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IS BETTER MINIMUM THAN STANDARD MOULDBOARD PLOUGHING TILLAGE FROM VIEWPOINT OF THE PORE-SIZE DISTRIBUTION AND SOIL WATER RETENTION CHARACTERISTIC CHANGES ?

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ABSTRACT. At present time exists a lot of soil tillage practices with different effects on soil productivity, therefore the effects of two tillage systems (conventional: CT, and miminum: MT) and two different soil types (Chernozem and Mollic Fluvisol) on soil physical quality indicators and water availability were evaluated in an on-farm study in the Krakovany (Danube Lowland, Slovakia). We evaluated pore-size distributions and selected hydro-physical properties (capillary rise, maximum capillary water capacity and retention water capacity). The total porosity (P) on average by 23% and by 14%, non-capillary pores (Pn) by 271% and by 114% and semi-capillary pores by 102% and by 192% were significantly greater for CT than MT in Chernozem and in Mollic Fluvisol, respectively. The content of capillary pores (Pc) was significantly greater for MT than CT on average by 13% and 8% in Chernozem and in Mollic Fluvisol, respectively. The average content of capillary rise (Θ_{CR}), maximum capillary water capacity (Θ_{MCWC}) and retention water capacity (Θ_{RWC}) were higher by 6, 10 and 13% under MT than CT in soil profile of Chernozem. The same effect of soil tillage systems in Mollic Fluvisol was not observed. In Chernozem under MT with increased P, Θ_{CR} significantly increased, however, under CT, the Θ_{CR} significantly decreased. At the same time we determined negative correlations between Pn and soil water retention characteristics under CT. Higher content of Pc resulted in higher values of capillary rise, maximum capillary water capacity and retention water capacity in both soil types under both tillage systems.

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Keywords: tillage systems; porosity; hydro-physical properties; Chernozem; Mollic Fluvisol.

INTRODUCTION

One of the most important negative consequences of modern agricultural production is probably the soil physical degradation resulting in erosion and soil compaction, which is attributed to deep and mainly intensive tillage practices (Esteve *et al.,* 2004). Tillage disrupts soil aggregates, compacts soil and disturbs plant and animal communities that contribute to aggregation and lowers SOM, CEC, nutrients, microbial activity and faunal activities that contribute to aggregation (Plante and McGill, 2002). Nevertheless, the conventional ploughing-based tillage systems are still dominant (Rusu, 2005). The current stage of development of agriculture in all developed economies is characterized by tendency to reduce material and energy intensity of production systems of field crops. In this context, more and more into the fore soil tillage technologies usually referred to as "conservation tillage" (Kotorová *et al.,* 2010). Basis of conservation tillage is a no-till system (Hobbs, 2007). In 2004/05 there were about 96 million hectares of land under no-tillage systems worldwide (FEBRAPDP, 2008) and these areas are raising to 106 million hectares (Derpsch, 2008). No-tillage is not used as much (10-30% of the land) even though it may be a better option to prevent soil degradation and increase plant-available water. There is evidence that management practices may alter soil quality based on soil chemical, physical, biological and hydrological properties. For example, Dao (1996) reported that no-till soil had lower bulk density than that under conventionally tilled soil. On the other hand, Roseberg and McCoy (1992) found that conventional tillage increased total porosity of the soil, but the macro-pores (effective pores) decreased in number, stability and continuity, compared with no-till soil. The most widely used practice except conventional tillage is reduced vertical tillage with a chisel-plough or minimum tillage with a disking. The production differences between the alternative systems and the classic one can be the result of different soil-climate conditions (Moroizumi and Horino, 2002). The efficiency of the alternative systems has to be verified and then subsequently put into practice.

Many soils in the Danube Lowland (Slovakia) are prone to physical and chemical degradation due to their sandy or silty texture, low organic matter content, and mainly incorrect soil management practices. There may be an appropriate solution the introduction of protective tillage systems, therefore our objective was to determine how conventional and miminum tillage practices affected soil physical quality indicators and water availability in an on-farm study in the Krakovany.

