Acta fytotechnica et zootechnica 2
Nitra, Slovaca Universitas Agriculturae Nitriae, 2012, s. 52 – 56

ORGANIC MATTER AND CHEMICAL PROPERTIES IN HAPLIC LUVISOL AS AFFECTED BY TILLAGE AND FERTILIZATION INTENSITY

PÔSOBENIE ROZDIELNEJ INTENZITY OBRÁBANIA A HNOJENIA PÔDY NA ORGANICKÚ HMOTU A CHEMICKÉ VLASTNOSTI HNEDOZEME

Vladimír ŠIMANSKÝ, Erika TOBIAŠOVÁ

Slovak University of Agriculture in Nitra, Slovakia

In the Slovak Republic, from a point of view of sustainable management, the conservation and maintenance of favourable chemical properties of soils is very important. Lately, annual average soil loss of agricultural land of around 1,000 hectares was recorded, which represents an approximate daily loss of 3 hectares. Permanent loss of soil must be dealt with and compensated by the improvement of its chemical properties. The aim of this work was to compare the effects of different tillage systems and fertilization on soil organic matter and chemical properties of Haplic Luvisol. Our results showed that in minimal tillage system, there was higher carbon sequestration, however, in conventional tillage, the quality of humus was better. In the long term, application of only NPK fertilizers had negative effect on soil organic matter content because its decrease was determined, which negatively influenced all chemical properties in Haplic Luvisol. In conventional tillage, a higher amount of total organic carbon negatively affected soil reaction, hydrolytic acidity and base saturation. At the same time, positive effects between humus quality and soil pH, hydrolytic acidity and base saturation in conventional tillage were determined.

Keywords: chemical properties, fertilization, Luvisol, soil organic matter, soil tillage

From the point of view of sustainable management, the conservation and maintenance of favourable chemical properties of soils is very important in the Slovak Republic. One of the main reasons why we should pay attention to improving the properties of our soils is a continuous decline in agricultural land in Slovakia. In last years, according to the Soil Science and Conservation Research Institute, annual average soil loss of around 1,000 hectares is recorded, which represents an approximate daily loss of 3 hectares. (The total area of the Slovak Republic is 4,903,380 hectares, thereof the agricultural land is 2,432,979 hectares.) Soil organic matter (SOM) is one of the most important indicators of quality of soil environment affecting the amount of chemical, biological and physical processes in the soil. The SOM is a key component of ecosystems. Its quantity and quality is affected by the whole complex of natural and anthropogenic influences. From anthropogenic impacts, soil tillage and fertilization have the greatest impact.

A lot of results have confirmed the fact that the conventional tillage is a reason for the loss of SOM (Hussain et al., 1998; Šimanský et al., 2008; López-Fando and Pardo, 2009). However, Angers et al. (1997) published that in reduced tillage in 0 – 0.10 m there is more soil organic carbon than in conventional tillage, but on the other hand, in reduced tillage in 0.20 – 0.40 m there is less soil organic carbon than in conventional tillage. In reduced tillage in deeper depths of soils the carbon sequestration was not observed (Baker et al., 2007). Rueda et al. (2007) presented that in zero-till and in minimal tillage of soil the carbon content, N, P, K, Fe, Mn, Cu and Zn were higher than in conventional tillage of soil. Soil tillage has effect on pH. In no-till, higher carbon content decreased pH of soil (Franzluebbers and Hons, 1996; Rueda et al., 2007). Losses of soil organic matter due to intensive tillage may be compensated by the application of farmyard manure, compost or crop rotation. Soil fertilization increased SOM (Bowman and Halvorson, 1998). Added fertilizers and organic inputs can help maintain soil fertility by improving chemical and biological properties of soil (Nardi et al., 2004).

This study was aimed to compare the effects of different tillage systems and fertilization applied on soil organic matter over 10 years and chemical properties of Haplic Luvisol. Tillage and fertilization effects on mentioned parameters were evaluated in time period 2007 – 2009 as well. Relationship between soil organic matter and chemical properties of Haplic Luvisol in dependence on tillage systems and fertilization treatments were determined.

