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IMPACT OF TILLAGE SYSTEMS ON CHEMICAL, BIOCHEMICAL AND BIOLOGICAL COMPOSITION OF THE SOIL

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Abstract

The influence of reduced tillage (RT) on the biochemical properties of soil and crops has been studied thoroughly worldwide. In contrast, we lack regular results on long-term (more than 20 years) RT and especially no-till (NT) impact on the composition of soil and main crops in semi-humid subarctic climate of the Baltic States. For this reason, investigations were carried out at the Research Station of Aleksandras Stulginskis University, Lithuania, in 2009-2012. The aim was to investigate the influence of RT and NT on soil pH, phosphorus (P) and potassium (K) concentrations, enzymatic activity and abundance of earthworms. This study comprised soils which were conventionally (CP) and shallowly (SP) ploughed, deeply chiselled (DC), shallowly disked (SC) and not tilled (NT). Primary tillage systems did not have significant impact on the soil pH or its P and K content but initiated the separation of soil layers into an upper one (0-15 cm), with a higher P and K status (55.5% P and 59.0% K of the total content), and a bottom one (15-25 cm), with lower concentrations of the elements (44.5 and 41.0%). Non-inversion tillage systems and NT raised the activity of soil enzymes such as saccharase by 32.2 to 60.8% and urease by 1.6- to 3.1-fold. The most marked rise in enzyme activity occurred in SC and NT soil. RT systems lead to an increase in the number and biomass of earthworms in the soil under wheat but the highest rise of the earthworm number and biomass was observed in NT plots, where the average count of earthworms doubled and their biomass increased by 3.7-fold compared with CP. In general, NT was the most efficient system in terms of the enrichment of soil biochemical properties.

Keywords: earthworms, enzyme activity, reduced tillage, soil pH, available phosphorus and potassium.

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INTRODUCTION

Mouldboard ploughing remains the main tillage method in European countries (Arvidsson et al. 2014) despite the rising popularity of reduced tillage (RT) systems, the which have grown by approximately 70% in acreage over the past 30 years (Alvarez, Steinbach 2009). No-till (NT) technologies mainly develop in countries with dry climate conditions, now occupying about 117 million hectares. In Europe, NT is carried out on about 1.15 million hectares (Lopez et al. 2012). Long-term intensive tillage reduces extractable P and K, surface pH, C and N content in surface soil (0-15 cm) due to crop removal, leaching, erosion and other factors (Malo et al. 2005). In experiments on RT, such systems reduced total P and Olsen-P loss by 30%. NT system was the best at accumulating total P, Olsen-P or inorganic P as well as at saving inputs on crop growing technologies (Redel et al. 2007, Jin et al. 2009). However, the impact of RT on soil electrical conductivity or pH was most often insignificant (Roldán et al. 2005).

Tillage intensity affects physical and chemical qualities of soil as well as the composition and abundance of soil fauna. According to the Roldán et al. (2005), soil enzymatic activity is the most effective indicator of an agrosystem's sustainability in soil quality assessments. In their experiment, NT ensured higher values of dehydrogenase, urease, protease, phosphatase and h-glucosidase activities. Similarly, in the experiment by Youjin et al. (2011), NT increased soil catalase and urease activities. However, secretion of soil enzymes during the crops' growth also strongly depended on the soil temperature, moisture regime, viability of nutrients (Guenet et al. 2012) and abundance of earthworms (Tao et al. 2009). Berner et al. (2008) concluded that the abundance of endogeic, horizontally burrowing adult earthworms was 70% higher under RT than under conventional tillage (CT) but their biomass was 53% lower in RT system. Crittenden et al. (2014) observed that RT in the conventional farming system significantly increased the epigeic species *Lumbricus rubellus*, although the total abundance of earthworms in organic farming was 45% lower in RT than in CT systems. Pelosi et al. (2014) noted that soil tillage intensity changed from NT to CT decreased the functional diversity and modified the functional trait profile within an earthworm community, even though the structural diversity (species number) and abundance were modified insignificantly by changing tillage intensity.