MATERIAL AND METHODS

This study was conducted at two sites in the Krakovany locality in autumn of 2014. Climate in the area is temperate with the average annual precipitation 650-800 mm and average annual temperature is 8.5-9°C. Locality was situated at the north of the Danube Lowland and was bordered by the west and east Malé Karpaty and Považský Inovec Mountains, respectively. First study area was located on the terrace of Váh River and was formed by Quaternary fluvial sediments, Pleistocene loess and loess which overlap accumulated gravel. Gravel grains of different sizes were formed mainly from granitites, quartzite and sandstone. Carbonates were represented less. Second study area was located on fluvial sediments along the Váh River.

In both areas, conventional tillage (CT, consisting of mouldboard ploughing to the 0.22–0.25 m depth in autumn, followed by disking, rolling/levelling and planting with dependence on cultivated crops) has been practiced for the last 60 years. Minimum tillage (MT, using the disking to a depth of 0.10-0.12 m in autumn, followed by rolling/levelling and planting with dependence on cultivated crop; however, every year in this tillage system the intensive weed control by disking between planted crops was done (i.e. after harvesting of crops) was implemented in both areas (part of the field) since 2009 - 5 years before this study was conducted. In both areas, the soils were classified (WRB, 2006) as follows: First study area: site 1 (S1) was managed under minimum tillage and site 2 (S2) under conventional tillage. Second study area: site 3 (S3) was managed under minimum tillage and site 4 (S4) under conventional tillage. In time of sampling the crops were as follows: in S1: soybean *(Glycine max* L.*)* with fore crop winter wheat *(Triticum aestivum* L.*)*, in S2: sunflower *(Helianthus annus* L.*)* with preview crop maize *(Zea mays* L.*)*, S3 and S4 maize *(Zea mays* L.*)* with preview crop winter wheat *(Triticum aestivum* L.*)*. The soil at both areas was: S1 and S2: a loamy Haplic Chernozem, S3 and S4: a loamy Mollic Fluvisol (WRB, 2006). Before soil sampling, pits were excavated in all sites (S1-S4). In the soil pits, the soil samples were collected (in triplicate) after 10 cm layers to a depth of 40 cm to cylinders with an inner diameter of 5 cm and height of 5 cm. Determination of physical (pore size distributions), hydro-physical properties (capillary rise, maximum capillary water capacity and retention water capacity) was then conducted using standard methods (Fiala *et al.,* 1999). Data were analysed using ANOVA (analysis of variance). Treatment means were compared using significant differences ($P< 0.05$), and post hoc analysis was performed by LSD test ($P< 0.05$). Unless otherwise stated, significant results are based on a probability level of $P= 0.05$. All statistical analyses were performed using the computer program Statgraphics Centurion XV.I (Statpoint Technologies, Inc., USA).

