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Impact of diverse tillage on soil moisture dynamics

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Abstract. The influences of traditional and reduced tillage on the water content dynamics of two soils were investigated in a long-term field experiment under nearly the same meteorological conditions for a winter wheat monoculture during three years. In addition to the moisture changes, the basic physicochemical properties, water retention, differential porosity and hydraulic conductivity of the investigated soils were measured. The results have shown the dependence between moisture and the tillage system applied for both types of soil. The soil water content was higher under reduced tillage in comparison to traditional management.

Keywords: soil, tillage, pores, water properties, moisture dynamics

INTRODUCTION

Recent agricultural methods aim to reach the highest plant yield using the lowest energetic costs. In sustainable plant production, protection of the environment is also important. Both goals can be reached through modifications of traditional plough tillage and by replacing the traditional method with a more efficient tillage. Many experiments have shown that the use of a no-tillage method is not good for either the yield or the environment (Mestelan *et al.*, 2006). No-tillage causes the yield to decrease and causes serious pollution of the environment due to the high level of fertilizers and herbicides used. Thus, the application of reduced tillage could be an appropriate decision (Holand, 2004). Many experimental results show that the use of reduced tillage, especially on soils with higher fertility and good culture status, does not cause significant decreases in plant yields (Derpsch, 2005; Enfors *et al.*, 2011). The effect of the tillage system on the level of wheat yield is ambiguous. The results of research conducted by Polish authors are varied; some claim a yield decrease with the use of reduced tillage or plough-less tillage, whereas others note a yield increase or no influence (Pabin *et al.,* 2003). Traditional plough tillage determines the most beneficial yields. Foreign reports present similar results. In cultures with short research periods of 1-4 years, no significant yield differences were noted (Holand, 2004), whereas in studies conducted in Switzerland with longer cycles *eg* 13 years, higher yields were achieved with a reduced tillage system (Anken *et al.,* 2004).

Simplifications in tillage technology, heading towards the shorter operation of agricultural tools, in effect lead to the maintenance of the natural connections between organisms and their habitats. Moreover, reduced tillage using crop residues leads to an increase of organic matter content in soils (Kęsik *et al.*, 2010). This organic matter is an important factor for an increase of soil structure stability and, over the long term, the better physical quality of the soil profile (Bronick and Lal, 2005; Keller *et al.*, 2007; Schwen *et al.*, 2011). The proper physical status of a soil arable layer protects the soil against wind and water erosion, surface runoff during heavy rainfalls and the reduction of mineralization processes (Abrishamkesh *et al.*, 2011; Dexter *et al.*, 2004).

Some research results emphasise the benefits resulting from reduced tillage, as evidenced by the large number of studies on long-term tillage cycles (Anken *et al.,* 2004; Derpsch, 2005). The use of reduced tillage maintains the ratios between porosity and density (Josa *et al.*, 2011; Mestelan *et al.,* 2006) close to natural conditions. Lower interference in the surface layer of the soil increases the soil density (McVay *et al.* 2006) and improves stability and moisture (Dexter and Czyż, 2011; Lipiec and Nosalewicz, 2004), while C_{org} content and P, K, Mg available forms increases (Tebrügge and Düring 1999). This method of tillage positively affects the soil environment, increasing its microbiological activity (Schjönning and Rasmussen, 2000;

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Urbanek and Horn, 2006) and maintaining adequate moisture, soil stability and physical quality (Czyż and Dexter, 2008). However, the results of other investigations show that the differences in the physical properties of soils under different management are invisible or nonexistent (Pabin *et al.*, 2003).

The aim of this research was to show the impact of two tillage systems (traditional and reduced) on soil moisture dynamics in a field experiment.

MATERIALS AND METHODS

Research on the hydrophysical characteristics of two soils were conducted over a period of three years (2007-2009). The first soil was derived from heavy loamy sand located at the Experimental Station of the Institute of Soil Science and Plant Cultivation – State Research Institute in Grabów (51°21'N, 21°40'E, 166 m a.s.l.), and the second soil was derived from silt loam (loess) located at a private farm in Rogów (50°48'N, 23°29'E, 230 m a.s.l.). Both sites are long-term field experiments that were started in 2002. At both sites, the winter wheat cv. Turnia was grown as a monoculture under two tillage systems:

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

The soil physicochemical properties were measured for soil samples collected from the experimental fields in a disturbed and undisturbed state (in soil cores, h = 5 cm, dia = 5 cm) in five replications from three depths of soil profiles, *ie* 5, 15 and 30 cm, before the harvest every year (Table 1).