The aim of our investigations was to evaluate (1) the long-term tillage effect on the soil pH, P and K content, and (2) soil enzymatic activity and abundance of earthworms.

MATERIAL AND METHODS

A long-term field experiment was established in 1988 on a field at the Experimental Station (54°52′ N, 23°49′ E) of the Aleksandras Stulginskis University (ASU), Lithuania. In 2001, the experiment was modified by including a no-till (NT) treatment. This paper presents the experimental data of 2009-2012. The soil is silty loam (on average 46% sand, 42% silt, 12% clay) Planosol *(Endohypogleyic-Eutric – Ple-gln-w)* (IUSS Working Group WRB, 2014). The relief of the experimental field is even. In 2000, after the second crop rotation, soil pH in the 0-15 cm layer varied from 7.39 to 7.48, the content of available phosphorus (P) ranged from 238 to 291 mg kg^{-1}, while that of potassium (K) was from 116 to 136 mg kg^{-1}. In 2012, the average soil pH was lower while the amounts of available P and K decreased by 35% and 13%, respectively, compared with the data obtained in 2000, which was due to two changes, lower mineral fertilization as well as the exclusion of organic fertilizers, catch or leguminous crops from agricultural practice (crop rotation) in the experiment, made in 2001. However, the soil under the experimental plots continued to have a high average amount of calcium (2200-3400 mg kg^{-1}) and a moderate share of humus (2.4-2.9%).

The region where the experiment was located is characterized by subarctic climate, with average temperature 6.2-6.7°C and annual precipitation 625 mm (means of the last 59 years). The variability of precipitation is from 39.6 (December) to 66.7% (October). In Lithuania, winters have been more humid and warmer over the past decade. Snow breaks have become more frequent as they have appeared several times in wintertime. Such conditions affect the leaching of nutrients from soil (especially from intensively tilled fields) and deteriorate the chemical quality of soil. Unfavourable wintering conditions damage plantations of winter crops and diminish their density. This negatively affects crop productivity and quality parameters later on in the growing season. Besides, frequent spells of drought at the time of crop germination in spring (end of April – beginning of May) reduce seed field germination and emergence, rate of crop development and other parameters in the future. Another problem is the increasing amount of rainfall and number of rainy days at the end of the main crop's growing period (end of July – August). This negatively influences the protein content in cereals or in maize grain, oil content in oilseed rape seeds and the sucrose content in beetroots. Meteorological conditions during our investigations (2009-2012) are specified in Table 1. Generally, the weather during the experiment was more humid, with summers warmer than usually. The long-term average data were calculated since 1974.

Five different primary tillage systems were examined, ranging from conventional deep or shallow inversion tillage, deep or shallow non-inversion tillage to no-till. The tillage systems are specified in Table 2 according to Gruber et al. (2011).

Table 1

Meteorological conditions during the investigation, Kaunas Meteorological Station, October 2009 – October 2012

Years/ months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average air temperature (°C)												
2009	-									5.4	3.9	-2.5
2010	-10.2	-3.9	0.1	7.4	13.7	16.5	21.9	19.7	12.0	4.8	3.8	-8.0
2011	-3.0	-8.6	0.1	8.9	12.7	18.1	19.6	17.5	13.6	7.4	3.5	1.9
2012	-2.7	-8.3	1.8	7.7	13.7	15.3	19.4	17.1	13.3	7.6	-	
LTA[a]	-3.5	-3.3	0.3	6.7	12.6	15.6	17.6	17.1	12.2	7.1	1.9	-2.0
Precipitation rate (mm)												
2009	-									101.2	75.3	47.3
2010	20.1	39.0	29.9	58.5	94.8	127.0	101.7	112.5	63.3	44.6	56.7	63.5
2011	39.8	57.3	10.6	25.2	46.9	82.7	144.0	152.4	73.9	21.6	15.5	47.2
2012	47.6	33.8	16.2	72.3	50.3	93.4	112.8	69.2	67.2	75.0	-	
LTA	42.8	29.6	40.0	38.1	47.2	66.7	83.0	73.2	53.8	54.8	48.2	49.5

