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SOIL STRUCTURE STABILITY AND DISTRIBUTION OF CARBON IN WATER-STABLE AGGREGATES IN DIFFERENT TILLED AND FERTILIZED HAPLIC LUVISOL

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Abstract

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The influence of tillage and fertilization on soil structure stability and the distribution of carbon in water-stable aggregates of loamy Haplic Luvisol were studied. Soil samples from the locality of Dolná Malanta (experimental station of SUA Nitra) were collected (in 2007–2009) from a depth of 0–0.2 m in two tillage variants: (1. conventional tillage, 2. minimal tillage) and three treatments of fertilization: (1. without fertilization, 2. crop residues and NPK fertilizers, 3. NPK fertilizers). The minimal tillage system has a positive effect on both the aggregation processes and sequestration of carbon in size fractions of water-stable aggregates, as well as ploughing of crop residues together with NPK fertilizers. On the other hand, application of only NPK fertilizers had a negative effect on SOM content. Under the minimal tillage system and in treatment with crop residues together with NPK fertilizers, what has been observed is a statistically significant increase in the total organic carbon contents by increasing size fractions of water-stable aggregates. Organic carbon did not influence the aggregation processes with dependence on tillage systems. Under conventional tillage as well as in treatment with ploughing crop residues with NPK fertilizers, a very important effect on aggregation had bivalent cations Ca^{2+} and Mg^{2+}.

soil structure stability, water-stable aggregates, organic matter, Luvisol

Aggregation processes in soils are influenced by a large number of factors such as changes in soil organic matter (SOM), moisture content and microbial activity, crop type, root development, tillage and fertilization or liming implementation. The structural stability is dependent on particle-size distribution, soil organic matter, vegetation and soil micro-organisms and its stability is influenced by exchangeable cations and sesquioxides (Amézketa, 1999; Bronick and Lal, 2005). One of the most important binding agents for forming stable aggregates is soil organic matter (Tisdall and Oades, 1982). Organic materials are important soil additives to improve soil physical properties. Degradation of soil structure occurs mostly due to the decrease in soil organic matter caused by excessive soil cultivation (Grandy *et al.*, 2002). For example, the conventional tillage may result in the disruption of soil structure and loss of soil organic matter compared with no-tillage (Beare *et al.*, 1994). Several studies have shown that where crop residues are returned, no-till can enhance soil aggregation and increase soil organic matter (Havlin *et al.*, 1990; Šimanský *et al.*, 2008).

The objective of this study was: 1. to quantify the extent to which tillage and fertilization treatments affect soil structure stability and carbon distribution in water-stable macro-aggregates of a Haplic Luvisol, 2. to determine the relationship between quantity of soil organic matter, exchangeable cations and parameters of soil structure stability of Haplic Luvisol with dependence on soil tillage and fertilization.

MATERIAL AND METHODS

The long-term experiment was carried out in the locality of Dolná Malanta [lat. 48°19’00”; lon. 18°09’00”]. There is an experimental base of the Slovak University of Agriculture in Nitra. The area is in a temperate climate with an annual average rainfall of 573 mm and a temperature of 9.8 °C. Soil in the area is, according to FAO classification, silt loam Haplic Luvisol (FAO, 2006). More information about the experimental base of SUA Nitra is published in Tobiašova and Šimanský (2009) or in Szombathová (2010).

In 1999, the Department of Plant Production of SUA Nitra established this experiment. It included two types of soil tillage (1. CT – conventional, 2. MT – minimal) and three treatments of fertilization (1. C_o – without fertilization, 2. CR+NPK – crop residues together with NPK fertilizers, 3. NPK – NPK fertilizers). Soil samples were taken from 0 to 0.2 m (depth), twice a year (spring and autumn) during 2007–2009.

Standard soil analyses were used for determination: soil reaction – potentiometrically (Fiala *et al.*, 1999), total carbon content according to Tyurin method (Hraško *et al.*, 1962), and exchangeable cations according to Kappen method (Fiala *et al.*, 1999).