Soil water retention curves were determined in a standard pressure chamber (Soil Moisture Comp., Santa Barbara, CA, USA) for potentials 0.1, 1, 16, 100 and 1500 kJ m^{-3} during the drying process. The water conductivity coefficient in a saturated zone was measured by a permeameter (Eijkelkamp Equip., Wageningen, The Netherlands) using the de Witt method. The water conductivity coefficient in the unsaturated zone was determined using the instantaneous profile method (IPM) based on the measurement of the soil water content and soil water potential in the selected layers of the soil sample using a laboratory TDR device during the process of drying (Malicki *et al.*, 1992; Walczak *et al.*, 1993).

The soil water retention curves were the base for calculation of the soil pore quantity. The following groups of pores were separated:

- large pores – dia > 18.5 μm (0.1-16 kJ m^{-3}),
- medium pores – 18.5 > dia > 0.2 μm (16 -1 500 kJ m^{-3}),
- small pores – dia < 0.2 μm (less than 1500 kJ m^{-3}).

Additionally, two subgroups of medium pores were calculated:

- pores – 18.5 > dia > 3 μm (16-100 kJ m^{-3}),
- pores – 3 > dia > 0.2 μm (100-1 500 kJ m^{-3}).

The TDR probes were permanently installed in each experimental field for soil moisture measurements at 5, 15 and 30 cm. The measurements were conducted from January 2007 to November 2009. During this period, the following numbers of observations were made: 15 in 2007, 2008, and 20 in 2009.

All the results were expressed as mean values from 3 years of investigations. The statistical analyses were performed with the use of a Student t-test for comparison of average values in each investigated year and also for the whole three-year period. All statistical calculations were made in the STATISTICA program.

RESULTS AND DISCUSSION

The results presented in Table 1 show that the soil from Grabów is formed from heavy loamy sand (fluvial outwash), whereas the soil from Rogów is formed from a silt loam (loess). The origins of these soils are glacial and postglacial, respectively. According to FAO classification, the first soil

T a b l e 1. Physico-chemical properties of investigated soils

Depth (cm)	Grain size distribution (dia in mm) (%)			$C_{org.}$ (%)	pH		Bulk density[a] (g cm^{-3})		Total porosity[b] (%)	
	2-0.1	0.1-0.02	<0.02		H_2O	KCl	TT	RT	TT	RT
				Eutric Fluvisol						
5	59	26	15	1.2	6.6	6.0	1.56	1.58	41	40
15	57	24	19	1.3	6.3	5.6	1.60	1.67	40	37
30	57	23	20	0.7	6.3	5.6	1.62	1.70	39	36
				Haplic Cambisol						
5	6	57	37	1.5	6.4	5.7	1.30	1.30	51	51
15	4	56	40	1.5	6.4	5.8	1.33	1.33	50	50
30	5	54	41	1.1	6.2	5.4	1.35	1.43	49	46

[a]SD 0.02, [b]calculated from bulk density, TT – traditional tillage, RT – reduced tillage.

is Eutric Fluvisol (EF); the second soil is Haplic Cambisol (HC). The organic carbon content ranged from 0.7 to 1.2% for Fluvisol and 1.1-1.5% for Cambisol. The acidity (pH) of both soils falls in the middle values. During sampling, the bulk densities of Fluvisol layers were much higher (1.56-1.70 g cm^{-3}) than those for Cambisol (1.30-1.43 g cm^{-3}). The total porosity values were inverted, with 36-41 and 46-51% for Fluvisol and Cambisol, respectively.

The soil water retention curve and conductivity coefficient of water in saturated and unsaturated zones affect the conditions of plant growth and plant development and yield. The water retention curve reflects the water storage capacity in the soil profile and thus, the availability of the water to the plant root system. The value of the soil water conductivity coefficient at a given value of water potential determines the possibility of water movement in a soil profile.

