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ORIGINAL PAPER

Effect of agricultural practice on chemical and biological properties of soil*

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Abstract

Soil from a field experiment was analyzed to determine: (1) earthworm (*Lumbricus*) number, (2) organic carbon content, (3) total nitrogen content, (4) available phosphorus content, (5) potassium content, and (6) magnesium content, depending on tillage systems and previous crops cultivated. A two-factor experiment was established in the system of randomized subblocks. Tillage systems (TS): conventional tillage (CT), reduced tillage (RT), and no-tillage (NT), were the main experimental factor; previous crops (CP): winter wheat, winter durum wheat, winter barley, and common pea, were the second-order experimental factor. Shallow ploughing and pre-sowing ploughing were performed in the CT system, double cultivation in the RT system, and only glyphosate treatment in the NT system. An over 2-fold higher number of earthworms per m^2 was recorded on RT and NT plots than on CT plots, as well as on plots after winter barley and pea than on plots after winter wheat and winter durum wheat. The contents of organic C and total N were higher in the NT and RT systems compared to the CT system, and also on plots after pea than on plots after all the other analyzed crops. The content of P was higher in the soil from the RT plot than in the soil samples from the CT and NT plots, as well as in the soil from plots after winter wheat than in that from plots after durum wheat, pea, and winter barley. Also, higher K and Mg contents were determined in the soil from the RT system compared to the CT and NT soil samples, as well as in the soil from plots after durum wheat than after pea, winter wheat, and winter barley

Keywords: earthworms, available macronutrients, organic carbon, tillage, crops

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INTRODUCTION

Soil tillage determines the air-water relations in the topsoil layer, the rate of organic matter mineralization, the microbiological and enzymatic activity of the soil, the availability of nutrients, and the number of geobionts (Elder, Lal 2008, Celik et al. 2011, Jurado et al. 2014, Kravchenko et al. 2016, Woźniak, Kawecka-Radomska 2016). As reported by Lipiec et al. (2006), Keller et al. (2007) as well as Pranagal and Woźniak (2021), soil cultivation with a furrow plough deteriorated the stability of soil aggregates and reduced water retention in the soil. For these reasons, it proves well on soils characterized by high water retention. In the case of semi-arid soils, definitely better results are achieved upon ploughless cultivation, e.g., in no-tillage (NT) or reduced tillage (RT) systems (De Vita et al. 2007, Peigné et al. 2007, Morris et al. 2010, Woźniak, Gos 2014). Ploughless tillage contributes to an increased organic carbon content of soil (Tabaglio et al. 2008, Ernst, Emmerling 2009) and stabilizes soil structure (Madari et al. 2005, Celik et al. 2012). As Woźniak and Kawecka-Radomska (2016) reported, soil cultivated in RT and NT systems exhibited higher enzymatic activity and had a higher earthworm number than soil from the conventional tillage (CT) system. In the study by Woźniak and Soroka (2018), the soil from NT plots had higher contents of organic C and total N than the soil from CT plots. In turn, Woźniak and Gos (2014) recorded a higher number of earthworms in the no-till systems compared to conventional tillage.

Soil abundance in organic matter and nutrients also depends on the mass and quality of post-harvest residues (Meena, Lal 2018, Woźniak 2022). Legumes developing in symbiosis with *Rhizobium* bacteria, which are capable of fixing free nitrogen from the air, are especially valuable crops. As Peoples et al. (2009) claim, due to their symbiotic interaction with the Rhizobia, legumes leave 30-40 kg of nitrogen per 1 tone of dry matter of roots and aerial parts. Soil is also positively affected by natural fertilizers (manure, compost) used in cultivation of root crops, fodder crops and vegetables (Rasool et al. 2008) as they provide it with high amounts of organic matter rich in macroelements, microelements, and organic C. In turn, cereals grown one after another exert less beneficial effects on soil properties. According to Olsson and Alström (2000) and Balota et al. (2004), the post-harvest residues left after cereal cultivation are little diversified, which leads to a reduction in soil saprophytes. According to Kretzschmar et al. (1992), Maillard et al. (2016) as well as Woźniak and Kawecka-Radomska (2016), cereals suppress the biological and enzymatic activity of soil.

