ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 107, No. 3 (2020), p. 195–202
DOI 10.13080/z-a.2020.107.025

Soil physical state as influenced by long-term reduced tillage, no-tillage and straw management

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Abstract

Since 1999, a long-term field experiment has been done at the Experimental Station of the Lithuanian University of Agriculture (currently – Vytautas Magnus University). The current research was conducted in 2013–2015. The aim of the study was to evaluate the effects of long-term tillage systems and straw management on soil penetration resistance, shear strength and soil aggregate stability. The soil of the experimental site was *Epieutric Endocalcaric Endogleyic Planosol*. A short crop rotation was introduced: winter wheat → spring barley → spring oilseed rape. According to two factor field experiment, the straw was removed from one part of the experimental field, and on the other part of the field the straw was chopped and spread at harvesting (factor A). Six tillage systems: conventional (deep) and shallow ploughing, shallow loosening, shallow rotovating, catch cropping and rotovating, and no-tillage, were used as a subplot (factor B). During a 16-year (1999–2015) period, long-term application of reduced tillage resulted in a significant increase in soil penetration resistance and shear strength. The results of current study show that the lesser the tillage depth, the higher the soil penetration resistance and shear strength. The effect of straw residue spreading was lower comparing with treatment without straw.

Soil aggregate stability was highly dependent on tillage. Shallow rotovating before sowing increased soil aggregate stability by up to 1.8 times, incorporation of plant residues of white mustard into the soil by a rotovator before sowing increased it by up to 2.0 times and no-tillage by up to 1.9 times, compared with conventional ploughing.

Key words: shear strength, soil aggregate stability, soil penetration resistance.

Introduction

Sustainable agricultural practices are crucial for the maintenance and improvement of soil functions. The long-term implementation of crop rotation and tillage influences the soil environment through inputs and disturbance of the soil, which, in turn, impact soil quality. Tillage has long-term impacts on the agroecosystems. Conservation tillage systems with minimal soil disturbance, including no- or reduced-tillage and residue retention or mulching, are thus often proposed as a means to improve agricultural sustainability. Reduced tillage has positive impacts on soil properties (Moraru, Rusu, 2013).

Conservation agriculture comes with a set of principles to implementation and development of sustainable technologies with the aim of retaining sufficient quantities of vegetal remains on the soil surface for soil protection against erosion, water evaporation and surface leakage, for better use of rainfall and improvement of physical, chemical and biological soil properties associated with long-term stable yield (Rusu, Moraru, 2015). Karlen et al. (2019) have noted that awareness of and interest in soil health has increased exponentially in the last decade. They proposed that excessive tillage is a major factor in the connection between the decline in soil health and degradation, i.e. erosion. Wilson et al. (2019) identified indicators of soil physical quality in a long-term no-tillage and showed that subsequent tillage so dramatically changed the soil physical properties of the surface that they were no longer valid soil quality indicators.

Positive effects on soil porosity and aggregate stability across a wide range of soil types and climates are attributable to conservation tillage systems (Moraes et al., 2016; Gao et al., 2017). However, the beneficial influence of conservation tillage practices, such as no or reduced soil disturbance, cover cropping and residue retention on soil physical properties and soil organic matter apparently rely on site-specific interactions, post-adoption period, climate conditions, the properties of the former management system and the choice of cover crop species (Hubbard et al., 2013; Derpsch et al., 2014).

No-tillage technology has many advantages for economic and environmental protection, and it is currently used on 117 million ha worldwide and 1.15 million ha in Europe (López et al., 2012; Romaneckas et al., 2015).

Please use the following format when citing the article:
Steponavičienė V., Bogužas V., Sinkevičienė A., Skinulienė L., Sinkevičius A., Klimas E. 2020. Soil physical state as influenced by long-term reduced tillage, no-tillage and straw management. Zemdirbyste-Agriculture, 107 (3): 195–202. DOI 10.13080/z-a.2020.107.025

Feiza et al. (2010) and Velykis and Satkus (2018) have reported that tillage and crop rotation are fundamental factors that influence soil quality and sustainability of cropping systems, soil physical properties depend on tillage intensity and soil depth.

Bogužas et al. (2010) have documented that the aggregate structure of soil did not change significantly with different tillage technologies. The most significant increases in soil aggregates stability were recorded at >1 mm (on average, 74.3% and 96.3%) and >0.25 mm (on average, 14.6% and 20.3%) in the shallow loosening or untilled soil (no-tillage) treatments, compared with conventionally ploughed soil at the beginning of vegetation. Similar tendencies were found at the end of plant vegetation, but the influence of tillage decreased.

