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Winter Wheat Yield and Soil Properties Response to Long-term Non-inversion Tillage

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ABSTRACT

The studies carried out over 2010-13 involved a static field experiment initiated in 1999 at Brody Research Station of the Poznan University of Life Science, Poland. The soil tillage systems for winter wheat were compared on a soil classified as Albic Luvisols. The aim of experiments was to evaluate impact of ploughless soil tillage on some soil physical, chemical, biological properties and winter wheat productivity parameters. Tillage systems included: Conventional Tillage based on moulboard ploughing (CT), Reduced Tillage with a stubble cultivator (RT), and No-Tillage (NT). The soil tilled under RT and NT recorded higher values of water content and soil bulk density, especially in the top layer. On the other hand, in the 10-20 cm layer, soil bulk density was significantly higher under CT than under RT and NT. Soil penetration resistance was lower under CT than under RT and NT from 0 to 20 cm depth. However, soil penetration resistance was consistently higher under CT than under RT and NT from 21 cm to 30 cm depth. Organic C and nutrient elements tended to accumulate in the surface horizons under RT and NT compared with CT. Enzymatic activities were found in the more superficial layers of soil under RT and NT than under CT. The grain yield decreased by 6.9% under NT compared to CT, and ranged over a similar level under RT and CT. The decreased yield in NT probably resulted primarily from a lower number of ears per unit area. In our opinion, in the future, more research is needed to determine the role of changing soil properties over time in crop yields, and no-tillage system needs to be improved to secure plant establishment and crop yield.

Keywords: Enzyme activities, Soil compaction, *Triticum aestivum* L., Tillage systems, Yield components.

INTRODUCTION

Mouldboard ploughing is the dominant primary tillage method in Poland, but non-inversion tillage, particular reduced tillage, is gradually increasing, particularly in large farms.

Adopting non-inversion tillage practices in Poland is used primarily to save costs through reduced time of labor, fuel, and machinery costs. At present, estimated area of non-inversion tillage practices is about 20% of land under annual crops. In Poland, non-inversion tillage systems are a relatively new concept, but, if widely adopted, it may have considerable environmental benefits. Deep tillage also involves a high draught requirement and heavy tractors and also increases the risk of soil compaction. In general, tillage depth and intensity should be kept as low as possible for good conditions for plant growth (Arvidsson *et al*., 2013; Morris *et al*., 2010; Soane *et al*., 2012).

There is a growing trend worldwide for the adoption of conservation tillage systems (no-tillage and reduced tillage) (Holland, 2004). Several studies have shown the positive effect of non-inversion tillage on improving soil

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physical (Arvidsson *et al*., 2013; Katsvairo *et al*., 2002; McVay *et al*., 2006; Romaneckas *et al*., 2012), chemical (Melero *et al*., 2011; Rahman *et al*., 2008; Urbanek and Horn, 2006) and biological properties (Melero *et al*., 2009; Ulrich *et al*., 2010) compared to conventional tillage. Furthermore, the improvement of soil structure allows better soil aeration and water infiltration, and the preservation of a surface cover of residue enhances microbial activity and diversity (Soane *et al*., 2012). The reduction of soil disturbance decreases mineralization of soil organic matter and it can result in larger storage of soil organic C. In general, the long-term effects of soil management practices on the size and activity of the microbial biomass have been closely related to soil organic matter content (Álvaro-Fuentes *et al*., 2013; Madejón *et al*., 2007; Melero *et al*., 2011; Swędrzyńska *et al*., 2013), whereas short-term effects are more complex and also depend on soil conditions, climate, cropping system and kind of crop residue (Al-Kaisi *et al*., 2005).

Furthermore, conservation tillage improves water content (Husnjak *et al*., 2002; Boydaş and Turgut, 2007) and reduces soil erosion (Holland, 2004; Morris *et al*., 2010). However, non-inversion tillage can also lead to soil compaction, which could affect seed germination, root growth, and crop yield (D'Haene *et al*., 2008). When mouldboard ploughing and no-tillage are compared, there are reports on enhanced root growth for no-tillage (Arvidsson *et al*., 2013; D'Haene *et al*., 2008; Hajabbasi, 2001).

The most common variables used to assess soil compaction in tillage studies are bulk density and penetration resistance. In several studies comparing tillage systems, greater bulk density and penetration resistance were found under reduced tillage and direct drilling, especially in the upper layer, than under conventional tillage (Özpinar and Çay, 2005; McVay *et al*., 2006; Blecharczyk *et al*., 2007; Boydaş and Turgut, 2007; Thomas *et al*., 2007).

