doi: 10.17221/567/2015-PSE

Soil characteristics and crop yields under different tillage techniques

G. Mühlbachová, H. Kusá, P. Růžek

Crop Research Institute, Prague-Ruzyně, Czech Republic

ABSTRACT

The field experiment with different soil tillage treatments has been carried out in Prague-Ruzyně locality (Czech Republic) since 1995. Data of two growing cycles in the years 2007–2010 and 2011–2014 were evaluated. Tillage technique was decisive for changes in soil characteristics and crop yields. Bulk density, organic carbon (C_{org}) and microbial biomass C (C_{mic}) were more equilibrated throughout all tested soil layers (0–0.1; 0.1–0.2 and 0.2–0.3 m) in conventional tillage (CT). In reduced tillage (RT) and no-tillage (NT) treatments significant accumulation of C_{org} and increase of C_{mic} in the surface layer were found, compared to CT. No significant differences in C_{org} and C_{mic} between two growing cycles were determined; however, mostly higher values were obtained in the top layer of NT during the second growing period. Higher bulk density under conservation tillage techniques did not negatively affect soil characteristics and should be taken in consideration for data evaluation as it can alter interpretation of their changes in the soil profile. Crop yields were comparable in CT and RT. Yield decrease in NT was mostly observed for winter wheat and pea. Beneficial effects of RT and NT conserving soil moisture on crop yield were not observed in dry years.

Keywords: ploughing; soil organic carbon; microbial activity; *Triticum aestivum*; *Pisum sativum*

Sustainable soil management systems require proper choice of cropping methods, tillage techniques, as well as ensured supply of nutrients; however, they also require subsequent soil quality evaluations. It is well known that soil quality and fertility are connected to the biological activity of soil (Mikanová et al. 2012).

Changes in the frequency and intensity of tillage practices alter soil properties, distribution of nutrients and soil organic matter within the soil profile (Hussain et al. 1999). Conventional tillage (CT) promotes the loss of the soil organic matter, which leads to a disruption of soil aggregates and contributes to soil erosion (Melero et al. 2009).

The increase of soil microbial activities and biomass after reduction of tillage has been reported by several authors, particularly in the top soil layer (Melero et al. 2009, Mikanová et al. 2009). Changes in the dynamics of the microbial community occur from the interactions between tillage, soil moisture, temperature, aeration, and substrate availability (Sainju et al. 2007). Rainfall can also play an important role in the dynamics and activities of the soil microbial communities as higher CO_2 fluxes were detected in CT plots than in the NT treatments immediately after rainfall or irrigation; additionally an exponential relationship was found between CO_2 emissions and the soil temperature (Jabro et al. 2008).

Many studies have investigated the effect of reduced soil tillage on crop yields, however the results are often contradictory owing to different soils and crops and using different tillage intensities. Some authors reported sustained or increased crop productivity in conservation (RT, NT) tillage, but usually a negative yield impact was observed depending on the duration and extent to which the conservation tillage is enacted, crop type, as well as on the climate region. Lundy et al. (2015) found smaller NT yields decrease compared to CT

Supported by the Ministry of Agriculture of the Czech Republic, Projects No. 0002700604, RO0414 and RO0415.

doi: 10.17221/567/2015-PSE

in temperate region (–3.7%) than in subtropical (–10.7%). The analysis of many European studies showed a potential negative effect of the number of years of conservation tillage (RT, NT) practice on relative crop yield that can be reduced using a good crop rotation including crops other than cereals (Van den Putte et al. 2010). Also the application of nitroegn (N) fertilizers significantly reduced NT yields declines.

The aim of this research was to evaluate the effect of different tillage practices on soil biological, microbial and physical characteristics in Orthic Luvisol, at Prague-Ruzyně (Czech Republic) as well as on crop yields. The potential relationships between microbial characteristics and meteorological conditions were also evaluated.

