doi: 10.17221/582/2016-PSE

Soil properties and yields of winter wheat after long-term growing of this crop in two contrasting rotations

J. Smagacz[1], M. Kozieł[2], S. Martyniuk[2]

[1]*Department of Systems and Economics of Crop Production, Institute of Soil Science and Plant Cultivation, State Research Institute, Puławy, Poland*
[2]*Department of Agricultural Microbiology, Institute of Soil Science and Plant Cultivation, State Research Institute, Puławy, Poland*

ABSTRACT

This study was based on a long-term field experiment established in 1967 in which winter wheat is grown in two rotations consisting of: potato-winter wheat-fodder crops-winter wheat (rotation A) and oat-winter wheat-winter rye-winter wheat (rotation B). In the years 2010–2013 selected soil properties and winter wheat yields as influenced by these rotations were analysed. The soils under winter wheat grown in crop rotations A and B contained similar amounts of total organic carbon (C) (0.76% and 0.80%, respectively) and did not differ significantly with respect to biological characteristics (contents of microbial biomass C and nitrogen (N), dehydrogenase and acid phosphatase activities). Averaged for 3 years, the highest grain yields were obtained for winter wheat grown after potato in rotation A (7.94 t/ha) and the lowest (6.0 t/ha) for wheat following winter rye in rotation B. The highest take-all index and the lowest numbers of ears/m^2 were the main factors influencing poor performance of winter wheat following rye.

Keywords: crop rotation; winter wheat yield; soil quality; total organic C; soil enzymes

It is well established and documented that grain yields of wheat, the most important cereal crop all over the world, are usually reduced by 10–30% when this crop is grown in monoculture or in short rotations than when grown in diverse rotations, particularly after broad-leaf preceding crops. Lower yields of wheat planted after wheat or other unfavourable forecrops result mainly from reduced ear densities and decreased yield components due to a higher pressure of weeds and fungal diseases under these conditions (Lund et al. 1993, Sieling et al. 2005, Kirkegaard et al. 2008, Anderson 2008, Babulicová 2014). While effects of crop rotation on yields of agricultural plants are usually assessed in short- or medium-term experiments, tracing of changes in soil quality as influenced by different crop rotations requires long-term studies (Reeves 1997, West and Post 2002). Such studies are particularly relevant to soil organic matter (SOM), the most important indicator of soil quality, which is also the most often reported attribute due to its impact on other physical, chemical and biological characteristics of soils. Results of long-term field experiments indicate that soils in diversified crop rotation systems accumulate more SOM and possess higher biological activity than soils under short rotations or monocultures of different crops such as soybean, corn or cotton (Reeves 1997, Martyniuk et al. 2001, Russell et al. 2005, Aziz et al. 2011, Van Eerd et al. 2014). With respect to soil properties as influenced by long-term continuous cropping of spring or winter wheat in North America, it was reported that soils under well-fertilized wheat monocultures (without summer fallow) accumulated similar amounts of total organic carbon (TOC) as soils under wheat rotated with soybean, canola, pea or lentil (Campbell et al. 2000, Wright et al. 2007) and had similar amounts of soil microbial biomass C (MBC) (Arshad et al. 2004). In Europe, Riffaldi et al. (2003) showed that soil on adjacent fields planted with winter wheat monoculture or with horticultural crops contained comparable amounts of TOC and MBC. On the other hand, Rychcik et al. (2006) found that soil continuously cropped with spring barley or winter

doi: 10.17221/582/2016-PSE

wheat accumulated significantly more TOC than the same soil under rotation of six different crops. To our knowledge, no such information is available for soil properties as influenced by a long-term cultivation of different cereals on the same field. The objective of this study was to compare selected soil properties and winter wheat yields as influenced by a long-term growing of this crop in rotation with potato and fodder crops and with other cereals (oat, winter rye).