Soil quality is also determined by soil hardness. Soil penetration resistance is influenced by soil density, structure, moisture as well as by the aggregate size. The smaller the diameter of the soil aggregates, the higher the hardness of the soil. Soil hardness increases with increasing soil density as the moisture content decreases (Feiza et al., 2008). Higher soil hardness was obtained by no-tillage, compared with deep and shallow ploughing. The hardness of the topsoil (0–10 cm) immediately after sowing was similar to that in shallow ploughing and deep ploughing treatments, while it was 49–54% higher in directly drilled soil. After harvesting, the hardness was the lowest in the soil, where deep ploughing had been used. It was 12–30% higher in shallow ploughing and 52–71% higher in no-tillage treatments, compared with the soil of conventional (deep) ploughing (Feiza et al., 2008; Feizienė et al., 2009). Soil strength is affected by soil water content, bulk density and clay content (or texture) of the soil (Guerif, 1994; Chung et al., 2013).

Tillage and rotation are fundamental factors influencing soil quality, crop performance and thus the sustainability of cropping systems. Conservation tillage is considered one of the most effective management practices to obtain mutual benefits in terms of erosion control, carbon sequestration and reduced input of energy and labour (Ball et al., 1994; Morris et al., 2010). Decreased soil physical quality, in terms of excessive compaction of the untilled topsoil, is regarded as one of the primary reasons for yield reductions (Ball et al., 1994). This is especially problematic on weakly structured soils in humid temperate climates (Munkholm et al., 2003; 2013; Ball et al., 2007).

The aim of the study was to evaluate the effect of long-term tillage systems and straw management on soil penetration resistance, shear strength and soil aggregate stability.

Materials and methods

Description of the site, the soil and the experimental design. Since 1999, a long-term field experiment has been done at the Experimental Station (54°52′50 N, 23°49′41 E) of the Lithuanian University of Agriculture (currently – Vytautas Magnus University). Research was carried out during the period of 2013–2015 in the long-term field experiment. The soil of the experimental site was *Epieutric Endocalcaric Endogleyic Planosol* (*Endoclayic*, *Aric*, *Drainic*, *Humic*, *Episiltic*) according to the WRB (2014) (Table 1). The long-term experiment was laid out in a split-plot design with four replications and a total of 48 plots. The initial plot size was 102 m^2 (6 × 17 m), and the harvested plot size was 30 m^2 (15 × 2.0 m).

Table 1. Soil site characteristics (0–20 cm)

Variable	Mean value
Sand %	33.7
Clay %	16.0
Silt %	50.3
pH_{KCl}	7.6
Buk density Mg m^3	1.45–1.57

Study object was soil physical properties. The spring oilseed rape (*Brassica napus* L.), winter wheat (*Triticum aestivum* L.) and spring barley (*Hordeum vulgare* L.) were grown in the experiment.

According to two-factor field experiment, straw (factor A) was removed (R) from one part of the experimental field (control), and on the other part of the field the straw was chopped and spread (S) at harvest. Factor B – 6 different tillage systems investigated as subplots: 1) conventional (deep) ploughing (CP) at 23–25 cm depth in autumn (control), 2) shallow ploughing (SP) at 10–12 cm depth in autumn, 3) shallow loosening (SL) with sweep cultivator and disc harrow at 8–10 cm depth in autumn, 4) shallow rotovating (SR) at 5–6 cm depth before next crop sowing, 5) catch cropping and rotovating (CCR) at 5–6 cm depth before next crop sowing, and 6) no-tillage (NT). White mustard (*Sinapis alba* L.) was undersown as a catch crop in the stubble only in catch cropping plots shortly after winter wheat and spring barley harvesting.

In 2013–2015, for ploughing, a plough PP-3-43 (Lithuania) with semi-helical shell boards, a chisel cultivator KLG-3.6 (Lithuania) and a disc harrow Väderstad Carrier 300 (Sweden) were used. Pre-sowing tillage was performed with a complex cultivator KLG-3.6. The crops were sown by a pneumatic no-tillage machine Väderstad Rapid 300C Super XL (Sweden). Mineral fertilizers were incorporated at sowing. Weeds were controlled by spray application using a sprayer Amazone UF-901 (UK). The crops were harvested by a plot combine Wintersteiger Delta (Austria).

In 2013, before spring oilseed rape sowing, the plots of no-tillage treatment were sprayed with a systemic herbicide Roundap (a.i. glyphosate 480 g L^{-1}) at a rate of 4.0 L ha^{-1}. The spring oilseed rape ‘Fenja’ was sown on 2 May at a seed rate of 4.50 kg ha^{-1} and a sowing depth of 2 cm. Placement fertilization with $N_{16}P_{16}K_{16}$ at 300 kg ha^{-1} was applied at sowing. After sowing, herbicide Brasan 1 L ha^{-1} (a.i. dmetachlor 500 g L^{-1}, 47.5% + clomazone 40 g L^{-1}, 4%) was applied. At the beginning of flowering, the crop was sprayed with a broad-spectrum, systemic fungicide Folicur 1 L ha^{-1} (a.i. tebuconazole 250 g L^{-1}, includes N, N-dimethyldecanamide). Spring oilseed rape was harvested on 9 August.

