Which soil tillage is better in terms of the soil organic matter and soil structure changes?

Ktoré obrábanie pôdy je lepšie z pohľadu zmien pôdnej organickej hmoty a štruktúry pôdy?

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Abstract

This study was performed to evaluate effects of minimum (MT) and conventional tillage (CT) on soil organic matter and soil structure in haplic Chernozems and mollic Fluvisols. The content of soil organic carbon (C_{org}) as well as parameters of stability and vulnerability of soil structure were quantified. The results showed that soil type had statistically significant influence on C_{org}. In haplic Chernozems the C_{org} content near the surface (0–0.1 m) was significantly higher under MT (by 6%) compared to CT, however, in layer 0–0.3 m under CT the average C_{org} content was by 16% higher than under MT. In mollic Fulvisols under MT, the average C_{org} content (17.5 ± 5.4 g*kg^{-1}) was significantly less for the 0–0.3 m layer than the CT (22.7 ± 0.4 g*kg^{-1}). In Chernozems, total content of water-stable micro-aggregates (WSA_{mi}) was higher in MT (90.8%) than in CT (69.5%). In mollic Fluvisols, the average content of WSA_{mi} was higher in CT (62.5%) than in MT (53.2%). The low aggregate stability and the high structure vulnerability were reflected also due to the high contents of WSA_{mi} in both soils. The stability of aggregates was a higher in mollic Fluvisols than in haplic Chernozems. In haplic Chernozems, better soil structure stability was under CT than MT, on the other hand, in mollic Fluvisols, the average value of coefficient of aggregate stability was lower by 32% in CT than MT.

Keywords: haplic Chernozem, mollic Fluvisol, soil organic carbon, tillage systems, vulnerability and stability of soil structure

Abstrakt

Vplyv minimálneho (MT) a konvenčného (CT) obrábania pôdy na zmeny pôdnej organickej hmoty a štruktúry pôdy boli uskutočnené na černozemi a čiernici kultizemných. V oboch pôdnych typoch pod rozdielnym spôsobom obrábania boli stanovené: obsah celkového organického uhlíka (C_{org}) a parametre stability a zraniteľnosti pôdnej štruktúry. Výsledky ukázali, že pôdny typ mal štatisticky významný vplyv na množstvo C_{org}. V černozemi do hĺbky 0,1 m pod minimálnym obrábaním pôdy bol obsah C_{org} vyšší o 6% v porovnaní s konvenčným obrábaním pôdy. Avšak, do hĺbky 0,3 m bol obsah C_{org} v porovnaní s MT o 16% vyšší v dôsledku konvenčného obrábania pôdy. V pôdnom type čiernica v dôsledku minimálneho obrábania bol priemerný obsah C_{org} (17,5 ± 5,4 g*kg^{-1}) štatisticky významne vyšší ako v CT (22,7 ± 0,4 g*kg^{-1}). V černozemi, v MT (90.8%) bol stanovený vyšší obsah vodoodolných mikro-agregátov (WSA_{mi}) v porovnaní s CT (69.5%). V čiernici, priemerne vyšší obsah WSA_{mi} bol v CT (62.5%) ako v MT (53.2%). Nízka stabilita agregátov a ich zraniteľnosť bola aj výsledkom vysokého obsahu WSA_{mi} v oboch pôdnych typoch. Celkovo vyššou stabilitou agregátov sa vyznačovala čiernica v porovnaní s černozemou. Vyššia stabilita agregátov bola v CT systéme v porovnaní s MT v černozemi. V čiernici priemerná hodnota koeficientu agregátovej stability bola nižšia o 32% v CT ako v MT.

Kľúčové slová: černozem, čiernica, pôdny organický uhlík, spôsoby obrábania, zraniteľnosť a stabilita štruktúry pôdy

