Original Paper

The long-term different tillage and its effect on physical properties of heavy soils

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Between 2006 and 2015 years the effect of different tillage of heavy clay loamy soils on their physical properties were studied. Field treatments were carried on Experimental workplace in Milhostov, in central part of the East Slovak Lowland. Conventional tillage, reduce tillage and no-tillage practises were examined. Soil samples were taken from topsoil in natural conditions without irrigation in spring time by Kopecky's rollers. From basic physical soil properties, the bulk density, total porosity and maximum capillary water capacity were analysed by known methods. The linear trend analysis was used for testing of long-term application of different soil tillage in relation to soil properties. Bulk density was in range 1,331–1,623 kg m^{-3}, the lowest average values (in aver. 1,466 kg m^{-3}) was found for reduce tillage. Total porosity answered to bulk density and its values was from 38.12% to 49.26%, higher values were at conventional and reduce tillage and lower at no-tillage practise. Maximum capillary water capacity values in range 31.65–42.03% reached level of values typical for heavy soils of the East Slovak Lowland. The trend analysis of 10-years-time series indicate decreasing of bulk density at conventional and reduce tillage variants, but its increasing for no-tillage variant. The time course of the total porosity had the opposite course than bulk density. Mainly for no-tillage variant, trend of decreasing of total porosity influence the possibility of air and water regimes changes for clay-loamy soil, which may result in a reduction of the transport function of soil. During observed period the changes of maximum capillary water capacity wasn't significant. Application of soil protective technologies for heavy soils as integrated system, in long-time horizon doesn't have to mean deterioration of basic soil physical parameters.

Keywords: heavy soils, soil tillage, physical soil properties, long-term treatments, trend analyse

1 Introduction

For the East Slovak Lowland high presence of heavy soil with high content of clay elements are characteristics. Soil types and soil textures alternate on short distances. Heavy Gleyic Fluvisols, Mollic Gleysols, Planosols and Gleysols are situated till on 65% of arable land acreage of the East Slovak Lowland. Different sustainable systems of husbandry on soil with various soil protective technologies are frequently studied. Economic pressures on decreasing of inputs to production process and also requirements on keeping soil fertility have very strong effect on surface expansion of these technologies. In spite of the fact, that for Slovak Republic conventional tillage with ploughing is typical, each time frequently soil protective technologies are used in plant production.

According to Lal et al. (2007) the no-tillage system can be effective in reducing erosion, maintaining soil surface by plant residues, and lowering energy need. Reduced working time and lower costs are additional reasons for adopting no-till (Soane et al., 2012).

For heavy soils of the East Slovak Lowland at no-tillage systems in comparison with conventional tillage higher values of bulk density were found out in works by Kotorová (2007), Mati and Kotorová (2007), Kotorová and Mati (2008), Kotorová et al. (2010) and Kotorová and Šoltysová (2011). By Tóth et al. (2012) the soil tillage has effect also on the content of water in soil. Effect of the soil tillage technology in relation to soil physical properties will become clear in the longer time period by its using in the concrete locality.

The best time-series are longer than five years. The trend component of the time-series is used for modelling of some of the soil parameters. The trend component is used to indicate the direction of the development of the evaluated indicator over time. Büchi et al. (2017) found that the bulk density was lower in the top layer in the reduced tillage treatments than in the conventional

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plough treatment, whereas it was similar in the other layers. This is in contradiction with many studies showing an increase in bulk density with the abandonment of plough (Alvarez and Steinbach 2009; Palm et al., 2014; Soane et al., 2012). However, this increase has also been shown to be only due to a transient compaction, which should disappear with time (Vogeler et al., 2009) and the minimum tillage is adequate to have overcome this initial compaction.

According Šútor et al. (2007), the best time-series are longer than five years and according to Chajdiak (2005), the trend component of the time-series is used for modelling of some of the soil parameters. The trend component is used to indicate the direction of the development of the evaluated indicator over time.

The aim of this work was to compare the development of basic soil physical parameters of heavy soils under different tillage technologies in longer time-series.

2 Material and methods

The study of selected physical soil properties under different tillage and long-time trend of its development was realized between 2006 and 2015 in Milhostov on the experimental workplace of NPPC – Agroecology Research Institute Michalovce. This workplace is located in central part of the East Slovak Lowland near of the city Trebišov (latitude 48° 40′ N, longitude 21° 44′ E, altitude 101 m).

