mm. The precipitation varied from 39.6% (December) to 66.7% (October). The length of vegetation season with active temperatures (SAT, ≥ 10 °C) is approximately 6 months. The SAT in 1990 was 2132 °C, in 1995–2371 °C and in 2018–2965 °C. The average of air temperatures across 24 hours and the precipitation rates are presented in Table 1 and 2.

Table 1. Average air temperature across 24 hours during faba bean vegetative seasons, Kaunas Meteorological Station

Year/ Month	April	May	June	July	August	September
2016	7.4	15.7	17.2	17.9	16.9	–
2017	5.6	12.9	15.4	16.8	17.5	13.4
2018	10.2	17.2	17.5	20.1	19.2	–
Long-term (1974–2017) average	6.9	13.2	16.1	18.7	17.3	12.6

Table 2. Rainfall (mm) during faba bean vegetative seasons, Kaunas Meteorological Station

Year/ Month	April	May	June	July	August	September
2016	41.2	36.4	83.9	162.9	114.9	–
2017	73.7	10.5	80.2	79.6	55.0	87.1
2018	64.8	17.6	57.6	137.5	96.6	–
Long-term (1974–2017) average	41.3	61.7	76.9	96.6	88.9	60.0

The beginning of the 2016 vegetative season was warmer than usually, with slightly lower precipitation rates. July and August were colder and much wetter. The vegetative season of 2017 might be characterized as colder than the long-term average, but with uneven distribution of precipitation. For example, April was excessively humid and May was extremely dry. All of the vegetative season of 2018 was warmer than usual. The distribution of precipitation was uneven. Similarly to 2017, May was droughty, but July and August were excessively humid.

The increase of air temperatures is a positive tendency for crop productivity realization; however, higher temperatures and rising of precipitation rates lead to destruction of soil aggregates, increased soil compaction and reduced bioactivity (Karmakar et al. 2016, Juhola et al. 2017, Sengar and Sengar 2017). In our earlier experiments, we have found that higher precipitation rates during maize vegetative period (May–September) had a negative impact on soil aggregate stability (SAS, aggregates >1 mm) to water (r= –0.549) (Romaneckas et al. 2015). In preside experiment, we found similar tendencies (r= –0.540 at $p \leq 0.05$). However we found positive correlation between SAS and average temperatures during vegetative period (April–August) (r= 0.658 at $p \leq 0.01$).

Experiment design and agricultural practices

Five primary soil tillage systems were investigated: 1. Deep mouldboard ploughing (DP = control treatment); 2. Shallow mouldboard ploughing (SP); 3. Deep cultivation-chiselling (DC); 4. Shallow cultivation-disking (SC); 5. No-tillage (direct sowing) (NT).

Crop rotation in the experiment: spring oilseed rape – winter wheat – maize (faba bean since 2016) – spring barley. The experiment was performed in 4 replications. There were 20 plots per crop in total. The initial size of the experimental plot was 126 m^2 (14 × 9 m). Randomized design of plot's distribution was used. The buffer strip was 1 m wide between the experimental plots and 9 m between the blocks. After crop harvesting, all experimental plots (except NT) were disked with a Väderstad Carrier 300 disc harrow (Table 3).

Table 3. Tillage practice in the experiment (according to Romaneckas et al. 2017)

Tillage system	Stubble tillage	Primary tillage	Implement	Depth of tillage (cm)	Pre-crop residue cover (%)
Deep ploughing	Yes	Inversion	Mouldboard plough	22–25	0–3
Shallow ploughing	Yes	Inversion	Mouldboard plough	12–15	2–4
Deep cultivation	Yes	Non-inversion	Chisel cultivator	25–30	40–51
Shallow cultivation	Yes, twice	No	Disc harrow	10–12	40–50
No-tillage	No	No	None	0	47–87

The John Deere 6620 tractor was used in the experiment. According to the experimental scheme, the primary tillage was carried out between September and October (Table 4). Soil was ploughed with the traditional plough Gamega PP-3-43 (Lithuania) with semi-screw shell boards, deep chiselling was carried out with the KRG-3.6 (Lithuania) ridge cultivator (chisel). SC plots were additionally disked with a Väderstad Carrier 300 disk harrow. NT plots were not tilled at all. Before sowing, the soil was cultivated with Laumetris KLG-3.6 (Lithuania) cultivator (except NT). Seeds were sowed with Väderstad Rapid 300C Super XL drill and fertilised at the same time. Additional fertilisation of crop was performed with fertiliser spreader Amazone-ZA-M-1201. Pesticides were spread with spreader Amazone UF-901. Faba bean was sown when topsoil reached physical maturity (Table 4). Distance between rows was 25 cm. The sowing rate was about 200–220 kg grain per ha (40–45 seeds per m^2). The sowing depth was 5–6 cm. Faba bean variety 'Fuego' (C2, mass of 1000 grain was 630 g) was sown.