Material and methods

Description of the experimental base SAU Nitra

The experimental site is located approximately 5 km east of Nitra (lat. 48° 19‘ 00“; lon. 18° 09‘ 00“) and is characterised by a temperate climate (average annual temperatures are 9.8 °C, with 573 mm of average annual rainfall). 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 and it is according to FAO classification as silt loam Haplic Luvisol. The particle-size distribution is 318.8 $g.kg^{-1}$ of sand, 567.0 $g.kg^{-1}$ of silt and 114.3 $g.kg^{-1}$ of clay. Some chemical characteristics of the soil (0 – 0.2 m) determined in 1999 in all treatments of tillage and fertilizations are given in Table 1.

Experimental description

Department of Plant Production of SAU Nitra established a long-term experiment in 1999. The experiment consisted of two tillage (1st CT – conventional, 2nd MT – minimal) and three fertilizer treatments (1st Co – without fertilization, 2nd CR + NPK – crop residues together with NPK fertilizers, 3rd NPK – NPK fertilizers). The field experiment was arranged in a randomised

Table 1 Quantity and quality of SOM and chemical properties in different treatments of tillage and fertilization in 1999

Parameters		CT	MT	Co	CR + NPK	NPK
Total organic carbon in g.kg^{-1} (1)		13.0±0.4	12.9±0.4	12.6±0.1	13.1±0.1	13.3±0.1
Carbon of humic acids and fulvic acids ratio (2)		0.54±0.08	0.57±0.03	0.53±0.05	0.53±0.01	0.61±0.03
pHKCl		5.70±0.07	6.60±0.66	5.82±0.05	6.37±1.01	6.27±0.86
Hydrolytic acidity (3)	mmol.kg^{-1}	16.08±0.56	7.33±5.60	16.64±1.20	10.30±2.89	10.18±1.84
Sum of basic cations (4)		151.2±2.94	191.1±3.58	152.9±2.40	185.23±4.92	175.4±3.71
Base saturation in % (5)		90.19±0.11	95.94±3.73	90.97±0.95	94.13±5.79	94.10±5.47
Ca^{2+}	in mmol.kg^{-1}	81.17±2.25	96.05±1.14	81.58±3.64	94.00±1.83	90.25±3.45
Mg^{2+}		32.03±3.65	31.95±3.90	27.65±5.77	35.54±0.62	32.78±4.01
Na^{+}		4.10±0.51	4.15±0.77	3.84±0.26	4.49±0.69	4.05±0.85
K^{+}		3.23±0.57	4.30±0.76	3.12±0.45	3.94±1.32	4.24±0.50

CT – Conventional tillage; MT – Minimal tillage; C_o – Without fertilization; CR + NPK – Crop residues together with added NPK fertilizers; NPK – NPK fertilizers

CT – konvenčné obrábanie; MT – minimalizačné obrábanie; C_o – bez hnojenia; CR+NPK – pozberové zvyšky + NPK hnojivá; NPK – NPK hnojivá

Tabuľka 1 Množstvo a kvalita organickej hmoty a chemické vlastnosti pôdy v jednotlivých variantoch obrábania a hnojenia pôdy v roku 1999
(1) celkový organický uhlík, (2) pomer uhlíka humínových kyselín k uhlíku fulvokyselín, (3) hydrolytická kyslosť, (4) suma bázických katiónov, (5) stupeň nasýtenia

block design with four replications. The tillage treatment plots measured 44 m by 35 m, and the fertilizer subplots were 10 m by 4 m. Conventional tillage means annual ploughing to the depth of 0.20 m, and minimal tillage means annual disking to the depth of 0.10 m. In CR + NPK treatment, crop residues were returned to the soil. The doses of NPK were calculated by balance method. Used fertilizers were mainly nitre ammonium with dolomite, potassium chloride and triple superphosphate. The field experiment had the following crop rotation: 1. red clover (*Trifolium pratense* L.); 2. pea (*Pisum sativum* L. subsp. *sativum;* 3. winter wheat (*Triticum aestivum* L.); 4. maize (*Zea mays* L.); 5. spring barley (*Hordeum vulgare* L.).