The long-term mean yearly precipitation shows 567 mm, during vegetation season 374 mm, the mean annual air temperature is 9.4 °C, during vegetation season 16.6 °C. From point of view of weather conditions evaluation, the experimental locality belong in climatic region T3, which is warm, very dry, lowland, continental (Linkeš et al., 1996).

The field experiments with different soil tillage were carried out on Gleyic Fluvisol. Gleyic Fluvisol was formed on heavy alluvial sediments by long-time impact of groundwater and surface water. The topsoil has lump aggregate structure with high binding ability and in whole profile it is heavy permeable. In depth 0.7–0.8 m of soil profile coherent layer of dark grey till yellow grey clay is found. Gleyic Fluvisol on experimental site is characterized as heavy, clayey-loamy soil with content of clay particles (I. category <0.01 mm) 51.43%.

In field experiment the effect of three soil tillage technologies – conventional tillage (CT), reduce tillage (RT) and direct sowing (NT) – were studied. The conventional tillage system consisted of current agro-technical operations: stubble ploughing, mean ploughing, smoothing, harrowing and sowing. The reduce tillage system consisted of these agro-technical operations: stubble ploughing by skive cultivator, soil preparation by skive cultivator before sowing and sowing by sowing machine Pneusej Accord. At no-tillage system direct sowing without ploughing by sowing machine Great Plains was used.

The study of soil tillage technologies was realized in field stationary treatment with right crop rotation. Order of field crops in individual experimental years was as follows: 2006 – spring barley (BA), 2007 – soybean (SO), 2008 – winter wheat (WW), 2009 – grain maize (GM), 2010 – BA, 2011 – SO, 2012 – WW, 2013 – GM, 2014 – BA, 2015 – SO.

Physical soil properties were determined from undisturbed soil samples taken once a year in spring (14-day after sowing of spring crops). Topsoil was sampled in cylinders of 100 cm^3 in depth 0.0–0.3 m with four replications. Soil bulk density (BD, kg m^{-3}), total porosity (TP, %) and maximum capillary water capacity (MCWC, %) were determined according to methods described by Hrivňáková et al. (2011).

For modelling of the development of soil parameters the trend analysis was used. The development of the trend component was expressed by equation $y = a + bx$ (Chajdiak, 2005). The trend lines can be assumed as the major trend of the development of selected soil parameters.

Obtained data were tested by statistical methods, from which analysis of variance was used.

3 Results and discussion

Soil tillage changes the conditions of environment for agricultural crops and it is also reason of changes of soil properties. Various soil tillage technologies are used in different combinations in dependence on soil conditions, meteorological factors, level of agronomical practices and agricultural mechanization. The tillage of soil has significant effect not only on physical and hydrophysical properties (Šimanský et al., 2008; Šimanský, 2017).

The bulk density is a basic physical property of soil and soil tillage has influence on its values. In observed experimental period years 2006–2015 the conventional tillage values of bulk density (Table 1.) were in range from 1,379 kg m^{-3} (in year 2012) to 1,546 kg m^{-3} (in year 2010). At reduce tillage values of this parameter were determined in the interval from 1,331 kg m^{-3} (in year 2014) to 1,545 kg m^{-3} (in year 2010). At no-tillage variant bulk density reached 1,392 kg m^{-3} (in year 2008) – 1,623 kg m^{-3} (in year 2011).

Similar results of bulk density for heavy soils on the East Slovak Lowland published Mati and Kotorová (2007), Kotorová and Mati (2008), Kotorová et al. (2010), Kotorová

Table 1 Bulk density [kg m^{-3}] of topsoil in Milhostov

Year	CT	RT	NT	$\bar{x}$ Y
2006	1,491,	1,459	1,41,6	1,455
2007	1,529	1,491,	1,521,	1,51,4
2008	1,471,	1,41,1,	1,392	1,425
2009	1,51,5	1,544	1,541,	1,533
2010	1,546	1,545	1,538	1,543
2011	1,41,2	1,51,8	1,623	1,51,8
2012	1,379	1,451,	1,521,	1,450
2013	1,531,	1,425	1,537	1,498
2014	1,437	1,331,	1,41,4	1,394
2015	1,420	1,481,	1,469	1,457
$\bar{x}$ T	1,473	1,466	1,497	1,479