In 2013, winter wheat ‘Ada’ was sown on 10 September at a seed rate of 200 kg ha^{-1}. At sowing, placement application of $N_9P_{15}K_{28}$ + S_6 300 kg ha^{-1} was performed. At winter wheat 2–3 leaf stage, the crop stand was sprayed with the herbicide Legacy Pro 2 L ha^{-1} (a.i. 40 g L^{-1} diflufenican, 300 g L^{-1} pendimethalin + 250 g L^{-1} chlorotoluron).

In 2014, after resumption of vegetation, on 14 March, the crop was fertilized with ammonium nitrate N_{41} 120 kg ha^{-1}. Two weeks later, N_{44} 130 kg ha^{-1} was applied. Winter wheat was harvested on 29 July.

In 2015, before spring barley sowing, the plots of no-tillage treatment were sprayed with Roundap 4.0 L ha^{-1} (a.i. glyphosate 480 g L^{-1}). Spring barley ‘KVS

Orphelia' was sown at a seed rate of 170 kg ha^{-1}, $N_{16}P_{16}K_{16}$ 300 kg ha^{-1} was applied at sowing. After emergence of dicotyledonous weeds, the herbicide Mustang (a.i. aminopyralid 10 g L^{-1} + florasulam 5 g L^{-1} + 2.4 D 180 g L^{-1}) was applied. At the tillering stage, the crop was additionally applied with ammonium nitrate N_{41} 120 kg ha^{-1}. After the first symptoms of diseases had appeared on leaves, the crop was sprayed with the fungicide Bumper (a.i. propiconazole 250 g L^{-1}). At flag leaf stage, the spring barley crop was additionally fertilized with ammonium nitrate N_{44} 100 kg ha^{-1} and sprayed with the fungicide Amistar 0.60 L ha^{-1} (a.i. azoxystrobin 250 g L^{-1}). Spring barley was harvested on 12 August.

Soil sampling and soil aggregate stability analysis. Soil properties of the experimental site were determined in 2013 and 2015 experimental years. Soil samples were collected for aggregate stability analysis at 0–10 and 10–25 cm depths of the plough layer from 10 spots of each plot. Then the samples were composited (250 g per sample) to give a representative plot sample for each depth. The soil was air-dried and then sieved into eight size fractions <0.25, 0.25–0.5, 0.5–1.0, 1.0–2.0, 2.0–4.0, 4.0–5.6, 5.6–8.0 and >8.0 mm diameter using a sieve shaker (Retsch GmbH, Germany). Aggregate stability of soil was determined at 0–10 and 10–25 cm depths by using a wet sieving apparatus (Eijkelkamp Agrisearch Equipment, The Netherlands). The air-dried soil aggregates (1–2 mm size) are wet sieved in distilled water and then stable aggregates are destroyed by 0.2% $(NaPO_3)_6$ solution, oven-dried at 105°C for 24 h and weighed (Al-Kaisi et al., 2014).

Shear strength was measured using a penetrometer Geonor 72410 (Eijkelkamp) at 0–10 and 10–25 cm depths of the plough layer after sowing or resumption of winter wheat vegetation in 10 spots per plot.

Soil penetration resistance was measured using a penetrologger 06.15SA (Eijkelkamp) at 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 cm depths after sowing of spring oilseed rape and spring barley or resumption of winter wheat vegetation in 10 spots per plot.

Meteorological conditions. The climate of Lithuania is moderately warm, transitioning from maritime to continental. Lithuania is in a cool temperate zone with moderately warm summers and moderately cold winters. According to the climate zoning, Kaunas region belongs to the middle lowland zone of Lithuania, the sub-region of the lower-reaches of the river Nemunas. Meteorological conditions were described by using the data from Kaunas Meteorological Station (Fig. 1).

In the first half of April, 2013 the weather was winter-cold, with temperatures in most areas dropping to −7–14°C (Fig. 1, 2013). The highest temperature in April was 18–23°C, while the average monthly temperature was 5.5°C, i.e. 1.2°C lower than the long-term average. Warm weather came in May, but at the beginning of the month frosts were still up to −3°C with the highest monthly temperatures rising to 27–31°C. The average temperature in May was 16.6°C, i.e. 4°C higher than the long-term