MATERIAL AND METHODS

Field trial. The field trials were carried out in Prague-Ruzyně (beet production area; altitude 340 m a.s.l.; latitude 50°05'N; longitude 14°20'E; annual precipitation 472 mm; annual average temperature 8.4°C; Orthic Luvisol (IUSS/ISTRIC/FAO (2006); clay-loamy texture, pH_{KCl} 7.0, pH_{H_2O} 7.8; C_{org} 1.4%; available nutrients (extracted by the Mehlich III method): P – 66 mg/kg; K – 213 mg/kg; Ca – 3897 mg/kg; Mg – 154 mg/kg; cation exchange capacity (CEC) – 227.6 $mmol_+$/kg). The experiment was started in 1995, when three tillage practices: conventional tillage (CT – mouldboard ploughing down to 0.22 m); reduced tillage (RT – chisel ploughing of the surface soil layer to a depth of 0.1 m), and no-tillage practice (NT – without tillage) were applied. Each tillage practice was carried out on 12 m wide and 95 m long band. In the autumn, P and K fertilizers were broadcast on the whole experimental field at the same dose given by the results of Mehlich III extraction. Mineral nitrogen fertilizers were applied during spring vegetation in doses given by the N_{min} (mineral nitrogen) method with view to the needs of cultivated plants (i.e. winter wheat 130–145 kg N/ha, oil seed rape 160 kg N/ha, pea without nitrogen). Two four-year period (2007–2010, 2011–2014) with the same crop rotations were evaluated: pea (*Pisum sativum*)-winter wheat (*Triticum aestivum*)-oil seed rape (*Brassica napus*)--winter wheat (*Triticum aestivum*). Crops were harvested in appropriate agro-technical terms. Published yields values are converted to standard moisture grains/seeds of various crops, i.e. 8% for oilseed rape, 14% for winter wheat and pea.

The data for the samplings varied through the years from May 14th to 26th. The soils were collected in 5 replications from the layers 0–0.1; 0.1–0.2 and 0.2–0.3 m. The moist soil samples were sieved in a 2 mm sieve.

Bulk density. The 100 cm^3 metallic cylinders were filled in the field from the middle of each layer. The weight on an oven-dry basis (at 105°C) was used for the calculations (Králová et al. 1991). All data on the soil C_{org}, C_{mic} were calculated considering bulk density in calculations.

Total organic carbon. C_{org} was determined photometrically at 600 nm in suspension of $K_2Cr_2O_7$ and H_2SO_4 according to Sims and Haby (1971).

Microbial biomass C. Measurements of the soil C_{mic} were performed using the fumigation-extraction (FE) method (Vance et al. 1987). C_{mic} was calculated from the relationship:

$$B_c = 2.64\ E_c$$

Where: E_c – difference between the organic C extracted from the fumigated and non-fumigated treatments.

Meteorological data. Data of temperatures and rainfall were collected by the meteorological station at the trial site. The average daily temperatures and the rainfall sum totals were calculated from the partial 15 min data sets for the period of 20 weeks before sampling. The soils were never sampled shortly after or during the rain (Table 1).

Statistical analysis. Statistical analyses were carried out using Statistica 9.0 software (StatSoft Inc., Tulsa, USA), with the results expressed as mean values from 5 replicates. The standard deviation was determined and visualized as the vertical bars in figures. The same letters in the table bellow figures represent statistically identical values of the examined tillage practices according to two-way ANOVA Duncan's test ($P < 0.05$) determining the significant differences among the data.

RESULTS AND DISCUSSION

The top layer in RT had similar bulk density to that in CT, due to the chisel ploughing of the upper 0.1 m of the soil, but it increased significantly in the deeper layers and was similar to NT. The bulk density in NT was the highest within all