The variety was created by Norddeutsche Pflanzenzucht Hans–Georg Lembke KG, Germany. Before sowing, the seeds were inoculated with a *Rhizobium leguminosarum* bacterial preparation (approximately 200 ml of preparation for 100 kg seeds) because, in poor soils bacterial preparations increase the productivity and quality of faba bean crop (Denton et al. 2013). Pests in faba bean cultivation were controlled at the beginning of crop flowering (BBCH 60–63) (Table 4). The crop was harvested with Wintersteiger Delta (Austria) combine harvester.

Table 4. Technological operations and timing in faba bean growing technology

Technological operation	2015–2016	2016–2017	2017–2018
Primary tillage	7 October 2015	17 October 2016	20 October 2017
Glyphosate herbicide application (4.0 l ha^{-1}, NT plots only)	6 April 2016	3 May 2017	15 April 2018
Pre-sowing tillage	25 April 2016	8 May 2017	23 April 2018
Local fertilization (NPK 7:16:32) 300 kg ha^{-1} and sowing	25 April 2016	8 May 2017	24 April 2018
Herbicide application (aclonifen, 3.0 l ha^{-1})	26 April 2016	9 May 2017	26 April 2018
Insecticide application (lambda-cyhalothrin, 0.15 l ha^{-1})	10 May 2016	7 June 2017	15 May 2018
Fungicide application (26.7% w/w boscalid and 6.7% w/w pyraclostrobin, 1 l ha^{-1})	13 June 2016	23 June 2017	18 June 2018
Harvesting	9 September 2016	27 September 2017	23 August 2018

Methods and analysis

The projection coverage of the pre-crop (spring oilseed rape) residues was determined after the primary tillage and sowing (5 May 2016, 15 May 2017, 4 May 2018). The 10 m length metal strip was used for measuring. The points of contact with plant residues were set every 10 cm (100 times per plot).

Soil aggregate stability to water was determined in 0–15 cm layer in no less than five spots per plot before pre-sowing tillage in spring (4 April 2016, 5 May 2017, 19 April 2018) and after the faba bean harvest (3 October 2016, 2 October 2017, 6 September 2018). For sieving, we used the wet-sieving methodology (Angers et al. 2006), using sieves with mesh diameters of 5–0.25 mm.

Soil penetration resistance was measured 4 times during the vegetation of each vegetative period (6 April 2016, 27 April 2016, 14 June 2016, 13 September 2016; 5 April 2017, 19 May 2017, 27 June 2017, 6 October 2017; 17 April 2018, 3 May 2018, 5 July 2018, 2 September 2018) in 0–50 cm layer, no less than 5 spots per plot, with penetrologer Eijkelkamp 06.15SA (Birs HydroMet GmbH).

Soil enzymatic activity was identified after faba bean harvest (3 October 2016, 2 October 2017, 6 September 2018) before primary soil tillage (in 0–15 cm layer). The activity of the soil enzyme urease was determined by the methods of Hofmann and Schmidt (1953), saccharase by Hofmann and Seegerer (1950) and Chunderova (1973).

The number of earthworms was established after faba bean harvesting before primary soil tillage (14 September 2016, 4 October 2017, 12 September 2018) at 3 spots per each plot in 0.25 m^2 area. The investigation was based on the use of formalin extraction. A 0.5 × 0.5 m metal frame was set to the ground to separate the area. A 0.5% formalin solution (not less than 8 l) was poured onto the ground in the frame (Clapperton et al. 2006). When the solution was absorbed, all earthworms on the surface of the soil were collected, counted and weighed.

Ten samples for faba bean biological yield of grain were taken from each plot of experiment in random spots (area 0.25 m^2). Grains were dried and data recalculated to 15% moisture content.

The data was analysed using one-way ANOVA. The treatment effect was tested using the P test and least significant difference (LSD). The experimental data were also tested with SigmaStat and SigmaPlot software. Significant differences between treatments and the control were expressed by * – significant difference at the 95% probability level ($p \le 0.05 > 0.01$); ** – significant difference at the 99% probability level ($p \le 0.01 > 0.001$); and $p > 0.05$ – no significant difference at the 95% probability level. Different letters within columns mean significant difference at $p \le 0.05$.