Soil samples were dried at laboratory temperature and hand divided by sieve (dry and wet sieve) to 7 size fractions. In fractions of aggregates, using the stability index of water-stable aggregates by Henin (Zaujec and Šimanský, 2006), values of mean weight diameters and critical level of organic matter were calculated. The obtained results were statistically evaluated. Mean values of all variables were compared using analysis of variance and separated by the LSD multiple-range test at the 95% confidence level. Correlation analysis to determine the relationships between SOM, exchangeable cations and soil structure stability were used as well. Significant correlation coefficients were tested on $P < 0.05$.

RESULTS AND DISCUSSION

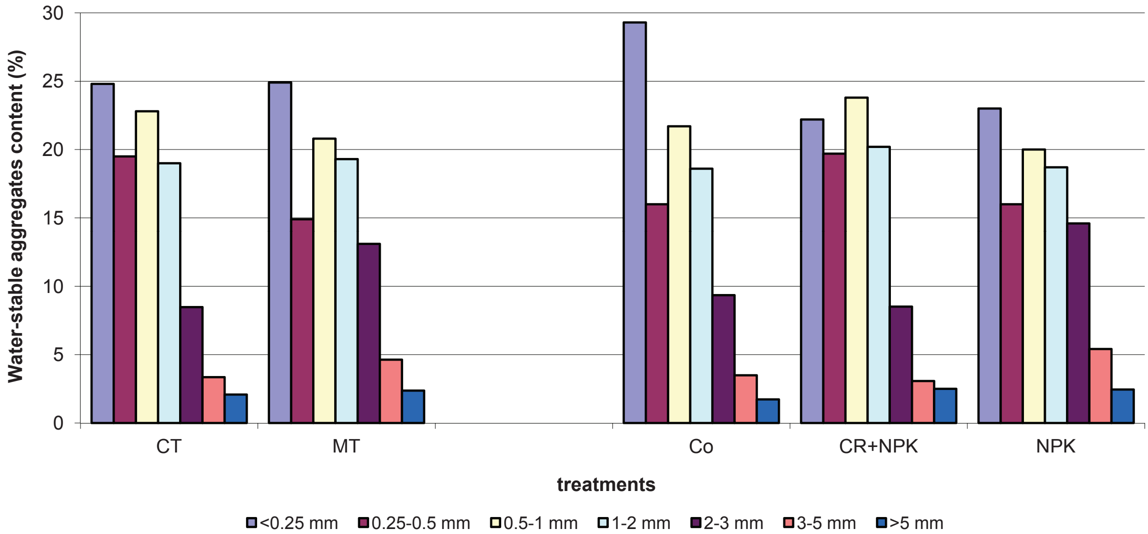
Aggregation

Intensive tillage is the reason of low aggregation (A’lvaro-Fuentes *et al.*, 2008). Minimal tillage had a positive impact on the mean weight diameter of water-stable aggregates (MWD-WSA) compared to conventional tillage. The same trend was observed in the values of stability index (Tab. I). Similar results published Šimanský *et al.* (2008). Hao and Chang (2002) confirmed the positive influence of fertilization on mean weight diameter. The values of stability index were higher than in control – in CR+NPK by 23% and in NPK by 14%. These results corresponded with the values of MWD-WSA in fertilization treatments. Tillage systems and fertilization had a statistically significant influence on the critical level of organic matter. These effects were more positive in MT than in CT as well as in CR+NPK compared to NPK and C_o. However, in the long term this effect was observed in CT, as illustrated by the results of 13 years (Šimanský *et al.*, 2008), because in intensive cultivated soils the effect of soil organic matter is more significant than in soils under minimal tillage (Szombathová, 2010). The portion of water-stable aggregates (WSA) with dependence on tillage systems and fertilization are shown in Fig. 1. Attention was mainly aimed to the portion of favourable size fractions of WSA from 0.5 to 3 mm, because this is favourable size fraction from the agronomical point of view (Sisák, 1994). The highest WSA content (0.5–3 mm) was observed in MT than in CT. Razafimbelo *et al.* (2008) also determined a significantly higher content of macro-aggregates under no-till in comparison with conventional tillage. At the same, in NPK treatment the content of WSA was higher compared with CR+NPK and C_o as well. On the other hand, application crop residues together with NPK fertilizers had positive effect on portion of micro-aggregates.