No-tillage cultivation, mulch, post-harvest residues, and also crop rotation are the major elements of conservation agriculture (Kertész, Madarász 2014). In this type of agriculture, soil exhibits high bioactivity, abundance of organic matter, and availability of nutrients. All of these are owed to the high activity of earthworms in the topsoil. Their role is linked to cycles of organic C and nutrients in the soil, gaseous exchange, and soil structure (Laossi et al. 2010). Thus, they play a key role in soil quality maintenance and improvement (Kretzschmar, Monestiez 1992, Capowiez et al. 2006). A high number of earthworms in the soil is not promoted by the conventional ploughing tillage and commonly applied chemical plant protection agents (Woźniak, Soroka 2018, Vidal et al. 2023).

The following research hypotheses were formulated based on the cited literature: (1) no-till cultivation contributes to increased contents of nutrients and organic carbon, and earthworm number in the soil compared to the conventional tillage, and (2) contents of nutrients and organic carbon as well as earthworm number in the soil are higher after legumes than after cereals used as previous crops.

The aim of this study was to evaluate the impact of tillage systems and crops grown on chemical properties of soil and earthworm number.

MATERIALS AND METHODS

Study site and experiment design

A field experiment was established in 2007 at the Uhrusk Experimental Farm affiliated with the University of Life Sciences in Lublin (south-eastern Poland, 51°18′N, 23°36′E). The results presented in the manuscript were collected in 2023. The experiment was established in the system of randomized subblocks, with three replications. The size of one subblock was 6 m × 25 m. The main experimental factor was the tillage systems (TS): conventional tillage (CT), reduced tillage (RT), and no-tillage (NT). The second-order experimental factor was the crops (CP): winter wheat (*Triticum aestivum* L.), winter durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) van Slageren), winter barley (*Hordeum vulgare* L.), and common pea *(Pisum sativum* L).

Tillage practices performed in the conventional system (CT) for cultivation of winter wheat (cultivar Bilanz), winter durum wheat (cultivar Sambadur) and winter barley (cultivar Zenek) included shallow ploughing at a depth of 10 cm and pre-sowing ploughing at a dept of 18 cm. On the plots with spring pea (cultivar Batuta), the cultivation measures in the CT system included shallow ploughing and pre-winter ploughing. In the RT system, cultivation was performed only on plots with winter wheat, winter durum wheat and winter barley, whereas a pre-sowing ploughing treatment was replaced with the use of a cultivation unit comprising a cultivator and string roller. On the plots of spring pea, only field cultivating was performed instead of shallow ploughing. In the NT system, glyphosate-containing herbicide (4 L ha^{-1}, 360 g L^{-1}) was sprayed on all plots. A tillage-sowing unit was used in the springtime on the plots with common pea. After crop harvest, post-harvest residue was left on all plots. The straw weight was 5.3 t ha^{-1} after winter wheat harvest, 4.6 t ha^{-1} after durum wheat harvest, 4.1 t ha^{-1} after winter barley harvest, and 2.3 t ha^{-1}after pea harvest.

Winter cereals were sown on the optimal agrotechnical dates, i.e., in the last week of September, whereas pea was sown in the first week of April. Sowing density of winter wheat and winter durum wheat was 380 seeds per m^2, that of winter barley – 280 seeds per m^2, and that of pea – 100 seeds per m^2.

Fertilization and plant protection

Winter wheat and winter durum wheat were fertilized with 160 kg N ha^{-1}, including 20 kg N ha^{-1} applied before sowing, 75 kg N ha^{-1} at the tillering stage, 45 kg N ha^{-1} at the shooting stage, and 20 kg N ha^{-1} at the ear formation stage. Fertilization with phosphorus (35 kg P ha^{-1}) and potassium (90 kg K ha^{-1}) was applied prior to the sowing of cereals. Winter barley crop was fertilized with 110 kg N ha^{-1}, including 20 kg N applied before sowing, 70 kg N ha^{-1} in the springtime at the tillering stage, and 20 kg N ha^{-1} at the ear formation stage. Fertilization with phosphorus (30 kg P ha^{-1}) and potassium (85 kg K ha^{-1}) was performed prior to barely sowing. In the case of common pea, mineral fertilizers were applied in singles doses of 20 kg N ha^{-1}, 17 kg P ha^{-1} and 66 kg K ha^{-1} in the springtime.

Winter cereals were protected against fungal diseases with flusilazole + + carbendazim at the tillering stage and propiconazole + fenpropidinat at the shooting stage. Weeds were eradicated with the following herbicides: MCPA + mecoprop + dicamba and fenoxaprop-P-ethyl. In the case of common pea, acetamiprid was used against pests, whereas bentazone was applied for weed control.