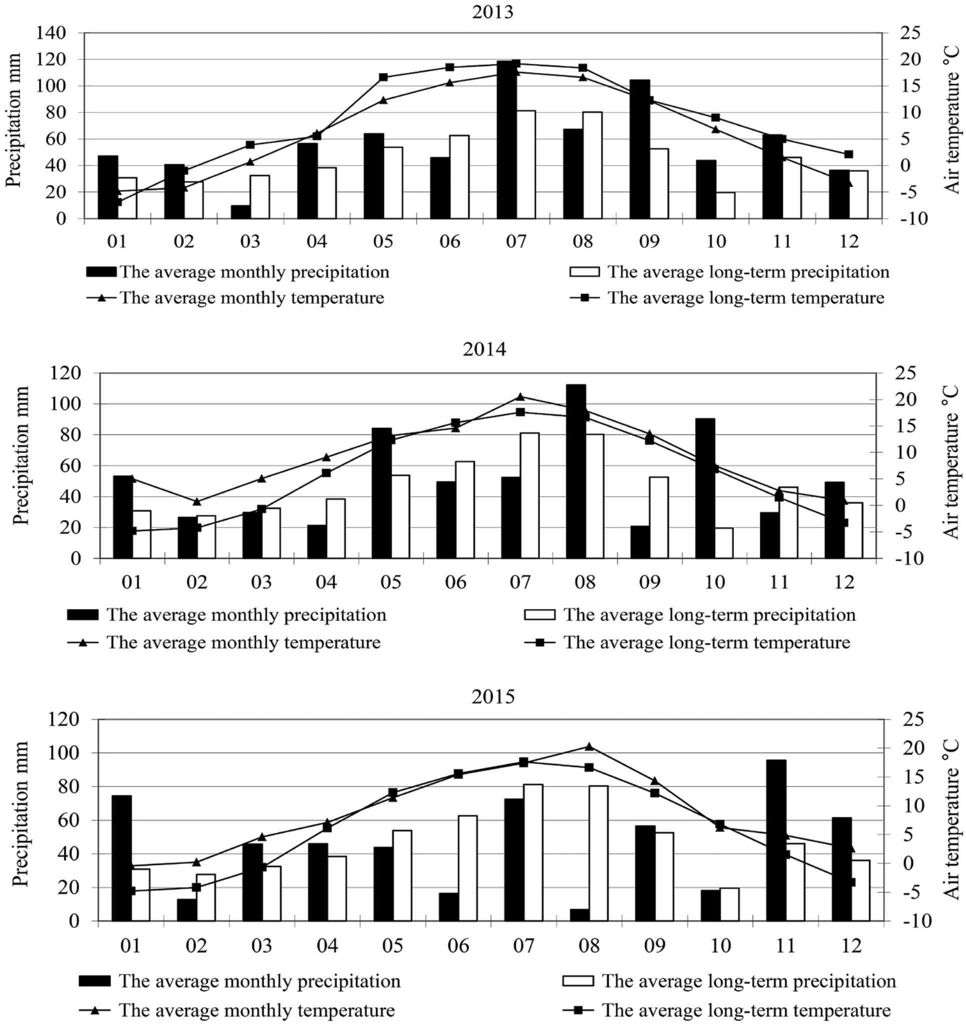


Figure 1. Meteorological conditions in 2013–2015 (data of Kaunas Meteorological Station)

average. Total rainfall in May was 63.8 mm, i.e. 16.5 mm higher than the average long-term rainfall. In addition, there was some hail. In June, July and August, very warm and moderately humid weather prevailed. The average temperature was almost the same as in June (19.2°C), i.e. 1.6°C higher than the long-term average.

In 2013, the period of winter wheat sowing had the average temperatures of 12°C and very rainy weather, with the rainfall exceeding the long-term average more than twice. Warm and humid weather was favourable for germination of winter wheat. October was warmer than the long-term average with the average temperatures ranging from 7°C to 7.5°C and lower than the long-term average (43 mm) rainfall.

The average temperature in November exceeded the long-term average by 4°C, while the rainfall did not significantly differ from the long-term average (20 mm). December was warmer than average. The average temperature in January was low, but normal (Fig. 1, 2014). The average monthly temperature in February was positive (1°C), and the precipitation was low at 22 mm. The temperature in March was quite high, compared with the long-term average (5°C and −2°C, respectively), while the precipitation was 24 mm. In early April, wheat vegetation resumed as the air temperature rose. In terms of rainfall, April was dry with 20 mm of rainfall per month. The average temperature in May was 13°C, close to the long-term average of 12°C. May was quite rainy with 81 mm of rainfall, i.e. 16 mm more than the long-term average. June was 2°C colder than the long-term average (16°C) with the average monthly temperature of 14°C and only about 10 mm of rainfall (long-term average was 50 mm). July was significantly warmer than usual, with the average monthly temperature of 20°C (long-term average was 17°C) and low rainfall, especially at the end of the month (50 mm, compared with a long-term average of 80 mm). The beginning of August was very dry, with warm and dry weather prevailing for weeks. As the heat receded, it began to rain and the average monthly rainfall was 110 mm.

The average monthly temperature in April, 2015 was 0.2°C higher than the long-term average, while the average monthly rainfall was 4.7 mm higher than the long-term average (Fig. 1, 2015). In May, the average temperature was 11.4°C, i.e. 1.8°C lower than the long-term average. The average rainfall this month was 43.8 mm, which was as much as 17.9 mm less than the long-term average. In June, conditions were unfavourable for crop growth and emergence of weeds. The average temperature in July was 1.3°C lower than the long-term average, and the rainfall exceeded the long-term average (72.4 and 24.2 mm, respectively). August was warm but very dry with an average monthly temperature of 20.3°C, i.e. 3°C higher than the long-term average. Rainfall in August was also very low; the monthly average only reached 6.9 mm, which was 82 mm less than the long-term average.