MATERIAL AND METHODS

This study was based on a long-term field experiment established in 1967, at the Grabów Experimental Station (51°21'N, 21°40'E and 167 m a.s.l.) belonging to the Institute of Soil Science and Plant Cultivation in Puławy, on a typical soil in Poland, classified as light loam (Cambisols) containing 26% of silt (0.05–0.002 mm) and 6% of clay (< 0.002 mm). Main characteristics of weather conditions at this site are presented in Table 1. In the experiment, winter wheat is grown in two 4-year crop rotations (A and B) with 50% share of this crop. In the crop rotation A wheat follows potato and fodder crops (potato-winter wheat-fodder crops-winter wheat). Fodder crops consist of a winter rye intercrop harvested at spring as green hay followed by corn for silage. In the crop rotation B preceding crops for winter wheat are oat and winter rye (oat-winter wheat-rye-winter wheat). All phases of the crop rotations were present each year and all crops were grown on 4 replicated plots arranged in a split-plot design. Harvesting area in each plot was 85 m^2. In both rotations cereal straw is removed but 30 t/ha of farm yard manure is applied every 4 years under potato or oat in crop rotation A and B, respectively. Conventional ploughing soil tillage and crop management system is used in this experiment. In the years 2010–2013 cv. Satyna of winter wheat was grown and each year it was fertilized with a fall-applied complex mineral fertilizer Polifoska to give 18 kg N/ha, 26.4 kg P/ha and 74.7 kg K/ha. Spring mineral N (NH_4NO_3) fertilization of wheat at the rate of 120 kg N/ha was applied in 3 doses: 60 kg/ha – at the beginning of spring growth, 36 kg/ha – at stem elongation (31–32 BBCH) and 24 kg/ha at heading (58–59 BBCH). In the years 2010, 2011 and 2013 when wheat plants were at the late milk stage (77 BBCH) 15 plants were dug out from each replicated plot to assess root systems infestation by the take-all fungus *Gaeumannomyces graminis* var. *tritici* (*Ggt*). Take-all severity was assessed and expressed as TAI (take-all index) according to Beale et al. (1998). In 2012, frost killing of winter wheat occurred and this year was not included in the present study. In May of 2010, 2011 and 2013 at shooting of wheat (31–32 BBCH) soil samples were collected from the plough layer (0–25 cm) between plant rows to assess biological soil properties. For this purpose field moist soil samples were passed through a 2 mm sieve and stored in a refrigerator (4°C). Within one week, soil samples were analysed for microbial biomass C and N (MBC and N) by the

Table 1. Long-term average (1976–2013) and monthly mean air temperature and total precipitation at Grabów experimental station

Month	Temperature (°C)				Precipitation (mm)			
	1976/2013	2009/2010	2010/2011	2012/2013	1976/2013	2009/2010	2010/2011	2012/2013
IX	13.1	14.9	12.1	14.5	62.1	32.3	135.7	21.8
X	8.2	6.9	5.4	8.1	42.3	90.7	6.1	83.5
XI	3.1	5.3	6.0	5.3	40.5	72.2	60.6	29.4
XII	–0.9	–1.3	–5.4	–3.4	36.8	55.0	27.7	27.4
I	–2.6	–8.6	–0.8	–3.6	32.2	22.1	30.4	45.4
II	–2.0	–2.2	–3.7	–1.1	26.5	26.2	25.6	37.5
III	2.0	3.0	2.9	–2.1	38.0	25.5	17.6	41.1
IV	8.2	9.0	10.3	8.3	44.0	20.8	35.9	29.9
V	13.8	13.9	13.9	15.3	63.6	114.0	74.5	112.0
VI	16.7	17.6	18.5	18.6	78.4	50.7	52.4	116.3
VII	18.6	21.5	18.4	19.7	89.7	53.4	298.8	20.8
VIII	17.9	19.9	18.8	19.2	77.6	155.1	35.6	11.6

doi: 10.17221/582/2016-PSE

chloroform-fumigation-extraction method and calculated according to the following formula:

$$C_{mic} = E_C/k_{EC}$$

Where: E_C – soluble C in fumigated samples – soluble C in control (unfumigated) samples and k_{EC} – 0.45 (Joergensen and Mueller 1996a), and:

$$N_{mic} – E_N/k_{EN}$$

Where: E_N – soluble N in fumigated samples – soluble N in control (unfumigated) samples and k_{EN} – 0.54 (Joergensen and Mueller 1996b).

An Automated N/C Analyzer (Multi N/C 2100, Analytik Jena, Jena, Germany) was used to measure C and N contents in soil extracts. Dehydrogenase activity was assessed according to Casida et al. (1964) using TTC (2,3,5-triphenyltetrazolium chloride) as the substrate and that of acid phosphatase, using ρ-nitrophenyl phosphate (PNP) as the substrate according to Tabatabai and Bremner method (1969). At full ripeness, wheat was harvested to measure grain yield and yield components (number of ears per square meter, grain bulk weight and one-thousand grain weight). After harvest in 2013 soil samples were collected from the plough layer (0–25 cm) to determine chemical soil properties [contents of: C org. (Tiurin method), P, K and Mg (Egner-Rhiem method), and to measure the pH_{KCl}] by the certified chemical laboratory of the Institute of Soil Science and Plant Cultivation in Puławy, Poland.

