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CHEMICAL PROPERTIES, SOIL STRUCTURE AND ORGANIC MATTER IN DIFFERENT SOIL MANAGEMENTS AND THEIR RELATIONSHIPS WITH CARBON SEQUESTRATION IN WATER-STABLE AGGREGATES

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Abstract: *The chemical properties, soil structure stability and soil organic matter of Haplic Luvisol and their relationships with carbon sequestration in water-stable aggregates were studied in different soil managements. In 1999, the Department of Plant Production of SAU-Nitra established a long-term experiment. Soil samples were taken in all treatments (conventional, minimal tillage and grassland; treatments: without fertilization, crop residues together with NPK fertilizers, NPK fertilizers). Tillage systems had a statistically significant influence on changes of soil pH. Conventional tillage affected more positively. A higher content of total organic carbon was determined in minimal tillage (by 8%) and in grassland (by 55%), but the quality of SOM was the best in conventional tillage. From the point of view of favourable size fractions of water-stable aggregates, the highest content was in grassland, on the other hand conventional tillage contributed negatively, but fertilization contributed positively. Obtained results showed carbon sequestration mainly in favourable size fractions of water-stable aggregates (from* $5x10^{-4}$ *to* $3x10^{-3}$ *m) in conventional tillage as well as in crop residues together with NPK fertilizers. Positive effects of stabile SOM and negative effects of labile SOM on aggregation processes were observed as well.*

Key words: *Soil Structure Stability; Water-stable Aggregates; Soil Organic Matter*

INTRODUCTION

The fundamental prerequisites for optimal exploitation, improvement and soil protection are its universal knowledge, its genesis, dynamics of soil processes and fertility formation. At present, studying of fertility parameters and its changes by natural as well as anthropogenic factors is the focus of the scientist teams. Intensive farming systems led to changes in carbon sequestration, chemical and physical properties of soils.

Soil cultivation influences chemical properties as pH (LIMONUOSIN and TESSIER 2007), portion Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} (THOMAS et al. 2007), soil sorptive complex soil organic matter (HUSSAIN et al. 1999) as well as physical properties (FABRIZZI et al. 2005) and soil structure stability (MIKHA and RICE 2004). These tillage effects, however, are environmentally dependent and different results have been reported under different types of soil and climate.

Agricultural fertilization entails significant economic and environmental costs. Added fertilizers and organic inputs can help maintain soil fertility by improving chemical and biological soil properties (NARDI et al. 2004) as well as the parameters of soil structure stability (LAYTON et al. 1993; HAO and CHANG 2002).

The basic unit of soil structure is aggregate (YOUNG and WARKENTIN 1975). Soil aggregate formation and aggregate stability have an important role in crop production and sustainable agricultural management (DINEL et al. 1991). Crucial for aggregate quality is its resistance to degradation by factors acting in given conditions. The structural stability is dependent most of all on soil texture, soil organic matter, vegetation and soil micro-organisms (AMÉZKETA 1999; VALLA et al. 2000; BRONICK and LAL 2005). Soil structure stability is influenced also by exchangeable cations (ZANG and NORTON 2002; BRONICK and LAL 2005), sesquioxides (AMÉZKETA 1999). One of the most important binding agents for forming stable aggregates is soil organic matter (TISDALL and OADES 1982).

The aim of this study was to characterise in different soil managements the chemical properties, soil structure stability and soil organic matter of Haplic Luvisol and their relationships with carbon sequestration in water-stable aggregates. Through parameters as are lability index, carbon pool index, carbon management index, we evaluated smaller changes and changes in a short time period in quantity and quality of soil organic matter in water-stable aggregates. We hypothesized that: (i) the different soil managements influence soil properties (ii) more carbon will be sequestered in native grassland and in fertilizer treatments than in arable and no-fertilizers treatments (iii) intensive cultivation will have negative effects on water-stable aggregates and soil organic matter (iv) higher content of soil organic matter in labile form is a reason for decreasing soil structure stability.

MATERIAL AND METHODS

The research was conducted in locality Dolná Malanta (lat. 48°19´00´´; lon. 18°09´00´´) in Slovakia. This is the experimental site of Slovak University of Agriculture. The area is in temperate climate. Annual average rainfall and temperature were 573 mm and 9.8°C, respectively. Soil in the area was developed on young neogene deposits composed of various clays, loams, sand gravels on which loess was deposited in the Pleistocene epoch. The soil is according to FAO classification a Haplic Luvisol (WRB 2006), and on average it contained 318.8 $g.kg^{-1}$ of sand, 567.0 $g.kg^{-1}$ of silt and 114.3 $g.kg^{-1}$ of clay. The total soil carbon content was 12.9 ± 0.36 $g.kg^{-1}$, hydrolytic acidity 11.7 ± 5.9 $mmol.kg^{-1}$, sum of basic cations 171.2 ± 7.7 $mmol.kg^{-1}$ the sorptive capacity 183.1 ± 7.6 $mmol.kg^{-1}$ and base saturation percentage was 93.1 ± 3.9 %. On average, the soil pH was 6.15 ± 0.65.

