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EFFECTS OF THE LONG-TERM APPLICATION OF TILLAGE SIMPLIFICATIONS ON SOME SOIL PROPERTIES AND YIELD OF CHOSEN SPRING PLANTS

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Abstract. At the Experimental Station of the Institute of Soil Science and Plant Cultivation in Jelcz-Laskowice, the Lower Silesia, three tillage systems have been compared in field experiments carried out on lessive soil developed from heavy loamy sand since 1993. Conventional tillage – ploughing to a depth of 25-30 cm and additional cultivation of soil for sowing with the use of traditional tools; reduced tillage – with the use of a cultivator to a depth of 10-15 cm and additional tillage with a sowing set; zero-tillage – direct sowing into untilled soil. In 2006-2009 the cultivated plants included: pea, spring barley, oat and spring wheat. In spring, physical properties of soil were determined. Long-term simplifications in tillage caused slower soil warming in spring and its higher bulk density. They did not unambiguously affect soil moisture, but they influenced increase of phosphorus and potassium content in the surface layer of soil. However, long-term simplifications in tillage caused decrease in the plant yield.

Key words: soil density, soil temperature, zero-tillage, soil moisture

INTRODUCTION

Conventional tillage, whose fundamental treatment is ploughing, is characterized by high labour- and energy-consumption. Simplification in tillage depends on the decrease of cultivation depth, replacing plough with cultivating-seeding sets, bring savings in work and energy expenditure [Hernanz *et al.* 1995, Vilde 1999, Orzech *et al.* 2004, Smagacz 2006]. However, yield of both winter and spring crops, with the application of tillage simplifications, and especially with the so called zero-tillage, are significantly lower than in conventional tillage [Blecharczyk *et al.* 1999, Dubas and Menzel 1999]. Continuing for years non-ploughing tillage causes numerous changes in physical and chemical properties in the soil environment, and affects the yield level in plants. Non-

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-ploughing tillage systems may cause an increase in weed infestation or lead to compensation of some weed species. The basic source of weed infestation in crops are weed seeds in soil, referred to as soil seed bank [Aldrich 1997]. Their largest amount can be observed in the layer to a depth of 20 cm. Distribution of seeds in the soil depends on many factors, among others, on the tillage system. With ploughing tillage they are distributed more or less evenly in the layer up to a depth of 20 cm, in a reduced tillage (zero-tillage) in the layer to 15 cm, in the zero-tillage however (direct seeding) most of them can be found in the layer to a depth of 10 cm, and their number decreases rapidly along with the depth [Dyer 1995, Witkowski 1998, Bochenek 2000, Sekutowski 2009].

The aim of the research was evaluation to what degree long-term reduced tillage will affect chosen physical and chemical properties of the soil and yield of chosen spring plant species compared with conventional tillage.

MATERIAL AND METHODS

The research was carried out at the Experimental Station of the Institute of Soil Science and Plant Cultivation in Jelcz-Laskowice in Lower Silesia (51°02' N; 17°21'E) on lessive soil formed from heavy loamy sand. Since 1993, three tillage systems have been applied on four stands of an area of app. 9 ha each: conventional – based on ploughing conducted to a depth of 25-30 cm; reduced – non-ploughing tillage, where the basic treatment was tillage to a depth of 10-15 cm with a set for post-harvest tillage and zero-tillage – with no mechanical tillage with a herbicide reduction of weed infestation and sowing seeds into the untilled soil with the use of a seed drill with disc coulters. In the years 2006-2009 every year 70 are areas were separated for seeding with four studied spring plants: pea, spring barley, oat and spring wheat. The experiment was carried out in four replications. The same mineral fertilization was applied on all plots: under pea and spring barley 62 kg N and 84 kg P_2O_5 each and 84 K_2O kg per ha, while under spring wheat and oat 96 kg N and 84 kg P_2O_5 each and 84 kg K_2O per ha. In spring, soil temperature was determined with an electronic thermometer. Temperature sensor at the tip of the probe was placed in the soil at a desired depth, after establishing the indication, the value was read from the display. Measurements were conducted at a depth of 3, 4 and 5 cm in five replications. On each experimental plot, soil samples were collected with a cylinder of 100 cm^3 in volume from the following layers: 0-5, 10--15 and 20-25 cm in 4 replications in order to determine soil moisture and density with a gravimetric method.

After harvesting crop plants, the yields were determined, and the results were subjected to statistical analysis calculating LSD with the use of analysis of variance, at the significance level of 0.05. Calculations were carried out with Anova program. In 2009 after harvest, pH in KCl was determined as well as the content of phosphorus, potassium and magnesium in soil samples collected from the following layers: 0-10, 10--20 and 20-30 cm.