Introduction

Soil is the basis of life, civilization, culture, livelihood and health. If humanity cannot pass healthy soil to the next generation, human cultures cannot be passed on and will surely perish. In literature is a lot of evidence that the degradation of soil was a key factor in the collapse of various civilizations (Minami, 2009). Agriculture changes the soil environment, mainly 20th-century, which has been bewitched by huge developments in science and technology, and by the attendant growth of productivity and population, has completely changed the soil and the environment. For example, very important intervention to the soil is itself cultivation. At present time exists a lot of soil tillage practices with different effects on soil productivity. Conventional ploughing-based tillage systems are still dominant (Rusu, 2005). However, alternative tillage systems are becoming economically and ecologically more attractive as they save energy and provide more favourable soil conditions (Husnjak et al., 2002). Arable soils under a long-term regime of frequent tillage usually suffer from losses in organic matter, increased nitrification, and deteriorated soil structure, thus reducing agricultural sustainability (Calderón et al., 2000). Conventional tillage (intensive soil tillage with mouldboard ploughing) increase soil erosion and degradation processes. These processes promote the deterioration of chemical, physical and biological soil properties (Plante and McGill, 2002). No-till, minimum (disking) or reduced tillage systems (chisel) increase C accumulation and aggregate stability (Derpsch, 2008; Šimanský et al., 2008). Also, larger species diversity can be measured compared to conventional tillage systems (Mäder et al., 2002). However, all depend on climatic conditions and soil types. Above-mentioned are negative and positive effects of conventional and minimum (disking) tillage system, respectively. Findings can be opposite. For example, the results of Šimanský et al. (2007) on arable Chernozems of Danubian Lowland showed that conventional tillage (mouldboard ploughing) in comparison to minimum (disking) was better with regard to soil structure and organic matter in water-stable aggregates, with similar decreasing of soil organic matter content. As is above-mentioned, change in frequency and intensity of tillage practices alter soil properties, distribution of nutrients, the soil organic matter content and quality in the soil profile (Dou and Hons, 2006; Moussadek et al., 2014; Šimanský et al., 2008).

However, this information cannot be just blindly take without verification and apply them in practice. A good farmer is trying to optimize soil management practices so that does not destroy the soil while ensuring adequate healthy and economical production. Therefore, the objective of this study was to evaluate the effects of different tillage systems on soil organic matter content and soil structure in one of the most fertile soils in Slovakia. The hypothesis was that minimum tillage would be certainly viable options that can produce beneficial effects on soil physical properties (soil structure) and soil organic matter.

Materials and methods

In spring of 2014, soil surveys were carried out to determine the soil properties in Krakovany locality. The study area is located in western part of Slovakia in altitude 165 m. Locality is situated at the northern of the Danube Lowland and is bordered by the west and east Malé Karpaty and Považský Inovec Mountains, respectively. Fluvial sediments are found along the rivers Váh and Dudváh. Terraces of Váh River are formed by Quaternary fluvial sediments, Pleistocene loess and loess which overlap accumulated gravel. Gravel grains of different sizes are formed mainly granitoids, quartzite and sandstone. Carbonates are represented less. Upper terraces of the river Váh are formed by Neogene sediments with the predominance of clay over sand. The mean annual temperature and precipitation were 8.5-9 ^{o}C and 650-800 mm, respectively.

Several sites with different soil types and soil tillage systems were included in the study. The site 1 (S1) was managed under minimum tillage in Chernozem, site 2 (S2) under conventional tillage in Chernozem. The site 3 (S3) was managed under minimum tillage in Fluvisol, site 4 (S4) under conventional tillage in Fluvisol. Soils were classified according to the World Reference Base for Soil Resources (WRB; FAO, 2006) based on the whole-profile soil morphology as follows: S1 and S2: loamy haplic Chernozem, S3 and S4: loamy mollic Fluvisol. In these sites, the soils had been cultivated for over 100 years according to the practices of the time, out during last 60 years conventional tillage was used. In 2009 in S1 and S3 minimum tillage system was established and in S2 and S4 standard mouldboard ploughing tillage "conventional" tillage (CT) was continued. Conventional tillage consisted 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. Minimum tillage (MT) consisted of 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). 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 annuus* L.*)* with preview crop maize *(Zea mays* L.*)*, S3 and S4 maize *(Zea mays* L.*)* with preview crop winter wheat *(Triticum aestivum* L.*)*.

In spring 2014, in each of four site a soil pit was excavated (total four pits) and the soil samples for determination of soil organic carbon (C_{org}) were collected for each of 0.1 m layer in both soil types to the depth of 0.3 m. Soil samples were dry sieved at sieve with mesh size of 2 mm and plant debris were removed. In soil samples sieved at sieve with mesh size of 0.25 mm the C_{org} content was determined indirectly by oxidation of organic carbon following the classical method of Tyurin (Dziadowiec and Gonet, 1999). Undisturbed soil samples for determination of stability and vulnerability parameters of soil structure were collected from the topsoil (0-0.3 m) of all 4 soil pits. Large clods were gently broken up along natural fracture lines and bulk soil samples were dried at laboratory temperature. Content of water-stable aggregates (WSA) was determined using by the Baksheev method (Vadjunina and Korchagina, 1986).