Department of Plant Production of SAU-Nitra established a long-term experiment in 1999. All the plots were of the following size: width 4 m and length 10 m and between plots was a harness 1 m wide. The field experiment had four repetitions of each of the studied factors (tillage system, fertilization). The field experiment included two types of soil tillage (1. CT – conventional, 2. MT – minimal) and soil samples for comparison were taken also from native grassland (3. NG - grassland), established in 1970. There were three treatments of fertilization (1. C_o – without fertilization, 2. CR+NPK – crop residues together with NPK fertilizers, 3. NPK – NPK fertilizers). Conventional tillage means annual ploughing to depth of 0.20 m and minimal tillage means annual disking to the depth of 0.10 m. In CR+NPK treatments, crop residues were returned to the soil. There were average annual doses of fertilizers following: N 80 $kg.ha^{-1}$, P (P_2O_5) 45 $kg.ha^{-1}$ and K (K_2O) 72 $kg.ha^{-1}$. The doses of NPK were calculated by balance method. Fertilizers were mainly ammonium nitrate (NH_4NO_3), potassium chloride (KCl), and triple superphosphate ($Ca(H_2PO_4)_2H_2O$). The field experiment had the following crop rotation: 1. cow-grass *(Trifolium pratense L.)* 2. pea *(Pisum sativum L. subsp. Hortense (Neitr.)* 3. winter wheat *(Triticum aestivum L.)* 4. maize *(Zea mays L.)* 5. spring barley *(Hordeum vulgare L.)*.

During 2008 and 2009 soil samples were collected for determination of chemical properties and structure stability in all treatments from depth 0-0.20 m. Each sampled zone included all treatments of tillage and fertilization and grassland six different locations were chosen randomly. For determination of chemical properties, soil samples were taken and mixed to average the sample. Roots and large pieces of litter were removed from the soil samples before air drying, and then soil samples were dried at laboratory temperature and grinded. For determination of parameters of soil structure stability, soil samples were taken with the aid of spade to maintain the soil in their natural aggregates. Soil samples were also air-dried at laboratory temperature, pre-sieved over a series of sieves, and then bulked into seven size fractions. These size fractions (dry sieve) were used for determination of water-stable aggregates (WSA).

Soil pH was determined potentiometrically (FIALA et al. 1999). We determined also sorptive characteristics of soil (HANES 1999) as well as total carbon content (TOC) according to Tyurin in modification of Nikitin (DZIADOWIEC and GONET 1999), labile carbon content (C_L) (LOGINOW et al. 1987), the fraction composition of humus substances according to Belchikova and Kononova (DZIADOWIEC and GONET 1999) and optical parameters of humus substances and humic acids. The following parameters of soil structure stability were calculated: vulnerability coefficient (VALLA et al. 2000), index stability of WSA by Henin (ZAUJEC and ŠIMANSKÝ 2006). In size fractions of WSA, we determined TOC and C_L content as well as carbon management index (CMI), lability index (LI) and carbon pool index (CPI) according to BLAIR et al. (1995) were calculated.

Statistical analyses were performed using Statgraphics Plus. To test for significant differences between the investigated treatments, analysis of variance was performed. Treatment differences were considered significant at P values <0.05 by LSD test. We used correlation analysis to determine the relationships between chemical properties, soil organic matter (SOM), soil structure stability and quantity of SOM in size fractions of WSA. Significant correlation coefficients were tested on $P < 0.05$.

RESULTS AND DISCUSSION

Soil pH and exchangeable cations

Chemical parameters of Haplic Luvisols with dependence on tillage systems and fertilization are summarised in Table 1. Tillage systems had statistically significant influence on soil pH. In NG (6.10±0.35), lower values of pH we determined than in MT (6.40±0.15) and CT (6.43±0.08). Fertilization had no effect on pH changes (Table 1). There were significant effects of tillage systems on exchangeable Ca^{2+}, but fertilization had no effect on its changes in soil sorptive complex. The highest content of exchangeable Ca^{2+} we determined in CT in comparison to MT and NG. Exchangeable Mg^{2+} was higher in soil under NG than in MT and CT as well as in soil, where crop residues have been ploughed together with NPK fertilizers in comparison to NPK and treatment without fertilization. Soil tillage systems and also fertilization had statistically significant influence on the portion of exchangeable K^+. A more favourable portion of exchangeable Na^+ was detected in NG and from fertilizer treatments in C_o and CR+NPK, however, without statistical signification (Table 1). Cation exchange capacity (CEC) was lower in soil under CT than under MT or NG. There were no significant effects of fertilization on CEC.

Table 1

Statistical evaluation of chemical properties and parameters of soil organic matter in Haplic Luvisol

Parameters		Treatments of tillage			Treatments of fertilization		
		Conventional tillage	Minimal tillage	Grassland	Without fertilization	Crop residues and NPK fertilizers	NPK
pH		6.43b	6.40ab	6.10a	6.35a	6.31a	6.28a
Exchangeable Ca^{2+}	($mmol.kg^{-1}$)	91.5b	90.3b	80.9a	90.7a	85.9a	86.2a
Exchangeable Mg^{2+}		26.0a	27.8a	35.9a	27.5a	32.0a	30.3a
Exchangeable Na^+		4.62a	4.41a	4.03a	4.32a	4.32a	4.43a
Exchangeable K^+		4.94a	6.58ab	8.78b	6.49ab	8.39b	5.41a
Cation exchangeable capacity		134.3a	135.5a	142.0a	136.8a	139.4a	135.4a

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

Soil organic matter

In NG, the total organic carbon content (TOC) (18.7± 0.42 g.kg^{-1}) was higher by 54% than in CT (12.1±0.50 g.kg^{-1}) and higher by 42% than in MT (13.1±1.10 g.kg^{-1}). These differences were statistically significant. The same trends were observed in the case of labile carbon content (C_L) in tillage treatments. Crop residues added into the soil together with NPK fertilizers increased TOC content by 6%, on the other hand, added NPK fertilizers decreased it by 4% in comparison to C_o. Content of C_L was not augmented by fertilizations. The quality of soil organic matter with dependence on tillage system and fertilization was evaluated also by use of carbon of humic acids, and fulvic acids ratio (C_{HA}:C_{FA}) as well as with optical parameters of humus substances (Q_{HS}) and humic acid (Q_{HA}). In CT, the average values of C_{HA}:C_{FA} ratio were wider than in MT and NG as well as in NPK they were wider than in CR+ NPK and C_o. The average values of Q_{HS} and Q_{HA} were more favourable in CT than in MT and NG. In case of Q_{HA}, these differences were statistically significant.