Weather conditions

Weather conditions in the research period were diverse, both the air temperature and rainfall were different from the long-term mean value (Table 1). In all years, in months March-August, except March 2006 and June 2009, it was warmer than on average.

Long-term monthly mean values of rainfall total in the period from April to July were lower than the optimum ones for the cultivated plants. However, in some years, there occurred months of the rainfall total reaching optimum values, and also of its visible deficiencies. In June 2009, rainfall total reached twice the optimum rainfall. Slightly lower rainfall totals, however, considerably exceeding optimum values, were observed in July 2007 and 2009. In the growing period, there also occurred periodical rainfall deficiencies. In July 2006 and in April 2007 rainfall totals were only 2.3 and 4.2 mm. In May 2006 and in June 2008, the amount of rainfall did not even reach half the optimum values for the cultivated plants.

Table 1. Air temperature and rainfall in Jelcz-Laskowice
Tabela 1. Temperatura powietrza oraz opady w Jelczu-Laskowicach

Year Rok	Month – Miesiąc						Annual values Wartości roczne
	March marzec	April kwiecień	May maj	June czerwiec	July lipiec	August sierpień	
Temperature – Temperatura, °C							
2006	1.5	9.4	14.2	19.0	23.2	17.2	9.8
2007	5.8	10.2	15.7	19.6	19.3	18.6	10.0
2008	4.0	8.6	13.9	18.6	20.0	18.6	10.1
2009	3.8	11.3	13.8	15.6	19.5	18.9	8.9
1961-2000	3.3	8.2	13.4	16.6	18.1	17.6	8.5
Rainfall – Opady, mm							
2006	28.9	50.2	29.9	95.6	2.3	162.4	605.2
2007	52.4	4.2	54.4	66.5	112.8	58.9	639.7
2008	49.2	55.1	40.7	29.3	44.2	95.6	525.5
2009	60.9	24.7	65.7	180.8	145.1	50.4	794.0
1961-2000	31.6	36.9	63.8	71.5	75.4	70.6	563.7
Plant – Roślina	Optimum rainfall – Opady optymalne						
Pea – Groch	–	53	80	92	79	–	–
Spring barley Jęczmień jary	–	46	68	83	78	–	–
Oat – Owies	–	48	68	84	80	–	–
Spring wheat Pszenica jara	–	56	71	73	84	–	–

RESULTS AND DISCUSSION

Long-term use of simplifications in tillage affected physical properties of soil. Soil moisture in the layer 0-25 cm, expressed in % of dry matter (Table 2), was characterized by diversification resulting from the interaction of the applied tillage techniques and also from the depth of the measured layer. Each year in the layer 0-5 cm, significantly higher soil moisture was observed after zero-tillage than after conventional tillage. Similar results were obtained in the Scottish research [Ball and Ritchie 1999, Ball *et al.* 1999], as well as the American [Lyon *et al.* 1998] and the Australian one [McGarry *et al.* 2000]. This most probably results from a lower water permeability of untilled soil (zero-tillage) than in the soil with a conventional tillage. Logical consequence of this is soil moisture in the layer 10-15 cm, where the situation is reverse, i.e. significantly higher water content was characteristic of soil in conventional tillage than in zero-

-tillage. This phenomenon has its confirmation also in the results of other studies [Pabin *et al.* 2001, 2002, Włodek *et al.* 2002]. As a result, mean soil moisture from four years in all layers did not differ significantly between compared tillage systems. Similar results were achieved by Lal and Ahmadi [2000]. Independently of the applied tillage treatments, the soil was characterized by a significant diversification in moisture on particular depths. However, a characteristic feature was occurrence of lower water content in deeper layers than in surface layers. This may indicate a process of soil moistening from above occurring when collecting samples.

Compared tillage systems significantly affected soil density in each year of research (Table 3). The highest density was characteristic of the soil in layers 0-5 and 10-15 cm after zero-tillage. Based on previous research [Pabin *et al.* 2009], it may be presumed that such a high soil density at the beginning of the growing period and decreasing soil moisture may have created unfavourable conditions for growth and yield of the cultivated plants. In the layer 20-25 cm, soil density reached a similar level independently of the tillage system. In the profile of arable layer, the least diversified density was characteristic of the soil after zero-tillage – these differences were insignificant: from 0.02 to 0.13 $g \cdot cm^{-3}$. In other cases, they oscillated within the range of 0.40-0.54 $g \cdot cm^{-3}$. Described diversity of soil density may have affected the speed of water movement and moisture distribution in the arable layer profile.