Results and discussion

Soil aggregate stability to water

According to the data of our investigations, the top layer of the soil we had more than 50% of structural aggregates which proved high soil stability. According to the research of Köpke and Nemecek (2010), faba bean cultivation improved soil physical structure. Likewise, in our experiment, long-term non-inversion tillage systems significantly prevented the destruction of soil structural aggregates (Table 5). Similarly, our earlier investigations on maize cultivation found that non-reversibly tilled and NT plots had the highest stability of soil aggregates (Romaneckas et al. 2015).

Table 5. Effects of different tillage practice on soil aggregate stability to water (SAS, %) (0–15 cm layer) before and after faba bean vegetative growth period

Tillage system	2016		2017		2018	
	Before	After	Before	After	Before	After
Deep ploughing	46.8b	47.7c	35.9b	42.8d	49.4c	36.7c
Shallow ploughing	49.9b	56.5bc	45.6b	44.7cd	55.0bc	41.8c
Deep cultivation	60.6*a	53.7c	60.6*a	57.8*bc	63.7*ab	56.2**b
Shallow cultivation	63.9**a	64.8**ab	65.0**a	65.7**ab	68.0**a	57.9**b
No-tillage	65.4**a	72.4**a	70.6**a	70.7**a	72.7**a	68.5**a
$LSD_{0.05}$	9.97	11.52	11.58	11.95	10.68	7.24
$LSD_{0.01}$	13.98	16.15	16.24	16.76	14.98	10.15

* = significant differences from the control treatment (deep ploughing) at $p \le 0.05$, ** = at $p \le 0.01$. Different letters within columns mean significant difference at $p \le 0.05$.

In their study, Blanco-Canqui and Ruis (2018) concluded that NT increased wet soil aggregate stability by 1 to 97%. In our presented experiment, during humid faba bean vegetative periods of 2016–2017, soil aggregate stability (SAS) after harvesting was mainly higher or similar than after wintering. However in droughty vegetative period of 2018, we found converse results. Moreira et al. (2016) results confirm that soil physical properties under NT are highly dynamic and influenced by soil disturbance at furrow opening, wetting and drying cycles and depth of sampling.

The stability of the soil aggregates to water was determined by differences in the amount of pre-crop (winter wheat) residues (r = 0.897 and 0.906 at $p \leq 0.05$). There was also a relationship between soil structural stability and number or biomass of earthworms (r = 0.910 and 0.902 at $p \leq 0.05$).

Soil penetration resistance

In 2016, the highest soil penetration resistance before pre-sowing tillage in spring was determined in untreated plots (NT) (Fig.1a). The trend has been observed from the soil surface to the depth of 45 cm. Other scientists confirm our findings (Bogunovic et al. 2018), but information from faba bean experiments is stills scarce. Only Badagliacca et al. (2018) established that the long-term continuous application of NT, compared to conventional tillage (CT), increases soil bulk density in faba bean cultivation. In the presented experiment, relatively hard soil was also observed in shallowly cultivated (disked, SC) plots, but even at the depth of 20 cm, it was rather friable.

