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Soil physical properties under winter wheat grown with different tillage systems at selected locations**

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A b s t r a c t. The aim of this research was to determine in 2006 and 2007 the effects of different tillage systems on the soil physical properties: bulk density, water content and stability. Analyses of physical properties of soil were performed on the long-term field experiment at the IUNG-PIB Experimental Station in Grabów (Mazowieckie voivodeship) on a heavy loamy sand and on a private farm in Rogów (Lublin voivodeship) on a silt loam soil. Winter wheat was grown in traditional and reduced tillage systems: 1) traditional tillage (TT) with surface mulching (chopped wheat straw) based on mouldboard ploughing (to 25 cm depth) and traditional soil management equipment, and 2) reduced tillage (RT) with surface mulching (chopped wheat straw) based on soil crushing-loosening equipment and a rigid-tine cultivator (to 10 cm depth). Soil physical properties were measured on samples collected from the field throughout the growing season. These included: particle size distribution (hydrometer method), soil water content and bulk density measured using 100 cm^3 cylinder samples (after drying at 105°C for 48 h). For the above, four replicates were collected from each of the following depths: 2-8, 13-18, 28-33, 47-53 and 67-73 cm. Soil stability was measured with a turbidimetric method using samples from 5-10, 15-20 and 30-35 cm depths. Soil stability was measured in terms of the content of readily-dispersible clay (RDC) in the soil samples. RDC was measured using a turbidimeter. Ten replicates were used for each soil and depth at each place.

The effect of the tillage system on the values of the physical properties was significant at both sites. Reduced tillage resulted in increased water content throughout the whole soil profile at Rogów. However, at Grabów, this effect was found only at the top depth. Also reduced tillage increased bulk density in both soils, especially in the 2-8 and 13-18 cm depth layers in comparison with traditional tillage. Reduced tillage reduced the amount of RDC and therefore increased soil stability, especially in the top layer (5-10 cm) in comparison with traditional tillage. The results showed that the reduced tillage system created a more-friendly environment for soil physical properties – particularly soil stability than the conventional system.

K e y w o r d s: soil water content, soil bulk density, soil stability in water, readily-dispersible clay (RDC), traditional and reduced tillage systems

INTRODUCTION

In Poland, there is growing interest in developing systems of reduced tillage with mulching (conservation tillage) as an alternative technology to traditional tillage to reduce emissions of greenhouse gases whilst producing good conditions for plant growth. Conservation tillage protects the sub-soil against compaction and erosion by water. It can: reduce water run-off throughout the year (Dexter *et al.,* 2004; Dexter and Czyż, 2007); reduce evaporative loses and increase water infiltration (Niedźwiecki *et al.,* 2006); and can also increase the stability of the soil through increased organic matter content (Czyż, 2003, 2005b; Dexter and Czyż, 2000), and increased biological activity (Gațe *et al.,* 2004, 2006a, 2006b; Urbanek and Horn, 2006; Schjønning and Rasmussen, 1989). Reduced tillage has effects on soil physical properties: bulk density, water content, soil stability (Fabrizzi *et al.,* 2005; Ferreras *et al.,* 2000; Hussain *et al.,* 1998; Rasmussen, 1999; Mielke and Wilhelm, 1998;

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Moreno *et al.,* 1997) and soil physical quality (Dexter, 2004). We are looking for soil physical conditions that give good plant production whilst at the same time protecting the environment.

The aim of the research was to compare two different tillage systems (traditional and reduced) on some physical properties of two soil types.

MATERIALS AND METHODS

Soils and their characterization

Field experiments were done in 2006 and 2007 in Grabów and Rogów on land that had been previously cultivated with the same tillage systems for 3 years prior to the experiment and which had been cropped with winter wheat. One experimental site was at an Experimental Station of IUNG Grabów, which belong to Institute of Soil Science and Plant Cultivation – State Research Institute (IUNG-PIB), in the Mazowieckie voivodeship (51°21'N, 21°40'E, 166 m a.s.l.) on a heavy loamy sand and the other was a private farm at Rogów, in Lubelskie voivodeship (50°48'N, 23°29'E, 230 m a.s.l.) on a silt loam soil that had been formed on loess. Table 1 gives the geographic positions measured by GPS for the experimental sites used in this paper. Table 2 shows particle size distributions and organic matter contents of the soils used at the experimental field sites.

Each experiment had two treatments with different soil tillage systems: traditional and reduced. At both experimental sites, winter wheat was grown under:

- traditional tillage (TT) with surface mulching (chopped wheat straw) based on mouldboard ploughing (to 25 cm depth) and traditional soil management equipment, and
- reduced tillage (RT) with surface mulching (chopped wheat straw) based on soil crushing-loosening equipment and a rigid-tine cultivator (to 10 cm depth).