Soil sampling and analyses

Sampling for determination of SOM parameters and chemical analyses were carried out during the years 2007 – 2009, from the depth of 0 to 0.2 m. For each sampled plots (with all treatments of tillage and fertilization), six different locations were chosen randomly. Soil samples were taken and mixed to average the sample and then soil samples were dried at laboratory temperature and ground. In soil samples, the following parameters were determined: soil pH potentiometrically, sorptive characteristics of soil as well as total organic carbon content (TOC) according to Tyurin, the fraction composition of humus substances according to Belchikova and Kononova (Fiala et al., 1999).

Statistical analysis

Statistical analyses were performed using Statgraphics Plus. Treatment effects on measured variables were tested by analysis of variance (ANOVA), and comparisons among treatment means were made using the least significant difference (LSD) multiple range test calculated at *P* <0.05. We used correlation analysis to determine the relationships between SOM parameters and chemical properties. Significant correlation coefficients were tested on *P* <0.05.

Results and discussion

Soil organic matter for the period 2007 – 2009

We compare the effects of various tillage and fertilization intensities on the quantity and quality of soil organic matter for the period 2007 – 2009. The results are illustrated in Figure 1. In MT, the accumulation of TOC was observed. On the other hand, in CT the content of TOC was lower. At present time, several studies (Šimanský et al., 2006; López-Fando and Pardo, 2009) confirm the fact that intensive cultivation contributes to reducing the organic matter content in soils. Fertilization did not show a statistically significant influence on changes in the TOC content. However, by applied NPK fertilizers in comparison to no fertilizer treatment the tendency of TOC decrease was determined. The fact that fertilizers contribute to increased mineralization of SOM has been confirmed (Munkholm et al., 2002), but on the other hand, fertilizers applied to the soil can result in a higher production

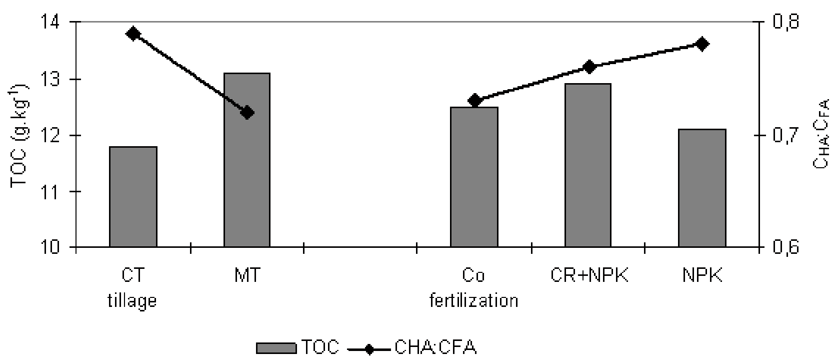

Figure 1 Quantity and quality of SOM in different tillage and fertilization (2007 – 2009)
CT – conventional tillage; MT – minimal tillage; C_o – without fertilization; CR + NPK – crop residues together with added NPK fertilizers; NPK – NPK fertilizers; TOC – total organic carbon content; C_{HA} : C_{FA} – carbon of humic acids to carbon of fulvic acids ratio

Obrázok 1 Množstvo a kvalita organickej hmoty pôdy v dôsledku rozdielneho obrábania a hnojenia pôdy
CT – konvenčné obrábanie; MT – minimalizačné obrábanie; C_o – bez hnojenia; CR + NPK – pozberové zvyšky + NPK hnojivá; NPK – NPK hnojivá; TOC – obsah celkového organického uhlíka; C_{HA} : C_{FA} – pomer uhlíka humínových kyselín k uhlíku fulvokyselín
(1) obrábanie pôdy, (2) hnojenie pôdy

Table 2 Statistical evaluation of chemical parameters of Haplic Luvisol in 2007 – 2009 (Dolná Malanta) – LSD multiple-range test

