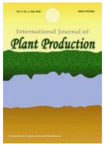

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Crop management effect on chemical and biological properties of soil

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Abstract

This study was aimed at evaluating the effect of crop rotation and various tillage systems on the chemical and biological properties of soil in the years 2013-2015. The first order factor included cropping systems: a) crop rotation (pea – winter wheat – spring wheat) and b) monoculture of winter wheat, whereas the second order factor were tillage systems: 1) conventional (CT), 2) reduced (RT) and 3) No-tillage (NT). In the autumn season, in the CT system, shallow ploughing (at the depth of 10–12 cm) and pre-winter ploughing (25–30 cm) were applied for pea and spring wheat crops, whereas shallow ploughing and pre-sow ploughing (20–22 cm) were applied for winter wheat crop; in the RT system, only a cultivator was applied for spring wheat and pea crops as well as a cultivator and a tillage set for winter wheat; in the NT system glyphosate was applied on all plots as well as a cultivator and a tillage set were used before winter wheat sowing. The study demonstrated that the soil sampled from plots with crop rotation contained more organic C and available forms of P, K and Mg and that it was characterized by a higher activity of dehydrogenase, phosphatase and urease than the soil sampled from monoculture. In addition, it was characterized by a higher number of earthworms than the soil from monoculture. The RT and NT systems affected an increase in the contents of organic C and total N and in the enzymatic activity of soil, compared to the CT system.

Keywords: Crop rotation; Enzymatic activity of soil; Organic carbon; Earthworms; Tillage system.

Introduction

Tillage systems and crop rotation affect the physicochemical and biological properties of soil and, consequently, influence crop yield (Woźniak and Soroka, 2014). Plant residues left on the surface of arable field in the no-till system protect the soil against physical and chemical degradation (Jordan et al., 2000; Madari et al., 2005) and affect its biological activity (Uri et al., 1999; Trasar-Cepeda et al., 2000). A study conducted by Woźniak and Gos (2014) demonstrated higher contents of organic carbon, total nitrogen and available forms of phosphorus in the soil cultivated without the use of plough, compared to the ploughing system. An increase was also noted in the number of earthworms, which according to Kretzschmar and Monestiez (1992) is indicative of the enhanced biological activity of the soil. In the experiment conducted by Crow et al. (2009), the increase in the number of earthworms affected a higher content of organic carbon in the soil. As reported by Laossi et al. (2010), the presence of earthworms had a beneficial effect on plant biomass because their vital activity increases the availability of nutrients to plants. In turn, Bruyn and Kingston (1997) demonstrated that the number of earthworms was strictly linked with the content of organic matter in the soil and with soil humidity. Unlike monoculture, crop rotation provides diversified organic matter to soil, which has a beneficial influence on microbiological transformations proceeding in the soil and on the population numbers of mesofauna. In turn, tillage affects the rate of organic matter degradation in the soil and transformations ongoing in the soil (Roldán et al., 2005; Micucci et al., 2006). Melero et al. (2009) reported a higher content of organic C, higher biomass of microorganisms and enhanced enzymatic activity in the soil cultivated in the conservation than in the ploughing system. According to Bandick and Dick (1999) and Balota et al. (2004), the enzymatic activity is a reliable factor showing the condition of soil environment and changes proceeding therein. For this reason, it may be found an indicator of soil quality and health status of soil (Janvier et al., 2007). As reported by Clarholm (1993), owing to their fastest response to agrotechnical factors, phosphatases are the most frequently analyzed enzymes in soils originating from arable fields.

In view of literature data, it may be hypothesized that the no-till system and appropriate crop rotation increase the content of organic C in the soil, which has a beneficial effect on the enzymatic activity of soil and the number of earthworms and consequently on plant biomass. Considering the above, this study was aimed at evaluating the effect of tillage systems and cropping systems on the chemical and biological changes proceeding in the soil from arable fields.