Soil physical properties were measured on samples collected from the field throughout the growing season. All soil samples were collected from between visible wheel tracks unless otherwise stated.

T a b l e 1. Geographical positions of the experimental soils

Sampling locations	Sampling	Tillage systems	Geographical position	
			Latitude N	Longitude E
Grabów	2006	TT	51°21' 4.0"	21°40' 31.4"
		RT	51°21' 3.8"	21°40' 32.1"
	2007	TT	51°21' 3.1"	21°40' 33.2"
		RT	51°21' 1.1"	21°40' 16.2"
Rogów	2006	TT	50°48' 4.0"	23°29' 18.5"
		RT	50°48' 3.8"	23°29' 12.4"
	2007	TT	50°48' 3.1"	23°29' 09.2"
		RT	50°48' 1.1"	23°29' 16.2"

T a b l e 2. Particle size distribution and organic matter content of the soils used in the field experiment

Depth (cm)	Percentage content of size fractions (mm)											Organic matter (%)
	1-0.5	0.5-0.25	0.25-0.10	0.10-0.05	0.05-0.02	0.02-0.006	0.006-0.002	< 0.002	Total			
									1-0.1	0.1-0.02	<0.02	
Grabów												
0-10	8	24	24	12	13	9	6	4	56	25	19	1.23
15-20	8	24	25	10	14	10	6	3	57	24	19	1.05
30-35	8	24	25	11	12	11	6	3	57	23	20	0.92
50	5	14	24	13	11	9	7	17	43	24	33	0.34
70	7	14	23	15	11	9	6	15	44	26	30	0.28
Rogów												
5-10	0	0	6	8	49	24	8	5	6	57	37	1.24
15-20	0	0	4	9	47	25	9	6	4	56	40	1.42
30-35	0	0	5	9	45	23	9	9	5	54	41	0.78
50	0	0	4	9	38	22	6	21	4	47	49	0.31
70	0	0	4	7	37	24	7	21	4	44	52	0.21

Methods

The particle size distributions of the soils studied were determined by Cassagrande's aerometric method modified by Prószyński (Lityński *et al.,* 1976). The organic matter contents of the soils were measured by wet oxidation by the Tiurin method (Ostrowska *et al.,* 1991).

For determination of dry bulk density, ρ (Mg m^{-3}), and soil water content volumetrically, θ (%, m^3 m^{-3} or %,vol.), and gravimetrically, w (kg kg^{-1}), soil samples collected from the field were used. The soil samples were collected from soil pits which were dug in the field under different treatments at both locations (Grabów and Rogów). For the above, four replicates were collected from each of the following depths: 2-8, 13-18, 28-33, 47-53 and 67-73 cm. The depth of sampling was selected to coincide with the depths of layers corresponding with the different tillage practices. Undisturbed soil cores were taken by pushing stainless steel cylinders of 100 ml vertically into the soil using a hammer, and for each layer and location 4 replications were sampled. The cylinders were then closed with stainless steel end caps and were placed in polythene bags to prevent water loss. Dry bulk density and water content of the soils were measured in the laboratory by weighing the soil samples before and after drying at 105°C in the oven for 48 h. The determinations were done immediately after returning from the field so that further water loss was avoided. The soil water content values were then calculated firstly as % volume using the following equation:

$$\theta = \frac{(m_w + t) - (m_d + t)}{100}, \qquad (1)$$

where: θ – volumetric water content (%, vol.), m_w – wet soil mass (g), m_d – dry soil mass (g), and t – tare of cylinder (g). Note that Eq. (1) assumes that the density of water, ρ_w = 1 g ml^{-1}.

Then dry bulk density (ρ) was calculated using the following equation:

$$\rho = \frac{m_d}{100}, \qquad (2)$$

where: ρ is dry bulk density (Mg m^{-3}), and the other terms are as described above.

Gravimetric water content (w) of the soils was then calculated as:

$$w = \left(\frac{\rho_w}{\rho}\right)\frac{\theta}{100}, \qquad (3)$$

where: w is the gravimetric water content of the soils (kg kg^{-1}), and the other terms are as described above.

A total of 160 samples were measured for dry bulk density (5 soil depths × 4 replicates × 2 places × 2 years × 2 tillage), and 160 samples for gravimetric water content (5 soil depths × 4 replicates × 2 places × 2 years × 2 tillage).

The method used for determination of readily-dispersible clay, RDC (NTU/(g l)$^{-1}$) and RDC (g (100 g soil)$^{-1}$), is that described by Czyż *et al.,* (2002); Dexter and Czyż (2000), and is rather similar to that described by Kay and Dexter (1990); Watts and Dexter (1997) and Watts *et al.* (1996a,b), but was adapted for Polish sandy soils.