Differentiated tillage system affected the soil temperature which was determined in spring (Table 4). After zero-tillage, the soil was cooler than after conventional and reduced tillage, on average by $4^{o}C$. Obtained effects probably resulted from a different thermal conductivity of soils of varied compaction degree [Baranowski and Bakowski 1977, Lipiec *et al.* 1987]. Significantly lower soil temperature after zero-tillage may have resulted from the mulch formed from crop residues, which constituted a thermal barrier delaying the soil heating process.

In the years 2006-2009, tillage simplifications applied since 1993, significantly decreased the yield of the following spring plants: pea, barley, oat and wheat (Table 5). Only in 2006 differences in the grain yield of spring barley and spring wheat were not statistically confirmed. The very low yield level in 2006 was probably caused by the rainfall deficiency. In May, rainfall total did not even reach half the water requirements of the cultivated plants, with high air temperatures which exceeded means from the long-term period. Mean yield of pea, spring barley and oat from the years 2006-2009 significantly decreased along with the increase of the degree of tillage simplification. Only in the case of spring wheat the differences were not confirmed statistically.

The applied tillage simplifications caused increase in the soil compaction, which could have inhibited root penetration into the profile and may have reduced absorption of nutrients and water by the plants later in the growing period, causing the yield decrease. Similar effects were observed by Blecharczyk *et al.* [2004], Dzienia and Dojsos [1999], Starczewski and Czarnocki [2004].

Table 2. Influence of tillage systems on soil moisture, % dry matter
Tabela 2. Wpływ sposobów uprawy roli na wilgotność gleby, % s.m.

Layer – Warstwa cm	Date – Termin																Mean – Średnia			
	29.03.2006				12.03.2007				31.03.2008				31.03.2009							
	Tillage – Uprawa																			
	T	U	Z	śr	T	U	Z	śr	T	U	Z	śr	T	U	Z	śr	T	U	Z	śr
0-5	15.0	15.3	16.6	15.6	14.8	15.1	16.4	15.4	12.0	13.4	14.9	13.4	14.6	15.6	17.8	16.0	14.1	14.9	16.4	15.1
10-15	16.5	15.5	14.8	15.6	16.2	15.4	14.3	15.3	13.4	15.2	12.9	13.8	15.4	15.3	12.8	14.5	15.4	15.4	13.7	14.8
20-25	14.0	14.1	14.2	14.1	13.9	14.1	14.2	14.1	13.4	13.4	12.4	13.1	15.4	13.6	15.3	14.8	14.6	13.8	14.0	14.0
Mean – Średnia	15.2	15.0	15.2	15.1	15.0	14.9	14.9	14.9	13.0	14.0	13.4	13.4	15.1	14.8	15.3	15.1	14.6	14.7	14.7	14.7
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:																				
Up		ns – ni				ns – ni				0,88				ns – ni				ns – ni		
G				0.89				0.98				ns – ni				0.91				0.694
interaction – interakcja:																				
Up x G		1.38				1.40				1.27				1.31				1.016		
L										0.892										
interaction – interakcja:																				
L x Up										ns – ni										
L x G										ns – ni										

Up – tillage – uprawa: T – conventional – tradycyjna, U – reduced – uproszczona, Z – zero-tillage – zerowa, śr – mean – średnia
G – depth – głębokość, L – years – lata
ns – ni – non-significant difference – różnica nieistotna

Table 3. Influence of tillage systems on bulk density of soil, g·cm^{-3}
Tabela 3. Wpływ sposobów uprawy roli na gęstość gleby, g·cm^{-3}

Layer – Warstwa cm	Date – Termin																Mean – Średnia			
	29.03.2006				12.03.2007				31.03.2008				31.03.2009							
	Tillage – Uprawa																			
	T	U	Z	śr	T	U	Z	śr	T	U	Z	śr	T	U	Z	śr	T	U	Z	śr
0-5	1.33	1.25	1.68	1.42	1.29	1.18	1.60	1.36	1.20	1.10	1.65	1.32	1.30	1.32	1.61	1.41	1.28	1.21	1.64	1.38
10-15	1.55	1.58	1.74	1.62	1.52	1.57	1.62	1.57	1.59	1.55	1.69	1.61	1.52	1.72	1.74	1.66	1.55	1.61	1.70	1.62
20-25	1.73	1.69	1.75	1.72	1.70	1.67	1.62	1.67	1.67	1.64	1.69	1.67	1.71	1.72	1.66	1.70	1.70	1.68	1.69	1.69
Mean – Średnia	1.54	1.51	1.72	1.59	1.50	1.47	1.62	1.53	1.49	1.43	1.68	1.53	1.51	1.59	1.67	1.59	1.51	1.50	1.67	1.56
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:																				
Up		0.071				0.062				0.055				0.072				0.037		
W				0.071				0.062				0.055				0.072				0.037
interaction – interakcja:																				
Up x W		0.095				0.090				0.079				0.104				0.071		
L										0.047										
interaction – interakcja:																				
L x Up										ns – ni										
L x W										0.054										

