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ORIGINAL PAPER

EFFECT OF CATCH CROPS AND TILLAGE SYSTEMS ON SOME CHEMICAL PROPERTIES OF LOESS SOIL IN A SHORT-TERM MONOCULTURE OF SPRING WHEAT*

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Abstract

The aim of the present study was to compare the chemical soil quality parameters in a three-year spring wheat monoculture as affected by the incorporation of biomass of selected catch crops into the soil under two tillage systems (plough tillage and no-tillage). The experiment was set up as a split-plot design with 5 replicates on 27 m^2 plots. The suitability of the following catch crops plants: white mustard, lacy phacelia, and a mixture of legumes (faba bean + spring vetch), was tested relative to the control treatment. The study was conducted in Czesławice (Poland), in 2013-2015. The experiment was established on loess soil with the grain size distribution of silt loam and classified as good wheat soil complex (soil class II). Soil samples were taken using a soil sampling auger from an area of 0.20 m^2 (from the 0-20 cm layer) in each plot in the spring period (before spring wheat was sown). This study hypothesized that the catch crops, in combination with conservation tillage, would result in an improvement in some soil fertility chemical indicators in a several-year monoculture of spring wheat. It was proven that, regardless of a tillage system, the catch crops (in particular the mixture of legumes and white mustard) beneficially affected the soil chemical properties (in particular the content of soil humus, organic C, P, Mg and micronutrients). Tillage systems did not cause significant differences in soil pH. The catch crops also contributed to a reduction in phenolic compounds in the soil. Tillage systems had a weaker impact on the soil chemical parameters. Despite this, plough tillage promoted more favorable soil chemical composition in spring (compared to the conservation tillage).

Keywords: catch crops, plough tillage, conservation tillage, monoculture, soil chemical composition.

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INTRODUCTION

In Poland, cereal crops occupy 74.3% of the total cropped area (Statistical… 2018). Thus, monoculture cropping of cereals has become a fact on many farms. Cereal monocultures cause many adverse changes in the natural habitat. These effects can be observed both in the soil environment and in the crop stand. As a consequence, grain yield quantity and quality are affected (Hansen et al. 2000, Kwiatkowski et al. 2016). Plough tillage is replaced more and more frequently by conservation tillage, and this process takes place in many countries (Derpsch, Friedrich 2009, Kassam et al. 2009). In Germany, conservation tillage comprises only those crops whose intensity is lower than that of conventionally tilled crops but higher than in the case of no-till (Gruber et al. 2011). Apart from the economic aspect, supporters of conservation tillage draw attention to its many other beneficial properties and advantages. Conservation tillage has been found to increase soil organic matter content and hence this tillage system increases soil biological activity (Berner et al. 2008, Vogeler et al. 2009, Gajda, Przewłoka 2012, Van den Putte et al. 2012). One of the methods of mitigating the negative effects of cereal monoculture is the cultivation of catch crops, mainly playing a major phytosanitary role. The assessment of the effectiveness of catch crops is varied and depends on the quality of the soil and the initial abundance of nutrients (Kwiatkowski et al. 2016, Wanic et al. 2019). Catch crops also decrease the risk of leaching elements beyond an agricultural ecosystem as well as reduce water and wind erosion. Catch crops improve the quality of the soil environment (its physical, chemical, and biological properties), and are a factor that reduces soil nitrogen losses (Lal et al. 2007, Leys et al. 2010, Gruber et al. 2011).

This study hypothesized that the use of phytosanitary and allelopathic impacts of catch crops, in combination with conservation tillage, would result in an improvement in some soil fertility chemical indicators in a several-year monoculture of spring wheat. The aim of this study was to determine the effects of some plant species grown as catch crops on the fertility of loess soil. Moreover, an answer was sought to the question to what degree the use of tillage reduction (conservation tillage) would influence the soil chemical parameters compared to plough tillage.