The amount of readily-dispersible clay in water using a standard dilution and shaking procedure was measured using turbidimetry. For each soil sample, 10 sub-samples were used. About 5 g of soil were weighed and placed in 150 ml plastic bottles and then de-ionized water was added to make 125 ml. The bottles were then shaken in a standardized way (four inversions end-over-end). The bottles were then allowed to stand for 18 h so that the larger particles would sediment, leaving only dispersed colloids (in this case, mostly clay) in suspension. A 30 ml sample of this suspension was extracted by pipette from the centre of each bottle and was transferred to a glass turbidity cell.

Also, 10 sub-samples of the same soil sample were prepared for determination of total clay. In this case, about 18 g of soil were weighed and placed in 750-1000 ml Berzelius glasses and were stirred intensively with 500 ml distilled water for 30 min. Then 125 ml from this suspension was poured into the plastic bottles and allowed to stand for 18 hours so that the larger particles would sediment, leaving only colloids (clay) in suspension. A 30 ml sample of this suspension was extracted by pipette from the centre of each bottle and was transferred to a glass turbidity cell.

The turbidity was measured by light-scattering using a Hach 2100 AN ratio turbidimeter as is illustrated in Figs 1 and 2. Turbidity values are linearly proportional to the concentration of colloids (clay) in suspension (Dexter and Czyż, 2000). The turbidimeter readings were expressed as NTU (Nephelometric Turbidity Units) and were normalized by dividing by the concentration of the original soil in the water to give NTU/(g l^{-1}). The mass of soil was corrected to dry mass for this calculation. Ten replicates were used for each soil and depth at each place. The total number of samples that were measured was 240 (24 soil layers × 10 replicates).

We also considered the proportions of the soil clay content that are readily dispersible. We did this by using high energy inputs (30 min of intense stirring) to disperse all the clay followed by 18 h of sedimentation and measurement of turbidity (as described above) to obtain the normalized turbidity, T (NTU/(g l^{-1})), due to the total clay. We then calculated a factor, K, as follows:

$$K = \left(\frac{C}{T}\right), \qquad (4)$$

where C is the total clay content (%) as measured in the particle size analysis. K is a calibration factor that relates turbidity measurements to amounts of clay in suspension. K may be expected to be different for different soils because of differences in clay mineralogy.

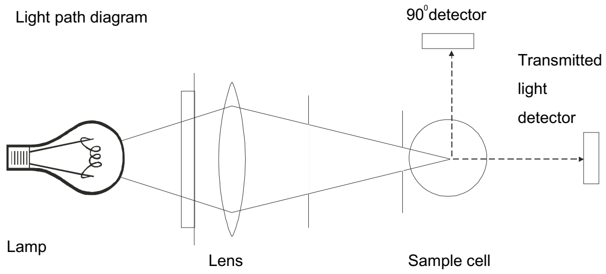

Fig. 1. Schematic diagram showing the principle of operation of the ratio turbidimeter.

Fig. 2. Model HACH 2100 AN Turbidimeter as used for determination of the content of readily-dispersible clay, *RDC*.

The results were expressed as mean values: mean ± SEM. All results compared reduced tillage with traditional tillage systems. Comparisons between the different tillage systems were made by using analysis of variance (ANOVA) and Student's t -test. Differences at P<0.05 were considered as significant. Statistical analysis of the measured values of water content, bulk density and soil stability at water (measure as readily dispersible clay RDC) were done using the MiniTab® program.

RESULTS AND DISCUSSION

It was found that the tillage system affected significantly the soil physical properties especially soil water content (Table 3). There is a significant (P<0.05) difference in the soil water content with reduced tillage relative to the traditional tillage of both soils. The effect of tillage system on soil water content was different in the two soils studied. At Grabów in year 2006, there was an effect of reduced tillage in increasing the soil water content in the top three layers: in the 2-8, 13-18, and 28-33 cm depth in comparison with traditional tillage. But in 2007, reduced tillage increased water content in the four layers: in the 2-8, 13-18, 28-33, and 47-53 cm depth in comparison with traditional tillage (Fig. 3). At Rogów, the reduced tillage system had greater soil water contents than traditional tillage in both years 2006 and 2007 at all depths (Fig. 4). The two different management practices (traditional and reduced tillage) which were applied to the soils at Rogów and Grabów seemed to have large and consistent effects on soil water content (Figs 3-5). Figure 5 shows that in both years, 2006 and 2007, the Rogów silt loam soil tilled under reduced tillage system has recorded higher values of water content 27.38 and 26.08 (%, vol.) than those in traditionally-tilled systems 26.28 and 22.76 (%, vol.). Also, at Grabów in both years, 2006 and 2007, values of water content in soil under reduced tillage system were 27.38 and 26.08 (%, vol.) greater when compared with traditional systems 18.29 and 11.03 (%, vol.), respectively. Comparison between the two years leads to the conclusion that the Rogów silt loam soils had greater water content in both years of the experiment in plots in relation to Grabów with heavy loamy sand where reduced tillage systems were applied in comparison with traditional tillage systems (Fig. 5).