It is difficult to estimate the consequences of the changes in soil quality on the seed emergence and growing conditions of the plants. The changes in the same property can have different effects on crop growth and yield (Ahmad *et al*., 2010; Arvidsson *et al*., 2014; Jug *et al*., 2011; Fernández *et al*., 2007; Košutić *et al*., 2005; Ozpinar and Ozpinar, 2011; Rieger *et al*., 2008; Woźniak and Kwiatkowski, 2013) depending on dominant soil and climatic conditions. In Europe, crop yields are often reported to be 3-5% lower for non-inversion tillage compared with mouldboard ploughing (Arvidson *et al*., 2013).

The objective of this experiment was to determine the effects of long-term tillage system (conventional moldboard plough, reduced tillage, and no-tillage) on some physical, chemical, and biological properties of soil and the crop yield of winter wheat.

MATERIALS AND METHODS

The studies carried out over 2010-2013 involved a static field experiment initiated in 1999 at Brody Research Station of the Poznan University of Life Science, Poland (52° 26' N; 16° 17' E, altitude 90 m) on a soil classified as Albic Luvisols developed on loamy sands overlying loamy material. Selected soil properties at the beginning of the experiment are presented in (Table1). Prior to the start of this experiment, only ploughing tillage was applied for crops (mainly cereals) and straw of cereals was removed.

Winter wheat *cv*. Türkis, was grown in a 4-year rotation of pea, winter wheat, spring barley, winter triticale. The sowing rate was

Table 1. Physicochemical properties at the experimental site (0-25 cm).

Properties	Value
Organic C (g kg^{-1})	8.1
P (g kg^{-1})	0.21
K (g kg^{-1})	0.12
Mg (g kg^{-1})	0.03
pH_{KCl}	6.5
Sand (g kg^{-1})	690
Silt (g kg^{-1})	190
Clay (g kg^{-1})	120
Bulk density (Mg m^{3})	1.41

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400 seeds per m^2 for all tillage sown. Three tillage systems were arranged in a randomized complete block design in four replications, resulting in a total of 12 plots. Each tillage plot was 30 m long and 5 m wide. The plots were separated by 0.3 m wide buffer strips and 6 m gap between blocks for the tractor. The straw of previous crop (pea) was removed from all plots in all years.

The following tillage systems were applied in continuation: (1) Conventional Tillage (CT); (2) Reduced Tillage (RT), and (3) No-Tillage (NT). The CT consisted of tilling with a disk harrow (2.5 m wide) to a depth of 8 cm after harvest of previous crop, ploughing to a depth of 25 cm with three furrows reversible plough (the first week of September) and pre-sowing tillage for seedbed preparation with a field cultivator followed by harrowing and rolling to a 8 cm depth in one week before sowing. The RT was tilled in the autumn (the second week of September) only with a stubble cultivator (2.5 m wide). The NT involved sowing directly into the stubble of the previous crop. The CT plots were drilled with suffolk coulters grain drill (Poznaniak L, 2.5 m wide, row distance of 15 cm) and the RT and NT plots with a double disk drill (Great Plains, Solid Stand 10' equipped in fluted coulter for residue cutting, double disk for seed placement and single press wheel, 3.05 m wide, row distance 17.8 cm). A Zetor Forterra 10641 for all tillage systems and sowing was used. Operating speeds used for ploughing and drilling were 1.5 and 1.8 m s^{-1} for other tillage treatments (cultivator, disk harrow). Speed was measured by using stop watch and engine tachometer. Sowing dates were dependent on soil water conditions and occurred between 20 and 28 of September and sowing depth in all tillage systems was 3-4 cm.

Fertilization was uniform for all tillage systems and each experimental year (120 kg N ha^{-1}, 35 kg P ha^{-1}, 66 kg K ha^{-1}). The herbicide programme for tillage systems used pre-plant and post-emergence applications. Before planting, 3 L ha^{-1} of glyphosate herbicide was applied on all plots with no-tillage and reduced tillage to control perennial weed and volunteers. For weed control during the growing season post-emergence, Legato Plus 600 SC herbicide (diflufenican + isoproturon) was applied at the rate of 1.4 L ha^{-1}. The seeds were dressed with Raxil Extra 060 FS fungicide (0.06 L per 100 kg seeds) containing thiuram and tebuconazole. For disease control Falcon 460 EC fungicide (tebuconazole+spiroxamine+triadimenol) was applied in 2010/2011 and 2011/2012 and Duet Ultra 497 SC fungicide (thiophanate-methyl+epoxiconazole) was applied in 2012/2013 at the rate 0.6 L ha^{-1} on all plots at GS 31 growth stage (Zadoks *et al*., 1974).