Parameters of soil structure stability

The aggregate stability evaluation by parameters mentioned in Table 2 was generally low in CT and MT, whereas in NG these parameters were the best with regards to the soil tillage systems. Fertilization did not significantly affect the stability of aggregates. However, better soil structure stability, evaluated by vulnerability coefficient, was in CR+NPK treatment (3.44±1.86) than in NPK (4.32±1.09) and C_o (4.91±3.33). Also, further parameters of soil structure stability showed a favourable influence of the addition of crop residues together with NPK fertilizers into the soil in comparison to C_o and NPK treatments.

Table 2

Statistical evaluation of parameters of soil structure stability in Haplic Luvisol

Parameters	Size fractions of water-stable aggregates in m	Treatments of tillage			Treatments of fertilization		
		Conventional tillage	Minimal tillage	Grassland	Without fertilization	Crop residues and NPK fertilizers	NPK fertilizers
Water-stable aggregates content (%)	<25x10^{-4}	28.2a	26.9a	8.9a	20.1a	17.9a	25.1a
	25x10^{-4}-5x10^{-4}	22.2a	17.7a	11.4a	15.9a	19.2a	16.1a
	5x10^{-4}-1x10^{-3}	23.7a	20.8a	14.6a	19.5a	21.5a	18.0a
	1x10^{-3}-2x10^{-3}	15.1a	18.1a	20.0a	15.9a	16.4a	20.9a
	2x10^{-3}-3x10^{-3}	5.4a	11.1ab	15.6b	10.0a	10.0a	12.0a
	3x10^{-3}-5x10^{-3}	2.9a	3.6a	12.7b	6.5a	6.4a	6.3a
	>5x10^{-3}	2.7a	2.6a	16.9b	7.1a	8.5a	6.6a
Vulnerability coefficient		5.68b	5.57b	1.12a	4.91a	3.44a	4.32a
% water-stable aggregates		73.5a	74.0a	91.9b	74.9a	82.4a	82.1a
Stability index		1.01a	1.09a	1.37b	1.01a	1.29a	1.17a

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

Water-stable aggregates content

Content of water-stable aggregates (WSA) with dependence on tillage systems and fertilization are presented in Table 2. Soil tillage systems had statistically significant influence on size fractions from 2x10^{-3} to 3x10^{-3} m (favourable fraction) and >5x10^{-3} m of WSA. In other size fractions we did not detect any significant differences with regard to soil tillage. Fertilization did not have statistically significant influence on size fractions of WSA (Table 2).

The highest content of macro-aggregates was determined in NG in comparison to CT and MT and in CR+NPK than in C_o and NPK. The share of macro-aggregates in size from 5x10^{-4} to 3x10^{-3} m is important from the agronomical point of view. Their content was higher by 14% in NG and by 13% in MT than in CT. In NPK (by 12%) and CR+NPK (by 6%), the content of WSA (from 5x10^{-4} to 3x10^{-3} m) was higher than in C_o.

Carbon in WSA

Soil tillage systems and fertilization had statistically significant influence on TOC content in WSA (Table 3). We have focused mainly on favourable size fractions of WSA. Content of TOC was higher in NG in comparison to CT (by 39%) and MT (by 5%) in size fraction from 1x10^{-3} to 2x10^{-3} m. In comparison to CT, in MT (by 22%) and in NG (by 11%) were higher TOC contents in size fraction from 2x10^{-3} to 3x10^{-3} m of WSA. The addition of only NPK fertilizers (NPK by 32%) and crop residues applied together with NPK fertilizers (CR+NPK by 22%) in comparison to C_o increased TOC content in size fraction from 5x10^{-4} to 1x10^{-3} m of WSA. In size fraction from 2x10^{-3} to 3x10^{-3} m of WSA, the average TOC content was lower in NPK (11.5±2.9 g.kg^{-1}) and C_o (14.1±2.1 g.kg^{-1}) than in CR+NPK (16.5±3.3 g.kg^{-1}). We observed, that TOC content in CT (r=0.921, *P*<0.01) and MT (r=0.923, *P*<0.01) in comparison to NG, linearly increased with greater fractions of WSA as well as in CR+NPK (r=0.889, *P*<0.01).

Table 3

Statistical evaluation of total and labile carbon contents in size fractions of water-stable aggregates in Haplic Luvisol

Parameters	Size fractions of water-stable aggregates in m	Treatments of tillage			Treatments of fertilization		
		Conventional tillage	Minimal tillage	Grassland	Without fertilization	Crop residues and NPK fertilizers	NPK fertilizers
Total organic carbon content in size fraction of water-stable aggregates (g.kg^{-1})	<25x10^{-4}	10.5a	12.6a	13.6a	11.1a	12.7a	12.9a
	25x10^{-4}-5x10^{-4}	10.8a	13.4b	13.6b	13.5b	13.5b	10.7a
	5x10^{-4}-1x10^{-3}	12.6a	13.0a	12.4a	10.7a	13.0b	14.2b
	1x10^{-3}-2x10^{-3}	11.4a	15.0b	15.8b	15.2a	15.4a	11.6a
	2x10^{-3}-3x10^{-3}	12.6a	15.4b	14.1ab	14.1ab	16.5b	11.5a
	3x10^{-3}-5x10^{-3}	13.5a	15.0a	14.2a	13.4a	15.3a	14.0a
	>5x10^{-3}	14.5a	16.0a	25.5b	17.5a	19.5a	19.1a
Labile carbon content in size fraction of water-stable aggregates (mg.kg^{-1})	<25x10^{-4}	1592a	1824a	2026a	1757a	1937a	1749a
	25x10^{-4}-5x10^{-4}	1819a	1954a	2314a	2134a	2145a	1808a
	5x10^{-4}-1x10^{-3}	1838a	1900a	2181a	2020a	2110a	1789a
	1x10^{-3}-2x10^{-3}	1714a	1941ab	2367b	2048a	2141a	1834a
	2x10^{-3}-3x10^{-3}	1759a	1950ab	2377b	2115a	2166a	1806a
	3x10^{-3}-5x10^{-3}	2019a	2052a	2603b	2130a	2447a	2096a
	>5x10^{-3}	2022a	2030a	2765b	2252a	2407a	2156a