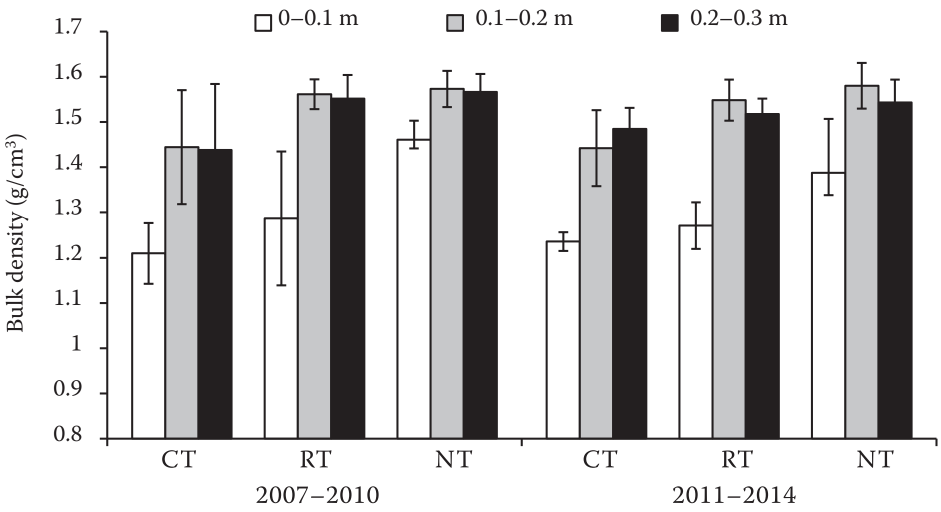
doi: 10.17221/567/2015-PSE

Table 1. Average temperature and sum of rainfall at Prague-Ruzyně

	Temperature (°C)					Rainfall (mm)			
	at sampling	10 days before	4 weeks before	7 weeks before	20 weeks before	10 days before	4 weeks before	7 weeks before	20 weeks before
2007	21.6	14.7	13.5	10.4	7.8	14.0	37.0	53.6	107.4
2008	16.0	14.2	12.3	8.2	6.0	10.6	83.2	142.2	167.8
2009	17.4	14.1	13.4	10.1	5.1	30.9	43.8	95.4	122.6
2010	10.1	11.1	11.6	7.9	3.5	30.3	59.9	109.4	144.0
2011	15.1	14.2	12.9	9.5	5.2	9.1	34.4	80.8	112.4
2012	19.4	14.1	12.8	11.0	5.2	8.8	50.4	65.3	114.6
2013	13.6	14.4	13.8	9.0	3.8	35.6	68.1	76.4	159.1
2014	9.2	11.6	11.0	10.6	6.3	13.1	43.9	77.8	93.1

three layers, and significantly different from CT, especially in the top layer (Figure 1). The 0.1–0.2 and 0.2–0.3 m layers were characterised by lower but more variable bulk density in CT; higher bulk densities were found in RT and NT, although these differences were not usually significantly different. These findings are in good agreement with the findings of Salinas-García et al. (2002), Bausenwein et al. (2008) and Chen et al. (2014). In addition, no significant differences in bulk density between two studied periods were observed.

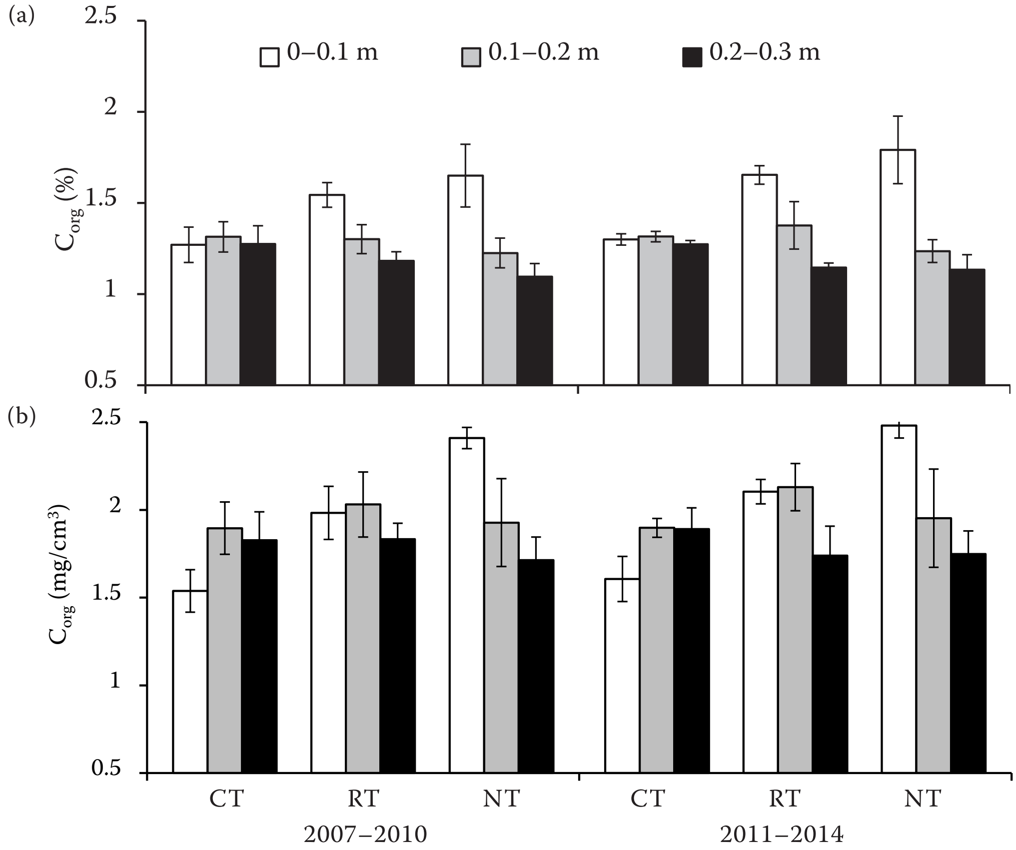
C_{org} contents were more uniformly distributed through the studied soil profile in CT, particularly if the data were expressed as percentage of the soil weight than in either RT or NT systems, during all of the years studied (Figure 2a). Slight but non-significant increase of C_{org} content, particularly in the top layer, was observed between two studied periods. The C_{org} contents in CT at the 0–0.1 m layer were the lowest among all of studied tillage practices. An accumulation of C_{org} in the top layer was observed in RT, and particu-