CT – conventional tillage, RT – reduce tillage, NT – no-tillage, $\bar{x}$ T – average of tillage, $\bar{x}$ Y – average of experimental year

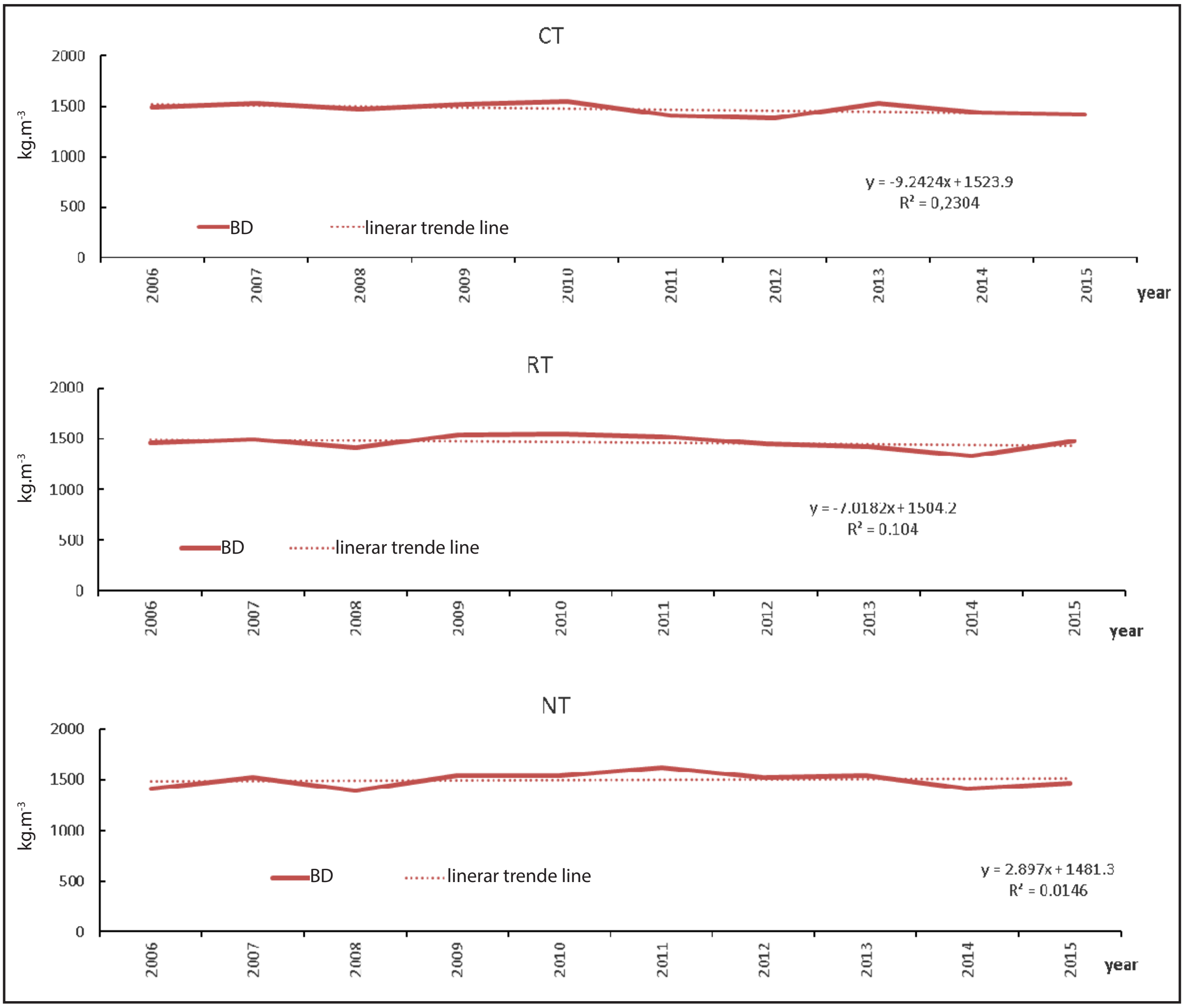

Figure 1 Linear trend of bulk density development for Gleyic Fluvisol

and Šoltysová (2011, 2015). In average, from point of view of soil tillage arrangement, bulk density increased in order of RT (1,466 kg m^{-3}) < CT (1,473 kg m^{-3}) < NT (1,497 kg m^{-3}). The lowest average bulk density (1,394 kg m^{-3}) was determined in year 2014 and the highest (1,543 kg m^{-3}) it was in year 2010. The effect not only tillage technology, but also the weather conditions is probable. The similar results also published Alvarez and Steinbach (2009) who found out that soil bulk density was significantly higher at no-till system in comparison with conventional tillage, but changes of this soil parameter were not determined between conventional and reduced tillage.

During the 10-years period, values of bulk density (Figure 1) were decreased at conventional tillage by 92.42 kg m^{-3} and reduce tillage by 70.18 kg m^{-3}. At no-tillage technology it however was increasing by 28.97 kg m^{-3}. The time course of bulk density in long-term series shows linear trend its development under all observed tillage technologies. The increasing of bulk density under no-tillage may be related to deterioration of soil properties a soil compaction. Presented development of bulk density correspond with results, which presented Ledvina et al. (2004), Dam et al. (2006), Głab and Kulig (2008) and also Elder and Lal (2008). The trend of bulk density for no-tillage variant (Figure 1) indicate the possibility of compaction of topsoil.

Total porosity is function of bulk density and the values of porosity correspond with bulk density values, when higher bulk density the values of porosity are lower (Table 2).

Total porosity corresponded with bulk density. The values of total porosity in range from 41.06 in year 2010 to 47.43% in year 2012 were determined under conventional tillage. The most favourable values of total porosity were determined under reduce tillage variant (41.10–49.26%). The lowest pore volume was ascertained under no-tillage variant (38.12–46.93%). Even though our results showed increasing of bulk density and decreasing of total porosity, according to Moreira et al. (2016) the soil physical properties evaluated suggest that under long-term NT the soil remained physically functional.