Up – tillage – uprawa: T – conventional – tradycyjna, U – reduced – uproszczona, Z – zero-tillage – zerowa, śr – mean – średnia
W – layer – warstwa, L – years – lata
ns – ni – non-significant difference – różnica nieistotna

Table 4. Influence of tillage systems on soil temperature, °C
Tabela 4. Wpływ sposobów uprawy roli na temperaturę gleby, °C

Depth – Głębokość cm	Date – Termin																Mean – Średnia			
	29.03.2006				12.03.2007				31.03.2008				31.03.2009							
	Tillage – Uprawa																			
	T	U	Z	śr	T	U	Z	śr	T	U	Z	śr	T	U	Z	śr	T	U	Z	śr
3	15.7	15.1	11.2	14.0	17.6	17.1	11.9	15.5	19.6	18.3	13.0	17.0	8.7	8.7	8.2	8.5	15.4	14.8	11.1	13.8
4	15.2	14.3	10.8	13.4	17.0	16.3	11.3	14.9	17.8	16.6	12.2	15.5	8.6	8.6	8.1	8.4	14.7	14.0	10.6	13.1
5	15.6	13.3	9.0	12.6	15.8	15.2	10.6	13.9	16.0	15.0	11.7	14.2	8.6	8.4	8.1	8.4	14.0	13.0	9.9	12.3
Mean – Średnia	15.5	14.2	10.3	13.4	16.8	16.2	11.3	14.8	17.8	16.6	12.3	15.6	8.6	8.6	8.1	8.4	14.7	13.9	10.5	13.1
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:																				
Up		0.80				0.71				0.43				0.18				0.54		
G				0.80				0.71				0.43				ns – ni				0.54
interaction – interakcja:																				
Up x G		ns – ni				ns – ni				0.62				ns – ni				ns – ni		
L										0.892										
interaction – interakcja:																				
L x Up										ns – ni										
L x G										ns – ni										

Up – tillage – uprawa: T – conventional – tradycyjna, U – reduced – uproszczona, Z – zero-tillage – zerowa, śr – mean – średnia
G – depth – głębokość, L – years – lata
ns – ni – non-significant difference – różnica nieistotna

Table 5. Influence of tillage systems on plant yields
Tabela 5. Wpływ sposobów uprawy roli na plony roślin, $Mg \cdot ha^{-1}$

Year – Rok	T	U	Z	śr	$LSD_{0.05}$ $NIR_{0,05}$	T	U	Z	śr	$NIR_{(0,05)}$
	pea – groch					spring barley – jęczmień jary				
2006	1.22	1.10	1.21	1.18	0.118	2.11	1.94	2.01	2.02	ns – ni
2007	2.45	1.92	1.94	2.10	0.183	2.83	2.54	2.12	2.50	0.285
2008	3.21	2.66	2.57	2.81	0.155	3.98	3.56	3.11	3.55	0.257
2009	2.67	2.43	1.97	2.36	0.238	3.83	3.34	2.84	3.34	0.196
Mean – Średnia	2.39	2.03	1.92	2.11	–	3.19	2.85	2.52	2.85	–
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:										
L				0.525					0.574	
Up		0.403					0.440			
	oat – owies					spring wheat – pszenica jara				
2006	2.32	2.39	2.17	2.29	0.160	2.72	2.69	2.87	2.76	ns – ni
2007	3.08	2.73	2.03	2.61	0.226	1.76	1.42	1.18	1.45	0.197
2008	3.70	3.49	3.22	3.47	0.282	3.71	3.27	2.92	3.30	0.298
2009	4.86	4.58	3.82	4.42	0.261	3.86	3.34	2.81	3.34	0.281
Mean – Średnia	3.49	3.30	2.81	3.20	–	3.01	2.68	2.45	2.71	–
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:										
L				0.642					0.733	
Up		0.493					ns – ni			

Up – tillage – uprawa: T – conventional – tradycyjna, U – reduced – uproszczona, Z – zero-tillage – zerowa, śr – mean – średnia
L – years – lata
ns – ni – non-significant difference – różnica nieistotna