Measurements of penetration resistance (MPa), bulk density (Mg m^{-3}) and volumetric water content (%) of the soil were taken at the stem elongation stage (GS 31) of winter wheat. Penetration resistance was measured to 30 cm depth with a total of sixteen replications per tillage treatment and year. An Eijkelkamp penetrologger was used for the measurements with a cone area 1 cm^2 with a semi-angle of 30°. Soil bulk density was determined by the core method (Blake and Hartge, 1986) at depths of 0-5 cm, 5-10 cm, and 10-20 cm using 100 cm^3 cores (in 16 replications for each depth, tillage treatment and year). The same cores were used to determine volumetric water content in the soil. Soil samples for chemical analyses were collected after harvest of winter wheat in 2013. The replication plot was represented by a mean sample consisting of 10 individual samples collected using an Egner sampler from the 0-5 cm, 5-10 cm, and 10-20 cm layer. After drying, the soil was crushed by hand and sieved through a 2 mm sieve. Organic carbon was determined by the Tiurin oxidation method, total N by Kjeldahl method, available form of P and K by Egner-Riehm method and available Mg by Schachtschabel method (Page *et al*., 1982).

Soil samples for biological analyses were collected at the stem elongation stage (GS 31) of winter wheat in each years in the same way as the samples for physical analyses. The performed examination of the soil enzymatic activity in conditions of different tillage systems was based on the determination of the activities of dehydrogenase and acid phosphatase (in four replications). The activity of dehydrogenases was identified by spectrophotometric method, using as substrate 1% TTC (Triphenyl-Tetrazole Chloride), after 24-hour incubation at 30 °C, at wave length 485 nm. Enzyme activity was expressed in µmol TPF (triphenyloformazan) kg^{-1} DM of soil $24h^{-1}$ (Thalmann, 1968). The activity of acid phosphatase was determined using as substrate p-nitrophenylophosphate sodium, after one hour incubation at 37 °C with wave length 400 nm. Enzyme activity was expressed in µmol PNP(p-nitrophenol) g^{-1} DM of soil h^{-1} (Tabatabai and Bremner, 1969).

Winter wheat was harvested annually in early August from a 20 m^2 area using a 1.5 m wide Wintersteiger Classic Plot Combine. Grain yield was recalculated on standardized 15% grain moisture weight in t ha^{-1}. The following winter wheat quality parameters were assessed: number of ears per m^2 before harvest (4 frames with dimension of 0.25 m^2 in growth stage GS 75), number of grains per ear (some 50 plants), and thousand grain weight in g (grains collected from the harvested grain mass, 2 times 500 grains were counted and weighed).

Table 2 presents monthly mean temperatures and sum of precipitation over the study period. Spring of 2011 had below-average rainfall with above-average temperatures, but there was rainfall in June and July. In 2012, extremely low temperatures in February with absence of snow resulted in winter killing of winter wheat plants. Precipitation distribution and temperatures during the spring of 2012 were above the 50-year average. In the spring of 2013, climatic conditions were generally favorable for the development of winter wheat and crop production.

The results were tested using standard variance analysis (ANOVA) for the randomized complete block. To determine the significance of differences between the system of group analysis of variance, we used T-test Tukey (HSD) at the probability of $P < 0.05$.

RESULTS AND DISCUSSION

Physical Properties

It was found that tillage systems affected significantly the soil physical properties (Table 3). There was a significant difference in the soil water content with RT and NT in

Table 2. Mean daily temperatures of air and sum of precipitation in vegetation period of winter wheat in 2010-13 and along with the 48-year mean (The agro-meteorological observatory in brody).

Month	Mean temperatures (°C)				Sum of precipitation (mm)			
	Years			Mean	Years			Mean
	2010/ 2011	2011/ 2012	2012/ 2013	1961– 2010	2010/ 2011	2011/ 2012	2012/ 2013	1961– 2010
IX	12.4	15.3	14.3	13.3	93.0	46.0	30.0	48.9
X	6.2	9.5	8.2	8.6	7.5	18.2	47.6	42.0
XI	4.4	3.2	4.8	3.6	133.8	0.6	54.8	45.3
XII	-5.6	3.4	-1.5	0.0	74.1	45.7	16.5	48.4
I	0.5	0.9	-1.9	-1.6	31.1	73.9	42.6	40.1
II	-3.2	-3.5	-0.2	-0.5	60.4	47.9	26.1	32.5
III	3.1	5.7	-2.5	2.9	25.0	20.0	12.0	40.4
IV	11.7	8.8	8.0	7.9	13.9	22.9	15.4	38.0
V	14.1	14.8	14.4	13.2	34.0	77.2	69.8	57.4
VI	18.6	16.0	17.3	16.6	52.6	163.0	125.3	61.8
VII	17.9	19.2	20.1	18.2	175.4	197.6	67.3	77.5
VIII	18.8	18.7	19.1	17.5	34.5	60.1	51.5	67.5

Table 3. Volumetric water content and soil bulk density as affected by tillage system (means of 2011-2013).