The mean weight diameters of aggregates for dry (MWD_d) and wet (MWD_{WSA}) sieving were expressed using the following equations:

$$MWD_d = \sum_{i-1}^{n} xiwi$$

where: *xi* is mean diameter of each size fraction (mm) and *wi* is portion of the total sample weight occurring in the corresponding size fraction, and *n* is the number of size fractions.

$$MWD_{WSA} = \sum_{i-1}^{n} xiWSA$$

where: *xi* is mean diameter of each size fraction (mm) and *WSA* is portion of the total sample weight occurring in the corresponding size fraction, and *n* is the number of size fractions.

The vulnerability coefficient (Kv) as well as coefficient of aggregate stability (Ks_{WSA}) was calculated as well according to equations:

$$Kv = \frac{MWD_d}{MWD_w}$$

where: MWD_d is mean weight diameter of aggregates for dry sieving (mm) and MWD_w is mean weight diameter of water stable aggregates (mm).

$$Ks_{WSA} = \frac{A}{B}$$

where: *A* is the weight of water stable aggregates in size fractions from 0.25 to 10 mm and *B* is the weight of water stable aggregates less than 0.25 mm.

Statistical analyses for all parameters were performed using the procedures from computer software Statgraphics Centurion XV.I (Statpoint Technologies, Inc., USA). A simple t-test was carried out to test significance between the soil organic carbon contents that were determined in different soil types as well as tillage plots in different depth of soil profiles. Significant differences were marked at P level ≤ 0.05. One-way analysis of variance was used to analyze differences in tested soil structure parameters. An LSD procedure was used at the P ≤ 0.05 level to determine, if there were significant soil structure parameters differences between soil types as well as tillage plots for the same depth. The Pearson test was used to estimate the correlation matrix between the stability and vulnerability parameters of soil structure.

Results and discussion

Content of C_{org} in both soils types (haplic Chernozem, mollic Fluvisol) and with dependence on soil tillage system is shown in Figure 1 A and B. Based on the t-test results, statistically significant differences in the C_{org} content for soil profiles (to the depth 0.3 m) were determined between Chernozems vs. mollic Fluvisols (t = -6,059, P = 0.002).

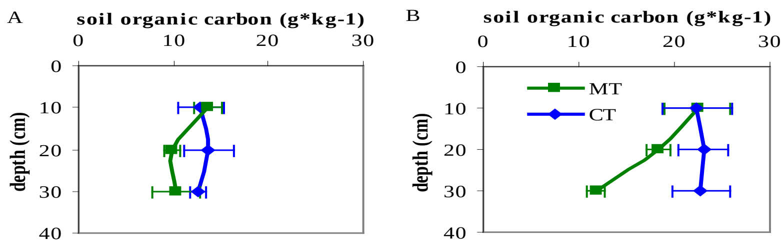

Figure 1. Content of soil organic carbon A) in haplic Chernozems, and B) in mollic Fluvisols. MT – minimum tillage, CT – conventional tillage

Obrázok 1. Obsah organického uhlíka A) v černozemi a B) v čiernici. MT – minimálne obrábanie pôdy, CT – konvenčné obrábanie pôdy

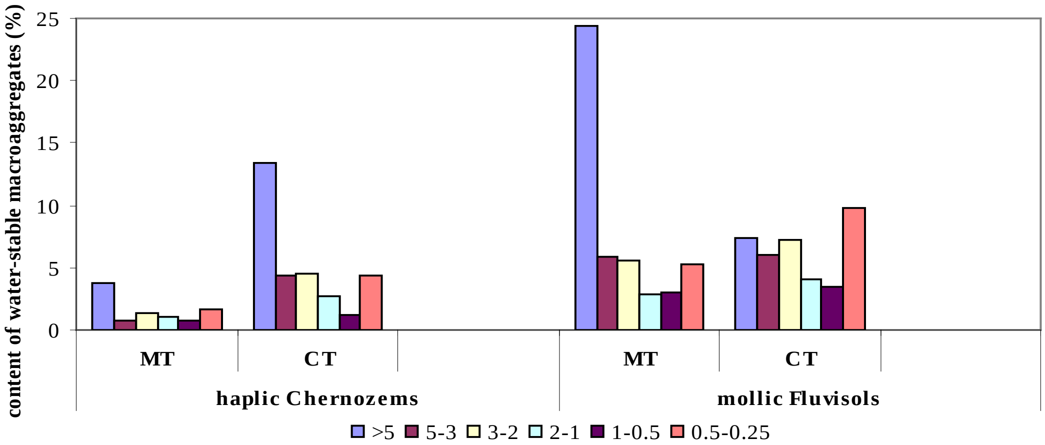

Figure 2. Content of water-stable macro-aggregates in mollic Chernozems and Fluvisols. MT – minimum tillage, CT – conventional tillage