The water retention curves for both soils under traditional and reduced tillage are presented in Fig. 1. There are no differences in water content between traditional and reduced tilled Fluvisol at 5 cm. The traditional tilled Fluvisol shows a greater ability to retain water at soil water potentials from 0.1 to 16 kJ m^{-3} (from full saturation to field water capacity) at 15 cm than soil under reduced tillage (approximately 5% vol.). For 30 cm, the water retention curves for Fluvisol have nearly similar courses for both tillage systems (differences are not higher than ±2 % vol.). The water retention curves of Cambisol at 5 and 15 cm show a certain variation depending on tillage, whereas in the deeper layer (30 cm), the difference is small. At 5 cm, the soil under reduced tillage shows a higher water retention (more than 16 kJ m^{-3}, max. 10% vol.), whereas at 15 cm, a higher water retention is found under traditional tillage (more than 16 kJ m^{-3}, max. 16% vol.). Under reduced tillage for Cambisol at 30 cm, the water retention is less by approximately 2-3% vol. than under traditional management.

The quantity of differently sized pores is presented in Table 2. The highest amount of large pores (dia >18.5 mm) in Fluvisol was 19% at 15 and 30 cm under traditional tillage, whereas at 5 cm, the amount is 17%. Under reduced tillage, this amount was lower (14-17%). In Cambisol under traditional tillage, the number of large pores decreases from 13 to 10% at 5 and 30 cm, respectively, whereas under reduced management, the highest value was 13% at 15 cm. Pores of 18.5<dia<0.2 mm (medium) in Fluvisol measured from 14 to 17% for both tillage styles, and their amount decreases with depth. A different situation was observed in Cambisol. Under traditional use, the maximum value was 19% at 5 cm, and the minimal value was 7% at 15 cm, whereas under reduced tillage, the maximum value was 22% at 15 cm, and the minimal value was 12% at 5 cm. An interesting distribution of small pores (dia<0.2 mm) was found under both managements in Fluvisol, where the highest values were measured at 15 cm (8%), whereas at 5 and 30 cm, the amount of these pores was lower, 5-7 and 6-7%, respectively. The quantity of small pores in Cambisol in both treatments was