Tillage systems	Volumetric water content (%)			Bulk density (Mg m^{-3})		
	Soil layer (cm)					
	0-5	5-10	10-20	0-5	5-10	10-20
CT [a]	17.1 c	19.5 c	19.9 b	1.54 a	1.66 a	1.79 b
RT [b]	18.3 b	20.3 b	20.8 a	1.57 b	1.67 ab	1.71 a
NT [c]	20.0 a	21.1 a	21.3 a	1.60 c	1.69 b	1.69 a

[a] Conventional Tillage; [b] Reduced Tillage, [c] No-Tillage. [d] Means in each column followed by the same letter are not significantly different (P< 0.05) according to Tukey test (HSD).

comparison with CT at all depths. The soil tilled under RT and NT recorded higher values of water content, especially in the top layer. Values of volumetric water content in 0-5 cm soil layer increased by 7% under RT and 17% under NT relative to CT. Values of water content in 5-10 cm soil layer increased by 4% under RT and 8% under NT relative to CT. In 10-20 cm soil layer difference in soil water content between RT and NT was not significant, and these parameters were significantly higher than under CT. Boydaş and Turgut (2007), Husnjak *et al*. (2002), and Soane *et al*. (2012) reported that, in general, conservation tillage significantly improved water availability to crops. Lower volume of macropores and higher volume of medium water holding pores are also possible reasons for higher water content in the soil after conservation tillage systems (Lipiec *et. al*., 2006; Morris *et al*., 2010). Furthermore, stubble residues on the soil surface reduced evaporation. However, soil water content is a very variable parameter and it depends on the dominant climatic and soil conditions. Generally, in the years with a high precipitation, no greater differences in soil water content are observed in CT and RT or NT, but in dry years greater water content is found after NT (McVay *et al*., 2006).

The soil tillage systems significantly modified soil bulk density in the spring vegetation period of winter wheat in all soil layers (Table 3). At 0-5 cm depth, RT caused an increase of the value of soil bulk density by 0.03 Mg m^{-3}, and NT by 0.06 Mg m^{-3} as compared with CT. In the 5-10 cm layer, soil bulk density did not differ among CT and RT, and was significantly higher under NT when compared to CT. In the 10-20 cm layer opposite observations were made than in the 0-5 cm depth. Soil bulk density was significantly higher under CT than under RT and NT. Similar results with the soil bulk density were reported by McVay *et al*. (2006), and Thomas *et al*. (2007). In turn, research results obtained in long-term experiments with NT indicate a decrease of the bulk density in the upper soil layer in comparison with the conventional tillage system. This would be related to the leaving stubble residues on top of non-tilled soils that provides organic matter and food for soil fauna, particularly for earthworms, which loosen surface soil by burrowing activities (Katsvairo *et al*., 2002). Hemmat (2009), on the contrary, observed that the soil bulk density in the 0-5 and 5-10 cm layers were not significantly affected by tillage treatments. The high soil bulk density reduces aeration and increases penetration resistance, limiting root growth and development of crops (Arvidsson *et al*., 2013; D'Haene *et al*., 2008; Hajabbasi, 2001).

Soil penetration resistance for all treatments showed an increasing trend with depth (Figure 1). Soil penetration resistance was lower under CT than under RT and NT from 0 to 20 cm depth, which is a likely result of ploughing. However, soil penetration resistance was consistently higher under CT than under RT and NT

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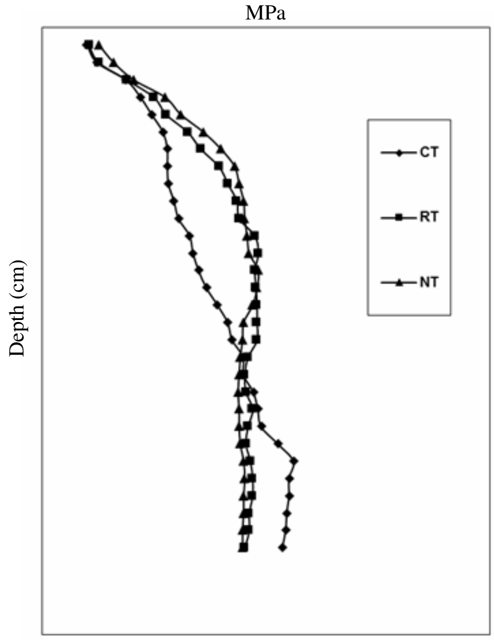

Figure 1. Penetration resistance as affected by tillage system: Conventional Tillage (CT), Reduced Tillage (RT), and No-Tillage (NT) (mean of 2011-2013).