The data were subjected to the analysis of variance (ANOVA) with significance of differences assessed at $P < 0.05$.

RESULTS AND DISCUSSION

The content of soil organic C, pH and all biological parameters such as microbial biomass C and N as well as enzymatic activities (dehydrogenase and phosphatase) assessed in this study for the soil on which winter wheat was grown for over 45 years in rotation with oats and rye (cereal rotation B) had values similar to those found for the soil on which winter wheat was rotated with potato and fodder crops (Table 2). Results of previous studies proved that soil quality can be deteriorated only in continuous wheat-fallow rotations, but when wheat or barley were grown in properly fertilized monocultures, soils under these conditions did not differ significantly with respect to their properties, e.g. TOC and MBC contents, from soils under more diversified crop rotations (Campbell et al. 2000, Wright et al. 2006, Smagacz and Kuś 2010). The results of our studies indicate that also soil under long-term rotation of winter wheat with other small grain cereals (rotation B) can maintain high microbial activity and accumulate similar amounts of TOC as the soil under the rotation with potato and fodder crops (rotation A), with the exception of P, K and Mg contents, which were lower in the latter rotation (Table 2). Lower amounts of these macronutrients in the soil of the crop rotation A was probably related to higher removal of these elements with fodder crops biomass (winter rye intercrop harvested as green hay followed by corn for silage). It is worth of noticing that although the amounts of TOC in soils of the compared rotations did not differ significantly, the soil in crop rotation B (cereal rotation) tends to contain about 6% more TOC than the soil in crop rotation A. A similar trend was also reported by Smagacz and Kuś (2010) who analysed these soils ten years earlier. With respect to TOC accumulation in the cereal rotation B, results of this study are in accordance with those reported by Rychcik et al. (2006) showing that soil under 36-year old monocultures of winter wheat, winter rye or spring barley accumulated even

Table 2. Selected chemical and biological properties of soil as influenced by two long-term crop rotations

Crop rotation	Soil organic C (%)	pH_{KCl}	P	K	Mg	Microbial biomass C	Microbial biomass N	Dehydro-genaze (μg formaza-ne/g soil)	Acid phosphat (μg ρNP/g soil)
			(mg/kg soil)			(μg/g soil)			
A (p-ww-fc-ww)	0.76	6.1	102	95	78	142	31.0	35.5	43.0
B (o-ww-wr-ww)	0.80	6.2	126	115	89	139	33.0	37.0	44.5
$LSD_{0.05}$	ns	ns	22	31	6	ns	ns	ns	ns

p – potato; ww – winter wheat; fc – fodder crops; o – oat; wr – winter rye; ns – non significant

doi: 10.17221/582/2016-PSE

Table 3. Take-all index on roots of winter wheat grown after different preceding crops in two long-term crop rotations

Crop rotation/ forecrop	Year			Mean
	2010	2011	2013	
A – potato	3.5	2.7	4.4	3.5
A – fodder crops	4.0	3.2	5.7	4.3
B – oat	6.8	1.5	4.5	4.3
B – winter rye	11.5	11.3	26.3	16.4
Mean	6.5	4.7	10.2	7.1

LSD – 3.7 – for forecrop (I); 3.8 – for years (II); 6.6 – for interaction (I × II)

Table 4. Numbers of ears per m^2 of winter wheat grown after different preceding crops in two long-term crop rotations

Crop rotation/ forecrop	Year			Mean
	2010	2011	2013	
A – potato	510	444	500	485
A – fodder crops	468	425	512	469
B – oat	473	402	498	458
B – winter rye	410	370	439	406
Mean	465	410	487	455

LSD = 28 – for forecrop (I); 22 – for years (II); 49 – for interaction (I × II)

significantly more TOC than the same soil under crop rotation consisting of six crops, including potato and corn.