Table 4 also shows the effect of different tillage system on soil bulk density. There is a significant (P<0.05) difference in the soil bulk density with reduced tillage relative to the traditional tillage of both soils. Reduced tillage increased bulk density in both soils in comparison with traditional tillage. Reduced tillage increased bulk density in both soils especially in the 2-8 and 13-18 cm layers in comparison with traditional tillage (Figs 6 and 7). At Grabów in both years 2006 and 2007 the values of soil bulk density were higher in all measurement depth, not including depth 67-73 cm in 2006 (Fig. 6). At Rogów for both years 2006 and 2007 the greatest effect of increased soil bulk density was in the top layers: 2-8, and 13-18 cm depth in comparison with traditional tillage. Also at Rogów, in the wet period in 2006, the effect of increased soil bulk density extended more deeply to the 28-33 cm depth layer relative to traditional tillage (Fig. 7). The effects of different tillage (reduced and traditional) on mean values of bulk density of all depth measurement for both soils are presented in Fig. 8.

The results with the soil bulk density showed similar trends to those obtained with these two soils observed in earlier research by Czyż (2005a). In this reference, the effects of different soil tillage systems on physical properties of heavy soil in a three-year field experiment were presented. The soil physical properties (soil bulk density, water content) in the 0-25 cm layer in the three different tillage systems: traditional (ploughing), reduced tillage and direct sowing. The value of soil bulk density, mean of three years, was highest with direct drilling (1.58 Mg m^{-3}), lower with reduced tillage (1.39 Mg m^{-3}), and the lowest with conventional (ploughing) tillage (1.24 Mg m^{-3}). Pranagal *et al*. (2005) presented results after 7 years of use of different tillage systems (traditional, reduced and direct drilling). Differences in bulk density were not significant with the loamy and loamy silt soils at the 0-10 cm depth. However, bulk density was greater in the 10-20 cm layer of loamy silt soils with direct drilling in comparison with traditional and reduced tillage systems.

Several authors have shown an increase in soil bulk density with reduced tillage or no-tillage system in comparison with the traditional tillage (plough) system. Some authors have shown in their experiments that such is the case with their soils (Fabrizzi *et al.*, 2005; Hussain *et al.*, 1998; Mielke and Wilhelm, 1998; Moreno *et al.*, 1997; Rasmussen, 1999). Fabrizzi *et al.* (2005) evaluated the effects of minimum tillage (MT) and no-tillage (NT) on compaction, and soil water storage, and its effects on crop yields in a productive soil of southeaster Buenos Aires province (Argentina). The study was conducted on a Typic Argiudoll during 1997 (maize) and 1998 (wheat) in a maize-wheat rotation. Bulk density was higher under NT than under MT in the 3-8 and 13-18 cm depth layers. NT showed greater soil water storage during the critical growth stage in maize, and most of the wheat-growing season. Also Rasmussen (1999) reviewed the impacts of ploughless soil tillage on yields and selected soil quality parameters in the Scandinavian countries (Denmark, Finland, Norway and Sweden). Soil conditions as well as climatic conditions vary widely, this resulting from variations in the length of the growing season, which is very short in the northern part of Scandinavia. The success

T a b l e 3. Mean values of soil water content* for the years 2006 and 2007

Experimental field**	Tillage systems	Mean values (%, $m^3 m^{-3}$)	Standard deviation (%, $m^3 m^{-3}$)	SEMean (%, $m^3 m^{-3}$)	P<0.05
Grabów	TT	14.74a	2.05	±0.84	0.050
	RT	16.68b	0.64	±0.26	
Rogów	TT	24.63a	2.57	±1.00	0.034
	RT	29.33b	3.92	±1.60	

*Results are expressed as means ± SEM of six different replicates, mean values with different letters (a, b) differ significantly (P<0.05).
**Experimental fields: Grabów (a heavy loamy sand) and Rogów (a silt loam soil).