I: *Statistical evaluation of total and labile carbon contents in size fractions of water-stable aggregates in Haplic Luvisol (Dolná Malanta) – LSD multiple-range test*

Parameters	Treatments of tillage		Treatments of fertilization		
	Conventional tillage	Minimal tillage	Without fertilization	Crop residues and NPK fertilizers	NPK fertilizers
Mean weight diameter of water-stable aggregates	0.73a	0.86a	0.71a	0.90b	0.76a
Index of stability	0.99a	1.01a	0.89a	1.10b	1.02a
Critical level of organic matter	3.02a	3.65b	3.11a	3.75b	3.14a

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



1: *The portion of water-stable aggregates with dependence on tillage systems and fertilization*

II: *Statistical evaluation of total and labile carbon contents in size fractions of water-stable aggregates in Haplic Luvisol (Dolná Malanta) – LSD multiple-range test*

Parameters	Size fractions of water-stable aggregates in mm	Treatments of tillage		Treatments of fertilization		
		Conventional tillage	Minimal tillage	Without fertilization	Crop residues and NPK fertilizers	NPK fertilizers
Total organic carbon content in size fraction of water-stable aggregates (g.kg^{-1})	<0.25	11.1a	12.9a	13.4a	12.2a	12.6a
	0.25–0.5	11.1a	13.4b	12.9b	12.9b	11.0a
	0.5–1	11.2a	13.0b	12.1a	12.3a	11.9a
	1–2	11.6a	14.3b	13.8b	13.8b	11.2a
	2–3	12.4a	14.6b	13.5ab	15.4a	11.6a
	3–5	13.7a	14.5a	13.6a	14.9a	13.8a
	>5	14.5a	15.4a	14.1a	15.4a	15.3a
Labile carbon content in size fraction of water-stable aggregates (mg.kg^{-1})	<0.25	1 749a	1 989a	1 851a	1 986a	1 770a
	0.25–0.5	1 959a	2 081a	2 115b	2 106b	1 840a
	0.5–1	1 939a	1 994a	2 025a	2 065a	1 810a
	1–2	1 820a	2 049b	1 965ab	2 046b	1 793a
	2–3	1 868a	2 028a	1 954ab	2 119b	1 770a
	3–5	2 147a	2 126a	2 068a	2 336b	2 007a
	>5	2 140a	2 091a	2 105a	2 219a	2 024a

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

Organic matter in water-stable aggregates

Results of soil organic matter in water-stable aggregates (WSA) under CT and MT as well as in all treatments of fertilization are shown in Tab. II. In both tillage systems (CT – r = 0.931, $P < 0.01$; MT – r = 0.934, $P < 0.01$) and from fertilization treatment only in CR+NPK (r = 0.914, $P < 0.01$) there has been a statistically significant (linear) increase in total organic carbon contents (TOC) by increasing size fractions of WSA. The highest TOC contents were obtained in size fractions of WSA in all treatments of tillage and fertilization (Tab. II). Šimanský and Tobiašová (2008) but also Biswas *et al.* (2009) demonstrated increased carbon content occurred for larger size fractions of aggregates. The highest average TOC content in all size fractions of WSA was determined under MT (14.0 ± 0.9 g.kg^{-1}) than under CT (12.2 ± 1.4 g.kg^{-1}), which was confirmed by results of Šimanský *et al.*, 2008). In NPK treatment (12.5 ± 1.6 g.kg^{-1}) the lowest average TOC in all size fractions of WSA was determined, compared with C_o (13.3 ± 0.7 g.kg^{-1}) and CR+NPK (13.8 ± 1.4 g.kg^{-1}). The effect of the tillage system on the accumulation of TOC content was significant for following size fractions of aggregates: 0.25–0.50 mm; 0.50–1 mm; 1–2 mm

III: *Correlation coefficients in treatment without fertilization (C_o), treatment with crop residues together with added NPK fertilizers (CR+NPK) and in treatment with added NPK fertilizers (NPK)*