Treatments (1)		Hydrolytic acidity (2)	Sum of basic cations (3)	Base saturation (4)	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
		in mmol.kg^{-1}		in %		in mmol.kg^{-1}			
Tillage	CT	6.14b	168.6a	96.5a	6.60a	97.7a	31.9a	4.68a	4.43a
	MT	5.25a	180.7b	97.2b	6.55a	97.4a	33.9a	4.58a	6.04a
Fertilization	C_o	5.08a	179.1a	97.3a	6.63a	97.6a	31.4a	4.57a	4.91ab
	CR + NPK	6.02b	173.0a	96.6a	6.55a	96.1a	35.3a	4.61a	6.40b
	NPK	5.99ab	171.8a	96.6a	6.56a	98.9a	31.9a	4.71a	4.38a

Different letters (a, b) indicate that treatment means are significantly different at P <0.05 according to LSD multiple-range test
CT – konvenčné obrábanie; MT – minimalizačné obrábanie; Co – bez hnojenia; CR + NPK – pozberové zvyšky + NPK hnojivá; NPK – NPK hnojivá

Tabuľka 2 Štatistické vyhodnotenie vybraných chemických vlastností hnedozeme za roky 2007 – 2009 (Dolná Malanta) – LSD test
Rozdielne písmená (a,b) medzi variantmi indikujú štatistickú preukaznosť na úrovni P <0,05 podľa LSD testu
(1) varianty, (2) hydrolytická kyslosť, (3) suma bázických katiónov, (4) stupeň nasýtenia

Table 3 Correlation coefficients between soil organic matter and chemical properties (2007 – 2009)

Parameters (1)	Tillage systems (4)	pH	Hydrolytic acidity (5)	Sum of basic cations (6)	Base saturation (7)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Total organic carbon (2)	CT	-0.852***	0.771**	-0.185	-0.750**	-0.591	-0.311	-0.318	0.158
	MT	0.218	-0.192	0.249	0.220	0.214	0.536	0.117	0.476
Carbon of humic acids and fulvic acids ratio (3)	CT	0.727**	-0.636*	0.140	0.638*	0.411	0.022	0.378	0.043
	MT	0.240	-0.306	0.009	0.280	0.437	0.455	0.069	0.271

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$
CT – konvenčné obrábanie; MT – minimalizačné obrábanie

Tabuľka 3 Korelačné koeficienty medzi pôdnou organickou hmotou a chemickými parametrami (2007 – 2009)
(1) parametre, (2) celkový organický uhlík, (3) pomer uhlíka humínových kyselín k uhlíku fulvokyselín, (4) spôsob obrábania, (5) hydrolytická kyslosť, (6) suma bázických katiónov, (7) stupeň nasýtenia

Table 4 Correlation coefficients between soil organic matter and chemical properties (2007 – 2009)

Parameters (1)	Fertilization (4)	pH	Hydrolytic acidity (5)	Sum of basic cations (6)	Base saturation (7)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
Total organic carbon (2)	C_o	0.121	0.159	0.518	-0.117	0.192	0.142	0.254	-0.286
	CR+NPK	-0.049	0.028	0.416	0.042	-0.121	0.099	-0.101	0.540
	NPK	-0.313	0.259	0.101	-0266	-0.228	0.110	-0495	0.458
Carbon of humic acids and fulvic acids ratio (3)	Co	0.857**	-0.649	0.751*	0.675	0.567	0.507	0.436	-0.068
	CR+NPK	0.259	-0.445	-0.400	0.361	0.525	0.225	-0.152	0.269
	NPK	0.129	-0.102	-0.256	0.096	0.071	-0.234	0.448	-0.065

*$P < 0.05$; **$P < 0.01$
C_o – bez hnojenia; CR + NPK – pozberové zvyšky + NPK hnojivá; NPK – NPK hnojivá

Tabuľka 4 Korelačné koeficienty medzi pôdnou organickou hmotou a chemickými parametrami (2007 – 2009)
(1) parametre, (2) celkový organický uhlík, (3) pomer uhlíka humínových kyselín k uhlíku fulvokyselín, (4) spôsob hnojenia, (5) hydrolytická kyslosť, (6) suma bázických katiónov, (7) stupeň nasýtenia

of biomass, which leads to increases in SOM content (Neff et al., 2002). TOC content under CR + NPK was higher than under C_o and by 7% higher than under NPK treatment. The quality of soil organic matter with dependence on tillage system and fertilization was evaluated by use of carbon of humic acids and carbon of fulvic acids ratio. Humus was better in CT than in MT. Applied NPK fertilizers had positive effect on increase of humus quality (by 7%) as well as ploughed crop residues together with NPK fertilizers (by 4%) in comparison to control (without fertilizers).