[a] – LTA is average of 38 years

Table 2

Tillage practice in the experiment

Tillage system	Stubble tillage	Primary tillage	Implement	Depth of tillage (cm)	Residue cover (%)
CP	yes	Inversion	mouldboard plough	22-25	3
SP	yes	Inversion	mouldboard plough	12-15	5
DC	yes	Non-inversion	chisel cultivator	25-30	16
SC	yes	Non-inversion	disc harrow	10-12	13
NT	no	No-till	none	0	45

The experiment was performed in a fully randomized design with four replications.The size of an experimental plot was 70 m^2. Four field crops (as separate experiments) were grown in a short-term rotation system: winter wheat, maize, spring barley, spring oilseed rape.

Stubble tillage was performed immediately after pre-crop harvesting and primary tillage took place at the beginning of October (the usual time for primary tillage in Lithuania). Pre-sowing tillage was performed with a complex cultivator, while sowing was done with a Väderstad Rapid 300C Super XL drill. The fertilization dosage was $N_{40+68}P_{40}K_{40}$ under spring oilseed rape, $N_{21+68+20}P_{57}K_{87}$ under winter wheat, $N_{40+61}P_{40}K_{40}$ under maize and $N_{40+68+7}P_{40}K_{40}$ under spring barley. An Amazone-ZA-M-1201 fertilizer spreader was employed.

Pests in oilseed rape fields were controlled with the insecticides Karate Zeon 5 SC (lambda-cyhalothrin, 150 g ha^{-1}) and Proteus OD (thiacloprid+deltamethrin, 0.75 L ha^{-1}); in winter wheat and spring barley – with Bulldock 025 EC (beta-cyfluthrin, 0.3 L ha^{-1}) or Karate Zeon 5 SC (150 g ha^{-1}). Maize was not treated with insecticides it is not typically infested by insects in the Lithuanian climate.

Diseases of winter wheat were controlled with the fungicides Falcon EC 460 (spiroxamine+tebuconazole+triadimenol, 0.5+0.5 L ha^{-1}), Fandango (prothioconazol+ fluoxastrobin, 1.0 L ha^{-1}), Folicur 250 EW (tebuconazol, 1.0 L ha^{-1}) or Bumper 25 EC (propiconazol, 0.5 L ha^{-1}); spring barley – Fandango (1.0 L ha^{-1}), Archer Turbo 575 EC (propiconazol+ fenpropidin, 0.5 L ha^{-1}) or Bumper 25 EC (0.5 L ha^{-1}) and spring oilseed rape – Orius 250 EW (tebuconazol, 1.0 L ha^{-1}). Fungicides were not applied in maize cultivation.

Several herbicides were used for weed control. In spring oilseed rape fields, they were Butisan Star (metazachlor+quinmerac, 2.0 L ha^{-1}), Fox 480 SC (bifenox, 0.5 L ha^{-1}) or Galera (picloram+clopyralid, 350 g ha^{-1}), in winter wheat – Boxer Gold (profulfocarb+metolachlor, 2.0 L ha^{-1}) with Lontrel (clopyralid, 75 g ha^{-1}), in maize – Maister WG (foramsulfuron+ iodosulfuron-methylsodium+ isoxadifen-ethyl, 150 g ha^{-1}) or Milagro (nicosulfurom, 1.5 l ha^{1}), in spring barley – Mustang 306 SE (metsulfuron+methyl ester, 0.6 L ha^{-1}). Only NT plots were additionally sprayed with the herbicide Roundup 360 SL (glyphosate, 4 L ha^{-1}) in autumn. All treatments were performed with a Amazone UF-901 sprayer.

Soil pH was measured by the potentiometric method with 1 N KCl extract (ISO 10390:2005). The content of available phosphorus was determined by the CAL method using a spectrometer. The same method, but with a flame photometer, was employed to determine available potassium. For the determinations, at least 20 soil samples were collected from each plot after harvest and combined into a composite sample. The sampling depths were 0-15 and 15-25 cm. The content of humus and calcium was measured in a PSCO/ISI IBM-PC 4250 NIR-42 analytical system, but these determinations were carried out only in 2010, which is why the resulting data are cited only sporadically.