Materials and Methods

A field experiment with cropping systems and tillage systems was established in the year 2007 at the Experimental Station Uhrusk (51° 18' 11" N, 23° 36' 46" E), that belongs to the University of Life Science in Lublin, south-eastern Poland. Results presented in this work were collected from plots on which winter wheat was grown in the years 2013–2015. The experiment was established in the system of randomized sub-blocks (6 m × 25 m) in three replications. The first order factor included cropping systems: a) crop rotation (pea – winter wheat – spring wheat) and b) monoculture of winter wheat, whereas the second order factor were tillage systems: 1) conventional (CT), 2) reduced (RT) and 3) No-tillage (NT). In the autumn season, in the CT system, shallow ploughing (at the depth of 10–12 cm) and pre-winter ploughing (25–30 cm) were applied for pea and spring wheat crops, whereas shallow ploughing and pre-sow ploughing (20–22 cm) were applied for winter wheat crop; in the RT system, only a cultivator (10–15 cm) was applied for spring wheat and pea crops as well as a cultivator and a tillage set (10–12 cm) for winter wheat; in the NT system glyphosate (4 L ha^{-1}) was applied on all plots as well as a cultivator and a tillage set were used before winter wheat sowing. In the springtime, a cultivator and a tillage set were used before sowing pea and spring wheat. Winter wheat was sown in the first week of October, whereas pea and spring wheat were sown in the first week of April.

The experiment was established on Rendzic Phaeozem soil (IUSS Working Group WRB, 2015) with the composition of sandy clay with 24.4% of silty fractions and 13.0% of dusty fraction. Weather conditions at the study area were presented in Figures 1 and 2.

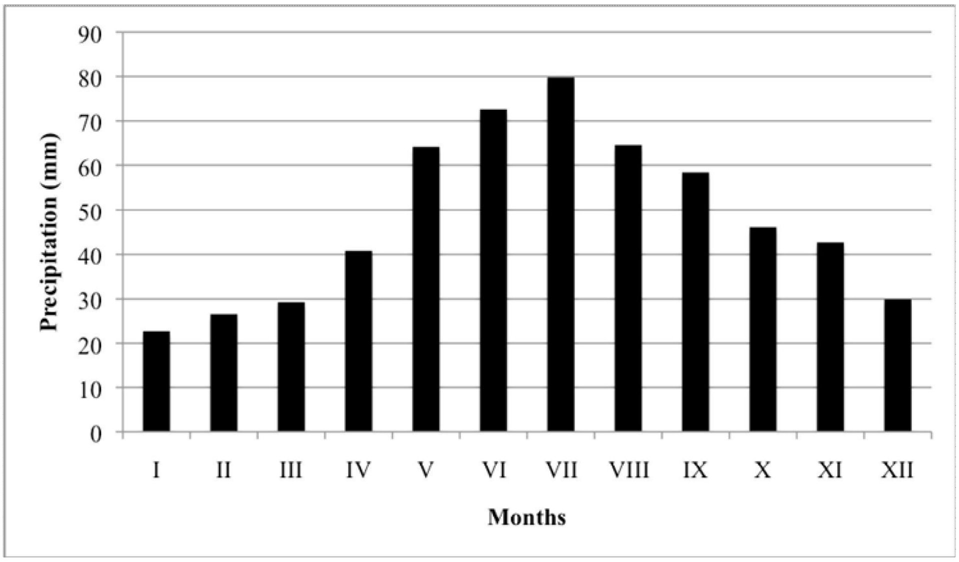

Figure 1. Total precipitation at the Uhrusk Experimental Station (average of forty-five years).