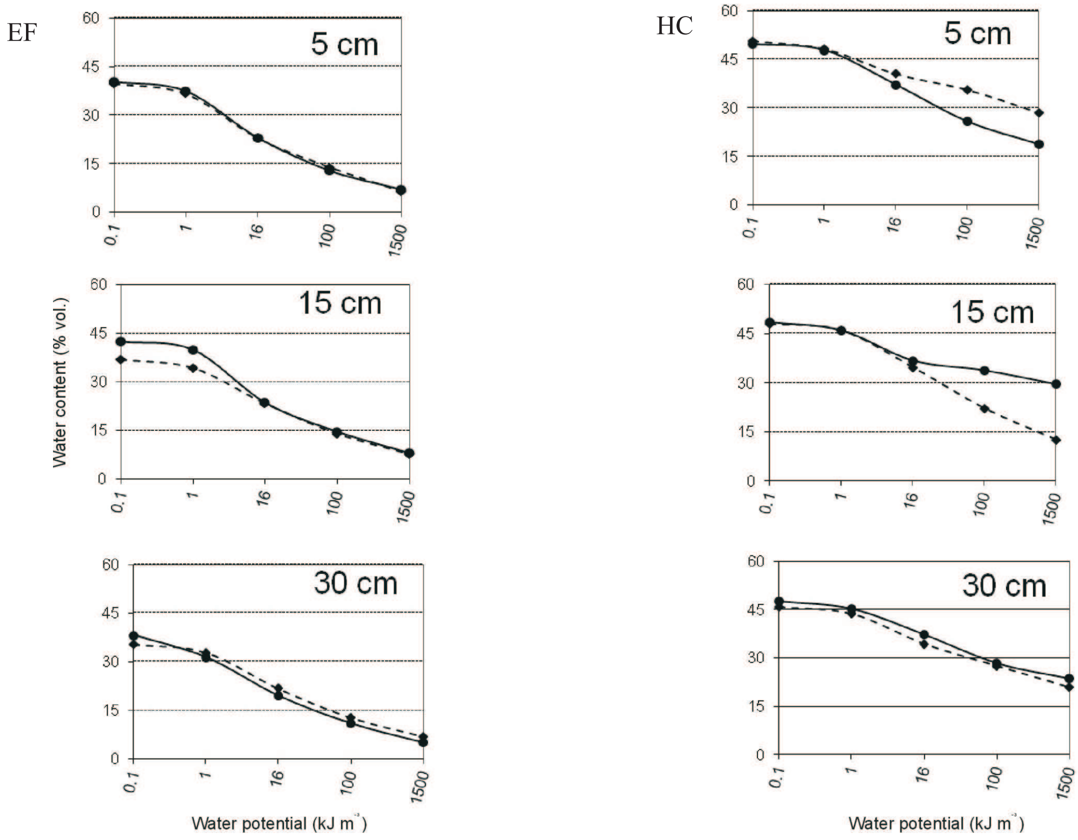

Fig. 1. Water retention curves for investigated soils at: 5, 15 and 30 cm. Solid lines – traditional tillage, dashed lines – reduced tillage.

T a b l e 2. Number of different size pores (%, dia in µm)

Depth (cm)	Eutric Fluvisol		Haplic Cambisol	
	TT	RT	TT	RT
dia > 18.5				
5	17	17	13	10
15	19	14	12	13
30	19	14	10	11
0.2 < dia <18.5				
5	16	17	19	12
15	16	16	7	22
30	14	15	14	13
3 < dia < *18.5*				
5	10	9	11	5
15	9	9	3	13
30	9	9	9	7
0.2 < dia < *3*				
5	6	8	7	7
15	7	6	4	10
30	6	6	5	7
dia < 0.2				
5	7	6	19	29
15	8	8	30	13
30	5	7	24	21

Explanations as in Table 1.

markedly higher than for Fluvisol. Under traditional tillage, the maximum value of small pores – 30% was measured at 15 cm and the minimal value – 19% at 5 cm. The reduced use caused a radical change; the highest value was 29% at 5 cm, whereas the value was only 13% at 15 cm of depth.

In the background of the description of pore quantity distribution, the most important information is the quantity of pores in which easily available water for the plants can be placed (18.5<dia<3 µm) (Table 2, marked italic). It can be seen that in Fluvisol, no difference exists between the soil layers and tillage. The quantity of these pores is the same: 9-10%. In the case of Cambisol, the amount of these pores varied very strongly at 5, 15 and 30 cm with 11, 3 and 9% under traditional tillage and 5, 13 and 7% under reduced tillage. Nearly the same distribution of 3<dia<0.2 µm pores (difficulty available water for plants) was observed in both investigated soils, but the values were lower. In Fluvisol, the amount of pores of this category varied from: 6 to 7% (TT) and 6 to 8% (RT), whereas in Cambisol, these amounts were 4-7% (TT) and 7-10% (RT).

The relationship between water conductivity coefficient and soil water potential for the investigated soils is shown in Fig. 2. In analysing this figure for Fluvisol, one can say that the conductivity coefficient demonstrates a large variability in its values. In the layer up to 5 cm, the courses of this characteristic for traditional and reduced tillage practically overlap. A high variation appears for the other depths. At 15 cm, the soil with reduced tillage shows better water conductivity properties as compared to traditional tillage. This difference is particularly significant for potential values higher than 3.16 kJ m^{-3}. This may be a result of the higher regularity and continuity of pores in reduced tillage, in which the destructive action of tillage tools is smaller. A similar situation occurs in Cambisol, in which at 5 cm, both characteristics overlap, whereas at 15 cm, better water conductivity properties are again shown by the soil under reduced tillage. At 30 cm in the soils from both locations, the characteristics of the conductivity coefficient overlap. The water conductivity coefficient is characterized by a large spatial variation, and the coefficient value is determined primarily by the regularity and continuity of the pores. Therefore, from analysis of the variation, one can conclude that, especially for the layer up to 15 cm, reduced tillage positively affects the shape and continuity of pores and thus creates better conditions for water movement.