Obrázok 2. Obsah vodoodolných makro-agregátov v černozemi a čiernici. MT – minimálne obrábanie pôdy, CT – konvenčné obrábanie pôdy

Within each of studied soil types, carbon distribution was different across the depth of tillage. The results showed that C_{org} content near the surface (0–0.1 m) was significantly higher under MT (by 6%) compared to CT, however, in upper layer (0–0.3 m) under CT the average C_{org} content was by 16% higher than under MT. In CT, the plant residues or organic matter (manures) due to mixing equally gets to a depth of ploughing and therefore the content of soil organic matter is relatively equable in tillage zone (Hussain et al., 1998; Tobiašová and Šimanský, 2009). On the other hand, the no-till, minimum or reduced tillage systems maintained a significantly greater amount of organic residue on the soil surface as compared with conventional tillage system (Olson et al., 2013). The same trend was observed in mollic Fluvisols. In MT, the average C_{org} content (17.5 ± 5.4 g*kg^{-1}) was significantly less than the CT (22.7 ± 0.4 g*kg^{-1}).

In Chernozems, total content of water-stable micro-aggregates (WSA_{mi}) was higher in MT (90.8 ± 1.71%) than in CT (69.5 ± 5.78%). In mollic Fluvisols the situation was diametrically different. Total content of WSA_{mi} was higher in CT (62.5 ± 6.57%) than in MT (53.2 ± 5.92%). Content of water-stable macro-aggregates (WSA_{ma}) in range 40-55% is satisfactory (Sisák, 1994). In Chernozems, under both tillage systems as well as in mollic Fluvisol under CT the contents of WSA_{ma} were under low level (on the basis above mentioned range). For example, Karlen et al. (1994) presented contents of WSA_{ma} in range 30-60%, however better soil structure is connected with upper level of mentioned interval. In individual size fractions of WSA_{ma} (except size fractions of WSA_{ma} 3-5 mm and 0.5-1 mm in mollic Fluvisol) statistically significant differences with dependence on soil tillage were observed in both soil types (Figure 2). In Chernozem, content of individual size fractions WSA_{ma} increased by intensive tillage the most significant in size fractions 3-5 mm then follows aggregates greater than 5 mm > 2-3 mm > 1-2 mm > 0.25-0.5 mm > 0.5-1 mm. In mollic Fluvisol due to intensive tillage system (CT) decreased content of WSA_{ma} >5 mm by 70%, while the content of other WSA_{ma} size fractions increased in the following order: aggregates in size fractions 0.25-0.5 mm (by 85%) > 1-2 mm (by 43%) > 2-3 mm (by 31%) > 0.5-1 mm (by 16%) > 3-5 mm (by 3%). The content of macro-aggregates in size from 0.5-3 mm is important from the agronomical point of view (Demo, 1995; Sisák, 1994; Šimanský, 2013; Šimanský and Bajčan, 2014; Šimanský et al., 2008). In both soil types, due to intensive tillage, content of WSA_{ma} 0.5-3 mm increased, however, its effect was significant in haplic Chernozems. The results of Šimanský and Bajčan (2014) on vineyard soils in Slovakia showed the highest content of WSA_{ma} 0.5-3 mm in Chernozems than Cambisols, Luvisols, Leptosols and Fluvisols. Šimanský et al. (2012) reported that it is connected with soil structure high resistance to damage by human activity. On the basis of individual size fractions of aggregates (dry and wet sieved) the parameters of structure stability and vulnerability were calculated (Table 1.) Very important parameters is average size of aggregates, therefore the mean weight diameters of aggregates dry (MWD_d) as well as wet (MWD_{WSA}) sieved were calculated. Rabbi et al. (2004) concluded that the soils with MWD_d between 1 and 3 mm could be classified as moderately water-stable. Therefore, on average, the soils of the agricultural field studied have favourable physical quality for plant growth. In both soil types under CT, the MWD_d was statistically significantly lower than under MT (Table 1). In Chernozems, the MWD_{WSA} aggregates content was statistically significantly higher under CT than MT. It can be connected with intensive disking of soil surface under MT in order weeds elimination between planted crops. The low aggregate stability and the high structure vulnerability were reflected also due to the high contents of WSA_{mi} (Figure 2) in haplic Chernozems. Intensive tillage disrupts soil aggregates (Balashov et al., 2010; Plante and McGill, 2002; Six et al. 2000; Slowinska-Jurkiewicz et al., 2013). Opposite situation was observed in mollic Fluvisols. It was connected with stability and vulnerability of soil structure - confirmed significant correlations between MWD_{WSA} and stability of aggregates (Ks_{WSA}) ($r = 0.909$, $P \leq 0.001$) and Kv ($r = -0.722$, $P \leq 0.001$).