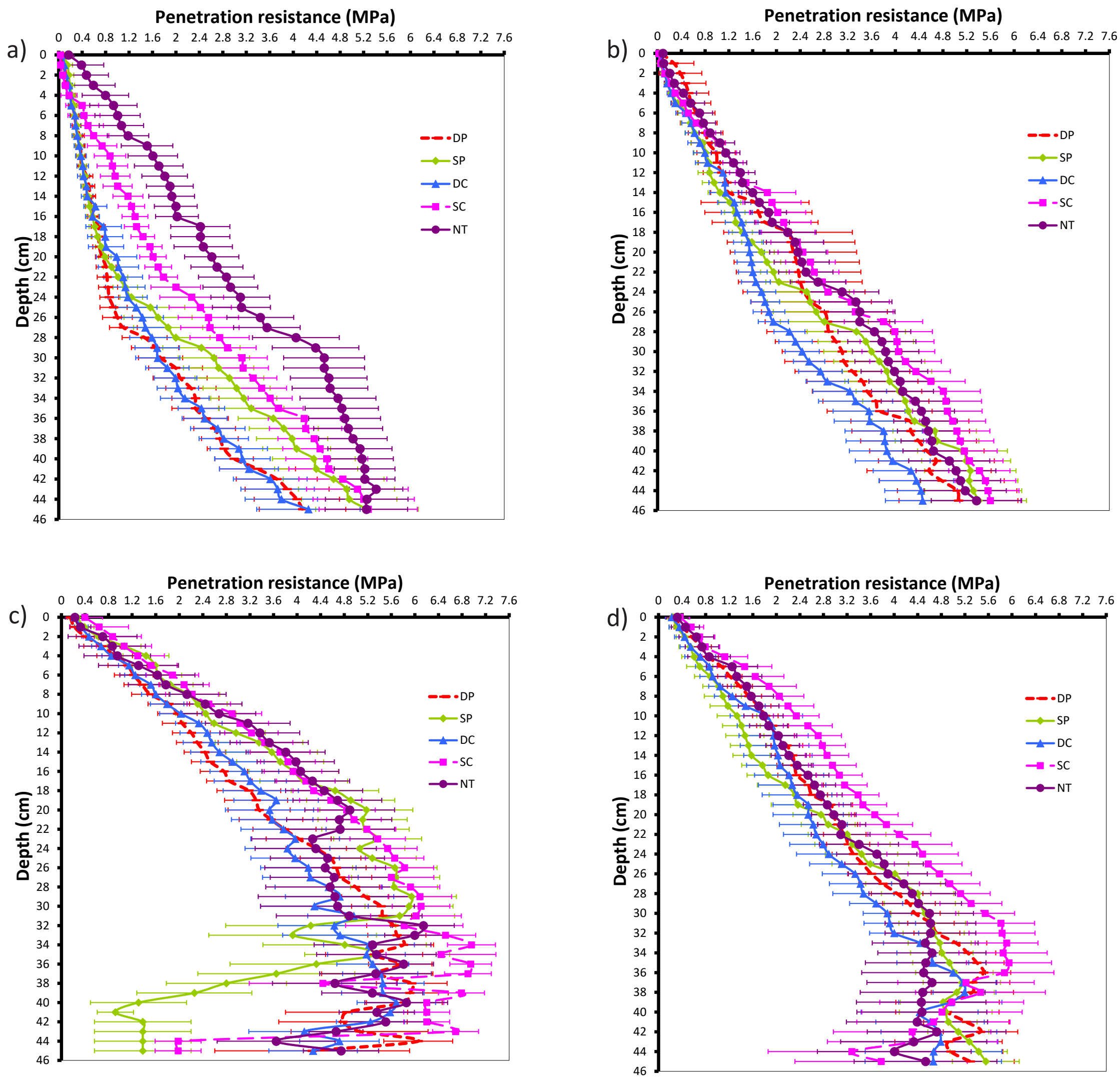

Fig. 1. Soil penetration resistance at different stages of experiment in 2016: a) before pre-sowing tillage in spring; b) after faba bean sowing; c) beginning of faba bean flowering; d) after harvesting. DP = deep ploughing, SP = shallow ploughing, DC = deep cultivation, SC = shallow cultivation, NT = no-tillage (direct drilling). Horizontal bars mean standard deviation.

The penetration resistance of the shallowly ploughed (SP) plots from the depth of 24 cm began to increase. The penetration resistance of the deeply ploughed (DP) and deeply cultivated (DC) plots was the lowest, and, even at a depth of 25 cm, the soil was classified as loose. During sowing, the soil surface was slightly compressed, but remained friable (Fig. 1b).

Much viewable differences of soil penetration resistance were observed at the depth of 14–16 cm. Soil of NT and SC plots remained harder and the most friable soil profile was in DC plots. In spite of this, at the depth of about 15 cm, the soil remained fluffy and in 25 cm it was hard. Such conditions are favourable to the development of most agricultural plants.

At the stage of faba bean flowering, the soil hardened significantly due to lack of precipitation (Fig. 1c). Only up to a depth of 6 cm, this soil was attributed as fluffy, and at a depth of 15 cm it was already hard, except for DP and DC plots. During the faba bean vegetation, SC plots became the hardest, and the penetration resistance of soil in DP, SP and NT plots became similar (Fig. 1d). DC plots had less penetration resistance in the soil layer of about 22–32 cm depth. Therefore, if the soil is cultivated this way, the roots of the beans fall deep and use nutrients and water deeper.