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

We evaluated also C_L content in size fraction of WSA with regard to the soil tillage systems and fertilization. Tillage systems (Table 3) had statistically significant influence on C_L content in size fractions of WSA from $1x10^{-3}$ to $>5x10^{-3}$ m, while fertilization did not have any significant effect. Higher C_L contents were found in NG than in CT and MT in all size fractions of WSA. Contents of C_L were linearly increased with greater fractions of WSA. This relationship with regard to the soil tillage systems was the highest in NG (r=0.933, *P*<0.001) than MT (r=0.869, *P*<0.01) and CT (r=0.793, P<0.05). We observed the highest C_L contents in greater size fractions of WSA with dependence on fertilization treatment. This tendency had linear characteristics. Crop residues applied together with NPK fertilizers were more effective in increasing C_L in WSA than in C_o and NPK treatments (Table 3).

Dynamics of TOC and C_L in size fractions of WSA from 2008 to 2009

The percentage changes in dynamics of TOC and C_L in size fractions of WSA in all treatments from 2008 to 2009 are presented in Figure 1A and 1B. In CT positive effects on increasing TOC in all fractions of WSA were observed. Very importantly we determined the most increase in favourable size fractions from $5x10^{-4}$ to $3x10^{-3}$ m (by 42%, by 65% and by 31%). In MT we also detected positive effects on increasing TOC in all fractions of WSA, but it was lesser than in CT. In NG, in size fraction $1x10^{-3}$ to $2x10^{-3}$ m, a decrease of TOC by 20% was determined and an increase (more than twice) in size fraction $>5x10^{-3}$ m (Fig. 2). From 2008 to 2009, the application of NPK fertilizers had positive influence on increase of TOC in all size fractions of WSA. In water-stable macro-aggregates in size fraction from $2x10^{-3}$ to $3x10^{-3}$ m the biggest difference was observed between treatment without fertilizers (C_o) and NPK. Also in CR+NPK increase of TOC was detected in all size fractions of WSA except of size fraction $>5x10^{-3}$ m (fig. 1A).

In CT, higher C_L (by 6 %) from 2008 to 2009 was only in size fraction $2x10^{-3}$ - $3x10^{-3}$ m of WSA. On the other hand, decreasing of C_L was determined in other size fractions of WSA. The biggest decreases of C_L in all size fractions of WSA were in NG (fig. 1B). In MT, in all size fractions of WSA (except from $2x10^{-3}$ to $3x10^{-3}$ m) the increase of C_L was observed, however the highest increase was in fraction of micro-aggregates. Crop residues with NPK fertilizers had influence on increase of C_L in all size fractions of WSA from 2008 to 2009. The results of TOC and C_L dynamics from 2008 to 2009 showed carbon sequestration mainly in favourable size fractions of WSA ($5x10^{-4}$ - $3x10^{-3}$ m) in CT and MT as well as CR+NPK and NPK.

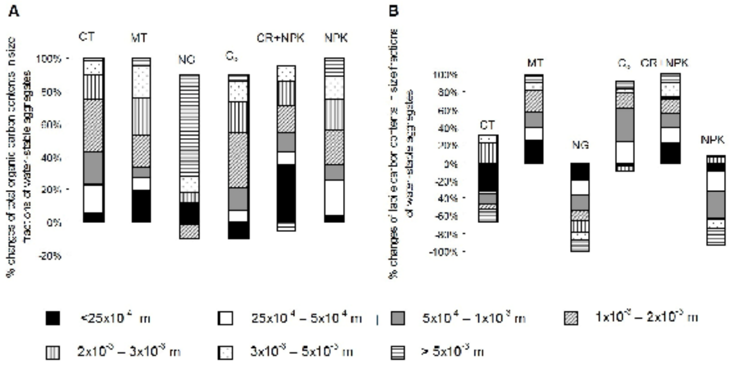

Figure 1A: Dynamics of total organic carbon contents in size fractions of water-stable aggregates
Figure 1B: Dynamics of labile carbon contents in size fractions of water-stable aggregates

Quality of SOM in WSA evaluated by LI, CMI and CPI

Through parameters lability index (LI), carbon pool index (CPI) and carbon management index (CMI) we evaluated qualitative changes in size fractions of WSA in a short time period (2008-2009). There were only CT and MT treatments and from fertilizers variants C_o, CR+ NPK and NPK were compared. The grassland (NG) was taken for each treatment as the reference. Soil tillage systems and fertilization did not have statistically significant influence on LI. However, in case of soil tillage we detected the highest values of LI in all size fractions of WSA in CT than in MT. It means that soil organic matter in CT is intensively decomposed by micro-organisms. Added NPK fertilizers (NPK) and also crop residues together with NPK fertilizers increased LI values in favourable size fractions of WSA. We determined statistically significant tillage effect on CPI in size fractions of WSA from $25x10^{-4}$ to $3x10^{-3}$ m (Table 4). These results showed more intensive degradation of soil in CT than in MT. All the same, the lowest CPI in NPK treatment in size fraction of WSA from $25x10^{-4}$ to $5x10^{-4}$ m and from $1x10^{-3}$ to $3x10^{-3}$ m was calculated. In tillage and fertilization treatments CMI values were calculated (Table 4). The lowest CMI values showed that SOM underlies to changes due to intensive cultivation.