The soil enzymatic activity was estimated at the end of the crop growing season, at the 0-15 cm depth, in 20 sites per plot. Samples were taken with an auger, analogously to soil sampling for soil chemical evaluation, and composite soil samples were made. The activity of the soil enzyme urease (EC 193 3.5.1.5) was measured by the Hofmann and Schmidt method and that of saccharase (invertase) (EC 3.2.1.26) was determinaed by the Hofmann and Seegerer method modified by Chunderova (Chunderova 1973, Balezentiene, Klimas 2009).

The number and biomass of earthworms in soil were determined before primary tillage, except in 2010, when the test was performed in the soil cultivated with oilseed rape and barley because the number and biomass of earthworms were significantly lower than in wheat stubble. Thus, a decision was made to assess the number and biomass of earthworms in wheat stubble during all experimental years. Briefly, a 0.5 x 0.5 m metal frame was hammered into the soil at 3 spots per plot. A dose of 0.55% formalin solution (no less than 10 L per spot) was poured on the framed soil (Baker, Lee 1993). After the solution had infiltrated into the soil, the earthworms that emerged on the soil surface were collected, counted and weighed. No earthworm test was conducted in the soil under maize because the maize harvest was carried out late, when the temperature tended to be too low.

The topsoil coverage with plant residues was established visually after primary tillage. For the visual assessment, a 10 m-long metal band was placed at 2 sites on each plot, perpendicularly to the tillage direction. The points of contact with plant residues were determined every 10 cm (100 spots).

All the experimental data were statistically evaluated using one-way analysis of variance (Anova) with the Selekcija software. Significant differences between mean values were evaluated with the Fisher's LSD test. Significant differences between treatments and the control treatment (conventional ploughing) were designated in the following way: * – differences are significant at the 95% probability level ($P < 0.05$), or ** – differences are significant at the 99% probability level ($P < 0.01$). The research data were also submitted to correlation analysis supported by SigmaStat and SigmaPlot software packages.

RESULTS AND DISCUSSION

Topsoil coverage with plant residue. In different tillage systems, the chemical composition of soil mainly depends on crop residue (organic matter), namely its quantity and type, incorporation depth and decomposition rate (McColl et al. 1995), the latter being mostly affected by the moisture content and temperature regime (Steiner et al. 1999). According to our investigations, the quantity of crop residues depended on the crop's type. The highest amount of residues was found after oilseed rape, wheat and maize harvest in the primary soil tillage treatment. Significantly more residues were determined on non-reversibly tilled or NT plots. Generally, after oilseed rape harvest and primary tillage, 26.5-, 21.9- and 65.0-fold more residues were found on the surface of soil in DC, SC and NT plots than on CP plots. In wheat, maize and barley fields, the amount of plant residues was 6.4, 5.0, 16.7 and 3.0, 2.4, 5.2 and 2.5, 1.9, 10.7 times higher, respectively (Table 3).

Soil chemical composition. Soil pH is an agrochemical characteristic which defines the soil's acidity, neutrality or alkalinity. Soil reaction is important for the weathering of minerals, intensity of microbiological processes, mineralization of organic matter, solubility of nutrients and other physicochemical processes (Mažvila et al. 1998). According to the Lithuanian Institute of Agriculture, annual liming of deeply and shallowly ploughed soil in-

Table 3

Impact of tillage systems on topsoil coverage (%) with crop residues after primary tillage in autumn, average of 2010-2011

Tillage system	Crops			
	spring rape	winter wheat	maize	spring barley
Conventional ploughing	5.2	0.8	3.3	3.3
Shallow ploughing	6.1	2.5	6.2	5.0
Deep cultivation	13.1	21.2**	21.0**	9.8**
Shallow cultivation	10.0	17.5**	16.6**	8.0**
No-till	55.6**	52.0**	55.2**	17.2**
LSD_{05}	5.68	5.96	9.14	2.40
LSD_{01}	7.96	8.36	12.82	3.36