	Layer (m)								
	0–0.1	0.1–0.2	0.2–0.3	0–0.1	0.1–0.2	0.2–0.3	0–0.1	0.1–0.2	0.2–0.3
		CT			RT			NT	
2007–2010	a	ab	bcd	ab	cd	cd	bcd	d	d
2011–2014	a	ab	cd	ab	d	cd	bcd	d	cd

Figure 1. Bulk density in different soil layers under CT (conventional tillage), RT (reduced tillage) and NT (no-tillage) tillage techniques in periods 2007–2010 and 2011–2014

doi: 10.17221/567/2015-PSE



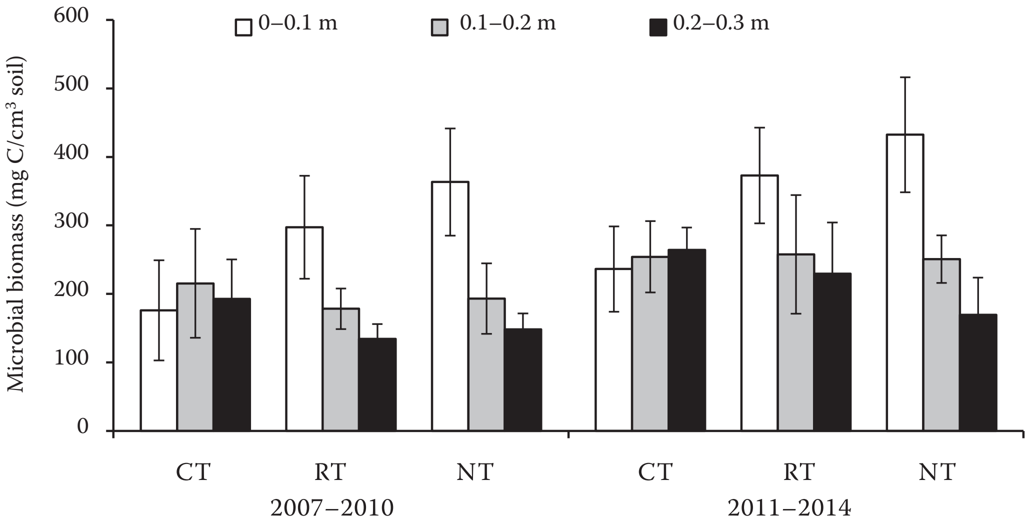
	Layer (m)								
	0–0.1	0.1–0.2	0.2–0.3	0–0.1	0.1–0.2	0.2–0.3	0–0.1	0.1–0.2	0.2–0.3
	CT			RT			NT		
C_{org} (%)									
2007–2010	abcd	abcde	abcd	ef	abcd	abc	fg	bcd	a
2011–2014	abcd	abcde	abcd	fg	cde	abcd	g	bcd	ab
C_{org} (mg/cm^3)									
2007–2010	a	abcde	abcde	cde	cde	abc	fg	bcde	abc
2011–2014	ab	abcde	abcde	cde	efg	abcd	g	bcde	abcd