Table 1. Parameters of soil structure stability and vulnerability

Tabuľka 1. Parametre stability a zraniteľnosti pôdnej štruktúry

	Soil types		Tillage system	
MWD_d	haplic Chernozem	4.31[a]	Minimum	5.03[b]
			Conventional	3.59[a]
	mollic Fluvisol	4.36[b]	Minimum	5.06[b]
			Conventional	3.66[a]
MWD_{WSA}	haplic Chernozem	0.59[a]	Minimum	0.25[a]
			Conventional	0.93[b]
	mollic Fluvisol	1.17[b]	Minimum	1.56[b]
			Conventional	0.77[a]
Kv	haplic Chernozem	14.4[b]	Minimum	24.7[b]
			Conventional	4.03[a]
	mollic Fluvisol	4.2[a]	Minimum	3.26[a]
			Conventional	5.14[a]
Ks_{WSA}	haplic Chernozem	0.27[a]	Minimum	0.10[a]
			Conventional	0.45[b]
	mollic Fluvisol	0.76[b]	Minimum	0.90[b]
			Conventional	0.62[a]

MWD_d - mean weight diameters of aggregates for dry sieving, MWD_{WSA} - mean weight diameters of aggregates for wet sieving, Kv - vulnerability coefficient, Ks_{WSA} - coefficient of aggregate stability

Different letters between lines (a, b) indicate that treatment means are significantly different at $P \leq 0.05$ according to LSD multiple-range test

If all investigated soil types were assessed separately, the stability of aggregates was a higher in mollic Fluvisols than in haplic Chernozems, however, the tillage systems in mentioned soil types had different effect on them. In Chernozems, the average value of Ks_{WSA} was higher (3.5 times) under CT than MT. In mollic Fluvisols, the average value of Ks_{WSA} was lower by 32% in CT than MT (Table 1). In Slovakia, haplic Chernozems (Bielek et al., 1998; Zaujec and Šimanský, 2008) and mollic Fluvisols (Bielek et al., 1998) are the most fertile soils. These soils have a favourable range of growing conditions for plants due to their optimal physical, physico-chemical and biological properties. In haplic Chernozems, worse soil structure will have relation with internal factors (nearly half the content of SOM compared to mollic

Fluvisols), but also with inappropriate soil management practices (elimination of the weed by intensive disking under MT). Mollic Fluvisols were better soils than haplic Chernozems due to better soil parameters (more favourable soil structure and higher SOM content).

Conclusion

This research provides information for farmers in optimizing soil management practices in arable soils. Results of this study demonstrated that from the view point of vulnerability and stability of soil structure in loamy haplic Chernozems with content of soil organic carbon ~1.40% the minimum tillage system (without mouldboard ploughing), but with intensive weed control by disking is not recommended. In the future, the soil organic carbon content will increase mainly in minimum tillage system, if the inappropriate soil management practices will be stopped. The excessive and frequent disking of the soil surface and the overall management of weeds can be reduced through crop rotation and intercropping cultivation in haplic Chernozem. In loamy mollic Fluvisols with content of soil organic carbon > 2% the minimum tillage system is recommended. To produce a comprehensive assessment of the soil with dependence on tillage system, it is just not sufficient to indicate only soil organic matter content and parameters of soil structure. Except mentioned results for the responsible assessing of the quality of the soil there are also several soil properties (chemical, physical) which have to be quantified, particularly if there are evaluated short-time experiments. All in all, on the basis of complete data farmers can improve corrections or suggest the right soil management practices for sustainable agriculture.

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