** – significant difference from the control treatment (CP) at $P < 0.01$, LSD_{05} – the least significant difference at 95% probability level, LSD_{01} – the least significant difference at 99% probability level

creases soil pH by 0.2 mol KCl dm^{-3}. In conditions of shallow non-inversion soil tillage, soil pH remains similar during four years of investigations (Čiuberkis et al. 2008). After the second rotation in their experiment, Stancevičius et al. (2003) found that different systems of primary soil tillage had no significant effect on soil pH in different layers. Our investigations confirm the above findings. During the last 10-12 years, the soil mean pH decreased from 7.39-7.48 to 6.6-6.9, but remained similar within the different tillage series. However, in NT conditions, with the highest quantity of residues on the soil surface compared with wheat and barley, the soil pH was the lowest. Similarly, López-Fando and Pardo (2009) found a significant negative correlation between soil pH and concentration of soil organic carbon (r = –0.78). Thus, NT and zero tillage systems (soils had highest concentrations of carbon) initiated an acidifying effect.

According to the investigations of some Lithuanian scientists, long-term reduced tillage (RT) or NT stratified the proportions of available P and K between soil layers. In RT or NT conditions, the upper (0-10 cm) soil layer contained more of the elements than the deeper one compared with conventional inversion tillage (Čiuberkis et al. 2008, Feiza et al. 2010). Likewise, in the present experiment, the arable horizon of soil in RT and NT tillage differentiated on average into an upper layer with a higher P concentration (55.5% of the total content) and a bottom one with a lower P content (44.5%) – Table 4.

Wei et al. (2014) established that NT system had less plant available P in the 0-20 cm layer compared to CP and therefore CP might be an effective practice to preserve soil P. OmidiA et al. (2008) largely confirmed a such conclusion. Conversely, in the short-term experiment of Muukkonen et al. (2007), NT increased the available P in clay soil. Our experiment generated comparable results (Table 4). In the 0-15 cm layer, non-inversion tillage or

Table 4

Impact of tillage systems on the content of available phosphorus (mg kg^{-1}) in soil at 0-15 and 15-25 cm depths, average of 2010-2012

Tillage system	Crops			
	spring rape	winter wheat	maize	spring barley
0-15 cm				
Conventional ploughing	188.2	134.0	163.2	134.4
Shallow ploughing	182.0	148.8	187.8	136.3
Deep cultivation	215.4	148.0	144.1	133.0
Shallow cultivation	199.5	163.2	157.8	169.2
No-till	202.9	149.2	202.6	155.6
15-25 cm				
Conventional ploughing	158.2	127.6	169.2	125.0
Shallow ploughing	177.2	145.1	147.7	125.4
Deep cultivation	152.2	114.2	120.0	95.5
Shallow cultivation	141.0	118.8	125.7	108.4
No-till	149.4	116.8	139.9	101.8

$P > 0.05$

NT mainly initiated an increase in the P concentration. Similarly to the experiment by Wei et al. (2014), the highest proportion of P in the 15-25 cm soil layer was established in CP and SP plots. This might be related to the precipitation and P leaching rates but the correlation analysis verified such tendencies only in spring oilseed rape cultivation. A moderate, insignificant negative correlation between the P concentration in the 15-25 cm layer and the precipitation rate during the crop growing season was demonstrated ($r = -0.495$).

Analogously to the concentration of P, no-till practice resulted in higher K and organic carbon concentrations in upper soil layers (Bertol et al. 2007). In our experiment, different RT and NT systems did not have a significant effect on the available potassium (K) content. However, the content of potassium in the upper soil layer in NT plots cropped with spring barley was significantly (by 37 %) higher than that in CP plots (Table 5). In most cases we also observed an increase of the K concentration in upper soil layer and its decrease in the deeper one compared to CP.