Figure 2. Soil organic carbon in different soil layers under CT (conventional tillage), RT (reduced tillage) and NT (no-tillage) tillage techniques in periods 2007–2010 and 2011–2014. (a) percentage of carbon (C) in a soil; (b) mg/cm^3

larly in NT. Significantly lower C_{org} was measured at the depths of 0.1–0.2 and 0.2–0.3 m in both RT and NT in comparison with the 0–0.1 m layer. Sequestration of C_{org} in soils, using the conservation tillage practices, has been reported by several authors (Reicosky 2003, Al-Kaisi and Yin 2005, Melero et al. 2009). Similarly, our experiment showed that the application of RT and NT increased the C_{org} contents in top layers of soil. The expression of C_{org} content per cm^3 of soil (Figure 2b), in which also the bulk density played an important role, showed that possible lower content of C_{org} could be observed in the top layer of the soil in CT. Respiratory activities expressed as CO_2-fluxes contribute to the losses of C_{org} from the soil (Alvaro-Fuentes et al. 2008, Jabro et al. 2008).

Bausenwein et al. (2008) defined the 0.1–0.28 m layer of RT as an intermediate layer, which is physically undisturbed, while being in full reach of

doi: 10.17221/567/2015-PSE



	Layer (m)								
	0–0.1	0.1–0.2	0.2–0.3	0–0.1	0.1–0.2	0.2–0.3	0–0.1	0.1–0.2	0.2–0.3
	CT			RT			NT		
2007–2010	a	abc	ab	abcd	a	a	bcd	ab	a
2011–2014	abc	abcd	abcd	bcd	abcd	abc	bcd	abc	a

Figure 3. Microbial biomass (C_{mic}) in different soil layers under CT (conventional tillage), RT (reduced tillage) and NT (no-tillage) tillage techniques in periods 2007–2010 and 2011–2014

the plant roots as well as close to the air supply. This definition corresponds to our data of C_{org} which in RT in the middle (0.1–0.2 m) layer even exceeded those in NT. The long-term effects of conservation tillage practices are important for a more precise evaluation of the data, as the short-term application of these practices probably did not lead to any significant increases of C_{org} (Liang et al. 2007). The crop residues could play a role in the input of fresh organic matter into the soils.

C_{mic} in CT showed the lowest amounts in the top layer, but had more uniformly distributed values in the entire soil profile, than was found in RT and NT (Figure 3). The largest C_{mic} was found in 0–0.1 m layer in NT. In comparison with the top layer, the C_{mic} in the 0.1–0.2 m layer was more uniform within the three tillage practices studied. Similarly, in the 0.2–0.3 m layer, it was largest in the CT practice, when compared with RT and NT during the time studied. The determined increase in C_{mic} between the both periods (2007–2010 and 2011–2014) observed in all studied soil layers, especially at RT and NT was not significant.

Similar to the C_{org}, the C_{mic} was more uniformly distributed within the soil profile in CT, possibly due to the distribution of crop residues in the deeper soil layers from the ploughing. As the quantity, quality and type of crop residues can significantly affect microbial characteristics, that is why two growing periods with the same crop rotation were studied. In contrast, the C_{mic} in RT and particularly NT, where the post-harvest residues remained either within the top layer or on the soil surface, was in accordance with Salinas-García et al. (2002) higher in the top layer, and it clearly stratified within the soil profile. Bausenwein et al. (2008) reported, that the data are lacking on the influence of RT on the soil organic matter and the size of the soil microorganisms. In our experiment, the C_{mic} in the 0–0.1 m layer in RT could utilize the greater oxygen supply due to the cultivation of the surface layer, together with post-harvest residues in the top layer. However, the C_{mic} in RT in many years of study was found to be even lower than in NT and did not profit of the intermediate layer as Bausenwein et al. (2008) suggested.