Growing seasons, preceding crops of winter wheat in the compared rotations and interactions between these factors had significant effects on infestation of winter wheat by the take-all fungus, numbers of ears/m^2, winter wheat grain yields and yield components (Tables 3–5, Figure 1). In all growing seasons only winter wheat grown after winter rye (rotation B) as a forecrop had significantly higher take-all index than wheat after any other preceding crop studied (Table 3). Wheat infestation by the take-all fungus was the most intensive in the 2012/2013 growing season, but only in the case of wheat following rye (rotation B) this effect was significant and was probably related to cold spring, particularly in March of 2013, facilitating infection of wheat roots by *Ggt*, especially when this crop was grown after a take-all susceptible crop, such as rye (Beale et al. 1998, Sieling et al. 2005). Winter wheat grown after rye in crop rotation B produced the lowest number of ears/m^2 (Table 4), which was the most likely a result of the highest take-all infestation found in the case of this forecrop of winter wheat (Table 3), and collectively these factors were presumably responsible for the lowest grain yields obtained for winter wheat grown after winter rye (Table 5). Averaged for all years, the grain yield of wheat following rye was about 24% lower than that of wheat

Table 5. Grain yields (t/ha) of winter wheat grown in 2010–2013 after different preceding crops in two long-term crop rotations

Crop rotation/ forecrop	Year			Mean
	2010	2011	2013	
A – potato	8.56	8.71	6.53	7.94
A – fodder crops	7.32	7.96	6.24	7.18
B – oat	7.62	7.05	6.44	7.04
B – winter rye	6.10	6.53	5.36	6.00
Mean	7.40	7.56	6.14	7.04

LSD = 0.42 – for forecrop (I); 0.33 – for years (II); 0.72 – for interaction (I × II)

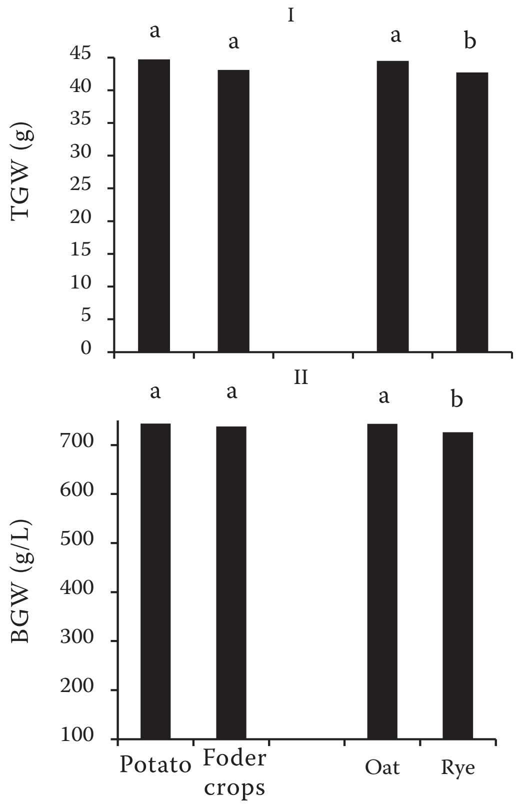

Figure 1. Thousand grain yield (TGW) (I) and bulk grain weight (BGW) (II) of winter wheat grown after different preceding crops in two long-term crop rotations (means of three years). Values with the same letter are not statistically different at $P < 0.05$

doi: 10.17221/582/2016-PSE

grown after potato, which was the best preceding crop for winter wheat in this study and elsewhere (Kirkegaard et al. 2007, Smagacz and Kuś 2010). After fodder crops and oat as the preceding crops winter wheat yielded 15% and 14% more than after winter rye, respectively, but about 10% lower than after potato (Table 5). Oat, corn and other crops not transmitting root diseases such as the take-all fungus were reported as beneficial preceding crops for winter wheat (Sieling et al. 2005, Kirkegaard et al. 2007, Anderson 2008). Figure 1 shows that the deterioration of grain quality as indicated by the lowest values of yield components (thousand grain weight and bulk grain weight) was an another factor contributing to the lowest grain yield obtained for winter wheat grown after winter rye as compared to those found for other preceding crops. In conclusion, this study has shown that soil under a long-term cultivation of winter wheat in rotation with other small grain cereals (rye, oat) can maintain high microbial activity and accumulate similar amounts of TOC as the soil under this crop grown in rotation with potato and fodder crops. However, grain yields of winter wheat following cereals, particularly rye, were generally lower than those obtained for winter wheat grown after non-cereal crops.

REFERENCES

Anderson R.L. (2008): Growth and yield of winter wheat as affected by preceding crop and crop management. Agronomy Journal, 100: 977–980.