The climatic conditions in 2017 were more humid than in 2016, and the soil was characterised as having a lower penetration resistance, especially at the beginning of vegetation. Prior to soil tillage in spring and after sowing, the highest soil penetration resistance was observed in NT plots (Fig. 2a and 2b). Nevertheless, the penetration resistance of the arable layer did not exceed 2 MPa and was friable; therefore, it did not interfere with the development of deep bean roots. At the time of faba bean flowering, the soil had dried up and its penetration resistance had increased, especially in the subsoil. The highest penetration resistance remained in the NT plots (Fig. 2c). After harvesting, a lot of precipitation fell, so the total penetration resistance of the soil decreased, the differences between the variants equalised, but DP soil remained the most friable (Fig. 2d).

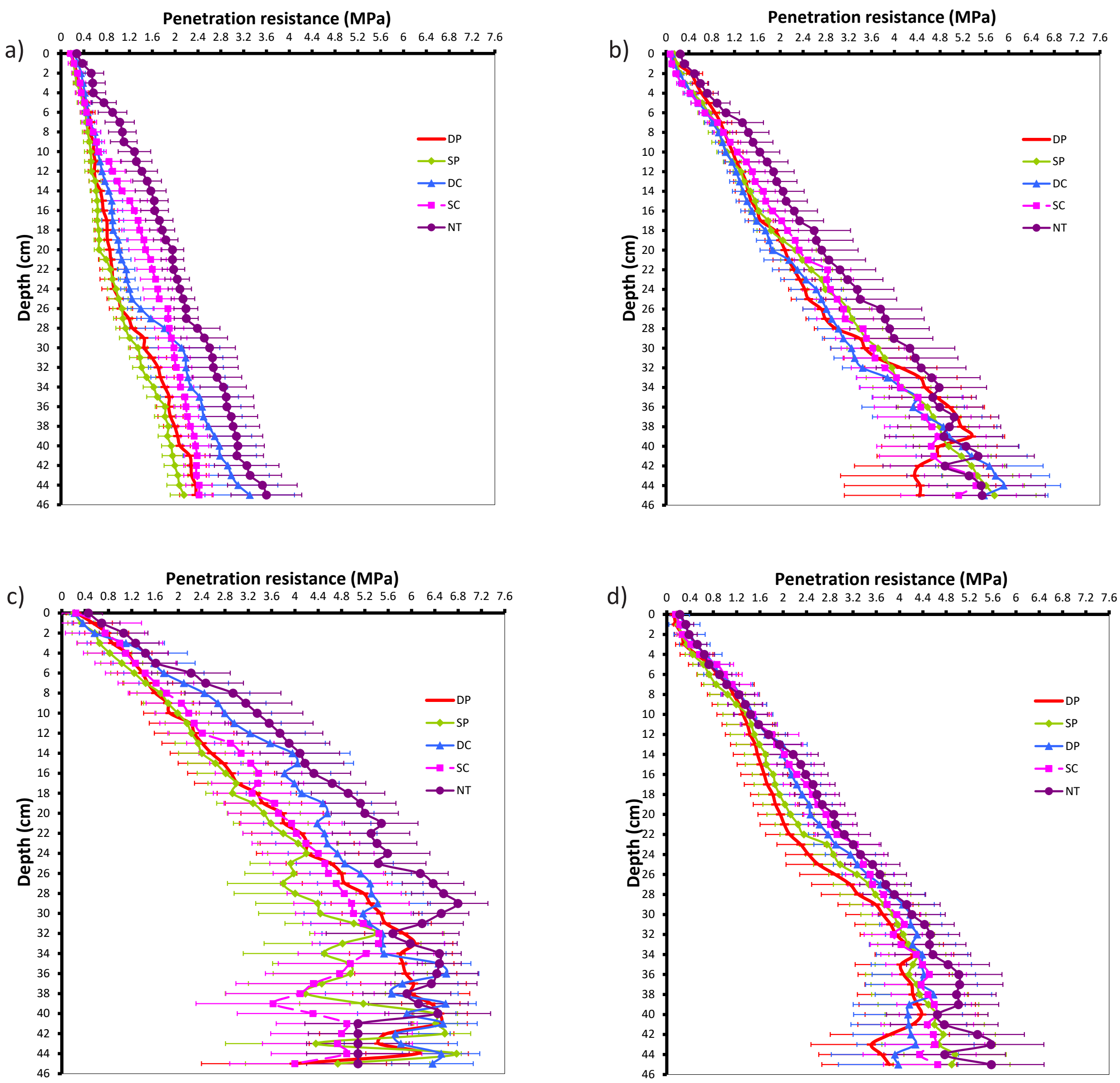

Fig. 2. Soil penetration resistance at different stages of experiment in 2017: a) before pre-sowing tillage in spring; b) after faba bean sowing; c) beginning of faba bean flowering; d) after harvesting. DP = deep ploughing, SP = shallow ploughing, DC = deep cultivation, SC = shallow cultivation, NT = no-tillage (direct drilling). Horizontal bars mean standard deviation.