Total porosity by valued time-series was decreased at conventional tillage 1.49% and at non-tillage variant by 0.76% (Figure 2). This decreasing wasn't statistically significant.

The course of total porosity in 10-year time-series was opposite to course of bulk density. At conventional and reduce tillage the porosity increased (CT: by +3.52%; RT: by +2.67%), but under no-tillage porosity decreased by 1.11%. However, these changes weren't statistically significant.

Maximum capillary water capacity is important hydro-physical indicator and characterizes amount of water for definite locality that is available for field crops (Šútor et al., 2007; Šimanský et al., 2016). It is depended on the sum of precipitation, the content of clay particles and the soil water storage. The large interval of this parameter is typical for heavy soils. In our experiment, the values of this soil indicator were found in range 31.65–42.03% (Table 3.). From point of view of soil tillage technologies, in average maximum capillary water capacity increased as follows: NT < CT < RT.

In Figure 3 the course of maximum capillary water capacity in 10-years studied time-series is shown. For conventional tillage and no-tillage variant decreasing of this indicator was determined (CT: by -3.87%; NT: by -2.50%), but for reduce tillage variant was determined its

Table 2 The total porosity (%) of topsoil in Milhostov

Year	CT	RT	NT	$\bar{x}$ Y
2006	43.16	44.38	46.02	44.52
2007	41.71	43.16	42.01	42.29
2008	43.92	46.21	46.93	45.69
2009	42.24	41.14	41.25	41.54
2010	41.06	41.10	41.36	41.17
2011	46.17	42.13	38.12	42.14
2012	47.43	44.68	42.01	44.71
2013	41.63	45.67	41.40	42.90
2014	45.22	49.26	46.09	46.86
2015	45.86	43.54	44.00	44.47
$\bar{x}$ T	43.84	44.13	42.92	43.63

CT – conventional tillage, RT – reduce tillage, NT – no-tillage, $\bar{x}$ T – average of tillage, $\bar{x}$ Y – average of experimental year