RESULTS AND DISCUSSION

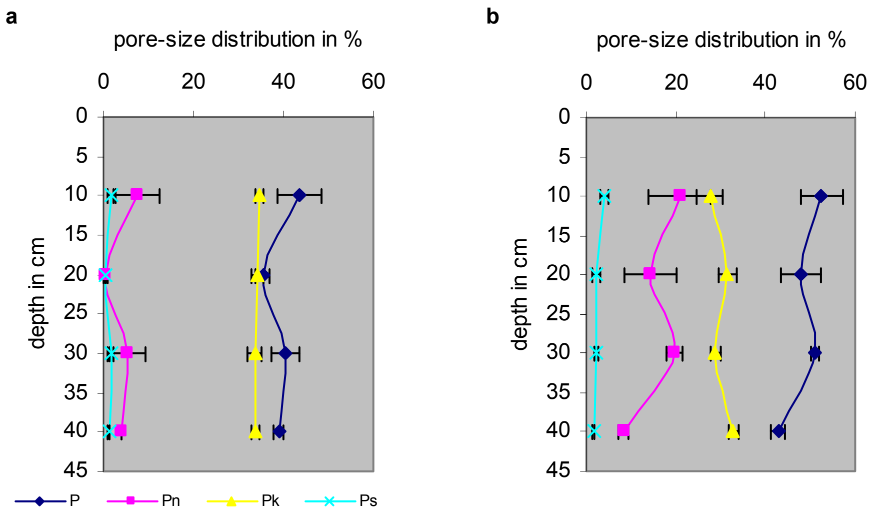
The pore-size distributions were different between tillage practices at all four depth increments in both soil types (*Figs. 1ab and 2ab*). The total porosity (P), non-capillary pores (Pn) and semi-capillary pores (Ps) were significantly greater for conventional (CT) than minimum tillage (MT) in both soil types (*Tab. 1*). For optimal topsoil condition of the soil profile, the values of the porosity interval should not fall below 40-50% (Fulajtár, 2006). In the Chernozem, the lowest value of P was in 10-20 cm, while the highest one was in upper layer (0-10cm) under MT. The same trend but no significant was observed in the Mollic Fluvisol under MT. Considering conventional tillage, in both soil types, the lowest values of P were in layer 30-40 cm and the highest in upper layer. Under CT in both soil types, the values of P were significantly higher in layer 0-30 cm, what is due to intensive soil homogenization. The same findings have been published by Sasal *et al.* (2006) and Kotorová (2007). Mentioned authors claimed that due to soil ploughing to the depth of 25 cm, the soils in this layer are less compacted and have higher total porosity. Lal and Shukla (2004) indicated that the content of macro-pores, which included non-capillary and semi-capillary pores, depends on the soil management practices and the micro-pores are influenced by particle-size distribution in soil (Lipiec *et al.,* 2006). In both soil types compacted layer was formed from upper 10 cm layer under MT, while under CT from the depth of 30 cm. Non-capillary pores are characterized by redundancies of gravitation water, therefore, they are key to water infiltration into the soil profile. Overall, a higher content of Pn was found at CT, compared with MT in the Chernozem but also in the Mollic Fluvisol (*Figs. 1ab and 2ab*). In both soil types at CT, the values of Pn were significantly higher in the upper 30 cm, compared to layer 30-40 cm. This state can be attributed to ploughing because as it result is formed higher total porosity with higher contents of non-capillary pores in top soil (Sasal *et al.,* 2006). Under the MT in both soil types (*Figs. 1a and 2a*), the values of Pn were the lowest in a layers of 10-20 cm and in the layer above and below Pn were significantly higher.

Table 1 – Analyses of variance of pore-size distribution and hydro-physical properties

	P	Pn	Pc	Ps	Θ_{CR}	Θ_{MCWC}	Θ_{RWC}
				Chernozem			
MT	39.6a	4.28a	34.1b	1.24a	36.5b	34.5b	34.1b
CT	48.6b	15.9b	30.2a	2.51b	34.5a	31.4a	30.2a
				Mollic Fluvisol			
MT	42.0a	4.76a	36.0b	1.28a	38.0a	36.6a	36.0b
CT	47.7b	10.2b	33.7a	3.75b	38.7a	35.3a	33.7a