Soil organic matter for the period 1999 – 2009

When the different tillage treatments (CT and MT) were compared at the end of the 10 years period (years 1999 and 2009), the TOC content was higher in MT than in CT. In 2009, the content of TOC was lower by 7% than in 1999 in CT. On the other hand, we observed increase of TOC content in MT from 1999 (12.9±0.4 g.kg^{-1}) to 2009 (13.2±1.2 g.kg^{-1}) but without statistical significance. In stable fraction of organic matter the significant changes can be observed only for a long time period (Hungate et al., 1996). For example, Hendrix et al. (2004) published that in minimal tillage over 20 years, 0.6 tons C per hectare and year was accumulated. Tillage systems had a positive effect on increase of soil organic matter quality. In CT the CHA : CFA ratio was higher in comparison to MT. Several authors (Pare et al., 1999; Šimanský et al., 2008) showed on the fact that quality of SOM in intensive cultivated soils is better. Fertilization is a very important factor influencing the transformation processes of SOM. Applied crop residues together with NPK fertilizers had a positive effect on increase of TOC content (by 4%) and SOM quality (by 21%). It corresponds with the results of Kubát and Lipovský (1996). Applications of NPK fertilizers only had a negative effect on TOC content because its decrease by 7% between the years 1999 and 2009 was determined. On the other had, the SOM quality increased by 33% in NPK treatment.

Soil reaction and sorptive parameters of soil

Soil reaction and sorptive parameters of soil in dependence on tillage systems and fertilization are in Table 2. Different tillage and fertilization intensities had no statistically significant effect on pH changes. Soil tillage and fertilization had statistically significant influence on values of hydrolytic acidity. In CT, a value of hydrolytic acidity was higher by 17% than in MT. The reason may be that in arable soils give out by the cultivation to intensive aeration with following more intensive mineralization, which is reflected on soil sorptive parameters (Nardi et al., 2004). The values of hydrolytic acidity were higher by 19% in CR + NPK treatment and by 18% in NPK treatment in comparison to control treatment (Table 2). Thomas et al. (2007) showed that N fertilizer application resulted in a significant reduction of soil pH, which means increase of hydrolytic acidity values and negative effects on the other soil sorptive parameters. We did not detect any significant effects of tillage intensities on exchangeable Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} (Table 2). The proportion of sum of base cations as Ca^{2+} was highest under conventional tillage and lowest under minimal tillage. In MT the portion of exchangeable Mg^{2+} was detected by 7% higher than in CT. This unusual behaviour might also be attributable to the fact that Mg^{2+} is known to be included in the structure of clay minerals, whereas Ca^{2+} can not be involved in isomorphic substitutions. As a consequence, the acidification of upper layers of no-tilled soil could have increased the dissolution of clay minerals, leading to an enhanced release of Mg^{2+} (Limousin and Tessier, 2007). Similar effect was observed in CR + NPK, which means that the applied crop residues had an effect on acidification of soils which let to dissolution of clay minerals. Fertilization exhibited statistically significant influence on the values of exchangeable K^{+} (Table 2). The highest value of K^{+} was determined in CR + NPK and the lowest content of exchangeable K^{+} was determined in NPK treatment.