The impact of the physical and chemical properties on soil water conditions under different tillage was analyzed over three years of the investigated cycle on the basis of the water dynamic in three layers. In Fig. 3, the dynamics of the water content in Eutric Fluvisol in traditional and reduced tillage are presented for 5, 15 and 30 cm. At 5 cm a significant difference between the water content for traditional and reduced tillage is observed. In the years 2008 and 2009, higher values of the water content were detected for reduced tillage for almost the whole measuring period, and these differences were 10% vol. In contrast, higher values of the water content were found for the traditional tillage from June until August 2007. A very similar situation occurred at 15 cm in the years 2008-2009, when higher values for water content were found for the reduced tillage. The only period in which the values of the water content were higher for the traditional tillage was between June and August 2007. At 30 cm, for the studied soil profiles, similar tendencies to those found at 5 and 15 cm were observed. Moreover, in the years 2008-2009, higher values of the water content were determined through the whole measuring period; only from June until August 2007 were higher values of water content found for traditional tillage. Hence, the soil profile under the reduced profile had higher water content.

In Fig. 4, the dynamics of water content in Cambisol in traditional and reduced tillage are presented for 5, 15 and 30 cm. At 5 cm, slightly higher values of water content for the reduced tillage in the whole measuring period were observed in 2007, while in years 2008-2009, the differences were insignificant, but generally the values of water content were higher for the reduced tillage. At 15 cm, the water content was higher for the reduced tillage in all measuring periods.

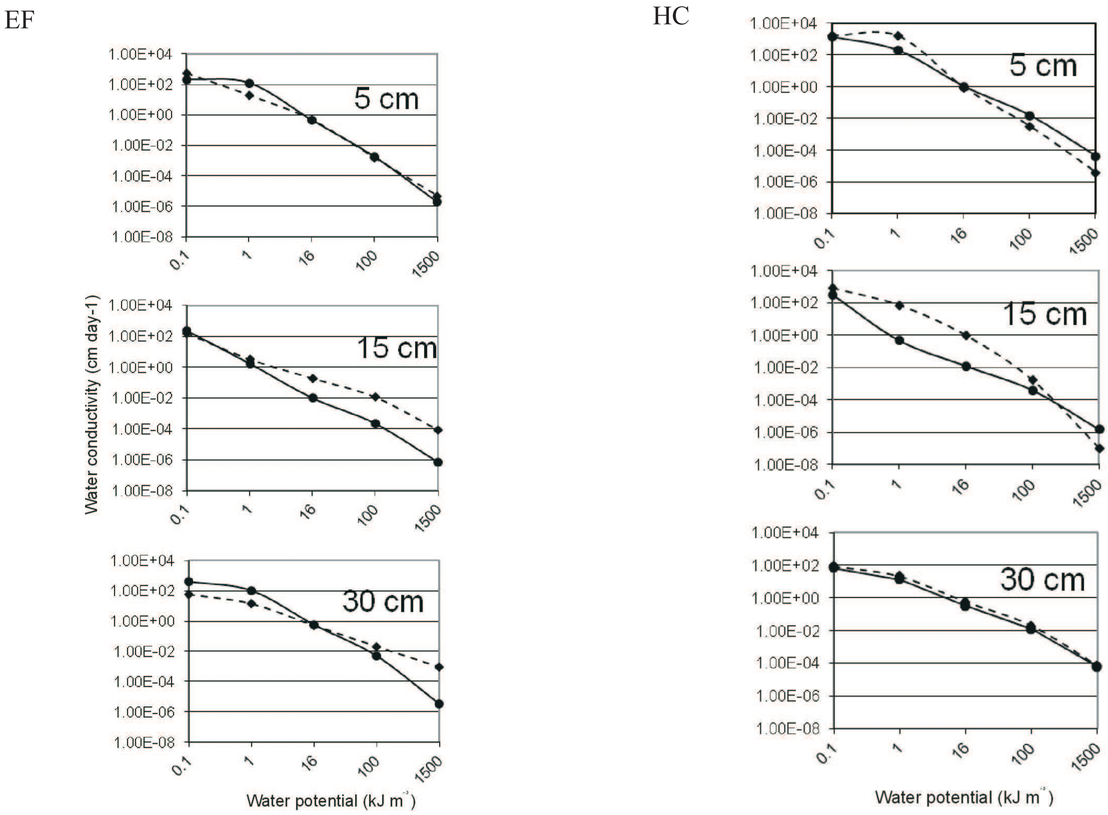

Fig. 2. Hydraulic conductivity curves for investigated soils at: 5, 15 and 30 cm. Solid lines – traditional tillage, dashed lines – reduced tillage.