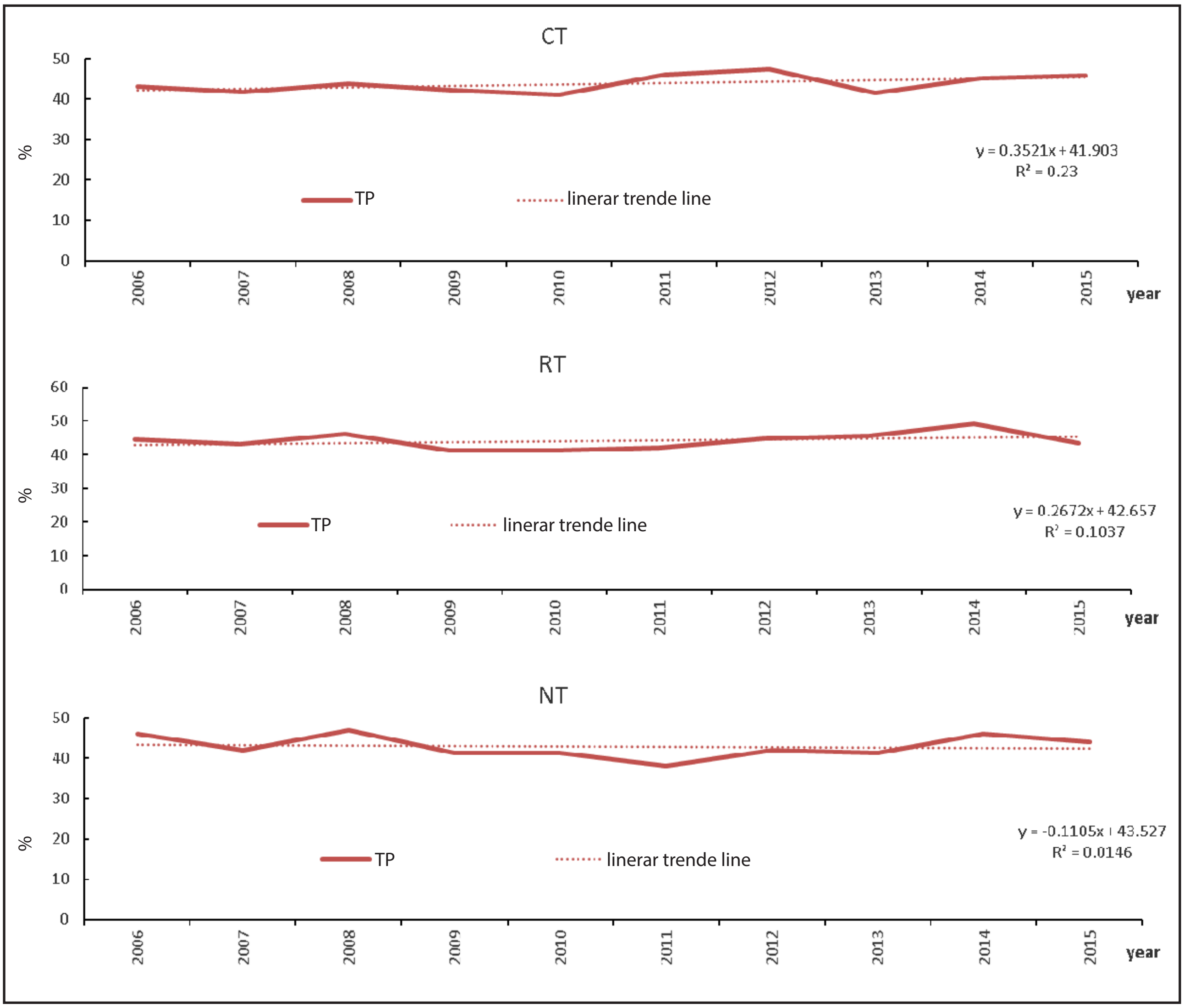

Figure 2 Linear trend of total porosity development for Gleyic Fluvisol

Table 3 The maximum capillary water capacity [%] of topsoil in Milhostov

Year	CT	RT	NT	$\bar{x}$ Y
2006	40.20	40.43	41.25	40.63
2007	35.38	36.45	35.65	35.83
2008	38.05	37.68	35.96	37.23
2009	39.24	39.73	38.58	39.18
2010	38.28	39.34	37.90	38.51
2011	40.64	39.78	36.52	38.98
2012	38.37	38.15	37.09	37.87
2013	37.58	38.73	32.90	36.40
2014	37.62	42.03	37.76	39.14
2015	31.65	37.54	37.37	35.52
$\bar{x}$ T	37.70	38.99	37.10	37.93