Arshad M.A., Franzluebbers A.J., Azooz R.H. (2004): Surface-soil structural properties under grass and cereal production on a Mollic Cyroboralf in Canada. Soil and Tillage Research, 77: 15–23.

Aziz I., Ashraf M., Mahmood T., Islam K.R. (2011): Crop rotation impact on soil quality. Pakistan Journal of Botany, 43: 949–960.

Babulicová M. (2014): The influence of fertilization and crop rotation on the winter wheat production. Plant, Soil and Environment, 60: 297–302.

Beale R.E., Phillion D.P., Headrick J.M., O'Reilly P., Cox J. (1998). MON65500: A unique fungicide for the control of take-all in wheat. In: Proceedings of the 1998 Brighton Conference – Pests and Diseases, 5A-4: 343–350.

Campbell C.A., Zentner R.P., Liang B.-C., Roloff G., Gregorich E.C., Blomert B. (2000): Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan – Effect of crop rotations and fertilizers. Canadian Journal of Soil Science, 80: 179–192.

Casida L.E.Jr., Klein D.A., Santoro T. (1964): Soil dehydrogenase activity. Soil Science, 98: 371–376.

Joergensen R.G., Mueller T. (1996a): The fumigation-extraction method to estimate soil microbial biomass: Calibration of the KEC value. Soil Biology and Biochemistry, 28: 25–31.

Joergensen R.G., Mueller T. (1996b): The fumigation extraction method to estimate soil microbial biomass: Calibration of the KEN value. Soil Biology and Biochemistry, 28: 33–37.

Kirkegaard J., Christen O., Krupinsky J., Layzell D. (2008): Break crop benefits in temperate wheat production. Field Crops Research, 107: 185–195.

Lund M.G., Carter P.R., Oplinger E.S. (1993): Tillage and crop rotation affect corn, soybean, and winter wheat yields. Journal of Production and Agriculture, 6: 207–213.

Martyniuk S., Gajda A., Kus J. (2001): Microbiological and biochemical properties of soils under cereals grown in the ecological, conventional and integrated system. Acta Agrophysica, 52: 185–192.

Reeves D.W. (1997): The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil and Tillage Research, 43: 131–167.

Riffaldi R., Saviozzi A., Levi-Minzi R., Cardelli R. (2003): Conventional crop management effects on soil organic matter characteristics. Agronomie, 23: 45–50.

Russell A.E., Laire D., Parkin T.B., Mallarino A.P. (2005): Impact of nitrogen fertilization and cropping system on carbon sequestration in Midwestern Mollisols. Soil Science Society of America Journal, 69: 413–422.

Rychcik B., Adamiak J., Wójcik H. (2006): Dynamics of the soil organic matter in crop rotation and long-term monoculture. Plant, Soil and Environment, 52: 15–20.

Sieling K., Stahl C., Winkelmann C., Christen O. (2005): Growth and yield of winter wheat in the first 3 years of a monoculture under varying N fertilization in NW Germany. European Journal of Agronomy, 22: 71–84.

Smagacz J., Kuś J. (2010): Influence of cereal crop rotation on yielding of cereals and selected chemical soil properties. Fragmenta Agronomica, 27: 119–134. (In Polish)

Tabatabai M.A., Bremner J.M. (1969): Use of ρ-nitrophenyl phosphate to assay of soil phosphatase activity. Soil Biology and Biochemistry, 1: 301–307.

Van Eerd L.L., Congreves K.A., Hayes A., Verhallen A., Hooker D.C. (2014): Long-term tillage and crop rotation effects on soil quality, organic carbon, and total nitrogen. Canadian Journal of Soil Science, 94: 303–315.

West T.O., Post W.M. (2002): Soil organic carbon sequestration by tillage and crop rotation: A global data analysis. Soil Science Society of America Journal, 66: 1930–1946.

Wright A.L., Dou F.G., Hons F.M. (2007): Soil organic C and N distribution for wheat cropping systems after 20 years of conservation tillage in central Texas. Agriculture, Ecosystems and Environment, 121: 376–382.

Received on September 2, 2016
Accepted on November 11, 2016

Corresponding author:
Dr. hab. Janusz Smagacz, State Research Institute, Institute of Soil Science and Plant Cultivation, Department of Systems and Economics of Crop Production, Czartoryskich 8, 24 100 Puławy, Poland; e-mail: smagacz@iung.pulawy.pl