Statistical analysis. All experimental data were processed using a two-factor analysis of variance (ANOVA) according to Leonavičienė (2007) from the statistical software package *SYSTAT*, version 10 (SPSS Inc., USA). 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 $P \leq 0.050 > 0.010$ (significant at 95% probability level), ** – when $P \leq 0.010 > 0.001$ (significant at 99% probability level), *** – when $P \leq 0.001$ (significant at 99.99% probability level).

Results and discussion

Soil penetration resistance. In 2013, spreading of straw did not have significant effect on the soil penetration resistance at the depth of 0–50 cm (Table 2). Tillage systems exerted a significant impact on soil penetration resistance. For spring oilseed rape crop, soil penetration resistance significantly increased after applying shallow ploughing (27.5–46.0%) at the depth of 10–25 cm, shallow loosening with a sweep cultivator and disc harrow in the autumn (27.4–46.9%) at the depth of 5–20 cm, shallow rotovating (20.8–61.1%) at the depths of 5–25 and 45–50 cm, catch cropping and rotovating in spring and no-tillage at the depth of 5–25 cm – 20.8–66.4% and 23.5–64.6% respectively, compared with conventional ploughing.

Table 2. Soil penetration resistance after spring oilseed rape sowing in 2013

Treatment	Soil penetration resistance MPa at different depths cm									
	5	10	15	20	25	30	35	40	45	50
Straw retention (factor A)										
R (control)	1.49	1.63	1.60	1.65	1.80	2.11	2.49	2.71	2.94	2.80
S	1.54	1.69	1.65	1.64	1.70	2.08	2.27	2.64	2.79	2.92
Tillage system (factor B)										
CP (control)	1.09	1.13	1.17	1.24	1.49	1.98	2.42	2.57	2.52	2.58
SP	1.30	1.59***	1.62***	1.81***	1.90**	2.15	2.27	2.40	2.59	2.56
SL	1.56***	1.66***	1.60***	1.58**	1.68	2.16	2.30	2.67	2.80	2.96
SR	1.65***	1.82***	1.80***	1.79***	1.80*	2.00	2.44	2.96	3.45**	3.30*
CCR	1.72***	1.88***	1.84***	1.75***	1.80*	2.14	2.45	2.86	2.94	3.10
NT	1.77***	1.86***	1.71***	1.70***	1.84*	2.14	2.40	2.57	2.82	2.67

Factor A: R – straw removed, S – straw chopped and spread; factor B: CP – conventional ploughing, SP – shallow ploughing, SL – shallow loosening, SR – shallow rotovating, CCR – catch cropping and rotovating, NT – no-tillage; differences significant at * – $P \leq 0.05 > 0.01$, ** – $P \leq 0.01 > 0.001$ and *** – $P \leq 0.001$; Fisher LSD test *vs* control

In 2014, straw spreading for winter wheat crop had a significant effect on soil penetration resistance at the depth of 15–35 cm, where it was 6.7–13.8% higher, compared with the treatment without straw (Table 3). The effect of tillage systems was even more obvious. Soil penetration resistance significantly increased after applying shallow ploughing at the depth of 15–35 cm (17.9–22.5%), shallow loosening with a sweep cultivator and a disc harrow at the depth of 10–45 cm (15.8–45.5%), shallow rotovating in spring at the depth of 5–35 cm

Table 3. Soil penetration resistance after resumption of winter wheat vegetation in 2014

Treatment	Soil penetration resistance MPa at different depths cm									
	5	10	15	20	25	30	35	40	45	50
					Straw retention (factor A)					
R (control)	2.42	2.78	2.60	2.39	2.39	2.39	2.54	2.79	3.06	3.05
S	2.46	2.92	2.86*	2.72***	2.67***	2.61***	2.71*	2.91	3.34	3.31
					Tillage system (factor B)					
CP (control)	1.85	2.08	2.00	1.96	2.01	2.13	2.35	2.59	2.85	3.11
SP	2.05	2.29	2.45*	2.58***	2.64***	2.67***	2.77***	2.83	2.98	3.07
SL	2.23	2.96***	2.91***	2.68***	2.61***	2.66***	2.74**	3.00*	3.41*	3.12
SR	2.78***	3.38***	3.08***	2.8***	2.6***	2.59***	2.65*	2.91	3.37	3.39
CCR	2.78***	3.21***	2.99***	2.6***	2.53***	2.46*	2.59	2.96*	3.32	3.20
NT	2.94***	3.18***	2.97***	2.72***	2.52***	2.49*	2.66*	2.83	3.26	3.20

Explanations under Table 2

(12.8–62.5%), catch cropping and rotovating in spring at the depths of 5–30 and 40 cm (14.3–54.3%) and no-tillage at the depth of 5–35 cm (13.2–58.9%), compared with conventional ploughing.

In 2015, straw spreading for spring barley did not have a significant influence ($P > 0.05$) on soil penetration resistance (Table 4).

Soil penetration resistance significantly increased after applying shallow rotovating at the depth of 5–20 cm (78.7–96.1%), catch cropping and rotovating in spring at the depth of 5–20 cm (57.4–87.4%) and no-tillage at the depth of 5–20 cm (56.6–77.2%), compared with conventional ploughing.