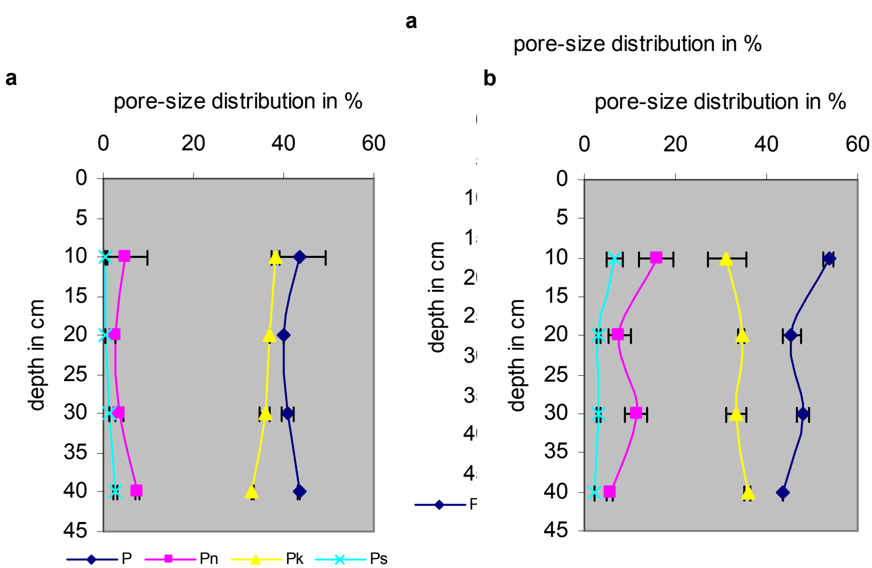
Notes: Different letters between lines (a, b) indicate significant differences at $P<0.05$ according to LSD multiple-range test.

MT – minimum tillage; CT – conventional tillage; P – total porosity; Pn – non-capillary pores; Pc – capillary pores; Ps – semi-capillary pores; Θ_{CR} – capillary rise; Θ_{MCWC} – maximum capillary water capacity; Θ_{RWC} – retention water capacity.



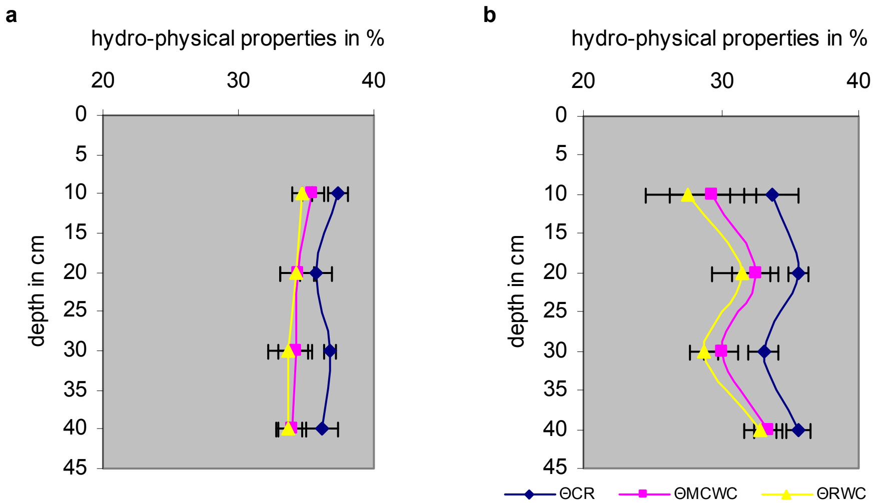
P – total porosity; Pn – non-capillary pores; Pc – capillary pores; Ps – semi-capillary pores

Figure 1 – Pore-size distribution in Chernozem: a) in minimum; b) in conventional tillage