The differences ranged from several to 10% vol. At 30 cm, higher values of the water content were observed for the traditional tillage at the beginning of the measuring period. In contrast, after June 30th, the water content was significantly higher for the reduced tillage. In the years 2008-2009 at the same depth, higher values of the water content were found for the reduced tillage. Only at the end of the measuring period in 2009 were higher values of the water content claimed for the traditional tillage. Generally, to 30 cm, better moisture conditions were established under the reduced tillage.

To compare the influence of tillage methods on water conditions of the soil under monoculture winter wheat cultivation, a statistical analysis was conducted for the mean values of water content comparison at different depths for the years 2007, 2008 and 2009 and for the mean values from the 3-year cycle. The average moisture for the analyzed soil layers and statistic t-student are shown in Table 3. Analysis of the data in Table 3 shows that Fluvisol in 2007 revealed no statistically significant differences between the tillage systems at the investigated depths. In 2008, in the entire soil profile, statistically significant differences were found between the tillage systems, and higher average moisture values were always noted under reduced tillage. In 2009, statistically significant differences in the soil moisture were only noted at 30 cm, where a higher value was noted under reduced tillage. For Cambisol in 2007, there were statistically significant differences in the average moisture values at 5, 15 and 30 cm. In 2008, a significant difference was found at 15 cm, while in 2009, no significant difference was noted for the whole profile. In 2007, at 5, 15 and 30 cm, higher average moisture values were noted in reduced tillage. Based on data analysis, it can be said that for Fluvisol, in the entire soil profile (at all depths), higher average moisture values were noted with reduced tillage, with statistically significant differences at 5 cm. Analysis of the data for Cambisol shows that at 5, 15 and 30 cm, higher average moisture values were noted with reduced tillage, and statistically significant differences were noted at 5, 15 and 30 cm on the soil under reduced tillage.The presented statistical analysis confirms the statement that in both soils, Fluvisol and Cambisol, there were better moisture conditions under reduced tillage.

Fig. 3. Water content of Eutric Fluvisol at: 5, 15 and 30 cm. Solid lines – traditional tillage, dashed lines – reduced tillage.