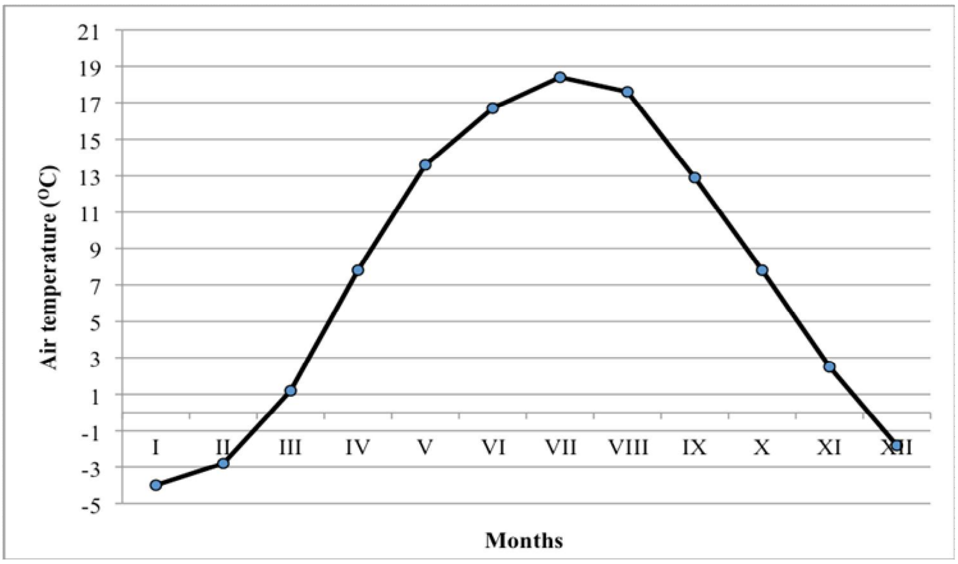

Figure 2. Air temperature at the Uhrusk Experimental Station (average of forty-five years).

The following determinations were conducted in the study: 1) organic C (with the Tiurin's method); 2) total N (with the Kjeldahl's method), $N\text{-}NO_3$ (colorimetrically using the method with phenol disulfonic acid), $N\text{-}NH_4$ (using the method with Nessler's reagent); 3) available forms of P (with the Egner-Riehm's method), K (with the Egner-Riehm's method) and Mg (with the Schachtschabels method); 4) soil enzymes: phosphatase (with the Tabatabai's method), dehydrogenase (with the Thalmann's method), urease (with the Zantua's method) and protease (with the Ladda and Butler's method); 5) heavy metals (Cd, Zn, Pb, Cr, Cu, Ni with the IPC-OES method); 6) soil pH (in 1 mol KCL dm^{-3} with the potentiometric method); 7) total sorption capacity (cmol (+) kg^{-1}) (with the Kappen's method); and 8) the number and mass of earthworms per m^2 (Woźniak and Gos, 2014). For the above determinations, 5 native samples (from 0-25 cm soil layer) were collected from each plot that constituted one general sample with the mass of 0.5 kg. All determinations were carried out in 3 replications. The number and mass of earthworms (*Lumbricus*) were assayed at the end of May. The assessment consisted in handy-picking of all earthworms (without species identification) from 2 soil samples collected from the area of 0.25 m × 1.0 m and a depth of 0.30 m and determining their number and mass (Woźniak and Gos, 2014).

Results achieved were developed statistically with 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 and Discussion

Chemical properties and enzymatic activity of soil

The content of organic C in the soil sampled from plots with crop rotation was significantly higher than in the soil from plots with monoculture. Also the RT and NT systems were increasing organic C content in the soil, compared to the CT system (Table 1). Also a study by Woźniak and Gos (2014) demonstrated higher contents of organic C, total N and P in the soil from no-till system than in the soil from the ploughing system. According to Micucci and Taboada (2006), the ploughing system results in significant aeration of soil, which contributes to rapid mineralization of organic matter, a decrease in organic C content and elution of nutrients. Also in our study, total N content in the CT system was lower than in the NT system (Table 2). Nitrogen in the form of $N\text{-}NO_3$ occurred in higher amounts on RT and NT plots than on CT plots, whereas nitrogen in the form of $N\text{-}NH_4$ – on plots with CT than with RT and NT systems. The rate of organic matter degradation in soil depends on biotic and factors. Organic matter degradation is facilitated by the presence of bacteria, fungi, actinomycetes and earthworms, by moderately high temperature and high moisture content of soil as well as by a lack of toxic agents, e.g. pesticides. Under such conditions, proteins are degraded under the influence of enzymes to ammonia that may be absorbed by plants, nitrified or released to the atmosphere (Nannipieri et al., 2003).

Table 1. Content of organic carbon in soil (g kg^{-1} d.m.) (in 0-25 cm soil layer).