The climatic conditions during 2018 vegetation were more arid and warmer than in the previous experimental years, but after winter, at the beginning of vegetation, moisture in the soil was sufficient and the penetration resistance was low (Fig. 3a and 3b). Unlike 2016 and 2017, in 2018 the soil remained quite fluffy during the whole bean vegetation, with only the subsoil hardening more. There were also no major differences in penetration resistance between tillage treatments, but in the middle and at the end of the vegetation, DP soil subsoil became harder (Fig. 3c and 3d). In Blanco-Canqui and Ruis (2018) experiments, NT had mixed effects on penetration resistance as well.

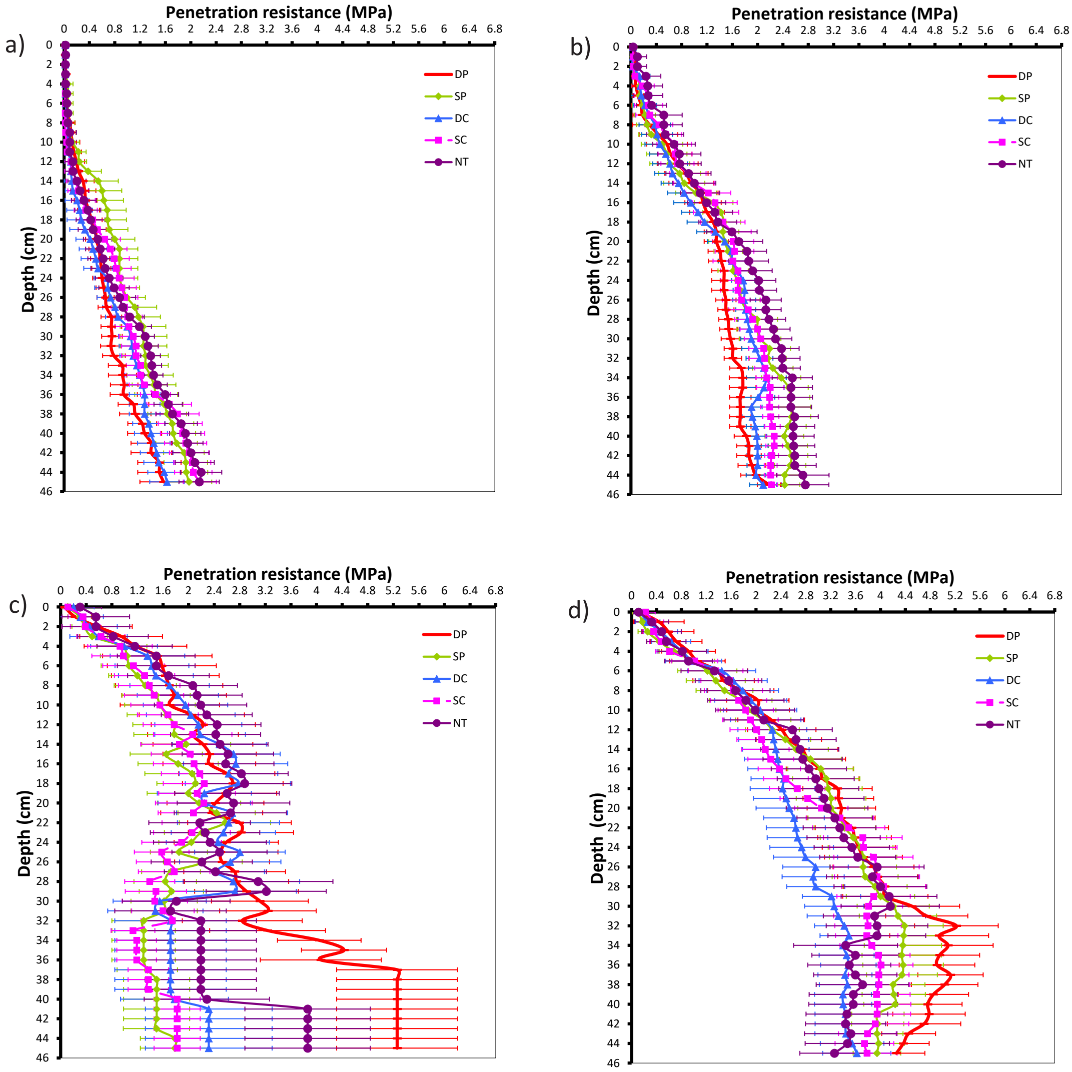

Fig. 3. Soil penetration resistance at different stages of experiment in 2018: a) before pre-sowing tillage in spring; b) after faba bean sowing; c) beginning of faba bean flowering; d) after harvesting. DP = deep ploughing, SP = shallow ploughing, DC = deep cultivation, SC = shallow cultivation, NT = no-tillage (direct drilling).