from 21 cm to 30 cm depth. Reduced tillage produced a similar overall penetration resistance profile to NT, although, penetration resistance under RT was lower over the 0-11cm, and higher over 12-30 cm depth relative to that under NT. Hence, seedling germination and early growth of winter wheat would experience somewhat more favorable soil strength conditions at 0-12 cm depth under RT than NT. The smaller soil strength at depths greater than 21 cm under RT and NT relative to CT may be the result of the development of a plough pan in CT. Penetration resistance values in all treatments in the 0-20 cm layer were below the 2-3 MPa critical level. Above this level is generally considered slow for root growth (Bengough and Mullins, 1990). At 20-30 cm depth, where the tractor wheels compact the soil during ploughing, compaction of the soil was lower under RT and NT. The effects of tillage systems on soil penetration resistance are highly variable. For example, soils under CT may have lower (Özpinar and Çay, 2005; Małecka *et al*., 2012; Shi *et al*., 2012), equal (Katsvairo *et al*., 2002) or higher (Blanco-Canqui *et al*., 2005) penetration resistance than those under NT or RT. It depends on soil type, clay content, water content, bulk density, soil depth, and time to last tillage operations.

Chemical Properties

A difference in management practices result in differences in chemical properties of soil which in turn, result in changes in functional quality of soil. Soil under ploughless tillage systems have greater storage of diverse plant biomass on undisturbed surface or in the soil surface layer, which results in considerable improvement in soil properties, particularly SOM and N content and decrease the *C/N* ratio compared to conventional tillage (Aziz *et al*., 2013; Karlen *et al*., 2013; Ulrich *et al*., 2010). Urbanek and Horn (2006) suggested that in conservation tillage the accessibility of organic C for microorganisms and leaching into deeper horizons of soil is lower, and less organic C is removed from the soil than in conventional tillage.

The data in Table 4 show that, after thirteen years, accumulation of organic C and total N at the soil surface (0-10 cm) was higher under RT and NT in comparison to CT. The concentration of organic C under RT and NT had increased significantly in the top layer (0-5 cm) by 19.5 and 36.6%, respectively, in comparison with CT. Stock of organic C in the 5-10 cm depth was not significant in the plots under CT and RT practices, but increased significantly under NT by 13.4 and 8.1%, respectively. Difference in stock of organic C between tillage systems was not significant at the 10-20 cm depth. Total N concentrations in RT and NT were greater by 9.7 and 14.0% in 0-5 cm layer, and by 3.3 and 7.6% in 5-10 cm layer, respectively, than under CT (Table 4). There were no significant differences between tillage systems at the 10-20 cm interval. The higher *C/N* ratio was obtained at 0-5 cm and 5-10 cm soil layers of the RT and NT plots, than under CT, however,

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Table 4. Organic C, total N and available form of P, K, and Mg concentration in the soil under tillage systems.

Component	Soil depth (cm)	Tillage systems		
		CT [a]	RT [b]	NT [c]
Organic C ($g\ kg^{-1}$)	0-5	8.20 c	9.80 b	11.20 a
	5-10	8.20 b	8.60 b	9.30 a
	10-20	8.30 a	8.70 a	8.40 a
Total N ($g\ kg^{-1}$)	0-5	0.93 b	1.02 a	1.06 a
	5-10	0.92 b	0.95 ab	0.99 a
	10-20	0.90 a	0.91 a	0.88 a
C/N	0-5	8.8 c	9.6 b	10.6 a
	5-10	8.9 b	9.1 ab	9.4 a
	10-20	9.2 a	9.6 a	9.5 a
P ($mg\ kg^{-1}$)	0-5	217 a	195 a	199 a
	5-10	206 a	198 a	191 a
	10-20	225 a	217 a	220 a
K ($mg\ kg^{-1}$)	0-5	130 c	176 b	202 a
	5-10	120 b	163 a	173 a
	10-20	129 a	144 a	139 a
Mg ($mg\ kg^{-1}$)	0-5	24.0 c	36.0 b	57.0 a
	5-10	18.0 c	32.0 b	40.0 a
	10-20	25.0 a	25.0 a	21.0 a

[a] Conventional Tillage; [b] Reduced Tillage, [c] No-Tillage. Means in each row followed by the same letter are not significantly different (P< 0.05) according to Tukey test (HSD).

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difference between CT and RT was not significant. Difference in soil *C/N* ratios between tillage systems was not significant at the 10-20 cm depth. Several studies have indicated that the introduction of ploughless tillage systems leads to increased organic C and total N closer to the soil surface (Al-Kaisi *et al*., 2005; Aziz *et al*., 2013; Karlen *et al*., 2013; Rahman *et al*., 2008; Ulrich *et al*., 2010).

Stocks of available K and Mg were greater in the soil surface layer (0-5 cm) under RT and NT, than under CT (Table 3). The situation was similar in a deeper layer (5-10 cm), where available K and Mg were greater in RT and in NT, than in CT. Other authors have also found available macronutrients values to be greater in the upper layers (0-10 cm) under RT and NT than under CT, the effect being apparently due to reduced mixing of mineral fertilizer (López-Fando and Pardo, 2009; Małecka *et al*., 2012). In our study, no significant effects of tillage practices were observed on available P, in all soil layers, and available K and Mg, in the 10-20 cm layer. At Brody Research Station, the tillage systems did not exert any significant effect on the content of available form of phosphorus in both analyzed layers, which may be related to very high initial contents of this element in this soil. In general, our results are in agreement with those obtained by the abovementioned studies.