Table 4

Statistical evaluation of soil organic matter parameters in size fractions of water-stable aggregates in Haplic Luvisol

Parameter	Size fractions of water-stable aggregates in m	Treatments of tillage			Treatments of fertilization		
		Conventional tillage	Minimal tillage	Grassland	Without fertilization	Crop residues and NPK fertilizers	NPK fertilizers
Carbon pool index in size fraction of water-stable aggregates	$<25x10^{-4}$	0.85a	1.01a	-	0.86a	0.95a	0.99a
	$25x10^{-4}$-$5x10^{-4}$	0.74a	0.92b	-	0.90b	0.90b	0.70a
	$5x10^{-4}$-$1x10^{-3}$	0.77a	0.92b	-	0.84a	0.84a	0.82a
	$1x10^{-3}$-$2x10^{-3}$	0.70a	0.90b	-	0.87b	0.88b	0.65a
	$2x10^{-3}$-$3x10^{-3}$	0.88a	1.08b	-	0.99ab	1.15b	0.80a
	$3x10^{-3}$-$5x10^{-3}$	1.02a	1.13a	-	1.01a	1.16a	1.05a
	$>5x10^{-3}$	0.67a	0.73a	-	0.65a	0.76a	0.70a

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

Correlation between chemical properties, soil organic matter, soil structure stability and quantity of SOM in size fractions of WSA

We observed the highest number of correlations between TOC content in size fractions from $25x10^{-4}$ to $5x10^{-3}$ m of WSA and K^+ (Table 5). A statistically significant correlation was detected between TOC content in size fraction from $1x10^{-3}$ to $2x10^{-3}$ m of WSA and Ca^{2+}. At the same time we determined a positive correlation between TOC content in size fractions of WSA and quantitative parameters of soil organic matter (Table 5), on the other hand no correlations were detected between TOC content in size fractions of WSA and qualitative parameters of SOM and structure stability. Statistically significant correlations were detected between C_L content in size fraction of WSA and K^+ (Table 6). TOC content correlated (positively) with C_L content in size fractions from $1x10^{-3}$ to $5x10^{-3}$ m of WSA. We determined the correlation between LI in size fraction of WSA and Ca^{2+}, K^+ (positive) and Na^+ (negative).

The highest correlations were determined in size fraction >5x10^{-3} m of WSA (Table 7). LI values in size fraction of WSA were in negative correlation relationships with colour quotient of humic acids. The highest correlation was in size fraction >5x10^{-3} m of WSA. The correlation coefficients of CPI in size fractions of WSA and chemical properties and parameters of structure stability in Haplic Luvisol are shown in Table 8.

Table 5

Correlation coefficients between chemical properties, soil organic matter, soil structure stability and parameters of soil organic matter in size fraction of water-stable aggregates

Parameters	Size fractions of water-stable aggregates in m						
	<25x10^{-4}	25x10^{-4}-5x10^{-4}	5x10^{-4}-1x10^{-3}	1x10^{-3}-2x10^{-3}	2x10^{-3}-3x10^{-3}	3x10^{-3}-5x10^{-3}	>5x10^{-3}
Total organic carbon content							
Exchangeable Ca^{2+}	0.141	0.455	0.498	0.628*	0.527	0.570	0.122
Exchangeable Na^{+}	-0.115	-0.550	-0.719**	-0.673*	-0.520	-0.447	-0.205
Exchangeable K^{+}	0.516	0.678*	0.725**	0.805**	0.858***	0.691*	0.064
Cation exchangeable capacity	0.281	0.597*	0.566	0.633*	0.620*	0.696*	0.163
Total organic carbon	0.459	0.648	0.458	0.588*	0.745**	0.709**	0.422
Labile carbon	0.605*	0.791**	0.763**	0.710**	0.726**	0.499	0.113
Labile carbon content							
Exchangeable K^{+}	0.590*	0.715**	0.667*	0.750**	0.467	0.714**	0.461
Total organic carbon	0.441	0.479	0.393	0.648*	0.693*	0.719**	0.462
Carbon lability in water-stable aggregates							
Exchangeable Ca^{2+}	0.686*	0.345	0.696*	-0.498	0.410	0.672*	0.873***
Exchangeable Na^{+}	-0.71**	-0.186	-0.477	0.672*	-0.475	-0.742**	-0.863***
Exchangeable K^{+}	0.443	0.285	0.606*	-0.497	0.086	0.697*	0.828***
Cation exchangeable capacity	0.385	0.019	0.427	-0.540	0.249	0.498	0.658*
Labile carbon	0.118	-0.041	0.147	-0.610*	-0.079	0.335	0.538
Colour quotient of humic acids	-0.659*	-0.416	-0.684*	0.439	-0.378	-0.694*	-0.863***
Carbon pool index in water-stable aggregates							
Exchangeable Ca^{2+}	-0.231	0.468	0.526	0.785**	0.348	-0.040	-0.885***
Exchangeable Na^{+}	0.259	-0.562	-0.740**	-0.801**	-0.346	0.189	0.845***
Exchangeable K^{+}	0.192	0.686*	0.740**	0.870***	0.753**	0.232	-0.694*
Cation exchangeable capacity	-0.040	0.605*	0.585*	0.716**	0.506	0.258	-0.660*
Total organic carbon	0.361	0.646*	0.453	0.495	0.796**	0.742**	0.022
Labile carbon	0.416	0.793**	0.765**	0.703*	0.684*	0.184	-0.474
Colour quotient of humic acids	0.200	-0.358	-0.508	-0.741**	-0.297	0.088	0.907***
Carbon management index in water-stable aggregates							
Exchangeable Ca^{2+}	0.349	0.812**	0.300	0.681*	0.793**	0.675*	0.811**
Exchangeable Na^{+}	-0.314	-0.752**	-0.335	-0.596*	-0.812**	-0.633*	-0.808**
Exchangeable K^{+}	0.079	0.904***	0.541	0.875***	0.832***	0.933***	0.857***
Cation exchangeable capacity	0.572	0.614*	0.508	0.612*	0.748	0.730**	0.618*
Labile carbon	0.056	0.597*	0.280	0.509	0.590*	0.515	0.548
Colour quotient of humic acids	-0.368	-0.794**	-0.287	-0.664*	-0.724*	-0.683*	-0.826***