Soil enzymatic activity

Our research suggests that reducing of soil tillage intensity from annual DP to other alternatives and NT, soil enzymes steadily increase (Table 6). Essentially, the highest enzyme activity was found in NT plots. The activity of saccharase was almost 0.7–2.0 times higher and urease was approximately 3–4 times higher than in DP plots. Activity of saccharase was closely related with activity of urease (r= 0.889 at $p \leq 0.01$). Besides, we found that average temperatures during vegetative period (April–August) had higher impact ($r_{saccharase}$ = 0.636 and r_{urease} = 0.590 at $p \leq 0.05$) on soil enzymatic activity than precipitation rates ($p > 0.05$).

Table 6. Effect of different tillage practise on soil enzymatic activity

Tillage system	Saccharase (mg glucoses 1 g of soil per 48 h)			Urease (mg NH_3 1 g of soil per 24 h)		
	2016	2017	2018	2016	2017	2018
Deep ploughing	23.2b	27.7b	27.4b	0.08c	0.16c	0.17b
Shallow ploughing	19.7b	27.2b	29.9b	0.11bc	0.16c	0.23b
Deep cultivation	27.4b	37.6b	36.1b	0.15bc	0.28bc	0.30b
Shallow cultivation	26.5b	33.8b	40.4ab	0.19*ab	0.39*b	0.55 **a
No-tillage (direct drilling).	38.6*a	49.2**a	50.0 **a	0.25**a	0.61**a	0.45 **a
$LSD_{0.05}$	11.12	10.80	13.58	0.102	0.217	0.144
$LSD_{0.01}$	15.59	15.15	19.03	0.144	0.304	0.202

* = significant differences from the control treatment (DP) at $p \leq 0.05$; ** = at $p \leq 0.01$. Different letters within columns mean significant difference at $p \leq 0.05$.

Similarly to our findings, Aschi et al. (2017) concluded, that Wheat-Beet-Faba Bean-Rape-Wheat rotation might promote microbial activities in agricultural soils. In fact, Siczek et al. (2018) found higher soil microbial activity in the rhizospheres of faba bean than in wheat.

Earthworm abundance

The abundance of earthworms in faba bean crops in Lithuania has not been determined at all, but it is clear that trends have remained similar to those of other crops. In the earlier field experiments of the Lithuanian scientists, the number of earthworms in ploughless plots increased by 23.4–53.4%, and their biomass by 18.3–62.7% compared to deep ploughing (Stancevičius et al. 2003).

In our previous investigations, we have found that the reduction of primary tillage from conventional ploughing to shallow cultivation resulted in more or less similar number and mass of earthworms, but in NT plots the number of earthworms in the wheat stubble increased on the average by 2 and the mass by 3.7 times compared to DP plots (Romaneckas et al. 2016). In the current experiment of faba bean cultivation, the highest number of earthworms was found in NT plots, however the differences were mainly insignificant (Table 7). There, the biggest biomass of earthworms was also found, but the differences were significant in most cases as well.

We found that average temperatures during vegetative period (April–August) had higher impact on earthworm mass ($r= 0.530$ at $p \leq 0.05$) than precipitation rates ($r= 0.321$ $p > 0.05$). Influence on the number of earthworm was weak.

Table 7. Effect of different tillage practise on number (m^{-2}) and fresh biomass ($g\ m^{-2}$) of earthworms

Tillage system	2016		2017		2018	
	number	biomass	number	biomass	number	biomass
Deep ploughing	133.3b	39.5c	81.5a	23.5c	90.2a	27.1c
Shallow ploughing	154.0ab	60.0bc	80.3a	42.9c	113.2a	33.7bc
Deep cultivation	109.3b	72.0*b	82.5a	49.9bc	158.5a	63.1*a
Shallow cultivation	81.0b	75.5**b	69.8a	96.0**ab	161.2a	57.0*ab
No-tillage	196.3*a	129.2**a	119.5a	134.7**a	156.5a	58.6*ab
$LSD_{0.05}$	54.09	23.25	51.21	49.49	74.13	27.58
$LSD_{0.01}$	75.83	32.59	71.79	69.38	103.92	38.66

* = significant differences from the control treatment (DP) at $p \leq 0.05$; ** = at $p \leq 0.01$. Different letters within columns mean significant difference at $p \leq 0.05$.