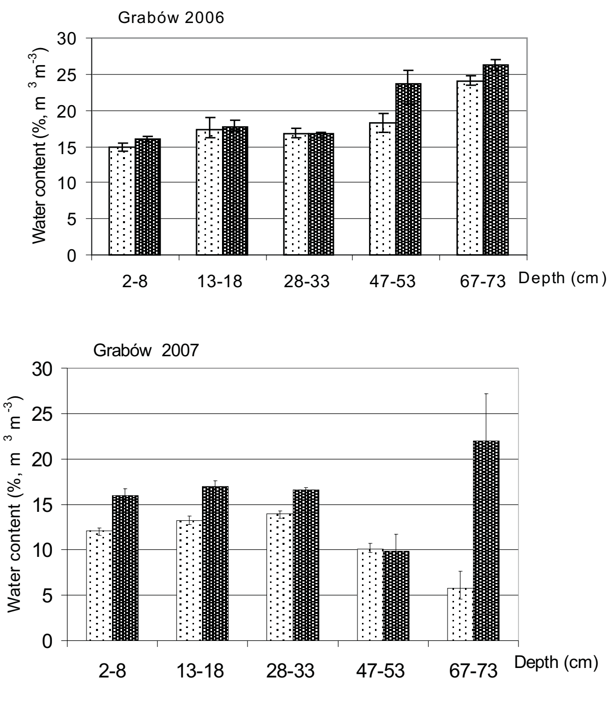

Fig. 3. Effects of tillage systems on soil water content at Grabów on a heavy loamy sand.

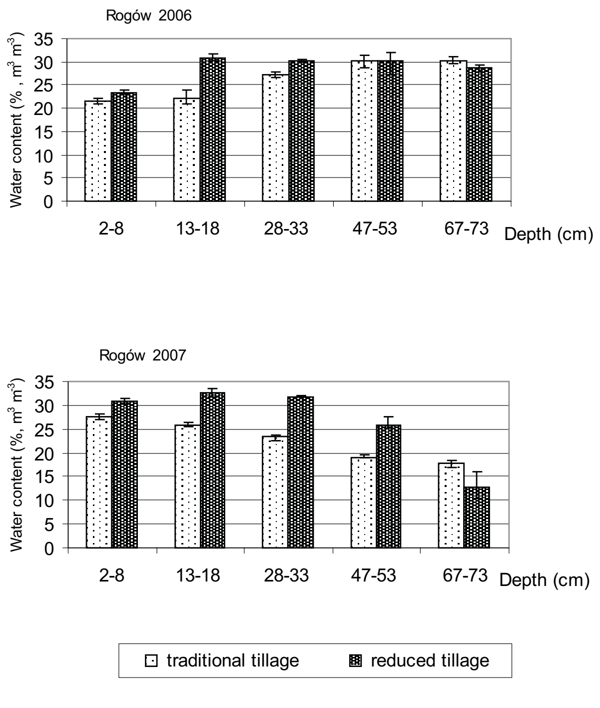

Fig. 4. Effects of tillage systems on soil water content at Rogów on a silt loamy soil.

of reduced tillage and direct drilling depends on the crop species as well as on the soil type and the climatic conditions. The best results seem to be obtained on the heaviest clay soils, which are the most difficult soils to prepare with conventional soil tillage methods. Satisfactory yields were obtained after ploughless tillage with winter wheat (*Triticum* sp.), winter oil seed rape (*Brassica* sp.) and late – harvested potatoes (*Solanum tuberosum* L.) One of the most striking effects of ploughless tillage is the increased density of the soil just beneath the depth of tillage. Increased soil density decreased the volume of macropores (>30-60 μm) and increased the volume of medium pores (30-0.2 μm), but the volume of small pores (<0.2 μm) was only slightly affected by soil tillage. Increased soil bulk density reduced the air-filled porosity, the air diffusivity and the air permeability as well as the hydraulic conductivity, and sometimes the root development. More plant residues were left on or near the soil surface after ploughless (non-inversion) tillage, which led to lower evapotranspiration and higher content of soil water in the upper (0-10 cm) soil layer. Hussain *et al*. (1998) after 8 years of continuous no-till (NT), chisel plough (CP), and mouldboard plough (MP) treatments measured the physical properties of an eroded, sloping soil in southern Illinois, USA. During the long-term study, the 8-year average core bulk density was 1.39, 1.32, and 1.31 Mg m^{-3} with NT, CP and MP systems, respectively, with NT significantly higher than either CP or MP. Higher bulk density with the NT system than with the MP system was attributed to a lower proportion of macropores. The method used to measure bulk density clearly affected the results, which contradict previous findings of other long-term studies on different soil situations.

However, some researchers have not found significant differences in bulk density between tillage treatments. For example, Ferreras *et al*. (2000) made measurements on a Chernozemic loam soil (Petrocalcic Paleudoll) with a petrocalcic horizon at a depth of 1.2 m in Balcarce (Buenos Aires, Argentina). The soil had been previously cultivated for 25 years. The aim of the study was to evaluate the effect of two tillage systems: conventional tillage (CT) and no-tillage (NT) on soil physical properties. Soil bulk density in the 3-8 and 15-20 cm layers was measured using the cylinder

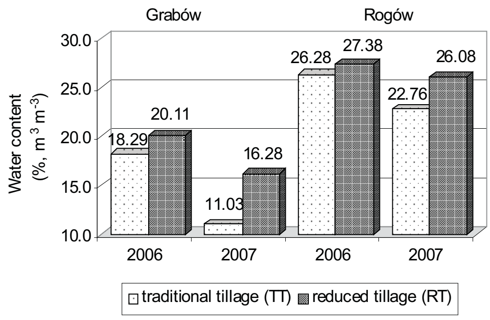

Fig. 5. Variation of the values of water content (%, m^3 m^{-3}) with different tillage systems: traditional (TT) and reduced tillage (RT) during two experimental years at Grabów (a heavy loamy sand) and Rogów (a silt loam soil). The values of water content represent the arithmetic mean values of all depths for each soil point.