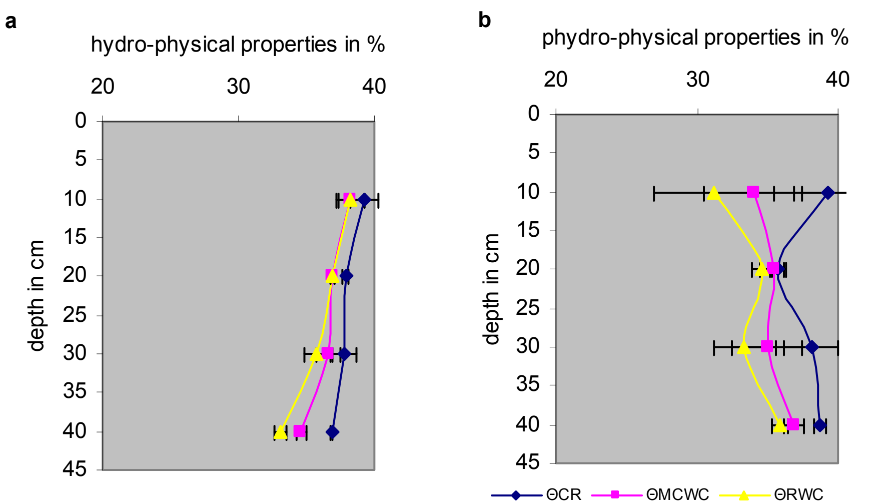
P – total porosity; Pn – non-capillary pores; Pc – capillary pores; Ps – semi-capillary pores.

Figure 2 – Pore-size distribution in Mollic Fluvisol: a) in minimum; b) in conventional tillage



Θ_{CR} – capillary rise; Θ_{MCWC} – maximum capillary water capacity; Θ_{RWC} – retention water capacity.

Figure 3 – Hydro-physical properties in Chernozem: a) in minimum; b) in conventional tillage



Θ_{CR} – capillary rise; Θ_{MCWC} – maximum capillary water capacity; Θ_{RWC} – retention water capacity.

Figure 4 – Hydro-physical properties in Mollic Fluvisol: a) in minimum: b) in conventional tillage

One-way ANOVA analysis showed the opposite trend for the content of capillary pores (Pc), which were significantly greater for MT than CT in both soil types (*Tab. 1*). In profile of the Chernozem, the Pc contents were relatively balanced under MT, however, under CT their volume increased with the depth (*Fig. 1ab*). In the Mollic Fluvisol, the opposite situations were observed. The highest volume of Pc was determined in layer 0-10 cm under MT and by the depth decreased. Under CT, the Pc fluctuated from 31.2% to 35.7% and tillage systems did not have statistically significant influence on Pc in the Mollic Fluvisol. Šimanský (2012) noted that the content of Pc significantly did not change due to different soil management practices in vineyard soils. The capillary pores or micro-pores according to Lipiec *et al.* (2006) are not significantly affected by soil management, which was not confirmed our results.

Statistical evaluation of soil water retention characteristics with dependence on different soil type and soil tillage systems is shown in *Figs. 3ab and 4ab*. Different soil tillage systems had statistically significant influence on soil water retention characteristics, but only in the Chermozem (*Tab. 1*). The average content of capillary rise (Θ_{CR}), maximum capillary water capacity (Θ_{MCWC}) and retention water capacity (Θ_{RWC}) were higher by 6, 10 and 13% under MT than CT in soil profile of the Chernozem. The same effect of soil tillage systems in the Mollic Fluvisol was not observed. Tillage systems had statistically significant influence only on Θ_{RWC} values. On average, a higher Θ_{RWC} was under MT than CT in both soil types. Values of Θ_{MCWC} confirmed that the soil can form the capillary pores and supply root system of plants by soil solution. Values of Θ_{MCWC} above 35% can be considered as favourable, which demonstrates sufficient content of capillary pores in the soil layer (Fulajtár, 2006). In addition in the profile of the Chernozem under CT, the Θ_{MCWC} values were below mentioned interval *(Fig. 3b)*. According to Fulajtár (2006) on Θ_{MCWC} values has important effect the particle-size distribution, so at a higher content of clay the Θ_{MCWC} values use to be higher. Several authors (Dam *et al.*, 2006; Kováč and Švančárková, 2003) found that tillage does not affect the Θ_{MCWC}. On the other hand, Kotorová (2007) stated that the values of Θ_{MCWC} were affected by tillage system. A higher average values during 1998-2006 on the clayey-loamy Gleyic Fluvisol were in CT than NT treatments.