CT – conventional tillage, RT – reduce tillage, NT – no-tillage, $\bar{x}$ T – average of tillage, $\bar{x}$ Y – average of experimental year

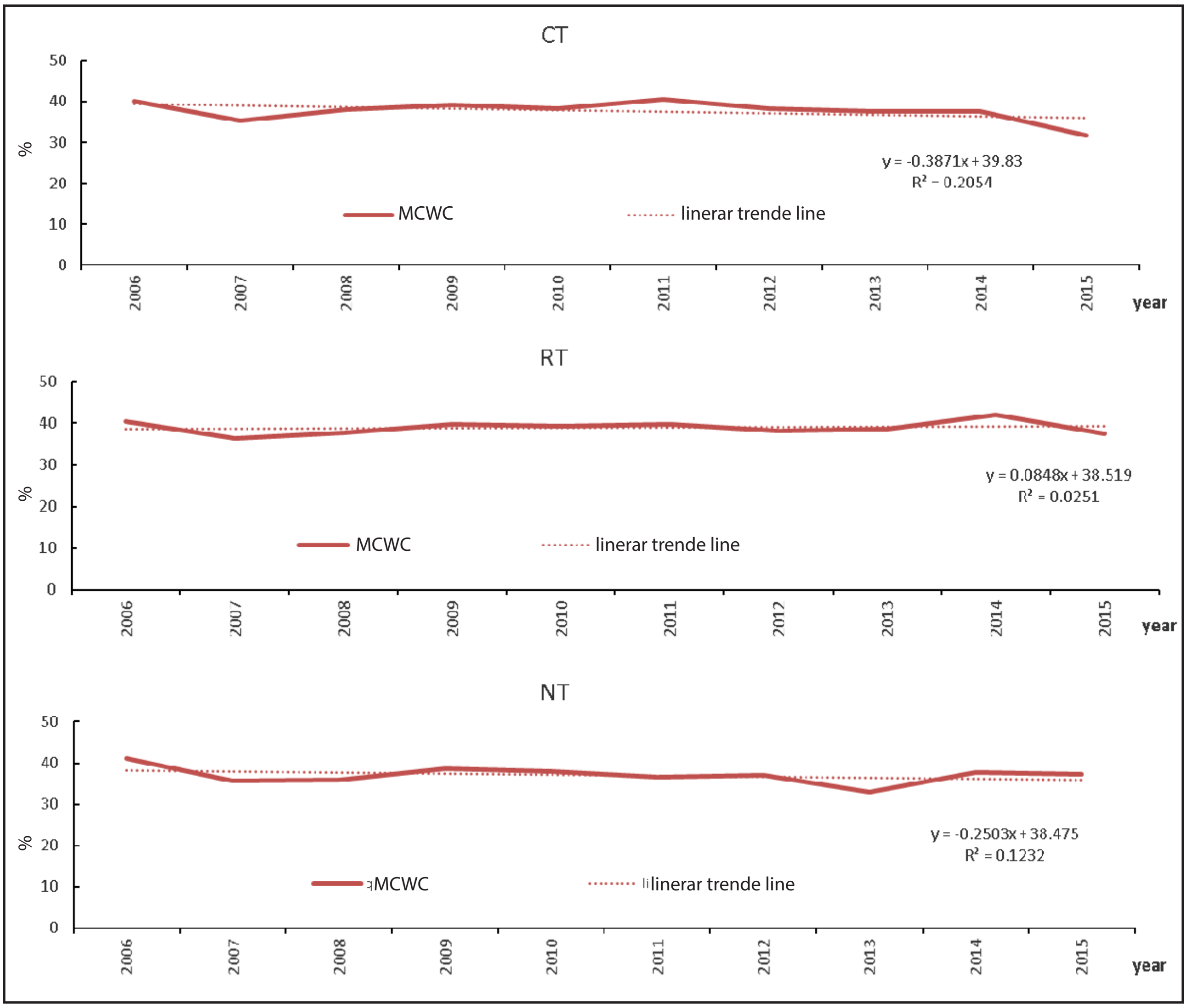

Figure 3 Linear trend of maximum capillary water capacity development for Gleyic Fluvisol

increasing by +0.85%. However, these changes, like for total porosity, weren't statistically significant.