MATERIALS AND METHODS

A field experiment on monoculture cropping of spring wheat (cv. Monsun) was established in 2012, while the study results included in this paper were collected over the period 2013-2015 (three-year monoculture). The experiment was established at the Czesławice Experimental Farm (51°30′N;

22°26′E), belonging to the University of Life Sciences in Lublin (Poland), on grey-brown podzolic soil (sandy), designated as PWsp, with the textural composition of silt (34% of fine particles) (WRB 2014) and classified as good wheat soil complex (soil class II). In the year when the experiment was started, the soil contained 1.44% of humus, pH = 6.2, while the content of P, K and Mg was, respectively, 160, 284, and 64 mg kg^{-1} soil. The experiment was set up as a split-plot design with 5 replicates on 27 m^2 plots. The experimental design included two factors: I. Type of catch crops in a spring wheat monoculture: A – control treatment (without catch crops); B – white mustard (cv. Borowska); C – lacy phacelia (cv. Stala); D – faba bean + spring vetch (cv. Amulet + cv. Hanka). II. Tillage practices used after harvest of the catch crops and before harvest of the cereal crop: 1) plough tillage – after the harvest of catch crops (October), their biomass was shredded and incorporated into the soil during autumn ploughing ; in the spring, a seedbed cultivator was used, mineral NPK fertilization was applied, and spring wheat was sown with a seed drill; 2) conservation tillage (no-tillage) – after the harvest of catch crops (October), their biomass was left in the field in the form of mulch (until 15 March); in the spring – the mulch was incorporated into the soil using a disk harrow, the field was smoothed with a spike tooth harrow, mineral NPK fertilization was applied, and spring wheat was sown with a seed drill.

During the experimental years, spring wheat was sown at the optimal agronomic time for the region (2^{nd} April). In all treatments, mineral NPK fertilization was applied (adjusted to the requirements of the individual catch crops species), and subsequently the cover crops were sown. Based on the availability of the major macronutrients in the soil used in the experiment and taking into account "economical" crop protection to be used, the following doses of mineral fertilizers (kg ha^{-1}) were applied for the individual crops included in the field experiment: spring wheat (N – 60, P_2O_5 – 50, K_2O – 80), white mustard (N – 40), lacy phacelia (N – 40), faba bean + spring vetch (N – 20). Each year, the catch crops were sown in the second ten days of August. The seeding dose was as follows, respectively: white mustard – 20 kg ha^{-1}, lacy phacelia – 5 kg ha^{-1}, faba bean + spring vetch – 100 + 40 kg ha^{-1}. Sowing of spring wheat (at an amount of 200 kg ha^{-1}) was carried out in the second ten days of April.

Soil samples were collected from the 0-20 cm layer, and the soil availability of major nutrients was determined. Soil samples were taken using a soil sampling auger from an area of 0.20 m^2 in each plot in the spring period (before spring wheat was sown). Humus content was determined by the Liechterfeld method using ln and 2n $K_2Cr_2O_7$ as an oxidizing agent. The $K_2Cr_2O_7$: H_2SO_4 ratio was 1:1. 2-hour and 1-hour heating in a water bath was carried out, and iodometric determinations were made. Soil pH was determined electrometrically in a 1 M solution of KCl (ISO 10390:2005), C organic content with a carbon analyzer, total nitrogen by the Kjeldahl method, content of available forms of phosphorus (PN-R-04023:1996) and potassium (PN-R-04022/Az1:2002) by the Egner-Riehm method, magnesium content (PN-R-04020:1994/Az1:2004) by atomic absorption spectrometry (AAS), and micronutrient content (Mn, Fe, Zn, Cu) by flame photometry (AAS – type FPF-2 Hitachi). Extraction of phenols from air-dried soil was carried out following the method given by Hruszka (1982), and their content was determined according to Swain and Hillis (1959). Analyses were performed in the District Chemical-Agricultural Station in Lublin.

The results were analyzed statistically by analysis of variance (ANOVA) using Statistica 2013. LSD values were determined by the Tukey's test at $p = 0.05$.