Higher levels of soil organic C and N, and available K, P, and Mg at the soil surface under conservation tillage were directly related to surface residue accumulation (Franzluebbers, 2002). Many of such soil modifications start 4-5 years after the beginning of the conservation tillage systems. Continuous, long-term ploughless management can sustain or even improve soil quality (Derpsch, 2007). According to the opinion of the mentioned author, after many years of the conservation tillage system, it may be possible to decrease mineral fertilization under plants grown in that system.

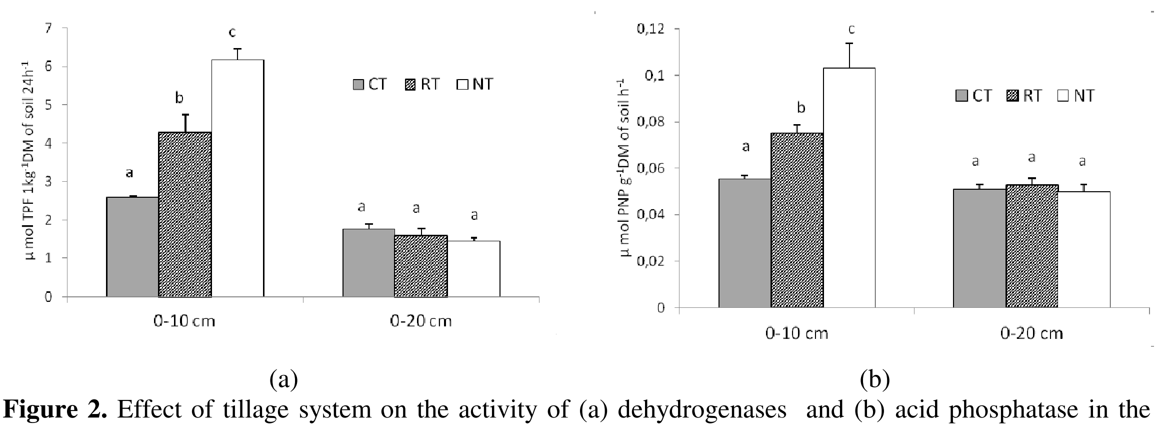
Biological Properties

Enzyme activities have been used in a variety of ways to assess issues of agronomic and environmental quality. They have been tested as indices of soil fertility, soil quality, soil productivity, pollution effect, and nutrient cycling potential (Madejón *et al*., 2007; Melero *et al*., 2009). In this research project, activities of dehydrogenases and acid phosphatase were analyzed.

For both activities, in 0-10 cm soil layer, values were significantly higher under RT and especially under NT than under CT (Figures 2 a-b). On average, in the period of this experiment, activities of dehydrogenases and acid phosphatase were higher under RT by 65% and 36% and under NT by 139 and 86%, respectively. This indicating a consistent improvement of soil quality under plougless tillage systems. Values of enzyme activities decreased with depth of soil profile, which is probably connected with numbers of microorganisms resulting from their spatial distribution (Levyk *et al*., 2007). In the case of the near-surface layer (0-10 cm), the activity of dehydrogenases was even several times higher than in deeper layers. Also, several authors have reported higher enzymatic activities under soil conservation tillage management than under traditional tillage management (Álvaro-Fuentes *et al*., 2013; Soane *et al*., 2012; Swędrzyńska *et al*., 2013; Ulrich *et al*., 2010). These results may be also related to high input of C sources through crop residues left on the surface, which stimulate the growth and activity of soil microorganisms. Besides, those results could also be related to the protection and stabilization of organic matter by soil microbial biomass and enzymatic activities. Several authors have indicated that enzymatic activities are closely correlated to organic carbon (Álvaro-Fuentes *et al*., 2013; Madejón *et al*., 2007; Melero *et al*., 2009; Soane *et al*., 2012; Swędrzyńska *et al*., 2013). Differences in enzymatic activity values between tilled and no-tilled soils may be due to changes in the populations of aerobic and facultative anaerobic microorganisms. Thus, ploughless tillage systems tend to have biochemical environments less oxidative than tilled soils (Melero *et al*., 2011). In this study, deeper layers values of enzyme activities were similar and significant differences between tillage systems were not found. This tendency has been observed elsewhere (Madejón *et al*., 2007; Melero *et al*., 2011; Ulrich *et al*., 2010). Nevertheless, from practical point of view, the activity stimulation of dehydrogenases and acid phosphatase is of considerable importance in liberation processes of plant nutrients.