Habitat conditions

The Uhrusk Experimental Farm is located on the eastern edge of the Chełmskie Pagóry, therefore having the features of both lowland landscape and highlands. The dome-shaped hills are made of chalk rock covered with washed moraine material on top (Dobrzański, Borowiec 1961). The field on which the experiment was established lies at 170 m above sea level.

According to the classification by the IUSS Working Group WRB (2015), the soil was a Rendzic Phaeozem with the following mineral fraction distribution: 2.0-0.05 mm sand – 53%, 0.05-0.002 mm silt – 24%, and <0.002 mm clay – 23%, and had slightly alkaline pH (pH = 7.1). The abundance of available phosphorus and potassium in the soil was high, and that of magnesium was average. The total nitrogen content of the soil was 0.68 g kg^{-1}, and that of organic carbon was12 g kg^{-1}.

The growing season in the study area began in the third week of March and lasted for 215 days. The sum of atmospheric precipitation reached 328 mm from September to February (autumn-winter period) and 358 mm from March to August (spring-summer period), (Figure 1). The number

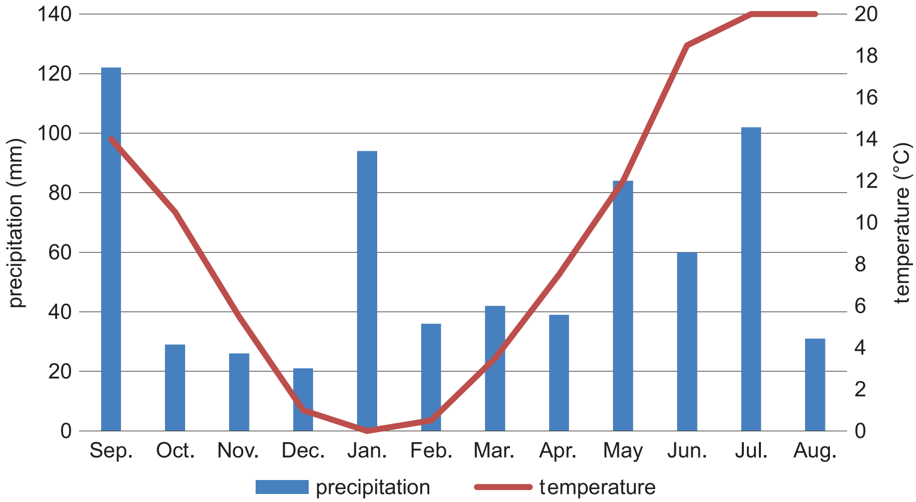

Fig. 1. Monthly sums of precipitation and average air temperatures from sowing to crop harvest (2022-2023)

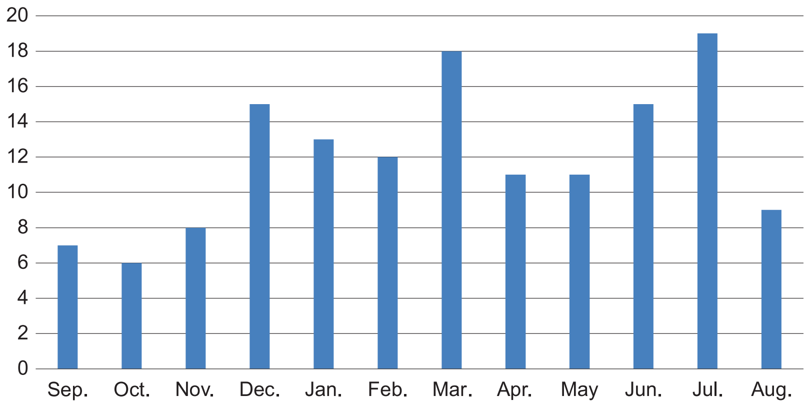

Fig. 2. Number of days with atmospheric precipitation from sowing to crop harvest (2022-2023)

of days with precipitation ranged from 6 to 15 in the autumn-winter period and from 9 to 19 in the spring-summer period (Figure 2).