Parameters	Fertiliza-tion	Critical level of soil organic matter	Stability index	Sum of mean weight diameter of WSA	Size fractions of water-stable aggregates in mm						
					<0.25	0.25–0.5	0.5–1	1–2	2–3	3–5	>5
Total organic carbon	C_o	0.093	–0.250	–0.168	0.148	–0.576	0.108	0.079	0.210	–0.403	–0.182
	CR+NPK	0.929***	0.183	0.245	–0.070	0.034	0.420	–0.427	0.176	0.437	0.516
	NPK	0.858**	–0.168	0.092	0.150	0.044	–0.339	–0.197	–0.076	0.153	0.118
pH	C_o	–0.310	0.305	0.361	0.380	–0.374	–0.255	0.160	–0.204	–0.340	–0.417
	CR+NPK	0.046	0.163	0.217	–0.098	–0.132	–0.582	0.450	0.108	–0.498	0.136
	NPK	–0.263	–0.169	0.349	–0.309	–0.376	0.071	–0.073	0.426	0.508	0.162
Exchangeable Ca^{2+}	C_o	0.417	–0.489	–0.351	0.783*	0.070	–0.298	–0.417	–0.554	–0.832*	–0.129
	CR+NPK	0.015	0.057	0.326	–0.425	–0.552	–0.284	0.778*	0.208	–0.295	0.077
	NPK	–0.112	0.022	0.590	–0.628	–0.541	0.260	0.266	0.607	0.423	0.515
Exchangeable Mg^{2+}	C_o	–0.837**	0.369	0.558	–0.366	–0.748*	0.069	0.616	0.573	0.425	–0.460
	CR+NPK	0.109	–0.415	–0.108	0.014	–0.485	–0.153	0.354	0.243	–0.219	–0.414
	NPK	0.155	–0.303	0.583	–0.428	–0.432	–0.047	–0.002	0.467	0.568	0.621
Exchangeable Na^{+}	C_o	–0.803*	–0.662	0.462	–0.402	–0.410	0.526	0.455	0.141	0.464	–0.484
	CR+NPK	–0.165	0.365	–0.408	0.562	0.278	–0.569	–0.205	–0.058	–0.475	–0.412
	NPK	–0.780*	0.170	–0.022	0.058	0.031	–0.236	–0.266	0.124	0.156	–0.175
Exchangeable K^{+}	C_o	0.722*	–0.200	–0.318	0.740*	0.599	–0.506	–0.600	–0.671	–0.708*	0.199
	CR+NPK	0.761*	0.527	0.575	–0.164	0.083	–0.004	–0.085	–0.057	–0.017	0.855**
	NPK	0.787*	0.396	0.489	–0.556	–0.435	0.165	0.607	0.259	0.291	0.655

*P < 0.05; **P < 0.01; ***P < 0.001

and 2–3mm ($P < 0.05$), and the stronger effect was obtained in MT rather than CT. Fertilization had a statistically significant influence on TOC content in the following size fractions of WSA: 0.25–0.50 mm; 1–2 mm and 2–3 mm. Application of only NPK fertilizers to the soil decreased the content of TOC by 15% in size fraction of WSA 0.25–0.5 mm and by 19% in size fraction of WSA 1–2 mm in comparison to C_o as well as CR+NPK. Application of mineral fertilizers to the soil decreased TOC content (Šimanský and Tobiašová, 2008). Ploughing of crop residues together with NPK fertilizers increased TOC content in size fraction of WSA 2–3 mm by 14% compared with the control. Added crop residues can positively affect the soil organic matter quantity (Duiker and Lal, 2000; Jurčová and Tobiašová, 2002; Szombathová *et al.*, 2004; Tobiašová *et al.*, 2005).

The TOC contents in the same WSA size fractions did not correlate with labile carbon contents (C_L) in the same size fractions of WSA. Labile carbon contents in WSA were different and only in CR+NPK treatment ($r = 0.796$, $P < 0.05$), a linear trend of increase of C_L content by increasing size fractions of WSA was found. The highest average C_L content in all size fractions of WSA was determined under MT (2051 ± 51 $mg.kg^{-1}$) rather than under CT (1946 ± 152 $mg.kg^{-1}$). However a statistically significant higher content of C_L (by 13%) was observed only the in size fraction of WSA 1–2 mm in MT than in CT. Application of NPK fertilizers decreased average C_L content in all size fractions of WSA by 8% and 13% compared with C_o and CR+NPK, respectively. Significant differences were detected between fertilization treatments in following size fractions of WSA: 0.25–0.5 mm; 1–2 mm; 2–3 mm and 3–5 mm significant differences were detect (Tab. II). Added NPK fertilizers decreased C_L contents in all size fractions of WSA. On the other hand crop residues together with NPK fertilizers had an influence by increasing C_L contents in all size fractions of WSA except size fraction of WSA 0.25–0.5 mm.