Grain Yield and Yield Components

Yield of winter wheat was closely related to the course of weather conditions,



(a) (b)

Figure 2. Effect of tillage system on the activity of (a) dehydrogenases and (b) acid phosphatase in the two layers of the soil profile (mean of 2011-2013). Significant differences between treatments are indicated with different letter ($P < 0.05$). Vertical bars are standard errors. CT: Conventional Tillage; RT: Reduced Tillage, NT: No-Tillage.

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especially with the sum of precipitation in the spring vegetation period and climatic conditions in the winter (Table 5). As for the tillage systems, on average, a greater grain yield was obtained in the years 2011 and 2013 in response to the favorable weather conditions (7.47 t ha^{-1}). The lowest winter wheat grain yield was in 2012 (5.78 t ha^{-1}), when extremely low temperatures in February in absence of snow resulted in winter killing of winter wheat plants. In this year, grain yield decreased by 23% compared with 2011 and 2013. This is in accordance with many authors who emphasized the importance of climatic conditions during the growing season for grain yield (Arvidsson *et al*., 2013; Jug *et al*., 2011). Tillage affects crop yield, mainly through its associated effects on soil loosening, crop establishment, weeds, and plant residues. In Europe, crop yields are often reported to be 3-5% lower for non-inversion tillage compared with mouldboard ploughing (Arvidsson *et al*., 2013).

In this study, winter wheat reacted differently to tillage compared to mouldboard ploughing (Table 5). There were no effects of tillage systems on grain yield and yield components during the second year. It was probably connected with winter killing of winter wheat plants. In this year, ear density was similar under CT, RT and NT methods. In the first and last experimental years, winter wheat grain yield under NT was significantly lower than in CT and RT. The yield of winter wheat under RT and CT ranged over a similar level during 2010-11 and 2012-13. This is in line with the results of Arvidsson *et al*. (2014), Jug *et al*. (2011), and Ozpinar and Ozpinar (2011). Some authors state that CT is significantly better for wheat than the RT (Ahmad *et al*., 2010; Košutić *et al*., 2005). Increased grain winter wheat under RT compared with CT has also been reported by Šíp *et al*. (2013). In general, winter wheat can be expected to

Table 5. Effect of tillage system on winter wheat grain yield and yield components.

Tillage systems	Years			Mean
	2011	2012	2013	
		Grain yield (t ha^{-1})		
CT[a]	7.77 a	5.80 a	7.61 a	7.06 a
RT[b]	7.85 a	5.80 a	7.64 a	7.10 a
NT[c]	6.79 b	5.75 a	7.16 b	6.57 b
Mean[d]	7.47 a	5.78 b	7.47 a	-
		Number of ears per m^2		
CT	482 a	285 a	509 a	426 a
RT	466 a	286 a	438 b	397 b
NT	408 b	277 a	401 c	362 c
Mean[d]	452 a	283 b	449 a	-
		Grain number in ear		
CT	36.5 c	44.3 a	31.0 b	37.3 b
RT	37.7 b	44.2 a	35.1 a	39.0 a
NT	38.7 a	45.0 a	35.9 a	39.9 a
Mean[d]	37.6 b	44.5 a	34.0 b	-
		1000 grain weight (g)		
CT	44.2 a	45.8 a	48.2 b	46.1 a
RT	44.7 a	45.9 a	49.8 a	46.8 a
NT	43.1 b	46.1 a	49.7 a	46.3 a
Mean[d]	44.0 c	45.9 b	49.2 a	-

[a] Conventional Tillage; [b] Reduced Tillage, [c] No-Tillage. [d] Means in each column followed by the same letter are not significantly different (P<0.05) according to Tukey test (HSD). Means in this row followed by the same letter are not significantly different (P< 0.05) according to Tukey test (HSD).

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have a good tolerance to compaction (Atkinson *et al*., 2009).

In our investigation, winter wheat yield under NT was lower compared with CT (Table 5). On average, in the period of this experiment, the yield of winter wheat in NT was significantly lower (by 6.9%), relative to CT. Similar results were reported by Fernández *et al*. (2007), and Rieger *et al*. (2008). Mechanisms for yield reductions under no-till vary according to local conditions. On light-textured soils in Denmark, compaction has been identified as the primary problem, whereas, in Sweden and Norway crop residues generally cause greater problems than compaction, while, in Finland no-till yield reductions have been attributed to crop residues, weeds, and compaction under wet conditions (Soane *et al*., 2012). Smaller winter wheat yield under NT compared with CT in this study (in Poland) may be due to increased soil compaction over the 0-11 cm layer, which limited germinations, root growth, development and yield of crops and left over plant residue on the surface, probably causing problems for drilling subsequent crops and increasing plant pathogens. However, it also depends on the type of soil. Arvidsson *et al*. (2013) concluded, too, that a possible explanation for poor results of winter wheat under NT is an increase in plant pathogens transferred from plant residues, which emphasizes the importance of crop rotation in ploughless tillage systems.