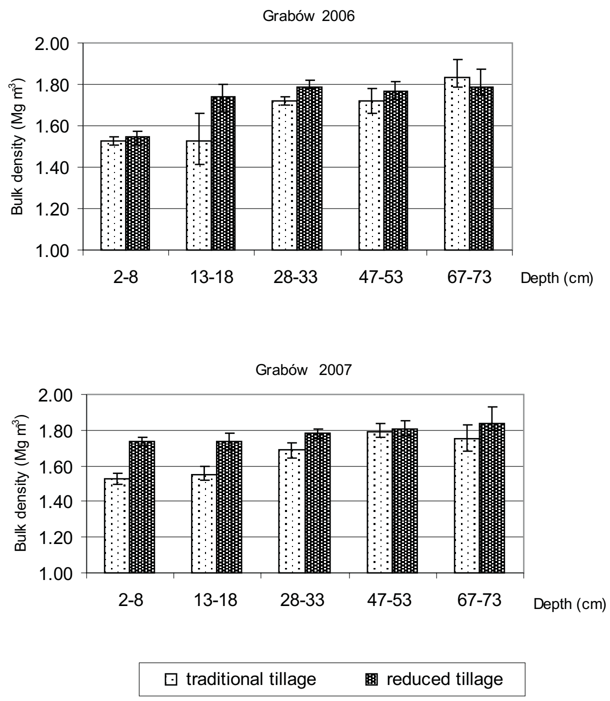

Fig. 6. Effects of tillage systems on soil bulk density on a heavy loamy sand at Grabów.

T a b l e 4. Mean values of soil bulk density* for the years 2006 and 2007

Experimental field**	Tillage systems	Mean values (%, m^3 m^{-3})	Standard deviation (%, m^3 m^{-3})	SEMean (%, m^3 m^{-3})	P<0.05
Grabów	TT	1.591 a	0.089	±0.036	0.029
	RT	1.723 b	0.088	±0.036	
Rogów	TT	1.370 a	0.148	±0.060	0.009
	RT	1.535 b	0.153	±0.062	

*, **Explanations as in Table 3.

and the paraffin methods. There were no significant differences between treatments ($P \leq 0.05$). Moreno *et al.* (1997) studied the effects of traditional and conservation tillage on soil physical properties, soil water replenishment and depletion, and crop development and yield under southern Spanish conditions. The experiments were carried out from 1992 to 1995 in a sandy clay loam soil (Xerofluvent). The traditional tillage (TT) treatment consisted mainly of the use of mouldboard ploughing, and the conservation tillage (CT) treatment was characterized by not using mouldboard ploughing, by reduction of the number of tillage operations and leaving the crop residues on the surface as mulch. In both tillage treatments a wheat (*Triticum aestivum* L.) – sunflower (*Helianthus annuus* L.) crop rotation was established. The soil bulk density in the 0 to 20 cm layer was significantly higher in the CT than in the TT treatment, mainly after tillage operations (between 10 and 24% higher in CT than in TT). But after 3 years of continuous tillage treatments, the soil bulk density did not increase.

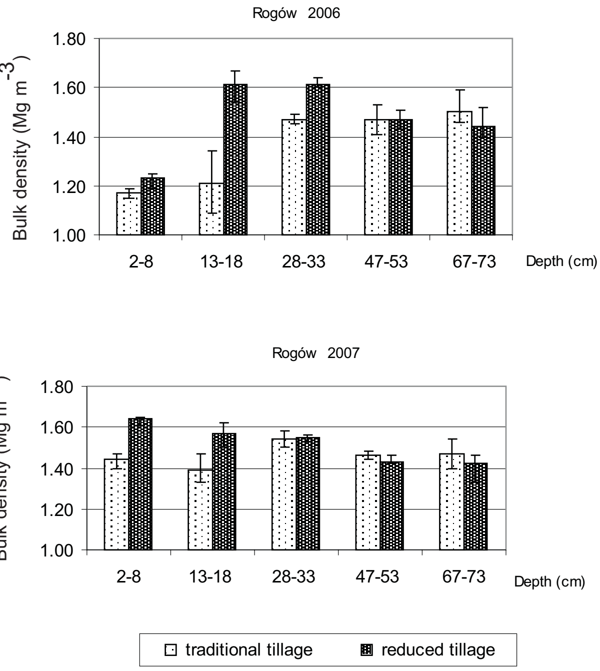

Fig. 7. Effects of tillage systems on soil bulk density on a silt loam soil at Rogów.