n.s. $P>0.05$; *$P<0.05$; **$P<0.01$; ***$P<0.001$

A positive and highly significant ($P<0.01$) linear correlation between CPI in favourable fraction of WSA (1x10^{-3} to 2x10^{-3} m) and Ca^{2+} was obtained, indicating that if CPI in the fore-mentioned fraction of WSA increased, content of exchangeable Ca^{2+} will increase as well. Thus, Ca^{2+} is promoted aggregation, which increased with increasing CPI values. Negative and significant correlations of CPI in size favourable fraction of WSA with Na^+ were determined. On the other hand, it means that lower values of CPI and higher content of Na^+ promote disaggregation. We observed higher K^+ and CEC increased CPI in favourable fractions of WSA. Positive and significant linear correlations of CPI with TOC and C_L contents were also detected (Table 8). The same trends were observed between CMI and chemical properties of Haplic Luvisol (Table 9). Positive correlations were obtained for CMI in size fractions of WSA versus Ca^{2+}, K^+ and CEC. On the other hand, negative correlations were obtained for CMI in size fractions of WSA versus Na^+ and Q_{HA}.

DISCUSSION

Soil pH, in NG and MT were lesser in comparison to CT. These results are consistent with those reported by LIMONUOSIN and TESSIER (2007). The effect is attributed to different processes such as the mineralization of organic matter and roots exudation (TAN 1998), as well as accumulation of organic matter in NG and MT in soil surface. Our results showed that fertilization had no statistically significant effect on pH changes (Table 1), however, the values of pH were lesser in CR+NPK and NPK treatments than in C_o. Applied crop residues increase hydrolytic acidity and decrease soil pH (ZAUJEC and ŠIMANSKÝ 2006). Also the results of NARDI et al. (2004) confirmed that the application of farmyard manure is reason for lesser values of soil pH. The soil reaction may also be affected by mineral fertilizers, especially NH_4^+ sources (HAVLIN et al. 1990). We observed a higher portion of exchangeable Ca^{2+} and Na^+ in CT than in MT and NG. Similar results were published by HUSSAIN et al. (1999). In CR+NPK a decreasing portion of Ca^{2+} and Na^+ in sorptive complex of Haplic Luvisol was observed in comparison to NPK (Table 1).

Intensive cultivation is a reason for the loss of SOM (HUSSAIN et al. 1999; DOU and HONS 2006). Our results confirmed loss of SOM as well. Application of crop residues increases SOM (HAVLIN et al. 1990). Crop residues added into the soil together with NPK fertilizers increased TOC content by 6%, on the other hand, added NPK fertilizers decreased its TOC content by 4% in comparison to C_o. Added fertilizers have a different influence on SOM. They can increase its content (RASOOL et al. 2008), but they can also be the reason for intensive mineralization of SOM (HALVORSON et al. 2002). In cultivated soils, the quality of SOM is better (DOU and HONS 2006), which confirmed our results.

Generally, intensive cultivation decreased aggregation, and disrupts soil aggregates (MIKHA and RICE 2004). We also determined the best soil structure stability to be in NG rather than in CT and MT as well as in CR+NPK rather than in C_o and NPK (Table 2). Organic matter plays an important role in soil aggregate stability. Application of crop residues increases SOM and improves aggregation (LAYTON et al. 1993). Fertilizers can have different effects on soil structure stability. It can improve soil structure stability (HAO and CHANG 2002), but on the other hand it can also have negative effects (HAYNES and NAIDU 1998).

The share of macro-aggregates in size from $5x10^{-4}$ to $3x10^{-3}$ m is important from the agronomical point of view (DEMO et al. 1995), therefore we were focused on these fractions of WSA. Soil tillage system had a statistically significant influence on size fractions from $2x10^{-3}$ to $3x10^{-3}$ m of WSA. The highest WSA content of this size fraction was in NG rather than in CT and MT (Table 2). RAZAFIMBELO et al. (2008) also determined significantly higher WSA content in rough soil in comparison to conventional tillage. Cultivation increased the proportions of the micro-aggregate fraction.

The concentration of organic carbon is the highest in size fractions of WSA in no-tillage than conventional tillage (DOU and HONS 2006), which confirmed our results (Table 3).

The results of TOC and C_L dynamics from 2008 to 2009 showed on carbon sequestration mainly in favourable size fractions of WSA ($5x10^{-4}$ to $3x10^{-3}$ m) in CT and MT as well as CR+NPK and NPK. The macro-aggregates are generally formed by soil particles held together by organic residue (roots and hyphae) which are highly concentrated in carbon (TISDALL and OADES 1982).