Correlation between soil organic matter and chemical properties

Correlations between quantitative and qualitative parameters of soil organic matter and chemical properties of Haplic Luvisol in dependence on tillage intensities are illustrated in Table 3. SOM quantity and quality significantly influenced soil pH. A higher amount of TOC negatively effected soil reaction, hydrolytic acidity and base saturation in CT. Limousin and Tessier (2007) determined a significant, negative correlation between pH and SOC concentration, indicating that greater SOC under no-till and zero-till may at least partially have had an acidifying effect. In MT, no significant correlations were observed (Table 3). Positive correlations were determined between $C_{HA} : C_{FA}$ and soil pH (0.727, $P < 0.01$), hydrolytic acidity (-0.636, $P < 0.05$) and base saturation (0.639, $P < 0.05$) in CT. Table 4 shows the correlations between quantitative and qualitative parameters of soil organic matter and chemical properties of Haplic Luvisol in dependence on fertilization intensities. In treatments with fertilization, no significant correlation between soil organic matter parameters and chemical properties of Haplic Luvisol was detected. Only in C_o, statistically significant positive correlations between quality of SOM and soil pH (0.875, $P < 0.01$) and sum of base cations (0.795, $P < 0.05$) were determined.

Conclusion

SOM data are very important from the point of view of the carbon sequestration and changes of chemical properties of soils. Our results (from the same depth) showed that in minimal tillage system, there is higher carbon sequestration. This study also confirmed several other investigations about the consequences of minimal tillage on chemical properties, for example as acidification. On the other hand, in terms of evaluation of sorptive parameters of Haplic Luvisol, the minimal tillage system was better in comparison to conventional tillage. Negative effects of SOM on sorptive parameters and soil reaction were determined only under conventional tillage system. From a point of view of the carbon sequestration, fertilization and ploughing of crop residues to the soil are very important. In the long term, application of NPK fertilizers only had a negative effect on SOM content because its decrease was determined, which negatively influenced all chemical properties in Haplic Luvisol.

Súhrn

Z hľadiska udržateľného hospodárenia má zachovávanie a udržiavanie priaznivých chemických vlastností pôd v Slovenskej republike veľký význam. Podľa údajov Výskumného ústavu pôdnej úrodnosti je v posledných rokoch zaznamenávaný neustály priemerný ročný úbytok pôdy približne na úrovni 1 000 ha, čo predstavuje približný denný úbytok 3 ha. Stratu pôdy je potrebné riešiť a kompenzovať jej negatívne dôsledky napríklad aj cez organickú hmotu pôdy a zlepšenie chemických vlastností pôd. Cieľom tejto práce bolo posúdiť vplyv rozdielnych spôsobov obrábania a hnojenia hnedozeme na zmeny v obsahu a kvalite organickej hmoty pôdy, ale aj na zmeny chemických vlastností pôdy. Získané výsledky poukázali na vyššiu sekvestráciu uhlíka pri minimalizačnom spracovaní pôdy v porovnaní s konvenčným spôsobom. Na druhej strane, kvalita humusu bola vyššia vo variantoch s konvenčným obrábaním pôdy. Z dlhodobého hľadiska mala aplikácia iba NPK hnojív negatívny dopad na množstvo organickej hmoty pôdy, čo sa prejavilo aj na zhoršení chemizmu pôdy. Vo variantoch konvenčne obrábaných bol zaznamenaný pozitívny efekt medzi kvalitou organickej hmoty a pôdnou reakciou, hydrolytickou kyslosťou a stupňom nasýtenia sorpčného komplexu.

Kľúčové slová: chemické vlastnosti, hnojenie, obrábanie, hnedozem, organická hmota pôdy

Acknowledgement

Project supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences (No. 1/0300/11).

References

ANGERS, D. A. – BOLINDER, M. A. – CARTER, M. R. – GREGORICH, E. G. – DRURY, C. F. – LIANG, B. C. – VORONEY, P. R. – SIMARD, R. R. – DONALD, R. G. – BEYAERT, R. P. – MARTEL, J. 1997. Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. In Soil Till. Res., 41, 1997, p. 191 – 201.

BAKER, J. M. – OCHSNER, T. E. – VENTEREA, R. T. – GRIFFIS, T. J. 2007. Tillage and soil carbon sequestration – what do we really know? In Agric. Ecosys. Environ., 118, 2007, p. 1 – 5.

BOWMAN, R. A. – HALVORSON, A. D. 1998. Soil chemical changes after nine years of differential N fertilization in a no-till dryland wheat-corn--fallow rotation. In Soil Sci., 163, 1998, p. 241 – 247.