Cropping system (CS)	Tillage system (TS)			Mean
	CT[z]	RT	NT	
CR[a]	5.61	6.90	6.70	6.40
M	5.39	4.80	5.10	5.10
Mean	5.50	5.85	5.90	-
$HSD_{0.05}$ for CS = 0.20; TS = 0.30; CS × TS = 0.60				

[a] CR – crop rotation (pea – winter wheat – spring wheat); M – monoculture of winter wheat; [z]CT – conventional tillage; RT – reduced tillage; NT – no-tillage.

Table 2. Content and forms of nitrogen in soil (in 0-25 cm soil layer).

Cropping system (CS)	Tillage system (TS)			Mean
	CT[z]	RT	NT	
	Total N (g kg^{-1} d.m.)			
CR[a]	0.82	0.91	0.91	0.88
M	0.80	0.89	0.90	0.86
Mean	0.81	0.90	0.91	-
	$HSD_{0.05}$ for CS = ns; TS = 0.08; CS × TS = ns			
	N-NO_3 (mg kg^{-1} d.m.)			
CR	32.0	31.3	30.7	31.4
M	27.9	31.6	32.7	30.7
Mean	30.0	31.5	31.7	-
	$HSD_{0.05}$ for CS = ns; TS = 1.0; CS × TS= 1.8			
	N-NH_4 (mg kg^{-1} d.m.)			
CR	1.29	1.19	1.04	1.17
M	1.69	1.07	0.87	1.21
Mean	1.49	1.13	0.95	-
	$HSD_{0.05}$ for CS = ns; TS = 0.13; CS × TS =0.24			

[a, z] Legend as in Table 1; ns – not significant $P<0.05$.

The soil sampled from plots with crop rotation was characterized by significantly higher contents of available forms of P, K and Mg than the soil from monoculture (Table 3). It could be due to pea grown in crop rotation and specifically to its roots and post-harvest residues that are rich in nutrients. The content of macroelements in the soil was also differentiated by tillage systems. Higher concentrations of available phosphorus were determined in the soil from CT and RT plots compared to NT plots, these of potassium in the soil from NT and RT plots compared to CT system and these of magnesium in the soil from NT system compared to RT and CT systems. Potassium and magnesium easily migrate in the soil and this migration process is accelerated by the ploughing system and heavy rainfalls.

Contents of heavy metals in the soil were at the level of their natural resources, however in the soil sampled from the monoculture the contents of Zn, Pb and Cr were higher than in the soil from crop rotation. Also higher contents of Cd, Zn, Pb, Cr, Cu and Ni were determined in the soils from plots with RT and NT systems compared to the soil from CT system (Table 4). It may be speculated that a specified amount of heavy metals reached the soil with fertilizers and remained in the topsoil (RT and NT plots) or was relocated during ploughing (CT plot).

The cropping and tillage systems had a significant effect on the enzymatic activity of soil (Table 5). In the soil sampled from crop rotation analyses showed higher activities of dehydrogenase, phosphatase and urease than in the soil from monoculture. In turn, the activity of protease was higher in the soil from monoculture than from crop rotation. In addition, higher activities of dehydrogenase and phosphatase were determined in the NT compared to the RT and CT systems, that of urease – in the RT compared to the NT and CT systems and that of protease – in the NT compared to the RT and CT systems. As reported by Roldán et al. (2005) and Janvier et al. (2007), dehydrogenases occur commonly in soils rich in organic matter, hence determination of their activity is indicative of the intensity of the respiratory metabolism of microorganisms. In turn, phosphatases stimulate transformations of organic compounds of phosphorus into inorganic phosphates (Eivazi and Tabatabai, 1977), whereas ureases participate in the process of ammonification, i.e. release of ammonia from urea, amino acids and purine bases (Nannipieri et al., 2003). In turn, proteases decompose peptide bonds in proteins to free amino acids and dipeptides and, thus, are easily available to microorganisms.

Table 3. Content of available forms of phosphorus, potassium and magnesium in soil (in 0-25 cm soil layer).