The quantity and quality of SOM are the most important characteristics influencing the sustainable development (ŠIMANSKÝ and ZAUJEC 2009). Through parameters LI, CPI and CMI, some scientists tried to observe smaller changes and changes in a short time period (VIERA et al. 2007; ŠIMANSKÝ and ZAUJEC 2009). Through mentioned parameters we evaluated qualitative changes in size fractions of WSA in a short time period. In CT, in all size fractions of WSA, SOM was intensively decomposed by micro-organisms and more intensive degradation of soil. Added NPK fertilizers and also crop residues together with NPK fertilizers increased decomposition processes, mainly in favourable fractions of WSA. Application of farmyard manure and crop residues into soil is reflected on higher lability of SOM (SHEN et al. 2001). Usually, CMI values are strongly influenced by N fertilization (VIERA et al. 2007). With regard to CMI, it may be stated that simultaneous mineral fertilization and organic manure cause an accumulation of SOM and the rate of these processes is proportional to the fertilizer doses (JANOWIAK et al. 2001).

Na^+ is a highly dispersive agent resulting directly in the break-up of aggregates (BRONICK and LAL 2005). We found a negative correlation between the size fraction $>5x10^{-3}$ m of WSA and Na^+ as well as a positive correlation with CEC (Table 5). DIMOYIANNIS et al. (1998) connected aggregate stability with CEC. Increased dispersivity from Na^+ can break up aggregates, making SOM more available for decomposition (BRONICK and LAL 2005), which also confirmed our results (Table 5). The highest number of correlations we observed between TOC content in size fractions of WSA and K^+, TOC and C_L. Our results showed in fact that soil organic matter is very important for aggregation processes (Table 5) and on the other hand the lability decreases aggregation processes in soil. A higher content of SOM in labile form is a reason for decreasing soil structure stability. An ideal topsoil structure of predominantly crumblike aggregates, best formed when organic matter is naturally high (2% organic carbon) and well humified (GREENLAND et al. 1975). The role of organic matter is less significant in the subsoil where the type of clay mineral and exchangeable cations are important. Results of OPARA (2009) showed that higher stability of micro-aggregates depends on higher organic matter content, and calcium and magnesium contents. A statistically significant correlation was detected between TOC content in size fraction from $1x10^{-3}$ to $2x10^{-3}$ m of WSA and Ca^{2+}. Bivalent Ca^{2+} and Mg^{2+} cations improve soil structure through cationic bridging with clay particles and soil organic carbon (ZANG and NORTON 2002). Iron oxides and aluminium oxides contribute to stable subsoil structures, as do clay minerals that have calcium ions as the dominant exchangeable cation. Polyvalent Al^{3+} and Fe^{3+} cations improve soil structure through cationic bridging and the formation of organo-metallic compounds and gels (AMÉZKETA 1999).

CONCLUSION

All in all, we summarize that tillage systems had a statistically significant influence on changes of soil pH. Conventional tillage affected more positively on soil pH and exchangeable Ca^{2+}. In comparison to conventional tillage, a higher content of TOC was determined in minimal tillage and in grassland, but the quality of SOM was the best in conventional tillage. From the point of view of favourable size fractions of WSA, the highest content was in grassland, on the other hand conventional tillage contributed negatively, but fertilization contributed positively. In conventional tillage were lower contents of TOC and C_L in size fractions of WSA, but on the other hand, the TOC content in WSA was linearly increased with greater fractions of WSA as well as in treatment with crop residues together with NPK fertilizers. Obtained results showed carbon sequestration mainly in favourable size fractions of WSA ($5x10^{-4}$ - $3x10^{-3}$ m) in conventional tillage as well as in variant with crop residues and NPK fertilizers. On the other hand, intensive cultivation and fertilization negatively contributed due to intensive decomposition by micro-organisms and more intensive degradation of soil, in all size fractions of WSA. A statistically significant correlation was detected between TOC content in size fraction from $1x10^{-3}$ to $2x10^{-3}$ m of WSA and Ca^{2+}. Ca^{2+} promoted aggregation, which increased with increasing carbon pool index. Higher K^+ and CEC also increased the carbon pool index in favourable fractions of WSA. A positive correlation between TOC content in size fractions of WSA and quantitative parameters of soil organic matter were determined. Our results supported the fact about positive effects of SOM for aggregation processes and on the other hand a higher content of SOM in labile form decreases aggregation processes in soil.

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BIBLIOGRAPHY

1. AMÉZKETA E. 1999. Soil aggregate stability: a review. J. Sustain. Agric. 14:83-151.
2. BLAIR GJ, LEFROY RDB, LISLE L. 1995. Soil carbon fractions, based on their degree of oxidation, and the development of a Carbon Management Index for agricultural systems. Austr. J. Agric. Res. 46:1459-1466.
3.. BRONICK CJ, LAL R. 2005. Soil structure and management: a review. Geoderma. 124:3-22.
4. CHENU C, LE BISSONNAIS Y, ARROUAYS D. 2000. Organic matter influence on clay wettability and soil aggregate stability. Soil Sci. Soc. Am. J. 64:1479-1486.
5. DEMO M, KOLLÁR B, HRAŠKO J. 1995. Soil tillage. Nitra : SUA.
6. DIMOYIANNIS DG, TSADILAS CD, VALMIS S. 1998. Factors affecting aggregate stability of Greek agricurtural soils. Commun. Soil Sci. Plant Anal. 10:1239-1251.
7. DINEL H, MEHUYS GR, LEVESQUE M. 1991. Influence of humic acid and fibric materials on the aggregation and aggregate stability of a lacustrine siltly clay. Soil Sci. 2:146-157.
8. DOU F, HONS FM. 2006. Tillage and nitrogen effects on soil organic matter fraction in wheat-based systems. Soil Sci. Soc. Am. J. 6:1896-1905.
9. DZIADOWIEC H, GONET SS. 1999. Methodical guide-book for soil organic matter studies. Warszawa: HSE Publishing Co.
10. FABRIZZI KP, GARCIA FO, COSTA JL, PICONE LI. 2005. Soil water dynamics, physical properties and corn and wheat responses to minimum and no-tillage systems in the southern Pampas of Argentina. Soil Tillage Res. 81:57-69.
11. FIALA K, KOBZA J, MATÚŠKOVÁ Ľ, BREČKOVÁ V, MAKOVNÍKOVÁ J, BARANČÍKOVÁ G, BÚRIK V, LITAVEC T, HOUŠKOVÁ B, CHROMANIČOVÁ A, VÁRADIOVÁ D, PECHOVÁ B. 1999. Valid Methods of Soil Analyses. Partialmonitoring system– Soil. Bratislava: SSCRI.
12. GREENLAND DJ, RIMMER D, PAYNE D. 1975. Determination of the structural stability class of English and Welsh soil, using a water coherence test. J. Soil Sci. 26:294-303.
13. HALVORSON AD, WIENHOLD BJ, BLACK AL. 2002. Tillage, nitrogen, and cropping system effects on soil carbon sequestration. Soil Sci. Soc. Am. J. 66:906-912.
14. HANES J. 1999. Analyzes of sorptive characteristics. Bratislava: SSCRI.
15. HAO X, CHANG C. 2002. Effect of 25 annual cattle manure applications on soluble and exchangeable cations in soil. Soil Sci. 167:126-134.
16. HAVLIN JL, KISSEL DE, MADDUX LD, CLAASSEN MM, LONG JH. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci. Soc. Am. J. 54:448-452.

