Yield and quality of spring wheat and soil properties as affected by tillage system

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ABSTRACT

The objective of this study was to analyze the effect of tillage systems and nitrogen fertilization on the grain yield and quality of spring wheat and on selected chemical and biological properties of soil. The first order factor was the tillage system: (1) conventional (CT) – shallow ploughing and harrowing after harvest of the previous crop, and pre-winter ploughing; (2) reduced (RT) – only a cultivator after harvest of the previous crop, and (3) no-tillage (NT) – only Roundup 360 SL herbicide (a.s. glyphosate) after harvest of the previous crop. The second order factor was nitrogen dose: (1) 90 kg N/ha and (2) 150 kg N/ha. Higher yields were demonstrated for spring wheat sown in CT and RT systems, compared to the NT system. In addition, grain yield was increased by a nitrogen dose of 150 kg/ha, compared to 90 kg/ha. Contents of protein and wet gluten in the grain were also increased by the higher nitrogen dose. The RT and NT systems were observed to increase the content of organic C, total N and available phosphorus in the soil, compared to the CT system. They also increased the number and mass of earthworms in the soil, compared to the CT system.

Keywords: tillage system; nitrogen fertilization; *Triticum aestivum*; chemical and biological properties of soil

Tillage determines the physicochemical and biological properties of soil and, hence, affects crop yielding. Plant residues left on the surface of soil in the 'no-till' system enrich it with organic matter (De Vita et al. 2007), which has beneficial effects on the physical properties and biological activity of soil (Roger-Estrade et al. 2010), including mainly the population of earthworms (House 1985). These organisms play a significant role in the soil environment as they accelerate the decomposition of harvest residues; borrow tunnels in the soil, whereas their coprolites are rich in minerals (Crow et al. 2009, Laossi et al. 2010). In contrast, the ploughing system increases soil susceptibility to erosion, accelerates mineralization of organic matter (Reeder 2000), and increases water evaporation (De Vita et al. 2007). Opinions on the effect of reduced tillage systems on cereals yielding are diversified, whilst their effects have been shown to depend on the site of study and range of reduced treatments applied (Jug et al. 2011, Woźniak 2013). As reported by Morris et al. (2010), crop yield depends on many habitat and agrotechnical factors which affect one another. Results of investigations by López-Bellido et al. (1998) and De Vita et al. (2007) indicate that in the areas with low precipitation, higher yields are noted for cereals cultivated in the no-till than in the conventional tillage system. This was also confirmed by findings of Guy and Cox (2002) and these by Hemmat and Eskandari (2004). The agrotechnical factors influence also the quality of grain (Morris et al. 2010), though a research by Gomez-Becerra et al. (2010) demonstrates that these characteristics are strongly dependent on the agroclimatic conditions.

The aim of this study was to analyze the effect of tillage systems and nitrogen fertilization on the yield and quality of spring wheat grain and on selected chemical and biological properties of soil.

MATERIAL AND METHODS

A field experiment with different cropping systems was conducted in the years 2009–2011 at Uhrusk experimental farm (51°18'12''N, 23°36'50''E) belonging to the University of Life Sciences, Lublin in south-eastern Poland. It evaluated grain yield and quality of spring wheat cv. Koksa as well as some chemical and biological properties of soil. The soil the experiment was established at is Rendzic Phaeozem (IUSS Working Group WRB 2006), soil with the composition of light poorly-sandy clay with clay fraction content of 24.2%, dust fraction content of 13.1%, pH_{KCl} = 7.2, rich in phosphorus and potassium. The experiment was established in 3 replications with the method of randomized sub-blocks. Blocks of 8 × 75 m were divided into 3 sub-blocks, and each of the sub-blocks into 2 plots. There were two experimental factors: I. tillage systems (main plots): (1) conventional tillage (CT); (2) reduced tillage (RT); (3) no-tillage (NT); and II. nitrogen doses (subplots): (1) 90 kg N/ha and (2) 150 kg N/ha. The conventional tillage included shallow ploughing (depth of 10–12 cm) and harrowing after the harvest of the previous crop (pea), and pre-winter autumn ploughing (25–30 cm). The reduced tillage included field cultivation (10–15 cm) after the harvest of the previous crop, whereas the no-tillage included only a treatment with Roundup 360 SL herbicide (a.s. glyphosate) – 4 L/ha. In the spring, a tillage set composed of a cultivator, a string roller and a harrow (10–12 cm), was used on all plots. Fertilization with nitrogen was conducted in 4 terms. The dose of 90 kg N/ha was used: (1) before sowing (40 kg/ha); (2) at a tillering stage (21/22 in Zadoks scale) (Zadoks et al. 1974) – 20 kg/ha; (3) at a shooting stage (31/32) – 20 kg/ha, and (4) at an ear formation stage (52/53) – 10 kg/ha. The dose of 150 kg N/ha was applied in the same terms at the following doses: 60, 40, 30, and 20 kg/ha. The phosphate (34.9 kg P/ha) and potassium (99.6 kg K/ha) fertilizers were applied in the spring before wheat sowing. Crop protection against fungi was assured by the application of Charisma 207 EC fungicide (a.s. famoxat + flusilasole) – 1.5 kg/ha at the stage 32/33, whereas weeds were reduced with the use of Chwastox Trio 540 SL (mecoprop + MCPA + dicamba) – 1.5 L/ha at the stage 22/23. In all study years, wheat was sown in the first decade of April, at sowing density of 450 seeds/m^2. The analyzed wheat cv. Koksa is characterized by good yield and grain quality, and is classified in the Common catalogue of varieties of agricultural plant species (EU 2007).