Production traits and statistical analysis

The study aimed to determine: (1) contents of organic C, total N and available forms of P, K, and Mg in soil, and (2) the number of earthworm (*Lumbricus*) per m^2. These determinations were performed in soil samples collected in August after crop harvest. The organic C content was determined with the Tiurin method, that of total N with the Kjeldahl method, those of available phosphorus (P) and potassium (K) with the Egner-Riehm, and magnesium (Mg) content with the Schachtschabels method. Determinations of these parameters were made with 3 replications in soil samples collected from the 0.30 m soil layer. The number of earthworms was established by hand-picking the earthworms from a surface area of 1 m^2 and 0.30 m layer of the soil, from each plot.

The results were processed statistically using the analysis of variance (ANOVA), whereas the significance of differences between mean values was evaluated with the Tukey's HSD test, $P<0.05$.

RESULTS

Number of earthworms and content of organic C in the soil

The number of earthworms in the soil was diversified by both the tillage systems and previous crops (Table 1). An over 2-fold higher earthworm number per 1 m^2 of the 0.30 m soil layer was recorded on RT and NT than on CT plots. Also, a significantly higher number of earthworms was determined in the soil from the plots with winter barley and peas than from those with winter wheat and winter durum wheat.

Table 1

Number of earthworms per 1 m^2 in the 0.30 m soil layer

Crops (CP)	Tillage system (TS)			Mean
	CT[a]	RT	NT	
Winter wheat	1.3	13.3	9.3	8.0
Winter durum wheat	13.3	14.7	6.7	11.6
Winter barley	14.7	26.7	33.3	24.9
Pea	9.3	25.3	28.0	20.9
Mean	9.7	20.0	19.3	-
$HSD_{0.05}$ for TS = 6.6; CP = 8.4; CP x TS = ns				

CT[a] – conventional tillage, RT – reduced tillage, NT – no-tillage, ns – not significant

The no-till system contributed to an increased organic C content in the soil compared to the conventional tillage system (Table 2), making it higher by 22.4% and 16.4% in NT and RT systems than in the CT system. Also, a higher organic C content was determined in the soil from the plots after pea than in the soil from the plots after winter wheat and winter durum wheat (by 25%) and after winter barely (by 73.7%). The organic C content was also affected by TS x CP interaction. On the plots after winter wheat and winter durum wheat, a significantly higher organic C content was determined in the NT system than in the RT and CT systems, whereas in the plots after winter barley more organic C was found in the RT than NT system, and in the plots after pea – in the NT than CT system.

Table 2

Content of organic C in the soil (g kg^{-1})

Crops (CP)	Tillage system (TS)			Mean
	CT[a]	RT	NT	
Winter wheat	12.5	12.2	15.1	13.2
Winter durum wheat	11.6	12.5	15.4	13.2
Winter barley	9.7	11.4	7.3	9.5
Pea	12.5	17.7	19.2	16.5
Mean	11.6	13.5	14.2	-
$HSD_{0.05}$ for TS = 0.8; CP = 1.0; CP x TS = 2.3				

CT[a] – conventional tillage, RT – reduced tillage, NT – no-tillage, ns – not significant

The evaluation of variance analysis components indicates that the number of earthworms in the soil was similarly affected by TS and CP, and that organic C content was influenced to a greater extent by CP than by TS (Table 3).

Table 3

Analysis of variance (*F*-value) conducted for earthworm number and organic C content in the soil

Specification	Value	TS	CP	TS × CP
Earthworm number	*F*	9.50	13.23	2.68
	p	< 0.01	< 0.01	ns
Organic C content	*F*	37.80	121.08	25.64
	p	< 0.01	< 0.01	< 0.01

ns – not significant

Contents of total N, available phosphorus, potassium, and magnesium in the soil

A significantly higher total N content was determined in the soil from NT and RT plots compared to that from CT plots, with the difference reaching 10-15% (Table 4). Also, a higher total N content was determined in the soil from the plots after pea than after winter wheat and winter durum wheat (by 15.5-25.3%), and also in the soil from plots after winter barley (by 48.6%). The organic C content was also affected by TS x CP interaction. In the soil from the plots after winter durum wheat, more total N was found in NT than CT system, in that from plots after winter barely – in RT than NT, whereas in that from plots after pea – in NT than in RT and CT systems.

The content of available phosphorus (P) was higher in the soil from RT than from CT and NT plots by 8.6% and 31.1%, respectively (Table 5). The phosphorus content of the soil was also affected by the previous crops.