Table 4. Soil penetration resistance after spring barley sowing in 2015

Treatment	Soil penetration resistance MPa at different depths cm									
	5	10	15	20	25	30	35	40	45	50
					Straw retention (factor A)					
R (control)	1.72	1.93	1.91	1.92	1.99	2.23	2.46	2.58	2.78	2.73
S	1.72	1.95	1.90	1.90	1.96	2.25	2.43	2.75	2.90	3.02
					Tillage system (factor B)					
CP (control)	1.17	1.27	1.28	1.36	1.68	2.14	2.14	2.71	2.67	2.70
SP	1.30	1.59	1.62	1.81	1.90	2.15	2.27	2.41	2.59	2.56
SL	1.56	1.66	1.60	1.58	1.68	2.16	2.30	2.67	2.87	2.96
SR	2.10**	2.49**	2.49**	2.43**	2.31	2.34	2.60	2.99	3.39	3.16
CCR	2.15**	2.38**	2.27*	2.14*	2.12	2.31	2.36	2.49	2.57	2.92
NT	2.06**	2.25*	2.17*	2.13*	2.17	2.34	2.54	2.70	2.95	2.94

Explanations under Table 2

According to Kadžienė et al. (2007), the threshold for soil hardness, when the roots of plants cannot penetrate into the soil, is considered critical. It depends on the plants cultivated as well as on the soil texture. The critical threshold for hardness is 2–3.6 MPa. When examining the hardness of soil after sowing or after resumption of winter wheat vegetation, the following tendency was observed in reduced tillage systems: the deeper the layer and the higher the hardness of soil regardless of the reduced tillage system.

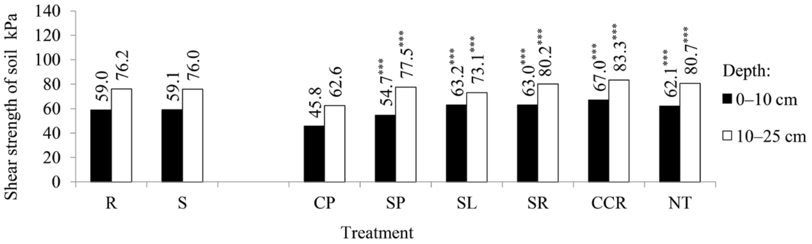
Alvarez and Steinbach (2009) also found that application of a reduced tillage system caused an increase in soil bulk density (at the 0–20 cm depth) and cone penetration resistance, in comparison with the conventional ploughing. In Lopez-Garrido et al. (2014) investigations, at the time of seedling emergence, repeated no-tillage represented the highest soil penetration resistance of the upper layer (6.04 MPa), compared with reduced tillage (0.65 MPa) and conventional ploughing (0.40 MPa). The adverse effects of soil disturbance produced by the tillage are minimized with minimum and no-tillage systems, some soil properties related to soil compaction progressively increase in these systems. The effect of tillage practices on soil physical properties depends on both the type of implement used and the soil conditions (Özgöz et al., 2007; Alesso et al., 2019).

Shear strength. When no-tillage was applied, the soil characteristics, that are closely related, change. As one characteristic changes, so do the others (Lopez-Garrido et al., 2014).

The research results in 2014 and 2015 might have been significantly influenced by warmer than usual climatic conditions and a shortage of humidity. This might have exerted significant effect on the critical threshold of soil penetration resistance. In 2013, at the beginning of spring oilseed vegetation, the effect of tillage systems on shear strength of soil was significant both in the upper 0–10 cm and the bottom 10–25 cm layers (Fig. 2). Compared with conventional ploughing, all the rest of the tillage systems significantly increased the shear strength of soil.

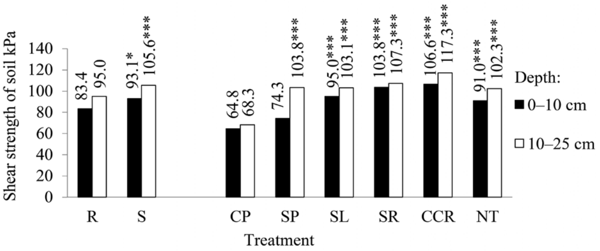
In 2014, which was drier than 2013, at the beginning of winter wheat vegetation, the soil shear strength at 0–10 cm layer was significantly 11.6% higher and at a deeper layer 10–25 cm it was 11.1% higher in the soil with straw, compared with the soil without straw (Fig. 3). The effect of tillage systems was significant in both 0–10 and 10–25 cm soil layers. Compared with conventional ploughing, in the treatments of other tillage systems the shear strength of soil increased in the upper 0–10 cm layer from 14.6% to 64.5% and in the deeper 10–25 cm layer from 49.8% to 71.7%.