Deubel et al. (2011) established that the concentration of K stratified between soil layers under RT. In the 0-15 cm layer, the K concentration increased by 118% without any significant decline in deeper soil layers. Averaged data of our experiment similarly showed that the arable layer stratified into an upper layer characterized by a higher potassium proportion (59.0% of the total content) and a bottom layer with a lower potassium status (41.0%). Also, a relationship was identified between the concentration of K in the up-

Table 5

Impact of tillage systems on the content of available potassium (mg kg^{-1}) in soil at 0-15 and 15-25 cm depths, average of 2010-2012

Soil tillage	Crops			
	spring rape	winter wheat	maize	spring barley
0-15 cm				
Conventional ploughing	91.5	76.2	96.0	75.0
Shallow ploughing	104.4	84.0	114.3	94.8
Deep cultivation	114.3	80.4	91.7	82.2
Shallow cultivation	118.8	83.1	108.8	97.2
No-till	126.0	98.4	116.6	118.2*
LSD_{05}	38.10	34.08	46.95	31.90
LSD_{01}	53.41	47.77	67.82	44.72
15-25 cm				
Conventional ploughing	81.0	69.6	90.7	74.4
Shallow ploughing	86.4	69.9	86.4	75.9
Deep cultivation	71.7	54.6	60.6*	52.8*
Shallow cultivation	64.5	59.1	69.9	53.8*
No-till	70.2	70.2	78.8	67.2
LSD_{05}	23.58	35.55	24.87	18.46
LSD_{01}	32.12	49.84	35.75	25.88

* – significant difference from the control treatment (CP) at $P < 0.05$, LSD_{05} – the least significant difference at 95% probability level, LSD_{01} – the least significant difference at 99% probability level

per soil layer (0-15 cm) and percentage of plant residue cover after winter wheat sowing ($r = 0.614$).

Soil bioactivity. According to the ACOSTA-MARTINEZ and TABATABAI (2001), enzyme activity relates with tillage systems and quantity of plant residues. PIOTROWSKA-DŁUGOSZ and WILCZEWSKI (2014) concluded that soil enzymatic activity positively and significantly depended on soil C_{org}, N_{tot} and pH_{KCl}. In our experiment, in nearly all the cases, RT as well as NT increased the activity of the soil enzyme saccharase, compared with CP plots; however, the differences were not always significant (Table 6). The greatest number of significant differences was established while analysing results of saccharase activity in SC and NT systems. Soil saccharase activity partly depended on pH of the upper soil layer (0-15 cm) ($r_{rape} = -0.508$; $r_{wheat} = -0.802$*), concentration of available P ($r_{barley} = 0.760$**) and K ($r_{rape} = 0.593$), amount of plant residues on the soil surface ($r_{maize} = 0.483$; $r_{barley} = 0.469$) and biomass of earthworms ($r_{wheat} = 0.309$); besides it was affected by the moisture content, aggregate-size distribution, wet stability of aggregates in upper soil layers and stand density or biomass of weeds.

Table 6

Impact of tillage systems on soil saccharase activity (mg glucose g^{-1} soil 48 h^{-1}) in cultivation of different crops, average of 2010-2012

Soil tillage	Crops			
	spring rape	winter wheat	maize	spring barley
Conventional ploughing	23.3	24.6	21.0	18.0
Shallow ploughing	38.6	31.9	21.0	23.4
Deep cultivation	38.5	31.1	23.6	31.0
Shallow cultivation	47.9*	32.0	22.8	37.0*
No-till	33.2	45.2*	22.9	29.4
LSD_{05}	23.06	16.39	11.92	13.60
LSD_{01}	32.32	23.00	16.70	19.07

* – significant difference from the control treatment (CP) at $P < 0.05$, LSD_{05} – the least significant difference at 95% probability level, LSD_{01} – the least significant difference at 99% probability level

Urease activity in the soil tilled using non-inversion methods and NT was also generally increased (but not always significantly), compared with that in CP plots (Table 7). CESEVIČIUS and JANUŠAUSKAITĖ (2006) found a relationship between soil urease activity and amount of residues. We obtained similar results (r_{maize} = 0.765**; r_{barley} = 0.625), but additionally found correlations between urease activity and the concentration of available P (r_{barley} = 0.760**, r_{maize} = 0.778**) and K (r_{wheat} = 0.505; r_{barley} = 0.698*) in the upper (0-15 cm) soil layer.