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. Záväzné metódy rozborov pôd. Čiastkový monitorovací systém – PôDA. 1. vyd. Bratislava : VUPOP, 1999, 142 s. ISBN 80-85361-55-8.

FRANZLUEBBERS, J. – HONS, F. M. 1996. Soil-profile distribution of primary and secondary plant-available nutrients under conventional and no-tillage. In Soil Till. Res., 39, 1996, p. 229 – 239.

HENDRIX, P. F. – FRANZLUEBBERS, A. J. – MCCRACKEN, D. V. 2004. Management effects on C accumulation and loss in soils of the southern Appalachian Piedmont of Georgia. In Soil Till. Res., 47, 2004, p. 245 – 251.

HUNGATE, A. – JACKSON, R. B. – FIELD, C. B. – CHAPIN, F. S. 1996. Detecting changes in soil carbon in CO2 enrichment experiments. In Plant and Soil., 187, 1996, p. 135 – 145.

HUSSAIN, K. R. – OLSON, S. A. – SIEMENS, J. C. 1998. Long-term tillage effects on physical properties of eroded soils. In Soil Sci., 163, 1998, p. 970 – 981.

KUBÁT, J. – LIPAVSKÝ, J. 1996. The effect of fertilization and liming on the carbon concetrations in arable soils. In Rost. výr., 42, 1996, p. 55 – 58.

LIMOUSIN, G. – TESSIER, D. 2007. Effects of no-tillage on chemical gradients and topsoil acidification. In Soil Till. Res., 92, 2007, p. 167 – 174.

LÓPEZ-FANDO, M. – PARDO, T. 2009. Changes in soil chemical characteristics with different tillage practices in a semi-arid environment. In Soil Till. Res., 104, 2009, p. 278 – 284.

MUNKHOLM, L. J. – SCHJONNING, P. – DEBOSZ, K. – JENSEN, H. E. – CHRISTENSEN, B. T. 2002. Aggregate strength and mechanical behaviour of a sandy loam soil under long-term fertilization treatments. In Eur. J. Soil Sci., 53, 2002, p. 129 – 137.

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. In Europ. J. Agronomy, 21, 2004, p. 357 – 367.

NEFF, J. C. – TOWNSEND, A. R. – GLEIXNER, G. – LEHMAN, S. J. – TURNBULL, J. – BOWMAN, W. D. 2002. Variable effects of nitrogen additions on the stability and turnover of soil carbon. In Nature, 419, 2002, p. 915 – 917.

PARE, T. – DINEL, H. – MOULIN, A. P. – TOWNLEY-SMITH, L. 1999. Organic matter quality and structural stability of a Black Chernozemic soil under different manure and tillage practices. In Geoderma, 91, 1999, p. 311 – 326.

RUEDA, M. I. – GUERRA, M. M. L. – YUNTA, F. – ESTEBAN, E. – TENORIO, J. L. – LUCENA, J. J. 2007. Tillage and crop rotation effects on barley yield and soil nutrients on a Calciortidic Haploxeralf. In Soil Till. Res., 92, 2007, p. 1 – 9.

ŠIMANSKÝ, V. – TOBIAŠOVÁ, E. – CHLPÍK, J. 2008. Soil tillage and fertilization of Orthic Luvisol and their influence on chemical properties, soil structure stability and carbon distribution in water-stable macro-aggregates. In Soil Till. Res., 100, 2008, p. 125 – 132.

ŠIMANSKÝ, V. – TOBIAŠOVÁ, E. – CHLPÍK, J. 2006. Influence of tillage system and fertilization on soil structure stability and chemical properties of Haplic Luvisol. In Acta Phytotechnica et zootechnica, vol. 9, 2006, no. 3, p. 75 – 80.

THOMAS, G. A. – DALAL, R. C. – STANDLEY, J. 2007. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. In Soil Till. Res., 94, 2007, p. 295 – 304.

Contact address:
doc. Ing. Vladimír Šimanský, PhD., Katedra pedológie a geológie, FAPZ, SPU, Tr. A. Hlinku 2, 949 76 Nitra, Vladimir.Simansky@uniag.sk