In 2015, the shear strength of soil was measured only in the upper 0–10 cm layer (Fig. 4), because May had less rainfall than usual. Due to the lack of moisture, the soil was too hard to make measurements. The monthly



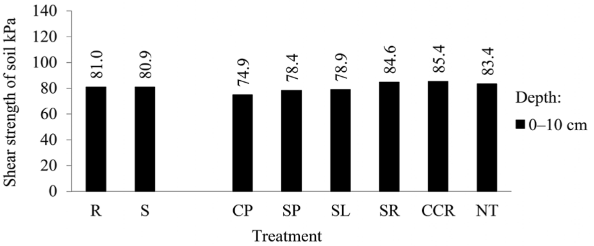
Explanations under Table 2

Figure 2. Shear strength of soil after spring oilseed rape sowing in 2013



Explanations under Table 2

Figure 3. Shear strength of soil after resumption of winter wheat vegetation in 2014



Explanations under Table 2

Figure 4. Shear strength of soil after spring barley sowing in 2015

rainfall in May averaged 43.8 mm, which was 17.9 mm less than the long-term average. The effect of tillage on shear strength in the upper 0–10 cm soil layer was significantly higher (by 12.9%) in shallow rotovating, in catch cropping and rotovating in spring (by 14%) and in no-tillage (by 11.3%) treatments, compared with conventional ploughing.

Comparison of the three-year data with the research results obtained by Alvarez and Steinbach (2009) revealed similar tendencies – shallow cultivation with a rotary cultivator before sowing, shallow rotovating in spring, no-tillage with direct drilling as well as the use of straw significantly increased the shear strength of soil. According to research carried out on sandy loam soils by the Lithuanian Research Centre for Agriculture and Forestry in Akademija, Kėdainiai district, the best physical properties of soil (density, shear strength and air permeability) were determined by conventional (deep) ploughing. Significantly poorer soil physical properties were found in no-tillage system. In the conditions of possible global warming, no-tillage helps to conserve the moisture content in the upper soil layer after sowing and during the early stages of plant growth (Feizienė et al., 2007; 2008; Feiza et al., 2010).

A summary of the data of the three experimental years suggests that a long-term application of reduced tillage results in a marked increase in soil penetration resistance as well as shear strength. The lesser was the depth of the tillage, the higher was the soil penetration resistance and shear strength. The effect of straw spreading on soil penetration resistance and shear strength was determined only in drier and hotter year of 2014.

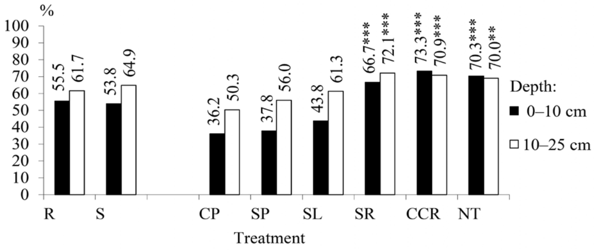
Soil aggregate stability. Soil structure is the aggregates of various sizes and shapes of mineral and organic granulometric elements (soil clumps). Good soil structure coupled with the choice of appropriate tillage ensures the yield (Bogužas et al., 2010). Hou et al. (2013) reported that the amount of macro-aggregate fraction decreased with conventional tillage practices in the 0–20 depth. This decreasing of >0.25 mm aggregate fraction in the soil with conventional tillage could be mainly due to the mechanical disruption of soil structure macro-aggregates from frequent tillage operations and reduced aggregate stability.

Type of soil has a great influence on the tillage practices to be applied. Reduced tillage diminishes the risk of moisture loss and maintains proper temperature, which is very important in shaping the seedbed. Due to various factors, soil structure may be degraded for mechanical, physical, biological or chemical reasons. Mechanically, the structure is dismantled by cultivating the soil, driving or raining. Soil structure decomposes and as calcium is leached from the upper layers, and the quantity of humus decreases. Soil stable aggregates lose adhesive and begin to decompose. Soil degradation should be controlled and efforts should be made to enrich the soil with organic matter (Morris et al., 2010; Soane et al., 2012).

Research results from year 2013 showed that soil aggregate stability was significantly higher in the 0–10 cm layer when the treatments of shallow rotovating before sowing, catch cropping and rotovating in spring and no-tillage were applied, compared with conventional ploughing 1.8, 2 and 1.9 times, respectively (Fig. 5). In the 10–25 cm layer, a significant increase in soil aggregate stability was determined: in shallow rotovating before sowing 1.4 times, in catch cropping and rotovating in spring 1.4 times and in no-tillage 1.4 times, compared with conventional ploughing. Straw spreading did not have significant influence on soil aggregate stability.

Data from 2015 showed significantly higher soil aggregate stability in the 0–10 cm layer in the treatments of shallow rotovating before sowing, catch cropping and rotovating in spring and no-tillage, compared with conventional ploughing by 30.5, 37.1 and 34.2 percentage points, respectively (Fig. 6).