Table 4

Content of total N in the soil (g kg^{-1})

Crops (CP)	Tillage system (TS)			Mean
	CT[a]	RT	NT	
Winter wheat	0.80	0.80	0.90	0.83
Winter durum wheat	0.80	0.90	1.00	0.90
Winter barley	0.70	0.80	0.60	0.70
Pea	0.91	1.03	1.17	1.04
Mean	0.80	0.88	0.92	-
$HSD_{0.05}$ for TS = 0.05; CP = 0.08; CP x TS = 0.12				

CT[a] – conventional tillage, RT – reduced tillage, NT – no-tillage, ns – not significant

Table 5

Content of available phosphorus (P) in the soil (mg kg^{-1})

Crops (CP)	Tillage system (TS)			Mean
	CT[a]	RT	NT	
Winter wheat	214.0	237.0	194.0	215.0
Winter durum wheat	195.0	174.4	123.5	164.3
Winter barley	202.0	214.0	164.0	193.3
Pea	155.0	206.0	153.0	171.3
Mean	191.5	207.9	158.6	-
$HSD_{0.05}$ for TS = 8.5; CP = 10.9; CP x TS = 24.6				

CT[a] – conventional tillage, RT – reduced tillage, NT – no-tillage, ns – not significant

The highest P content was determined in the soil from the plots after winter wheat, a lower one in that from the plots after winter barely (by 11.2%), and the lowest one in the soil samples from the plots after pea (by 25.5%) and winter durum wheat (by 30.6%). The content of phosphorus in the soil was also influenced by TS x CP interaction. On the plots after winter wheat, winter durum wheat and wintery barley, its significantly higher content was found in RT and CT systems than in the NT system, whereas on the plots after pea – in RT than in CT and NT systems.

The different tillage systems affected also the potassium (K) content of the soil (Table 6). Its significantly higher value was determined in the soil from RT than CT and NT systems (by 9.5% and 8.6%, respectively). Thew soil potassium content was also determined by the previous crops, i.e., its highest value was determined in the soil from the plots after winter durum wheat, a lower one on plots after winter wheat (by 7.9%) and pea (by 18.3%), and the lowest one on plots after winter barley (by 58.8%). Also, the TS x CP interaction was observed to influence the K content of the soil. With winter wheat used as the previous crops, a higher potassium content

Table 6

Content of available potassium (K) in the soil (mg kg^{-1})

Crops (CP)	Tillage system (TS)			Mean
	CT[a]	RT	NT	
Winter wheat	168.6	169.6	131.4	156.5
Winter durum wheat	155.0	150.0	202.0	169.0
Winter barley	74.4	143.5	101.3	106.4
Pea	157.5	145.5	125.6	142.9
Mean	138.9	152.1	140.1	-
$HSD_{0.05}$ for TS = 3.1; CP = 4.0; CP x TS = 9.1				

CT[a] – conventional tillage, RT – reduced tillage, NT – no-tillage, ns – not significant

was determined in the soil from CT and RT than from NT plots, with winter durum wheat – in the soil from NT than from CT and RT plots, with winter barley – in the soil from RT than NT and CT plots, and finally with pea used as CP – in the soil from CT and NT plots.

The tillage systems affected also the magnesium (Mg) content of the soil (Table 7). Significantly more Mg was determined in the soil from RT plots compared to that from CT and NT plots (by 4.3% and 3.7%, respectively).

Table 7

Content of available magnesium (Mg) in the soil (mg kg^{-1})

Crops (CP)	Tillage system (TS)			Mean
	CT[a]	RT	NT	
Winter wheat	87.5	78.6	64.2	76.8
Winter durum wheat	74.6	89.3	103.3	89.1
Winter barley	47.1	68.5	62.1	59.2
Pea	88.6	74.4	69.8	77.6
Mean	74.5	77.7	74.9	-
$HSD_{0.05}$ for TS = 2.1; CP = 2.6; CP x TS = 5.9				

CT[a] – conventional tillage, RT – reduced tillage, NT – no-tillage, ns – not

Also, a higher Mg content was found in the soil from the plots after winter durum wheat, less in that from plots after pea and winter wheat (by 14.8% and 16.0%, respectively), and the least Mg was determined in the soil from the plot after winter barley (by 50.5%). The soil magnesium content was also affected by TS x CP interaction. On the plots after winter wheat and pea, its highest content was determined in the CT system, on plots after winter durum wheat – in the NT system, and on plots after winter barely – in the RT system.

The evaluation of variance analysis components shows that the contents of total N, K and Mg in the soil were influenced to a greater extent by CP than TS, unlike the P content, which was more distinctly affected by TS than CP (Table 8).