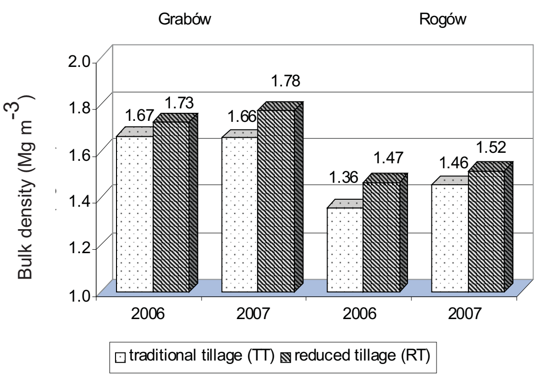

Fig. 8. Variation of the values of soil bulk density (Mg m^{-3}) with different tillage systems: traditional (TT) and reduced tillage (RT) during two experimental years at Grabów (a heavy loamy sand) and Rogów (a silt loam soil). The values of soil bulk density represent the arithmetic mean values of all depths for each soil point.

The effect of different tillage system on values of soil stability is presented in Table 5. There is a significant ($P<0.05$) difference in the values of soil stability with reduced tillage relative to the traditional tillage of soil in Grabów. Soil stability was not significantly different in Rogów. The reduced tillage system increased the soil stability in the tested soil profiles, especially top layer in comparison with traditional tillage. Soil stability in water was significantly greater in the top layer (5-10 cm) at both places, because the content of readily-dispersible clay (RDC) was smaller (Fig. 9). In Grabów for both years 2006 and 2007 values of RDC were smaller for all layers measured in field with reduced tillage system comparison with traditional tillage (Fig. 10). But in Rogów for both years 2006 and 2007 values of RDC were smaller only at depth (5-10 cm) in comparison with traditional tillage (Fig. 9). The reduced tillage at Rogów, the soil stability decreased with increasing depth (perhaps because of increasing content of potassium with depth). We think that further research into the effect of potassium on soil stability could be valuable.

Previous research into the stability of 210 Polish soils showed that RDC in the arable layer was positively correlated with potassium content. On average, the content of readily-dispersible clay (RDC) in Polish soils was found to be 0.484 g 100 g^{-1} soil. This value is known to be affected by land use (Czyż *et al.*, 2002). In this work, we obtained mean values of K (from equation 4) of:

$$K = 0.432, \text{ for the Grabów soil,} \quad (5)$$

and

$$K = 0.306, \text{ for the Rogów soil .} \quad (6)$$

Multiplication of turbidity in NTU/(g l^{-1}) by these factors K gives the gravimetric concentrations of readily-dispersible clay given in Table 5.

Changes in dispersible clay due to changes in management practices have been suggested by Kay and Dexter (1990) to be manifested earliest in the weakest failure zones. Such zones have a distribution of strengths which is related to water content and processes which change pore characteristics and/or the cementation between structural units (Kay and Dexter, 1990). Cementing materials may be of organic or inorganic form. Among inorganic materials are included dispersed clay particles which become effective on drying by precipitation or flocculation at inter-granular points at low water contents (Kay and Dexter, 1990). Soils with high contents of readily-dispersible clay in the presence of water may experience the collapse of their structure with the consequent loss of the inter-aggregate pores and soil homogenization (Czyż *et al*., 2002). Problems associated with clay dispersion include: anaerobic soil that is unsuitable for plant root growth, reduced infiltration of water with associated risk of run-off, flooding and erosion (Czyż *et al*., 2002; Dexter and Czyż, 2000). Also, such soils can form crusts at the surface or can hard-set, both of which characteristics are associated with poor crop emergence and increased energy requirement for tillage (Czyż *et al*., 2002; Dexter and Czyż, 2000). Readily-dispersible clay is also related to soil strength. A soil with a high content of readily-dispersible clay will be weaker when wet and stronger when dry than a soil with a low content of readily-dispersible clay.

On the basis of the results obtained we concluded that the tillage systems affected the soil physical properties. It was shown that the reduced tillage system improved some soil conditions (soil water content and soil stability). The reduced tillage system increased the soil bulk density in the tested soil profiles, especially the top layer in comparison with traditional tillage.

Table 5. Mean values of readily-dispersible clay* for the years 2006 and 2007

Experimental field**	Tillage systems	Mean values	Standard deviation	SEMean	P<0.05
		($\%, m^3 m^{-3}$)			
Grabów	TT	0.899a	0.185	±0.075	0.000
	RT	0.353b	0.136	±0.055	
Rogów	TT	0.989a	0.121	±0.049	0.932
	RT	0.971a	0.492	±0.200	

*, **Explanations as in Table 3.