Cropping system (CS)	Tillage system (TS)			Mean
	CT[z]	RT	NT	
	P (mg kg^{-1} d.m)			
CR[a]	145.9	145.8	120.4	137.3
M	118.9	113.9	116.9	116.4
Mean	132.4	129.6	118.6	-
	$HSD_{0.05}$ for CS = 7.3; TS = 10.9; CS × TS = 19.1			
	K (mg kg^{-1} d.m)			
CR	300.0	345.0	355.0	333.3
M	232.5	325.0	400.0	319.2
Mean	266.3	335.0	377.5	-
	$HSD_{0.05}$ for CS = ns; TS = 22.4; CS × TS= 39.3			
	Mg (mg kg^{-1} d.m)			
CR	71.4	63.9	75.8	70.4
M	66.0	72.8	66.4	68.4
Mean	68.7	68.4	71.1	-
	$HSD_{0.05}$ for CS = 1.7; TS = 2.3; CS × TS = 4.5			

[a, z] Legend as in Table 1; ns – not significant P<0.05.

Table 4. Content of heavy metals in soil (in 0-25 cm soil layer).

Cropping system (CS)	Tillage system (TS)			Mean
	CT[z]	RT	NT	
		Cd (mg kg^{-1} d.m)		
CR[a]	0.22	0.27	0.35	0.28
M	0.24	0.39	0.33	0.32
Mean	0.23	0.33	0.34	-
	$HSD_{0.05}$ for CS = ns; TS = 0.06; CS × TS = 0.12			
		Zn (mg kg^{-1} d.m)		
CR	26.6	31.3	31.1	29.6
M	29.4	31.8	30.7	30.6
Mean	28.0	31.5	30.9	-
	$HSD_{0.05}$ for CS = 0.9; TS = 1.4; CS × TS= 2.5			
		Pb (mg kg^{-1} d.m)		
CR	24.8	26.6	27.4	26.3
M	26.1	26.6	28.4	27.0
Mean	25.4	26.6	27.9	-
	$HSD_{0.05}$ for CS = 0.6; TS = 0.9; CS × TS = ns			
		Cr (mg kg^{-1} d.m)		
CR	20.2	19.9	19.8	20.0
M	18.4	23.6	23.5	21.8
Mean	19.3	21.8	21.7	-
	$HSD_{0.05}$ for CS = 0.7; TS = 1.0; CS × TS = 1.8			
		Cu (mg kg^{-1} d.m)		
CR	8.3	11.6	10.0	10.0
M	9.7	10.9	9.6	10.1
Mean	9.0	11.3	9.8	-
	$HSD_{0.05}$ for CS = ns; TS = 0.7; CS × TS = 1.3			
		Ni (mg kg^{-1} d.m)		
CR	15.3	16.0	16.3	15.9
M	15.3	17.0	16.1	16.1
Mean	15.3	16.5	16.2	-
	$HSD_{0.05}$ for CS = ns; TS = 0.5; CS × TS = 0.8			

[a, z] Legend as in Table 1; ns – not significant P<0.05.

Table 5. The enzymatic activity of soil (in 0-25 cm soil layer).

Cropping system (CS)	Tillage system (TS)			Mean
	CT[z]	RT	NT	
Dehydrogenase (mg TPF kg^{-1} d.m. 24 h^{-1})				
CR[a]	1.752	2.701	2.558	2.337
M	1.941	1.250	2.507	1.899
Mean	1.847	1.975	2.532	-
$HSD_{0.05}$ for CS = 0.211; TS = 0.324; CS × TS = 0.650				
Phosphatase (mg PNP kg^{-1} d.m. h^{-1})				
CR	9.410	7.890	11.419	9.573
M	7.379	7.316	9.059	7.918
Mean	8.394	7.603	10.239	-
$HSD_{0.05}$ for CS = 0.678; TS = 1.009; CS × TS = ns				
Urease (mg N-NH_4^+ kg^{-1} d.m. 24 h^{-1})				
CR	2.369	4.641	3.960	3.657
M	2.843	3.623	2.637	3.034
Mean	2.606	4.132	3.298	-
$HSD_{0.05}$ for CS = 0.379; TS = 0.563; CS × TS = 0.991				
Protease (mg tyrosine kg^{-1}d.m. h^{-1})				
CR	0.729	1.044	0.653	0.809
M	0.779	0.818	1.243	0.946
Mean	0.754	0.931	0.948	-
$HSD_{0.05}$ for CS = 0.100; TS = 0,149; CS × TS = 0.262				

[a, z] Legend as in Table 1; ns – not significant P<0.05.