doi: 10.17221/567/2015-PSE

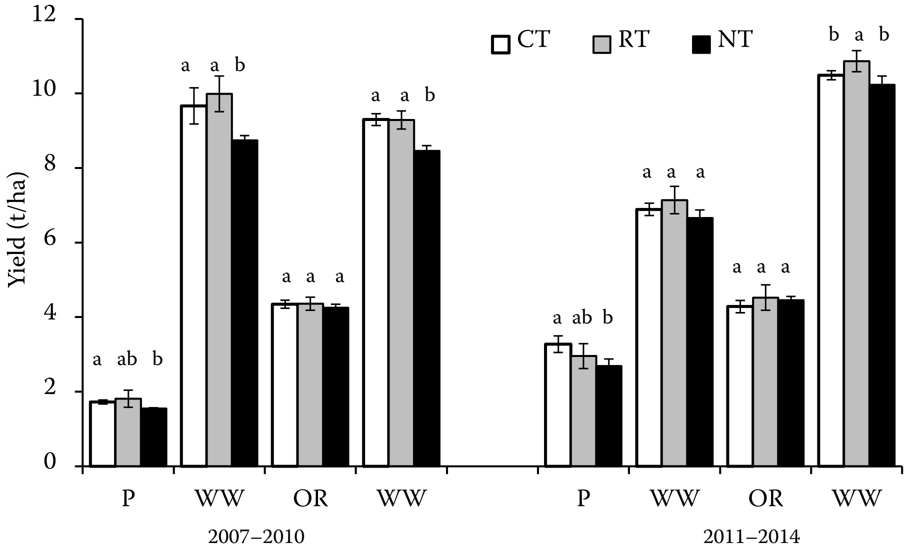


Figure 4. Relative yield of pea (P), winter wheat (WW) and oil seed rape (OR) under different tillage techniques in periods 2007–2010 and 2011–2014. CT – conventional tillage; RT – reduced tillage; NT – no-tillage

The variability of soil microbial characteristics during the studied years could be partly attributed to the different climatic conditions in the years (Table 1). In fact, it was previously found that the soil-active C fractions and microbial communities varied between seasons, due to differences in temperature, water content, and substrate availability (Sainju et al. 2007).

Our results did not confirm the effects of temperature or precipitation in the field experiment as no significant relationships between meteorological and microbial characteristics in the present field experiment have been found till now. The accumulation of C_{org} and microbial characteristics was observed in the top layer in RT and NT. The tillage technology was decisive for changes of soil biological and microbial characteristics in the soil profile as the effect of crops has not been confirmed till now, either; however NT showed a tendency to increase biological and microbial parameters in the second growing cycle. During the eight years of study (i.e. 12^{th}–20^{th} yield of the experiment) the soil bulk density in RT or NT had no negative impact on C_{org} and C_{mic} in the top layer, but clear stratification of these characteristics was observed in the soil profile. The different bulk densities under conservation tillage techniques are necessary to take into account for evaluation of soil characteristics as they can improve the estimation of real value of the studied parameters. Data of more crop rotations are necessary to better specify also the effect of single crop.

Crop yields in different years in CT and RT were comparable (Figure 4) without significant differences (except winter wheat in 2014). Yield decrease in NT compared to CT and RT was mostly observed for winter wheat (–3% to –10%) and pea (–10% to –18%). Similarly Rieger et al. (2008) obtained winter wheat grain yield decreased by 3% under NT compared to CT and RT. Also Malhi and Lemke (2007) observed greater production of seed and straw of wheat and rape under CT than NT, but they found no effect of tillage on pea yield. Analysis of data set comparing crop yields of CT, RT and NT in Europe showed yield reduction under conservation tillage, considerably larger when NT was applied. When RT was used, no significant yield effect was observed for most crops except maize and winter cereals, where the effect was limited (4%) (Van den Putte et al. 2010). The lowest yields were recorded in dry years 2007 and 2012. Published beneficial effect of RT and namely NT on soil moisture conservation observed in dry year or in a dry region (Malhi and Lemke 2007) did not appear significant in these years in comparison with normal rainfall years.