Table 8

Analysis of variance (F-value) conducted for contents of total N and available forms of P, K and Mg in the soil

Specification	Value	TS[a]	CP	TS × CP
Total N	F	64.12	269.90	40.39
	p	< 0.01	< 0.01	< 0.01
P	F	107.94	67.80	12.69
	p	< 0.01	< 0.01	< 0.01
K	F	645.46	6584.8	2550.2
	p	< 0.01	< 0.01	< 0.01
Mg	F	37.23	1367.7	549.60
	p	< 0.01	< 0.01	< 0.01

TS[a] – tillage system, CP – crops

DISCUSSION

Both, the tillage systems and previous crops significantly affect the earthworm number as well as the content of organic C, total N and available forms of phosphorus, potassium, and magnesium in the soil. Investigations conducted by Kretzschmar and Monestiez (1992), Capowiez et al. (2006) as well as Woźniak and Soroka (2018) demonstrated that the conventional tillage caused damage to the earthworm habitat, resulting in their lower number. House and Parmelee (1985) recorded 50 earthworms per m^2 in the soil that was not cultivated mechanically and their absence in the soil cultivated with a plough. The presence of earthworms in the soil is facilitated by post-harvest residues left on field surface and by the no-till cultivation system (Laossi et al. 2010, Orzech, Załuski 2020). Earthworms accelerate decomposition of post-harvest residues, bore channels in the soil, and their coprolites are rich in minerals (Crow et al. 2009). Woźniak and Gos (2014) reported a higher earthworm number in the post-harvest period when the post-harvest residues still remained on the field than in the plant growth period. These observations were also confirmed in a later study by Woźniak (2022), showing that the earthworm number per m^2 was 23.9% higher under conditions of no-till and mulch than in the conventional ploughing tillage. Roger-Estrade et al. (2010) demonstrated that the no-till system and post-harvest residues promoted soil bio-activity, thereby increasing organic C content of the soil. Also in the present study, the organic C content was significantly higher in the no-till systems than in the conventional tillage system, with the difference ranging from 16.4% to 22.4%. As reported by Döring et al. (2005), Herridge et al. (2008), Kertész and Madarász (2014) as well as Woźniak (2022), the organic C content of the soil depended also on the load and quality of the introduced organic matter. In the present study, the highest organic C content was determined in the soil from the plots after pea, a lower one in the soil from the plots after winter wheat and winter durum wheat, and the lowest one in the soil from the post-winter barley plots. Even though pea left a lower mass of post-harvest residues than the cereals did, the quality of this biomass expressed by the C/N ratio was far more beneficial compared to cereal straw (Woźniak, Soroka 2018). In turn, a higher mass of straw remained after winter wheat and winter durum wheat than after winter barley, which also corresponded to a higher organic C content in the soil from those plots. Analogous observations were made for the total N content of the soil. Due to the symbiosis with *Rhizobium* bacteria, legumes leave several dozen kg of nitrogen in the soil (Peoples et al. 2009). For this reason, they prove to be very good previous crops for cereals as well as industrial and fodder crops.

The tillage systems and previous crops also affect the content of P, K and Mg in the soil (Woźniak, Gos 2014, Woźniak, Kawecka-Radomska 2016). In the present study, the content of potassium and magnesium was affected most by previous crops, whereas that of phosphorus depended more strongly on a tillage system. The rate of organic matter mineralization depends on the water-air ratio in the soil, soil pH and microbiological activity, and many other interacting factors (Romaneckas et al. 2016).

CONCLUSIONS

An over 2-fold higher number of earthworms was recorded in the no-tillage systems (RT and NT) than in the conventional tillage system (CT). Also, more earthworms were observed on the plots after winter barley and pea than after winter wheat and winter durum wheat. The content of organic C and total N was higher in the soil from NT and RT systems than in the soil from the CT system as well as in the soil from plots after pea than in the samples from the plots after winter wheat, winter durum wheat and winter barley. The phosphorus content of the soil was higher on RT than CT and NT plots and also on the plots after winter wheat than after winter durum wheat, pea and winter barley. In addition, higher contents of potassium and magnesium were determined in the soil samples from RT than CT and NT plots as well as in those from the plots after winter durum wheat compared to the plots after pea, winter wheat and winter barley.

Author contribution

The concept of the study and field research, data analyses and writing of the manuscript: AW.

Conflicts of interest

The author has declared that no competing interests exist.

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