Water retention depends on soil structure and porosity (Dexter, 2004; Czachor *et al.*, 2015). There are numerous differences between pore size distribution and water retention characteristics with relation to soil type and soil tillage systems (*Tab. 2*). In the Chernozem under MT, with increased P, Θ_{CR} significantly increased, however, under CT, the Θ_{CR} significantly decreased. Kay

(1998) claimed that a higher amount of soil organic matter can increase biological activity, which can lead to increasing porosity. Our results confirmed higher content of soil organic carbon under MT than CT in this experiment (Šimanský *et al.,* 2016). The intensive cultivation is main reason of soil organic matter mineralization (Ogle *et al.,* 2004) and decrease of microbial activity, which can decrease the proportion of smaller pores due to decreased CO_2 production (Bescansa *et al.,* 2006). Negative correlations between P and Θ_{MCWC} as well as Θ_{RWC} were determined under CT in both soil types. In MT of both soil types no significant relationships were determined between Pn and water parameters. However, we determined negative correlations between Pn and soil water retention characteristics under CT. Based on results we concluded that intensive tillage system containing higher amount of Pn caused lower retain of water in both soil types. A similar conclusion was reached also by Fernández Ugalde *et al.* (2009). The volume of capillary pores had significant influence on values of soil water retention characteristics in both soil types under different soil tillage systems. Higher content of Pc resulted to higher values of capillary rise, maximum capillary water capacity and retention water capacity. Negative correlations between Ps and Θ_{MCWC}, Θ_{RWC} were observed in both soil types under CT. Important negative correlations between Ps and soil water retention characteristics were determined under MT in the Mollic Fluvisol, when compared to the Chernozem (*Tab. 2*).

Table 2 – Correlation coefficients *(r)* between pore-size distribution and selected hydro-physical properties

		Θ_{CR}	Θ_{MCWC}	Θ_{RWC}		Θ_{CR}	Θ_{MCWC}	Θ_{RWC}
Chernozem								
P	MT	0.648*	n.s.	n.s.	CT	-0.700*	-0.866***	-0.896***
Pn	MT	n.s.	n.s.	n.s.	CT	-0.815**	-0.934***	-0,947***
Pc	MT	0.640*	0.953***	1.000***	CT	0.875***	0.989***	1.000***
Ps	MT	n.s.	n.s.	n.s.	CT	n.s.	-0.686*	-0.771**
Mollic Fluvisol								
P	MT	n.s.	n.s.	n.s.	CT	n.s.	n.s.	-0.710**
Pn	MT	n.s.	n.s.	n.s.	CT	n.s.	-0.777**	-0.879***
Pc	MT	0.904***	0.985***	1.000***	CT	0.581*	0.958***	1.000***
Ps	MT	-0.658*	-0.847***	-0.915***	CT	n.s.	-0.665*	-0.829***

Notes: *$P<0.05$; ** $P<0.01$; *** $P<0.001$; n.s. – non-significant.
MT – minimum tillage; CT – conventional tillage; P – total porosity; Pn – non-capillary pores; Pc – capillary pores; Ps – semi-capillary pores; Θ_{CR} – capillary rise, Θ_{MCWC} – maximum capillary water capacity; Θ_{RWC} – retention water capacity.

CONCLUSION

The suppression of tillage resulted to decreased total porosity, non-capilary porosity and semi-capillary porosity, mainly in soil layer of 10-20 cm. However, other hydro-physical soil quality indicators, such as capillary rise, maximum capillary water capacity and retention water capacity were improved after 5 years of continuous minimum tillage. Conventional tillage system containing higher volume of non-capillary pores caused lower retain of water. We conclude that the implementation of minimum tillage resulted to a better functioning of the studied soils. Farmers should consider adopting minimum tillage practices in other localities of Danube Lowland with similar soil and climate characteristics.

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