Analyses were carried out for: grain yield, grain quality traits (total protein content, wet gluten content, bulk density of grain), chemical properties of soil (organic C, total N content, available phosphorus, potassium, and magnesium), and biological properties of soil (number and mass of earthworms). Wheat grain was harvested from plots with a Wintersteiger harvester and converted into 14% humidity. Contents of total protein and wet gluten were determined with the NIR (near infrared) method on an Inframatic 9200 apparatus, whereas grain bulk density was assessed using a densimeter with a volume of 1 L. Organic carbon, total N content and available forms of phosphorus, potassium and magnesium in soil were determined in a specialist agrochemical laboratory. All assays were carried out in 3 replications for each plot. The number and mass of earthworms (*Lumbricus*) were determined in two terms: (1) in June (wheat ear formation) and (2) in August (after harvest). The evaluation consisted in hand-picking of all earthworms (without species identification) from 2 soil samples collected from the area of 0.25 × 1.0 m at a depth of 0.30 m from each plot and determination of their number and mass. Results achieved were elaborated 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

Yield and quality of spring wheat grain. The grain yield of spring wheat sown in the CT and RT systems was higher by 13.5% and 8.4%, respectively, than in the NT system (Table 1). Also other studies (Morris et al. 2010, Jug et al. 2011, Woźniak 2013) demonstrate higher cereal yielding in the conventional system than in different modifications of the no-till system. According to De Vita et al. (2007), in areas with precipitation below 300 mm in the vegetation period better results are achieved with the ploughing than with the no-till system. In our study, the sum of precipitation in each vegetation period of wheat was higher than 300 mm (Table 2), which was reflected in higher grain yields in the ploughing system compared to the no-till system. Wheat grain yield was significantly increased by the

Table 1. Grain yield and quality of spring wheat depending on tillage system and nitrogen doses

Nitrogen dose (kg/ha, ND)	Tillage system (TS)			Mean
	CT	RT	NT	
Yield (t/ha)				
90	4.39	4.21	3.80	4.13
150	4.92	4.58	4.25	4.58
Mean	4.65	4.39	4.02	–
$HSD_{0.05}$ for TS = 0.32; ND = 0.28; TS × ND = 0.41				
Total protein (%)				
90	13.2	12.8	13.1	13.0
150	14.0	13.9	14.0	13.9
Mean	13.6	13.3	13.5	–
$HSD_{0.05}$ for TS = ns; ND = 0.3; TS × ND = ns				
Wet gluten (%)				
90	28.9	28.8	28.8	28.8
150	32.6	32.3	31.1	32.0
Mean	30.8	30.6	30.0	–
$HSD_{0.05}$ for TS = ns; ND = 1.1; TS × ND = ns				
Grain density (kg/hL)				
90	72.7	72.3	71.7	72.2
150	73.9	73.0	72.1	73.0
Mean	73.3	72.6	71.9	–
$HSD_{0.05}$ for TS = 0.5; ND = 0.3; TS × ND = 1.2				

CT – conventional tillage; RT – reduced tillage; NT – no-tillage; ns – not significant; $P < 0.05$

fertilization dose of 150 kg N/ha (by 9.8%), compared to the dose of 90 kg N/ha. One of the causes of the increased yield is the increased assimilation area of leaves (leaf assimilation index, LAI), whereas as reported by Spasojević et al. (2012) higher LAI values correspond with higher yields. Contents of protein and wet gluten in the grain depended only on nitrogen fertilization (Table 1). The dose of 150 kg N/ha increased protein content of the grain by 0.9% and wet gluten content by 3.2%, compared to the dose of 90 kg N/ha. In turn, grain density was higher in the CT system than in the RT and NT systems, and was additionally increased by the fertilization dose of 150 kg N/ha. Similar dependencies were observed in studies by Wooding et al. (2000) and Johansson et al. (2001).

Chemical properties of soil. In the soil from RT and NT plots, the content of organic carbon was significantly higher than in the CT soil (Table 3). Also in investigations conducted by De Vita et al. (2007) and Mikanová et al. (2012) organic C content in the topsoil was higher in the no-till than in the ploughing system. According to Reeder (2000), the ploughing system accelerates mineralization of organic matter and hence a lower content of organic C is observed in these plots than in the soil from no-till system. The content of organic C in the soil was also increased by the fertilization dose of 150 kg N/ha, compared to 90 kg N/ha. This may be due to higher mass of harvest residues (roots and stubble) remaining on plots fertilized with high doses of nitrogen. Similar observations were made for total N content in the soil. Also the content of available phosphorus in the soil was lower in plots with the CT system, compared to NT and RT systems, whereas contents of potassium and magnesium were not determined by tillage systems nor nitrogen doses.