The cropping and tillage systems affect also soil pH (Table 6). In the soil sampled from plots with crop rotation, the pH value increased compared to the soil from monoculture. The higher soil pH was also determined in the RT system compared to the NT and CT systems. The soil sampled from plots with crop rotation was characterized by almost twofold higher total sorption capacity than the soil from the monoculture. It indicates a significantly higher capacity for ionic exchange in the soil from crop rotation than from the monoculture.

Table 6. Soil pH and total sorption capacity (in 0-25 cm soil layer).

Cropping system (CS)	Tillage system (TS)			Mean
	CT[z]	RT	NT	
Soil pH_{KCL}				
CR[a]	7.48	7.90	7.80	7.72
M	7.78	7.78	7.23	7.60
Mean	7.63	7.84	7.51	-
$HSD_{0.05}$ for CS = 0.10; TS = 0.18; CS × TS = 0.31				
Total sorption capacity (cmol (+) kg^{-1})				
CR	43.49	43.58	40.64	42.57
M	29.46	24.58	20.18	23.18
Mean	36.48	34.08	30.41	-
$HSD_{0.05}$ for CS = 17.10; TS = ns; CS × TS = ns				

[a, z] Legend as in Table 1; ns – not significant P<0.05.

Number and mass of earthworms in the soil

The presence of earthworms in soil used for agricultural purposes is indicative of its biological activity (Kretzschmar and Monestiez, 1992). Usually, the number of earthworms is higher on plots without cultivating measures than on intensively cultivated plots (Woźniak and Gos, 2014). As reported by Crow et al. (2009), the activity of earthworms contributes to the stabilization of organic carbon content in the soil. In turn, studies conducted by Bruyn and Kingston (1997) demonstrated that the number of earthworms is positively influenced by a high content of organic matter in the soil. In our experiment, the number of earthworms m^{-2} was significantly higher by 29% in the soil from crop rotation than in that from monoculture (Table 7). Certainly, it results from the higher and diversified mass of post-harvest residues left after cultivated crops, especially after pea, compared to homogenous residues left after cereals in the monoculture. Analogous observations were made for the mass of earthworms (g m^{-2}). It was significantly higher (by 25.8%) in crop rotation than in the monoculture. The number of earthworms was also affected by tillage systems. In the CT system, it was lower by 45.7% than in RT system and by 41.6% than in NT system. In turn, the mass of earthworms in the CT system was lower by 49.6% than in the RT system and by 44.7% than in the NT system. In a study by Woźniak and Gos (2014), a higher number of earthworms were found in the soil from the no-till than from the ploughing system and in the period of summer compared to spring.

Table 7. Number and mass of earthworms in soil (in 0-30 cm soil layer).

Cropping system (CS)	Tillage system (TS)			Mean
	CT[z]	RT	NT	
Number of earthworms m^{-2}				
CR[a]	12.7	21.0	20.0	17.9
M	7.5	16.1	14.6	12.7
Mean	10.1	18.6	17.3	-
$HSD_{0.05}$ for CS = 1.9; TS = 2.8; CS × TS = ns				
Mass of earthworms g m^{-2}				
CR	7.5	14.3	13.0	11.6
M	5.2	10.8	9.8	8.6
Mean	6.3	12.5	11.4	-
$HSD_{0.05}$ for CS = 2.1; TS = 3.2; CS × TS = ns				

[a, z] Legend as in Table 1; ns – not significant P<0.05.

In summary, it may be concluded that crop rotation and tillage systems affected the chemical and biological properties of soil. The soil sampled from crop rotation contained more organic C and more available forms of P, K and Mg and was characterized by higher activities of dehydrogenase, phosphatase and urease than the soil from monoculture. In addition, it was characterized by almost twofold higher total sorption capacity than the soil from monoculture. In the soil from crop rotation, analyses showed also a higher number of earthworms, compared to the soil from monoculture. The RT and NT systems affected an increase in the content of organic C and total N and a higher enzymatic activity compared to the CT system. The content of heavy metals in the soil was at the level of their natural resources, but it was insignificantly differentiated by both tillage and cropping systems.

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