The presented time-series with linear trend confirmed, that application of extreme tillage technologies, as are no-tillage systems without ploughing, is prospective also on heavy soils with higher content of clay particles. The physical and hydro-physical properties of these soil textures aren't significantly deterioration.

In accordance with Moreira et al. (2016) can be concluded that the physical properties indicated that the soil under long-term NT may have reached a physical equilibrium condition, which can be modified by short-term events

Table 4 Analysis of variance for observed soil water storage parameters

Source of variability	Degree of freedom	BD		P_t		θ_{MCWC}	
		F	*P*	*F*	*P*	*F*	*P*
Tillage	2	6.64	++	5.67	++	18.99	++
Year	9	15.28	++	15.29	++	16.88	++
Residual	105						
Total	119						

$^{++}P < 0.01$; $^{+}P < 0.05$
BD – soil bulk density, P_t – total porosity, θ_{MCWC} – maximum capillary water capacity, *F* – observed value, *P* – probability

Table 5 Statistical evaluation of observed soil physical parameters values ($\alpha = 0.05$)

Source of variability	Factor	Observed parameter		
		BD (kg m^{-3})	TP (%)	θ_{MCWC} (%)
Soil tillage	CT	1473.1 a	43.84 b	37.701 a
	RT	1465.6 a	44.127 b	38.986 b
	NT	1497.2 b	42.919 a	37.098 a
Year	2006	1455.33 b	44.52 c	40.6267 f
	2007	1513.67 cd	42.2933 ab	35.8267 a
	2008	1424.67 ab	45.6867 cd	37.23 bc
	2009	1533.33 d	41.5433 ab	39.1833 e
	2010	1543.0 d	41.1733 a	38.5067 de
	2011	1517.67 cd	42.14 ab	38.98 de
	2012	1450.33 b	44.7067 c	37.87 cd
	2013	1497.67 c	42.9 b	36.4033 ab
	2014	1394.0 a	46.8567 d	39.1367 e
	2015	1456.67 b	44.4667 c	35.52 a

BD – soil bulk density, TP – total porosity, θ_{MCWC} – maximum capillary water capacity, CT – conventional tillage, RT – reduce tillage, NT – no-tillage, ascenders (a, b, c, d, e, f) between factors suggestive of statistically significant references ($\alpha = 0.05$) – LSD test

such as excessive machinery traffic, weather conditions variability and changes in crops grown in the crop rotation system. The modification of the soil properties suggested that soil quality was improved in the reduced tillage treatments (Büchi et al., 2017). Our results, also from point of view of long-term observation, confirmed the suitability of reduce tillage for heavy soils.

From Table 4 and Table 5 it becomes clear statistically significant effect of tillage technology and year on bulk density, total porosity and maximum capillary water capacity of clay-loamy soil in Milhostov.

The highest impact of tillage technologies and experimental year was determined for maximum capillary water capacity. The effect of experimental year on other observed parameters was lower, but similar as for maximum capillary water capacity.

4 Conclusions

Bulk density of Gleyic Fluvisol in Milhostov reached 1,331–1,623 kg m^{-3} and the lowest values (in average 1,466 kg m^{-3}) were found for reduce tillage variant. Values of total porosity were in range from 38.12 to 49.26%, whereby lower values were determined under no-tillage technology. Maximum capillary water capacity values from 31.65% to 42.03% reached level of values typical for soils on the East Slovak Lowland.

The trend analysis for years 2006–2015 show the decreasing of the bulk density and the increasing of the total porosity under conventional and reduce tillage. The course of these soil indicators under no-tillage variant was the opposite. The development trend of maximum capillary capacity during observed period wasn't significant.

From point of view of tillage technology, for clay-loamy soil the reduce tillage is better than conventional tillage or no-tillage. Effect of used technology will be shown after their longer application.

The soil protective technologies are one method for keeping and conservation of the soil fertility. For their successful is needful application as whole the farming system and the continuity of this system is very important. Using of the protective technologies may also contribute to keeping of stability of ecologically sensitive the heavy soils.

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