A significant increase in soil aggregate stability was determined in the 10–25 cm layer as well: in the treatment of shallow rotovating before sowing 21.8 percentage points, catch cropping and rotovating in spring 20.5 percentage points and in no-tillage 18.7 percentage points, compared with conventional ploughing. Soil



Explanations under Table 2

Figure 5. Soil aggregate stability after spring oilseed rape sowing in 2013

aggregate stability is the lowest if the soil is annually deeply or shallowly ploughed, and incorporation of straw residues has a tendency to increase aggregate stability. Similar trends were found in the research conducted by Bogužas et al. (2010) and Velykis and Satkus (2018). No-tillage has a positive effect on soil structure, significantly reducing the amount of small aggregates and increasing the amount of stable aggregates not only in the upper 0–10 cm layer but also in the 10–25 cm layer. Al-Kaisi et al. (2014) have found that an increase in large aggregates in untilled soils is the result of the presence of large quantity of crop residue on the soil surface and minimum soil disturbance, which facilitates soil structural stability.

Conclusions

During a 16-year (1999–2015) period of field experiments, the following long-term changes in soil physical state occurred:

1. Long-term application of reduced tillage resulted in a significant increase in soil penetration resistance and shear strength. It was found that the lesser the depth of the tillage, the higher the soil penetration resistance and shear strength. The effect of straw retention was lower comparing with treatment without straw.

2. Soil aggregate stability was highly dependent on the tillage. Shallow rotovating before sowing increased soil aggregate stability by up to 1.8 times, while incorporation of plant residues of white mustard into the soil by a rotovator before sowing increased it by up to 2 times and no-tillage – by up to 1.9 times, compared with conventional (deep) ploughing.

3. Soil aggregate stability was the lowest when the soil was deeply or shallowly ploughed every year, while the incorporation of plant residues tended to increase soil aggregate stability. In the upper 0–10 and 10–25 cm layers, reduced tillage and no-tillage had a positive effect on soil aggregate stability.

Acknowledgements

This work was supported by the National Science Program "The effect of long-term, different-intensity management of resources on the soils of different genesis and on other components of the agro-ecosystems" (grant No. SIT-9/2015) funded by the Research Council of Lithuania.

Received 16 09 2019
Accepted 02 04 2020

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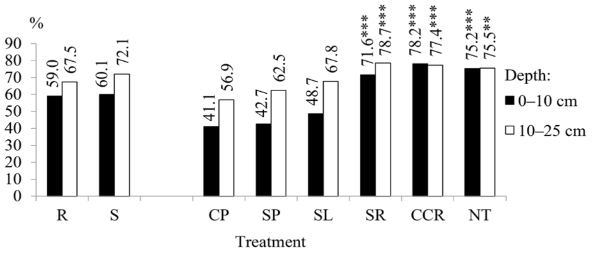

Explanations under Table 2

***Figure 6**.* Soil aggregate stability after spring barley sowing in 2015

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ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 107, No. 3 (2020), p. 195–202
DOI 10.13080/z-a.2020.107.025

Dirvožemio fizikinė būklė po ilgalaikio supaprastinto bei bearimio žemės dirbimo ir šiaudų panaudojimo

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Santrauka

1999 m. Lietuvos žemės ūkio universiteto (dabar – Vytauto Didžiojo universitetas) Bandymų stotyje įrengtas stacionarus ilgalaikis lauko eksperimentas. Tyrimas atliktas 2013–2015 metais. Eksperimento tikslas – įvertinti ilgalaikio žemės dirbimo ir šiaudų panaudojimo įtaką dirvožemio kietumui, šlyties pasipriešinimui ir dirvožemio trupinėlių patvarumui. Tyrimo vietos dirvožemis – giliau glėjiškas pasotintasis palvažemis. Taikyta tokia žemės ūkio augalų sėjomaina: žieminiai kviečiai → vasariniai miežiai → vasariniai rapsai. Vienoje eksperimentinio laukelio dalyje šiaudai pašalinti, kitoje susmulkinti ir paskleisti (A veiksnys). Ir fone be šiaudų, ir fone su paskleistais šiaudais tirtos 6 žemės dirbimo sistemos (B veiksnys). Po 16 eksperimento vykdymo (1999–2015) metų taikant mažesnio intensyvumo žemės dirbimo sistemą labai padidėjo dirvožemio kietumas ir šlyties pasipriešinimas. Tyrimo rezultatai parodė, kad kuo mažesnis žemės dirbimo gylis, tuo kietesnis dirvožemis ir didesnis šlyties pasipriešinimas. Taip pat nustatyta, kad augalinių liekanų paskleidimo poveikis buvo mažesnis lyginat su variantu, kuriame augalinės liekanos buvo pašalintos. Dirvožemio trupinėlių struktūros patvarumas labai priklausė nuo žemės dirbimo intensyvumo. Palyginus su giliuoju arimu, paviršinis purenimas rotoriniu kultivatoriumi prieš sėją jį padidino 1,8 karto, baltųjų garstyčių žalioji trąša, įterpta rotoriniu kultivatoriumi prieš sėją, – 2 kartus, o ilgą laiką nedirbtoje dirvoje šis rodiklis padidėjo 1,9 karto.

Reikšminiai žodžiai: dirvožemio kietumas, dirvožemio trupinėlių struktūros patvarumas, šlyties pasipriešinimas.