Grain yield

Long-term tillage practise had insignificant influence on faba bean grain yield, except in obsoleted cases in 2018 (Table 4). Yield variation mainly depended on the differences in crop density (Romaneckas et al. 2017).

In our previous investigations at the same base of experiment, we did not find any significant yield differences in many other agricultural crops (Romaneckas et al. 2006, Romaneckas et al. 2009, Avižienytė et al. 2013, Romaneckas et al. 2019). In contrast to our study, Badagliacca et al. (2018) found significant increase in the faba bean grain yield in not tilled plots, by 23% compared with conventional tillage (deep ploughing and harrowing).

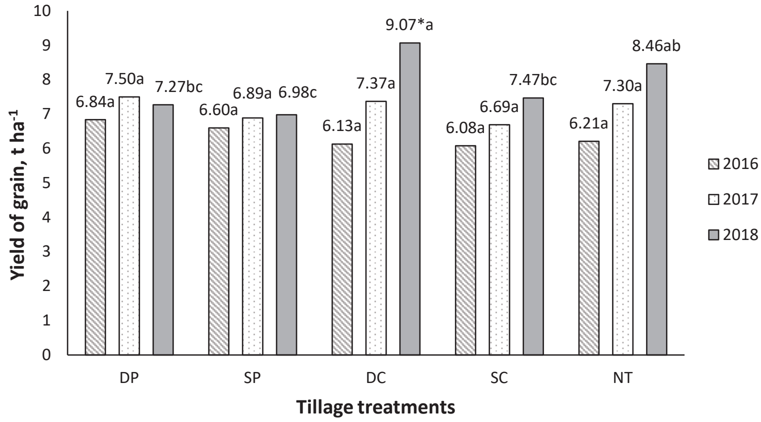

Fig. 4. Effects of different tillage practice on faba bean grain yield (t ha^{-1}). * = significant differences from the control treatment (DP) at $p \leq 0.05$; ** = at $p \leq 0.01$. Different letters within columns mean significant difference at $p \leq 0.05$. DP = deep mouldboard ploughing (control treatment); SP = shallow mouldboard ploughing; DC = deep cultivation-chiselling; SC = shallow cultivation-disking; NT = no-tillage (direct sowing).

What regards to our experiment, differences of meteorological conditions had a greater and more significant impact (at $p \leq 0.05$) than tillage treatments. The average grain yield in the experiment was 7.12 t ha^{-1} and about 2 t ha^{-1} higher than the average of Lithuanian farms. Similarly with our findings, Alarcón et al. (2018) in 9-year Spanish field investigations found, that annual meteorological variability had higher impact on yield of the legumes (pea and vetch) than the tillage systems. Arvidsson et al. (2014) concluded, that pea yields in shallowly non-inversely tilled plots were similar or slightly lower than in ploughed ones under Swedish conditions.

Conclusions

1. The greatest differences in soil penetration resistance were established before the pre-sowing tillage in spring. NT plots were those that hardened the most during wintering, but the differences in penetration resistance during vegetation were low, except in rainy 2017, when penetration resistance of NT plots remained the highest until the end of vegetation.

2. Reduced tillage intensity significantly increased soil aggregate stability to water. During the vegetation, the roots of faba beans influenced the increase in soil stability, which was most pronounced in the of 0–15 cm soil layer.

3. Substituting deep soil tillage with other alternatives has increased soil enzyme activity. Significantly highest enzyme activity was found in NT plots. The activity of saccharase was 0.7–2.0 and urease was about 3–4 times higher than in the deeply ploughed control plots.

4. Significantly highest number and biomass of earthworms was found in NT plots. According to the average data, the number of earthworms in untreated plots was about 60%, and their biomass was more than 3 times higher than in DP.

5. Differences of faba bean grain yield between long-term tillage treatments were insignificant. Yield varied more between vegetative seasons ($p \leq 0.05$).

6. In general, reduced tillage practise could be an efficient way to stabilize soil properties and ensure high productivity of faba beans.

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