Some earlier findings from the same, long-term experiment, after the second crop rotation, were reported by STANCEVIČIAUS et al. (2003), who detected a rise in the number of earthworms in RT plots by 23.4-53.4% and in their biomass – by 18.3-62.7% compared to CP. Similar results were found by

Table 7

Impact of tillage systems on soil urease activity (mg NH_3 g^{-1} soil 24 h^{-1}) in cultivation of different crops, average of 2010-2012

Soil tillage	Crops			
	spring rape	winter wheat	maize	spring barley
Conventional ploughing	0.044	0.113	0.037	0.042
Shallow ploughing	0.058	0.056	0.070	0.052
Deep cultivation	0.097	0.068	0.051	0.056
Shallow cultivation	0.116*	0.100	0.065	0.097*
No-till	0.082	0.108	0.124*	0.108*
LSD_{05}	0.0557	0.1637	0.0843	0.0520
LSD_{01}	0.0787	0.2289	0.1179	0.0742

* – significant difference from the control treatment (CP) at $P < 0.05$, LSD_{05} – the least significant difference at 95% probability level, LSD_{01} – the least significant difference at 99% probability level

other scientists (Epperlein, Metz 1998, Rasmussen 1999). The current results likewise suggest that the number of earthworms present in the soil and their biomass were only slightly modified by the simplification of primary tillage from CP to SC. However, in the case of NT (undisturbed soil), on average, the number of earthworms doubled and their mass increased by 3.7 times compared with the CP soil (Table 8). In another tillage and green manuring

Table 8

Impact of tillage systems on number and fresh biomass of earthworms in winter wheat stubble

Soil tillage	2010		2011		2012		Mean	
	(no m^{-2})	mass (g m^{-2})	(no m^{-2})	mass (g m^{-2})	(no m^{-2})	mass (g m^{-2})	(no m^{-2})	mass (g m^{-2})
Conventional ploughing	76	22.3	100	30.6	98	40.5	91	31.1
Shallow ploughing	84	29.6	81	25.0	104	41.9	90	32.2
Deep cultivation	87	44.1	102	40.1	109	49.1	99	44.4
Shallow cultivation	75	55.3*	83	30.3	130	59.9	96	48.5
No-till	168**	125.0**	163*	91.8**	227**	103.0**	186**	106.6**
LSD_{05}	38.7	24.70	45.1	28.39	61.8	20.69	49.5	24.79
LSD_{01}	54.3	34.63	63.2	39.81	86.7	29.01	69.4	34.76

* – significant difference from the control treatment (CP) at $P < 0.05$, ** – significant difference at $P < 0.01$, LSD_{05} – the least significant difference at 95% probability level, LSD_{01} – the least significant difference at 99% probability level

experiment conducted at the Experimental Station of ASU, Bogužas et al. (2010) obtained similar results after five years of RT and NT application. We established relationships between earthworm mass and content of wheat residues on the soil surface ($r = 0.918$**) and the main soil physical properties.

CONCLUSIONS

1. In most cases, different primary tillage systems did not have significant influence on soil pH, P and K contents. However, the arable layer of RT and NT soils differentiated into an upper layer characterised by a higher P and K status (55.5% P and 59.0% K of the total content) and a bottom layer with lower P and K concentrations (44.5 and 41.0%).

2. RT and NT systems increased the activity of soil enzymes: saccharase activity increased by 32.2 to 60.8% and that of urease by 1.6- to 3.1-fold (except for SP). The most marked rise in enzyme activity occurred in SC and NT soil. This increase was partly dependent on soil physical properties, content of plant residues and weed abundance in crops.

3. Having reduced primary tillage from CP to SC, the number and biomass of earthworms in the soil under wheat differed inappreciably. However, on average, the number of earthworms in NT doubled and their mass increased by 3.7 times compared with CP soil.

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