Table 2. Weather conditions at the Uhrusk experimental farm

Year	Month						Total or mean
	March	April	May	June	July	August	
Precipitation (mm)							
2009	106.9	27.0	81.5	169.3	42.7	60.0	487.4
2010	29.2	34.4	150.5	72.6	57.5	128.5	472.7
2011	12.0	34.5	42.0	87.4	147.2	64.1	387.2
1963–2010	29.3	40.8	64.2	72.6	79.8	64.6	351.3
Air temperature (°C)							
2009	1.0	10.1	13.1	16.4	20.1	17.8	13.1
2010	1.9	8.8	14.8	18.5	21.6	19.7	14.2
2011	2.1	10.2	14.2	18.5	20.1	18.5	13.9
1963–2010	1.2	7.8	13.6	16.7	18.4	17.6	12.6

Table 3. Chemical properties of soil depending on tillage system and nitrogen doses

Nitrogen dose (kg/ha, ND)	Tillage system (TS)			Mean
	CT	RT	NT	
Organic C (g/kg dm)				
90	5.15	7.32	7.30	6.59
150	5.50	8.05	8.12	7.22
Mean	5.32	7.68	7.71	–
$HSD_{0.05}$ for TS = 0.70; ND = 0.54; TS × ND = 1.01				
Total N (g/kg dm)				
90	0.59	0.96	0.88	0.81
150	0.72	1.10	0.98	0.93
Mean	0.66	1.03	0.93	–
$HSD_{0.05}$ for TS = 0.14; ND = 0.11; TS × ND = ns				
Available P (g/kg dm)				
90	0.09	0.12	0.19	0.13
150	0.11	0.16	0.23	0.17
Mean	0.10	0.14	0.21	–
$HSD_{0.05}$ for TS = 0.09; ND = ns; TS × ND = ns				
Available K (g/kg dm)				
90	0.17	0.21	0.20	0.19
150	0.29	0.19	0.26	0.22
Mean	0.23	0.20	0.23	–
$HSD_{0.05}$ for TS = ns; ND = ns; TS × ND = ns				
Available Mg (g/kg dm)				
90	0.05	0.03	0.03	0.04
150	0.03	0.02	0.03	0.03
Mean	0.04	0.03	0.03	–
$HSD_{0.05}$ for TS = ns; ND = ns; TS × ND = ns				

CT – conventional tillage; RT – reduced tillage; NT – no-tillage; dm – dry weight; ns – not significant; $P < 0.05$

Number and mass of earthworms in soil. The RT and NT systems were significantly increasing the number of earthworms in the soil, compared to the CT system (Table 4). A higher number of earthworms was assessed in the post-harvest period (August) than in the period of ear formation (June). In turn, doses of N had no impact on the number of earthworms, hence these data were not presented in Table 4. Analogous observations were made for the mass of earthworms. Its significantly higher values were noted in the NT and RT systems than in the CT system as well as in the post-harvest period than during wheat vegetation. Also a study by House (1985) demonstrated a negative effect of ploughing on earthworms population. In the non-cultivated soil, the number of earthworms reached 50 per m^2, whereas in the soil cultivated with a plough the earthworms were absent. According to Laossi et al. (2010), the presence of earthworms increases plant biomass in conditions of soil both rich and poor in minerals. Results of a research by Crow et al. (2009) demonstrate that the activity of earthworms contributes to the stabilization of organic carbon in the soil. Also in our study the higher number and mass of earthworms in the soil were accompanied by a higher content of organic C in the soil.

Table 4. Number and mass of earthworms depending on tillage system and term of analysis

Term of analysis (TA)	Tillage system (TS)			Mean
	CT	RT	NT	
Number of earthworms (m^2)				
June	4.0	28.5	30.0	20.8
August	18.0	37.2	36.0	30.4
Mean	12.0	32.8	33.0	–
$HSD_{0.05}$ for TS = 5.4; TA = 4.7; TS × TA = 7.2				
Mass of earthworms (g/m^2)				
June	2.8	11.5	12.5	8.9
August	11.8	13.6	14.0	13.1
Mean	7.3	12.5	13.2	–
$HSD_{0.05}$ for TS = 3.1; TA = 2.9; TS × TA = 4.7				

CT – conventional tillage; RT – reduced tillage; NT – no-tillage; ns – not significant; $P < 0.05$

In conclusion, it can be stated that higher yields were demonstrated for spring wheat sown in CT and RT systems, compared to the NT system. In addition, grain yield was increased by a nitrogen dose of 150 kg/ha, compared to 90 kg/ha. Contents of protein and wet gluten in the grain were also increased by the higher nitrogen dose, i.e. 150 kg/ha. The RT and NT systems were observed to increase the content of organic C, total N and available phosphorus in the soil, compared to the CT system. They were also increasing the number and mass of earthworms in the soil, compared to the CT system.

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