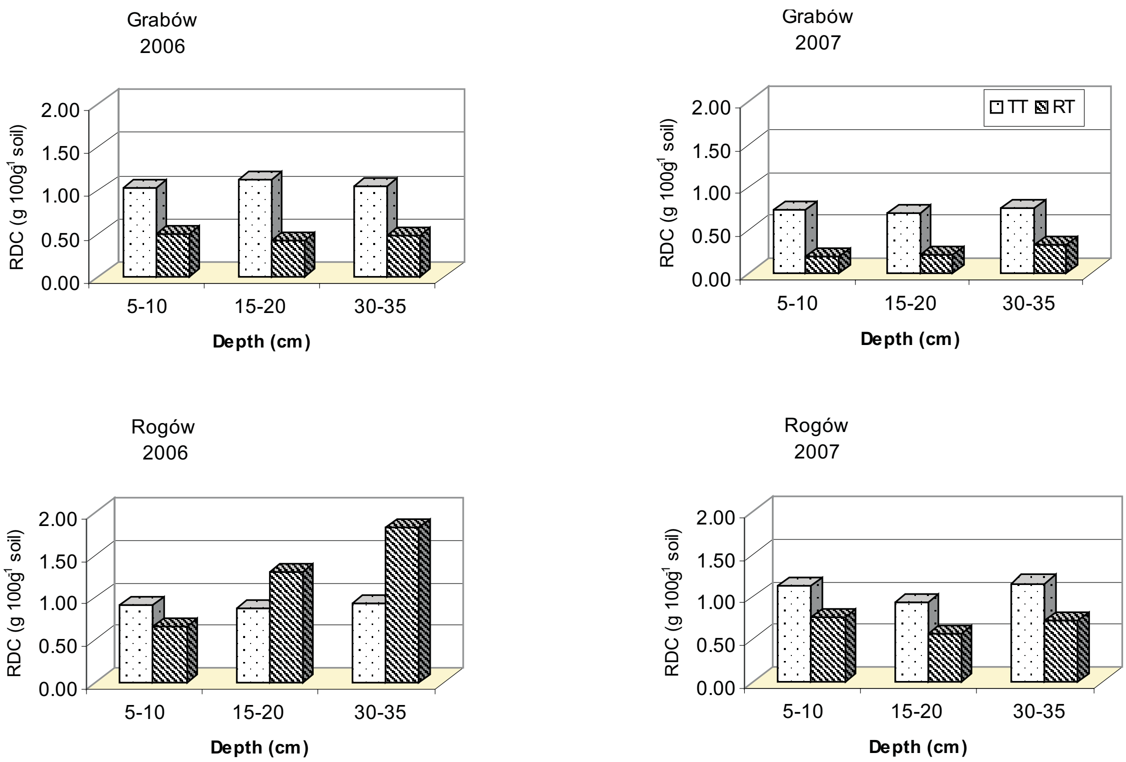

Fig. 9. Effects of tillage systems on soil stability in water on a heavy loamy sand at Grabów and a silt loam soil at Rogów.

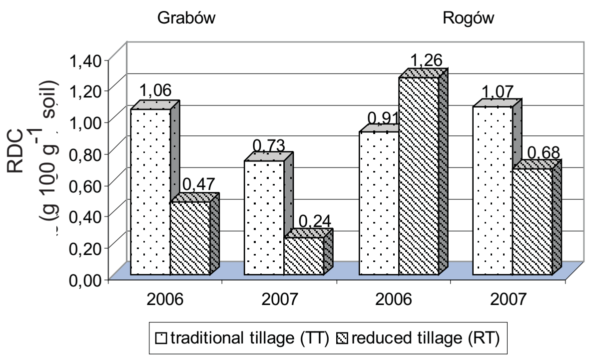

Fig. 10. Variation of the values of readily-dispersible clay, RDC (g 100 g^{-1} soil) with different tillage systems: traditional (TT) and reduced tillage (RT) during two experimental years at Grabów (a heavy loamy sand) and Rogów (a silt loam soil). The values of RDC represent the arithmetic mean values of all depths for each soil point.

CONCLUSIONS

1. Reduced tillage increased water content throughout the whole profile on a silt loam soil at Rogów. However, at Grabów on a heavy loamy sand, this effect was mostly found only at the top depth.

2. Reduced tillage increased bulk density in both soils, especially in the 2-8 and 13-18 cm depth layer, in comparison with traditional tillage.

3. Reduced tillage decreased the quantity of readily-dispersible clay (RDC) and therefore increased soil stability, especially in the top layer 5-10 cm in both soils in comparison with traditional tillage.

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