The decreased yield in NT resulted primarily from a lower plant density in the tillering and, in consequence, from a lower number of ears per unit area. In NT, the mean number of ears per m^2 was smaller by 15.0% than in CT. In RT, winter wheat was characterized by a significantly lower than average number of ears per m^2 in comparison with CT. As to 4-year average and the first and last experimental years, the number of grains in ear for ploughless tillage systems resulted in the higher grains number in ear. The average number of grains per ear was higher under RT and NT, than under CT. A possible explanation for this result is that, in conditions of less plant density and number of ears per unit area, winter wheat formed higher grains number in ear. Numerous experiments performed to compare the effect of tillage systems on yield components of cereals have given different results. Our results are in contrast to Jug *et al*. (2011) who found smaller number of grains per spike under RT and NT than in CT. In the study by López-Bellido *et al*. (2000) different tillage systems did not have a significant influence on the number of grains per spike. The average thousand-grain weight was similar for the three tillage systems, but different between the years. In 2011, the lowest weight was obtained by NT, but in 2013 by CT. Lower number of ears per m^2 in RT and NT is often compensated by greater 1,000-grain weight (Jug *et al*., 2011; Romaneckas *et al*., 2012).

In conclusion, this experiment showed that, over a 13-year period, differences in tillage practices (CT, RT, NT) in winter wheat production on the soil classified as Albic Luvisols led to changes in soil properties, especially in the top layer. The most favorable soil physical (higher water content), chemical (increased organic C, total N, available K, and Mg), and biological properties (higher enzyme activities) were recorded under reduced tillage and especially under no-tillage than under conventional tillage.

A primary tillage system with stubble cultivator non-inversion tillage gave similar yield of winter wheat as the mouldboard ploughing, under Polish conditions. Yield in no-tillage was lower than for mouldboard ploughing. The decreased yield in NT resulted primarily from a lower plant density and, in consequence, from a lower number of ears per unit area. The investigations indicating that the major problems in no-tillage were caused by soil compaction and plant residue on the surface. Surface crop residue need to be carefully managed so as to maximize the benefits of the residue.

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عملکرد گندم زمستانه و واکنش ویژگی های خاک به خاکورزی بدون برگردان خاک در یک دوره طولانی

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چکیده

این پژوهش ها که در طی سال های ۱۳-۲۰۱۰ اجرا شدند در ادامه پژوهش هایی مزرعه ای بود که در سال ۱۹۹۹ در ایستگاه تحقیقاتی Brody در دانشگاه علوم طبیعی Poznan در لهستان آغاز شده بود. در این بررسی، سامانه های خاکورزی گندم زمستانه روی خاکی که به عنوانAlbic Luvisols رده بندی شده بود مقایسه شد. هدف مطالعه ارزیابی خاکورزی بدون خیش روی برخی ویژگی های فیزیکی، شیمیایی و زیستی خاک و پارامتر های بهره وری گندم زمستانه بود. سامانه های خاکورزی عبارت بود از: خاکورزی مرسوم بر مبنای استفاده از گاوآهن برگردان دار (CT)، کم خاکورزی (RT) با کاربرد پنجه کلشی(stubble cultivator)، و بدون خاکورزی (NT). اندازه گیریهای آزمایش نشان داد که خاک های تیمارهای RTو NTرطوبت و جرم مخصوص بیشتری داشتند، به ویژه در لایه

بالای خاک. بر عکس، در لایه ۲۰–۱۰ سانتی متری، جرم مخصوص خاک در تیمار CT به طور معنی داری بیشتر از RT و NT بود. مقاومت فرو روی در لایه20-0 سانتی متری خاک در تیمار CT کمتر از RT و NT بود. با این وجود، در لایه ۳۰–۲۱ سانتی متری، مقاومت فرو روی در تیمار CTهمواره بیشتر از RT و NT بود. مقدار کربن آلی و عناصر غذایی در تیمارهای RTو NT گرایش بیشتری از تیمارCT به انباشت در لایه بالای خاک نشان دادند. همچنین، فعالیت های آنزیمی در لایه های سطحی خاک در تیمارهای RT و NTبیشتر از تیمار شاهد CTبود. عملکرد محصول در تیمار NT ۶/۹٪ کمتر از CT بود و محدوده تغییرات آن شبیه محدوده تیمارهای RT و CT بود. کاهش عملکرد در NT احتمالا در نتیجه کمتر بودن تعداد خوشه در واحد سطح بود. به نظر نویسندگان، تحقیقات بیشتری در آینده لازم است تا نقش تغییرات ویژگی های خاک بر عملکرد محصول در طول زمان مشخص شود و سامانه بی خاکورزی هم می بایست در جهت استقرار گیاه و عملکرد بهبود یابد.

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