Relationship between parameters influencing aggregation and structural stability parameters with dependence on tillage and fertilization

Organic matter is an important agent responsible for binding soil mineral particles (Oades and Waters, 1991) and it has a major influence on the bonding micro-aggregates and elementary particles in macro-aggregates (Tisdall and Oades, 1982; Labudová *et al.*, 2009). There were detected significant positive correlations between total organic carbon and critical level of soil organic matter in CT ($r = 0.660$, $P < 0.05$) also in MT ($r = 0.835$, $P < 0.05$). Between TOC and size fractions of WSA there were no correlations, meaning that organic carbon did not have any effect on aggregations with dependence on tillage system. Painuli and Pagliali (1990) showed that organic matter in soil with higher clay content may be responsible for aggregation. Mbagwu (1989) observed that the role of soil organic carbon

(SOC) as an aggregating agent diminishes in the presence of other dominating aggregating agents, such as polyvalent metals and silicate clay. Values of Ca^{2+} correlated significantly with MWD-WSA (r = 0.685, $P < 0.05$), but only under CT, implying that increase in Ca^{2+} resulted in improved rate of aggregation, which is consistent with the results of Šimanský *et al.* (2008). Under MT a negative effect was detected, but without statistical significance. At the same under CT values of Mg^{2+} positive correlated with the size fraction of WSA 1–2 mm, which means that aggregation is promoted by the bivalent cations. On the other hand, exchangeable Na^{+} has a negative effect on the aggregation under CT. A higher portion of Na^{+} on sorptive complex is the reason for the decreasing of the critical level of soil organic matter (r = –0.753, $P < 0.01$) as well as size fraction of WSA > 5 mm (r = 0.732, $P < 0.01$). Cation Na^{+} can affect dispersity of clay and the result of this process is the destruction of aggregations (Haynes and Naidu, 1998). These effects were not observed under MT. Positive correlations were observed between exchangeable K^{+} and the size fraction of WSA > 5 mm (r = 0.847, $P < 0.001$) under CT and critical level of soil organic matter (r = 0.757, $P < 0.01$) under MT.

Very important correlations were detected between total organic carbon and the critical level of soil organic matter in CR+NPK as well as NPK treatment (Tab. III). It means that mainly the ploughing of crop residues together with NPK fertilizers has importance effect on decreasing loss of soil. Obtained results confirmed the fact that Ca^{2+} is very important for aggregation and cation Na^{+} can affect dispersity of clay and the result of this process is the destruction of aggregates (Tab. III). Positive effects on the aggregation were observed in CR+NPK and a negative in NPK treatment.

SUMMARY

The influence of tillage and fertilization on soil structure stability and the distribution of carbon in water-stable aggregates of loamy Haplic Luvisol in the locality of Dolna Malanta (Experimental site of SUA Nitra) were studied. In 1999, the Department of Plant Production of SUA Nitra established long-term experiment. It included two types of soil tillage (1. conventional, 2. minimal) and three treatments of fertilization (1. without fertilization, 2. crop residues together with NPK fertilizers, 3. NPK fertilizers). Soil samples were taken from 0 to 0.2 m (depth), twice a year (spring and autumn) during 2007–2009. Standard soil analyses were used for determination: chemical properties and soil structure stability.

All in all, a minimal tillage system has a positive effect on aggregation processes and the sequestration of carbon in size fractions of water-stable aggregates as does the ploughing of crop residues together with NPK fertilizers. On the other hand, application of NPK fertilizers only, had a negative effect on SOM content. Under the minimal tillage system and in treatment with crop residues together with NPK fertilizers what has been observed is a statistically significant increase in total organic carbon contents by increasing size fractions of water-stable aggregates.

Total organic carbon did not influence the aggregation processes with dependence on tillage systems. Under conventional tillage as well as in treatment with ploughing crop residues with NPK fertilizers this very important effect on aggregation had bivalent cations Ca^{2+} and Mg^{2+}.

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