17. Haynes RJ, Naidu R. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutr. Cycl. Agroecosyst. 51:123-137.
18. Hussain KR, Olson SA, Ebelhar SA. 1999. Long-Term Tillage Effects on Soil Chemical Properties and Organic Matter Fractions. Soil Sci. Soc. Am. J. 63:1341-1349.
19. IUSS Working Group WRB. 2006. World reference base for soil resources 2006. Rome: FAO.
20. Janowiak J, Spychaj-Fabysiak E, Murawska B. 2001. Evaluation of Labile Carbon (C_L) Content in Soil on the Basis of Soil Organic Matter Sussceptibility to Oxidation with $K_2Cr_2O_7$ and Changing Values of Carbon Management Index. In: Zaujec A, Bielek P, Gonet SS, editors. Humic Substabces in Ecosystems 4. Bratislava: SSCRI. p. 45-49.
21. Layton JB, Skidmore EL, Thompson CA. 1993. Winter-associated changes in drysoil aggregation as influenced by management. Soil Sci. Soc. Am. J. 57:1568-1572.
22. Limousin G, Tessier D. 2007. Effects of no-tillage on chemical gradients and topsoil acidification. Soil Tillage Res. 92:167-174.
23. Loginov W, Wisniewski W, Gonet SS, Ciescinska B. 1987. Fractionation of organic carbon based on susceptibility to oxidation. Pol. J. Soil Sci. 20:47-52.
24. Mikha MM, Rice CW. 2004. Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. Soil Sci. Soc. Am. J. 68:809-816.
25. Nardi S, Morari F, Berti A, Tosoni M, Giardini L. 2004. Soil organic matter properties after 40 years of different use of organic and mineral fertilisers. Europ. J. Agronomy. 21:357-367.
26. Opara CC. 2009. Soil microaggregates stability under different land use types in southeastern Nigeria. Catena. 79:103-112.
27. Rasool R, Kukal SS, Hira GH. 2008. Soil organic carbon and physical properties as affected by long-term application of FYM and inorganic fertilizers in maize-wheat system. Soil Till. Res. 101:31-36.
28. Razafimbelo TM, Albrecht A, Oliver R, Chevallier T, Chapuis-Lardy L, Feller Ch. 2008. Aggregate associated-C and physical protection in a tropical clayey soil under Malagasy conventional and no-tillage systems. Soil Till. Res. 98:140-149.
29. Shen H, Xu ZH, Yan XL. 2001. Effect of fertilization on oxidizible carbon, microbial biomass carbon and mineralizable carbon under different agroecosystems. Commun. Soil Sci. Plant Anal. 32:1575-1588.
30. Šimanský V, Tobiašová E, Zaujec A. 2007. Influence of tillage on soil structure stability with regard to quantity and quality of soil organic matter. Agrochemistry. 47:27-30.
31. Šimanský V, Zaujec A. 2009. Suitable Parameters for Soil Organic Matter Changes Evaluation in Agro-ecosystems. Folia oecologica. 36:50-57.
32. Tan KW. 1998. Principles of Soil Chemistry. New York: Marcel Dekker.
33. Thomas GA, Dalal RC, Standley J. 2007. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. Soil Tillage Res. 94:295-304.
34. Tisdall JM, Oades JM. 1982. Organic matter and water-stable aggregates in soils. J. Soil Sci. 33:141-163.
35. Tripathi RP, Sharma P, Singh S. 2005. Tilth index: an approach to optimize tillage in rice–wheat system. Soil Tillage Res. 80:125-137.
36. Valla M, Kozák J, Ondráček V. 2000. Vulnerability of aggregates separated from selected anthorsols developed on reclaimed dumpsites. Rostl. Vyr. 46:563-568.
37. Vieira FCB, Bayer C, Zanatta JA, Dieckow J, Mielniczuk J, He ZL. 2007. Carbon management index based on physical fractionation of soil organic matter in an Acrisol under long-term no-till cropping systems. Soil Tillage Res. 96:195-204.
38. Young RN, Warkentin BP. 1975. Soil properties and behaviour. New York: Oxford.
39. Zaujec A, Šimanský V. 2006. Influence of Bio-stimulators on Soil Structure and Soil Organic Matter. Nitra: SUA.
40. Zhang XC, Norton LD. 2002. Effect of exchangeable Mg on saturated hydraulic conductivity, disaggregation and clay dispersion of disturbed soils. J. Hydrol. 260:194-205.