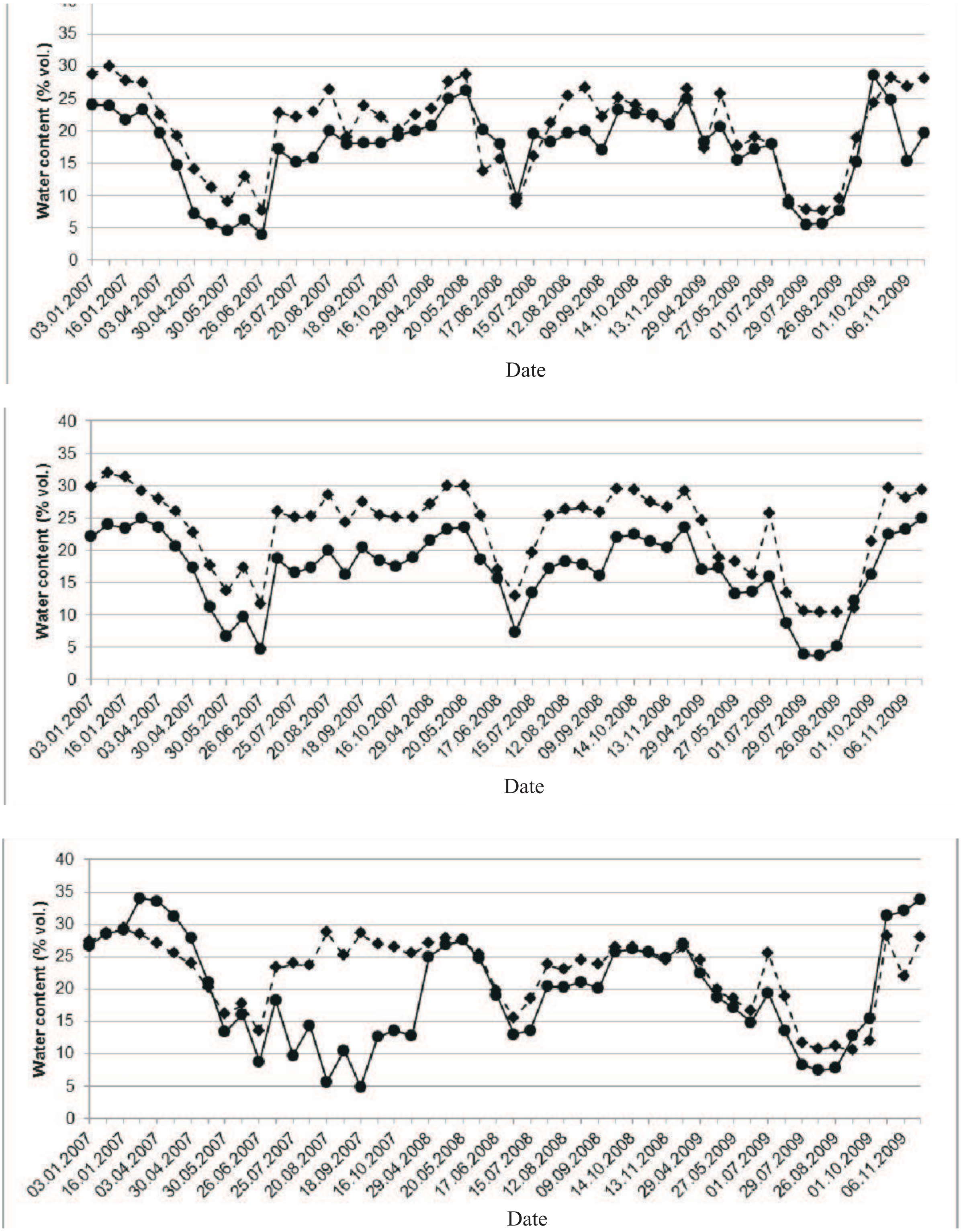

Fig. 4. Water content for Haplic Cambisol at: 5, 15 and 30 cm. Solid lines – traditional tillage, dashed lines – reduced tillage.

Table 3. Mean annual moisture and t-Student values for Eutric Fluvisol and Haplic Cambisol

Depth (cm)	Soil moisture (% vol)								
	2007			2008			2009		
	TT	RT	t	TT	RT	t	TT	RT	t
Eutric Fluvisol									
5	14.77	14.24	0.3240	**13.68***	**18.19**	-2.8439	12.35	16.41	-1.9613
15	16.30	15.20	0.7396	**14.51**	**18.11**	-2.4244	13.83	16.15	-1.2574
30	17.22	15.74	1.0875	**14.93**	**19.00**	-2.9438	**12.64**	**17.13**	-2.1274
Haplic Cambisol									
5	15.81	20.61	-2.2446	20.21	21.43	-0.6681	16.35	18.99	-0.9551
15	17.62	24.59	-3.8616	18.61	25.27	-3.7914	14.75	19.81	-1.8287
30	18.65	24.43	-2.3920	22.29	23.89	-1.0371	18.83	18.88	-0.0170

*Average moisture statistically differing at significance level $\alpha = 0.05$ are marked with bold font.

CONCUSIONS

1. These investigations confirmed that reduced tillage positively affects the physical properties of the soil.

2. Particularly, it can be observed that there is no diversity in the content of pores corresponding to easily available water in the top 30-cm layer of Fluvisol, independent of the applied tillage method. For Cambisol, the diversity of pore content corresponding to easily available water is observed for different tillage methods in the top 30-cm soil layer, but the total pore content for the whole top layer for traditional tillage and reduced tillage are similar, 23 and 25%, respectively.

3. Analysis of the water conditions in the soil profiles shows that for both soils, Fluvisol and Cambisol, during the entire 3-year research period, the moisture conditions were better at all depths of the soil profile under reduced tillage compared to traditional tillage.

4. Better water conductivity conditions for Fluvisol and Cambisol are seen by the soil under reduced tillage compared to traditional tillage, which may mean that the reduced tillage method positively affects the shape and continuity of the pores.

5. Statistical analysis confirms that for both soils, there were better moisture conditions under reduced tillage compared to traditional tillage.

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