RESULTS

Soil pH, content in humus, phosphorus, potassium and magnesium were similar (statistically insignificant), both in the variant with plough tillage and conservation tillage. In plough tillage, only a tendency of slightly higher levels of these soil quality parameters was found (Table 1). Regardless of a tillage system, the soil humus content was found to be significantly higher, relative to the control treatment, in the case of legume and white mustard cover cropping (Table 1). When considering the impact of the catch crops on soil pH, their positive effect was noticed, which was statistically proven in the case of white mustard (Table 1). The tillage systems did not cause significant differences in soil humus content and soil pH. Soil macronutrient content was mainly modified by catch crops. In the spring period, the P content in the soil sown with the catch crops was significantly higher than in the control treatment (Table 1). During the spring period, the K content in the soil was higher compared to the control treatment (without catch

Table 1

Soil humus content, soil pH and soil macronutrient content – on average over the study period

Specification	Humus content (%)	Soil pH (1M KCl)	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})
Plough tillage	1.55	6.4	175	285	71
Conservation tillage	1.53	6.3	168	284	69
LSD $_{(0.05)}$	n.s	n.s	n.s	n.s.	n.s.
A – control treatment	1.44	6.1	163	281	65
B – white mustard	1.58	6.5	174	286	72
C – lacy phacelia	1.53	6.4	172	286	71
D – faba bean + spring vetch	1.60	6.4	176	284	72
LSD $_{(0.05)}$	0.081	0.37	9.9	n.s	3.99

n.s. – not significant

crops), on average by 2 - 4 mg kg^{-1} (Table 1). In the spring period, all the catch crops used in the present experiment contributed to a significant increase in the magnesium content compared to the control treatment (Table 1). The tillage systems affected differently the micronutrient content in the soil under the spring wheat monoculture (Table 2). Significant differences in the content of micronutrients were found in favor of plough tillage with respect to the content of iron (an increase by about 519 mg kg^{-1}) and zinc (an increase by about 6.3 mg kg^{-1}). The differences in the soil manganese and copper content as affected by the tillage systems were within the limit of experimental error. The catch crops generally contributed to an increase in the soil content of the studied micronutrients, but white mustard had the greatest positive (statistically significant relative to the control treatment) effect on their content (Table 2). Conservation tillage contributed

Table 2

Soil micronutrient content – on average over the study period

Specification	Micronutrient (mg kg^{-1})			
	Mn	Fe	Zn	Cu
Plough tillage	284	5145	39.4	6.91
Conservation tillage	269	4626	33.1	6.84
LSD $_{(0.05)}$	n.s.	331	3.4	n.s.
A – control treatment	264	4788	34.8	6.16
B – white mustard	296	5138	38.9	7.97
C – lacy phacelia	274	4812	35.7	6.69
D – faba bean + spring vetch	271	4803	35.4	6.67
LSD $_{(0.05)}$	27.1	325	3.32	1.34

n.s. – not significant

to a significant increase in the organic carbon and total nitrogen content in the topsoil layer (on average by 6%) compared to plough tillage. All the catch crops included in this experiment, regardless of a tillage system, caused a statistically proven increase in the soil organic C content relative to the control treatment, but did not have a significant effect on the total nitrogen content (Table 3). Monoculture cropping can promote accumulation of phenols in the soil, which are generally considered to be one of the reasons for reduced productivity of agroecosystems. This study demonstrates that tillage system (plough or conservation tillage) did not significantly influence phenol accumulation in the soil, but a trend was found towards a lower phenolic content in the conservation tillage treatment. Irrespective of a tillage system, the catch crops resulted in a significant decrease in the percentage of phenolic compounds in the soil, on average by 16% (phacelia and the legume mixture) and 33% (white mustard) – Table 3.