Nutrient content in soil and its pH on fields where the experiment was carried out is presented in Table 6. According to IUNG instructions [Obojski and Strączyński 1995], the soil under experiment should be included in the acidic type. Phosphorus content in the layer 0-20 cm reached mean and high level. In the level 0-10 cm, the amount of phosphorus after conventional tillage was 6.1 mg 100 g of soil. Tillage simplifications contributed to the increase in phosphorus content in the discussed layer. After reduced tillage, phosphorus content was 7.6 mg, and after zero-tillage 8.2 mg per 100 g of soil. Also the magnesium content reached the level of mean values. As in the case of phosphorus, magnesium content in the layer 0-10 cm of the soil increased along with the increase in the degree of tillage simplification. In case of potassium, changes were not so regular, however the content of this element was higher after reduced tillage than after conventional one. Thus, results of other studies are confirmed [Blecharczyk *et al.* 2004, Włodek *et al.* 2003] indicating increase in the nutrient concentration in the surface soil layer with reduced tillage.

Table 6. Some chemical properties of soil after completion of the experiment
Tabela 6. Niektóre właściwości chemiczne gleby po zakończeniu doświadczenia

Tillage Uprawa	Layer – Warstwa cm	pH in – w KCl	Content, mg per 100 g^{-1} soil Zawartość, mg 100 g^{-1} gleby		
			P*	K*	Mg
Conventional Tradycyjna	0-10	5.0	6.1	8.9	3.7
	10-20	5.0	6.1	7.4	3.4
	20-30	5.0	4.8	6.6	3.7
Reduced Uproszczona	0-10	5.2	7.6	11.4	3.9
	10-20	5.2	7.3	8.0	4.4
	20-30	5.1	5.8	7.4	3.4
Zero Zerowa	0-10	5.1	8.2	9.1	4.1
	10-20	5.0	6.5	7.0	3.7
	20-30	5.0	4.4	5.2	3.6

* according to the Egner-Riehm – według Egnera-Riehma

CONCLUSIONS

1. Soil moisture expressed in percentage of dry matter of soil determined in spring on average for the layer 0-25 cm did not depend on the tillage system. Fundamental diversity concerned moisture distribution in the profile of the arable layer. Surface layer of 0-5 cm was always moister after application of zero-tillage than after conventional tillage, however in the lower layers, 10-15 and 20-25 cm, soil after conventional tillage contained more water than after zero-tillage.
2. In early spring, density of untilled soil (zero-tillage) was always higher than soil density in the conventional tillage system.
3. Tillage simplifications affected the speed of warming up of soil. Temperature of soil not tilled in a conventional way was in spring higher on average by 4°C than soil temperature measured at the same time after zero-tillage.
4. The following spring plants: pea, barley, oat and wheat, reacted with a significant yield decrease to the long-term reduced tillage.
5. Long-term elimination of ploughing tillage caused an increase of nutrient concentration in the soil layer 0-10 cm.

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WPŁYW WIELOLETNIEGO STOSOWANIA UPROSZCZEŃ W UPRAWIE ROLI NA NIEKTÓRE WŁAŚCIWOŚCI GLEBY I PLONY WYBRANYCH ROŚLIN JARYCH

Streszczenie. W Stacji Doświadczalnej IUNG-PIB w Jelczu Laskowicach na Dolnym Śląsku prowadzono od 1993 roku doświadczenie łanowe na glebie płowej wytworzonej z piasku gliniastego mocnego, w którym porównywano trzy systemy uprawy roli: tradycyjny: orka na głębokość 25-30 cm z doprawieniem roli do siewu tradycyjnymi narzędziami uprawowymi; uproszczony – uprawa kultywatorem do głębokości 10-15 cm, doprawianie zestawem uprawowo siewnym; zerowy – siew bezpośredni w glebę nie uprawianą. W latach 2006-2009 uprawiano groch, jęczmień jary, owies i pszenicę jarą. Wiosną oznaczano właściwości fizyczne gleby. Wieloletnie uproszczenia uprawy spowodowały wolniejsze nagrzewanie się gleby wiosną oraz większą gęstość objętościową, nie wpłynęły jednoznacznie na wilgotność gleby, przyczyniły się do wzrostu zawartości fosforu i potasu w wierzchniej warstwie gleby. Wieloletnie uproszczenia uprawy roli spowodowały obniżenie plonów roślin.

Słowa kluczowe: gęstość gleby, temperatura gleby, uprawa zerowa, wilgotność gleby

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