Table 3

Organic carbon and total nitrogen content, C/N ratio, and content of phenolic compounds in the 0-20 cm soil layer – on average over the study period

Specification	Organic C (g kg^{-1})	N (g kg^{-1})	C / N	Phenolic compounds (mg kg^{-1})
Plough tillage	29.8	2.91	10.2 / 1	1.1
Conservation tillage	31.5	3.09	10.2 / 1	1.0
$LSD_{(0.05)}$	0.47	0.15	-	n.s
A – control treatment	28.4	2.95	9.6 / 1	1.2
B – white mustard	31.8	3.06	10.4 / 1	0.8
C – lacy phacelia	31.0	3.05	10.2 / 1	1.0
D – faba bean + spring vetch	31.6	3.08	10.2 / 1	1.0
$LSD_{(0.05)}$	0.65	n.s.	-	0.14

n.s. – not significant

DISCUSSION

The ploughing-in of catch crops biomass results in a change in the soil physico-chemical properties (Harasimowicz-Herman, Herman 2006, Brant et al. 2009). Pałys et al. (2009) claim that in such a case the soil content of organic carbon as well as of nitrogen, phosphorus and potassium increases. Researchers have different opinions on the effect of catch crops on soil pH. In the opinion of Rajewski et al. (2012), the ploughing-in of a catch crops causes an increase in soil pH, but Eichler et al. (2004) showed a decrease in this indicator, whereas Pałys et al. (2009) did not find stubble crops to impact soil pH. The study by Wojciechowski (2004) demonstrated that cover cropping also had a beneficial effect on the decrease in soil compaction in the plough layer. In an experiment conducted by Parylak et al. (2002), the compaction of a light soil decreased by nearly 18% as a result of ploughing in a catch crops in a several-year triticale monoculture.

To sum up the results of the present study, the impact of a tillage system on the soil chemical composition was marginal. It manifested itself only in an increase in the soil Fe and Zn content under plough tillage and an increase in the soil organic C content under conservation system. The cover cropping caused greater changes in soil chemistry. The aforementioned cultures, especially white mustard, positively influenced soil humus content, content of macronutrients (in particular in the spring period) and micronutrients, organic C content, total N content, and C:N ratio as well as they contributed to an increase in the soil phenolic content in the soil plough layer. Lepiarczyk (2000), Harasimowicz-Herman, Herman (2006), and

Kwiatkowski et al. (2014) report similar results of an analysis of the effect of catch crops on soil fertility. Alvarez (2005), Takata et al. (2008), D'haene et al. (2009), and Van den Putte et al. (2012) found that tillage reductions promoted an increase in soil organic carbon content, which is a finding similar to determinations in the present study. Furthermore, a study by Kraska (2011) reveals – similarly to this research – that the content of some macro- and micronutrients was higher under the conventional system than under no-tillage. In turn, Włodek et al. (2012) proved a significant increase in the soil content of copper, manganese, iron and zinc as well as of available forms of potassium (Bielińska, Mocek-Płóciniak 2012) under no-tillage conditions. Biskupski et al. (2009) suggest that discrepanices in the results of studies on the soil content of available forms of elements under different tillage systems can be due to the occurrence of a lower soil temperature where tillage reductions were used, compared to plough tillage. This, in turn, may have an effect on deceleration of chemical reactions taking place in the soil (Zhengchao et al. 2013). In the study by Kraska (2011), the soil where a red clover undersown crop and a lacy phacelia catch crop were sown as cover crops contained most phosphorus. A study by Kwiatkowski et al. (2016), in turn, reveals that the introduction of catch crops into a spring wheat monoculture increased the soil content of nitrogen, phosphorus and potassium. Skinder et al. (2007), on the other hand, did not find catch crops to have a significant impact on soil phosphorus, magnesium and carbon content. Kuś and Jończyk (2000) as well as Jaskulski and Jaskulska (2004) reported that the introduction of catch crops clearly decreased the soil N, P, K and Mg content during the pre-winter period compared to the spring period. Gruber et al. (2011) also found that stubble crops reduced the NPK leaching and losses in the soil.

CONCLUSIONS

1. Catch crops beneficially affected the soil chemical properties, in particular the content of soil humus, organic carbon, phosphorus, magnesium and micronutrient (Mn, Fe, Zn, Cu) as well as having an effect on reducing the percentage of phenolic compounds.

2. Plough tillage (ploughing-in of catch crops biomass in autumn) caused a a higher soil content of chemical components in the spring period than conservation tillage. The hypothesis adopted for this study was thus confirmed only partially.

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