REFERENCES

Al-Kaisi M.M., Yin X., Licht M.A. (2005): Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. Agriculture, Ecosystems and Environment, 105: 635–647.

doi: 10.17221/567/2015-PSE

Álvaro-Fuentes J., López Sánchez M.V., Arrúe Ugarte J.L., Cantero-Martínez C. (2008): Management effects on soil carbon dioxide fluxes under semiarid Mediterranean conditions. Soil Science Society of America Journal, 72: 194–200.

Bausenwein U., Gattinger A., Langer U., Embacher A., Hartmann H.-P., Sommer M., Munch J.C., Schloter M. (2008): Exploring soil microbial communities and soil organic matter: Variability and interactions in arable soils under minimum tillage practice. Applied Soil Ecology, 40: 67–77.

Chen X.W., Liang A.Z., Jia S.X., Zhang X.P., Wei S.C. (2014): Impact of tillage on physical characteristics in a Mollisol in Northest China. Plant, Soil and Environment, 60: 309–313.

Hussain I., Olson K.R., Ebelhar S.A. (1999): Long-term effects on soil chemical properties and organic matter fractions. Soil Science Society of America Journal, 63: 1335–1341.

IUSS/ISTRIC/FAO (2006): World Reference Base for Soil Resources. Rome, FAO.

Jabro J.D., Sainju U., Stevens W.B., Evans R.G. (2008): Carbon dioxide flux as affected by tillage and irrigation in soil converted from perennial forages to annual crops. Journal of Environmental Management, 88: 1478–1484.

Králová M., Dražďák K., Pospíšil F., Hadačová V., Klozová E., Luštinec J., Kutáček M., Sahulka J. (1991): Selected methods of chemical analysis of soils and plants. Studie ČSAV, Akademia, 160. (In Czech)

Liang A.Z., Zhang X.-P., Fang H.-J., Yang X.-M., Drury C.F. (2007): Short-term effects of tillage practices on organic carbon in clay loam soil of Northeast China. Pedosphere, 17: 619–623.

Lundy M.E., Pittelkow C.M., Linquist B.A., Liang X., van Groenigen K.J., Lee J., Six J., Venterea R.T., van Kessel C. (2015): Nitrogen fertilization reduces yield declines following no-till adoption. Field Crops Research, 183: 204–210.

Malhi S.S., Lemke R. (2007): Tillage, crop residue and N fertilizer effects on crop yield, nutrient uptake, soil quality and nitrous oxide gas emissions in a second 4-yr rotation cycle. Soil and Tillage Research, 96: 269–283.

Melero S., López-Garrido R., Murillo J.M., Moreno F. (2009): Conservation tillage: Short- and long-term effects on soil carbon fractions and enzymatic activities under Mediterranean conditions. Soil and Tillage Research, 104: 292–298.

Mikanová O., Javůrek M., Šimon T., Friedlová M., Vach M. (2009): The effect of tillage systems on some microbial characteristics. Soil and Tillage Research, 105: 72–76.

Mikanová O., Šimon T., Javůrek M., Vach M. (2012): Relationships between winter wheat yields and soil carbon under various tillage systems. Plant, Soil and Environment, 58: 540–544.

Reicosky D.C. (2003): Tillage-induced CO_2 emissions and carbon sequestration: Effect of secondary tillage and compaction. In: Garcia-Torres L., Benites J., Martinez-Vilela A., Holgado-Cabrera A. (eds.): Conservation Agriculture: Environment, Farmers Experiences, Innovations, Socio-economy, Policy. Dordrecht, Kluwer Academic Publishers, 291–300.

Rieger S., Richner W., Streit B., Frossard E., Liedgens M. (2008): Growth, yield, and yield components of winter wheat and the effects of tillage intensity, preceding crops, and N fertilisation. European Journal of Agronomy, 28: 405–411.

Sainju U.M., Schomberg H.H., Singh B.P., Whitehead W.F., Tillman P.G., Lachnicht-Weyers S.L. (2007): Cover crop effect on soil carbon fractions under conservation tillage cotton. Soil and Tillage Research, 96: 205–218.

Salinas-García J.R., Velázquez-García J. de J., Gallardo-Valdez M., Díaz-Mederos P., Caballero-Hernández F., Tapia-Vargas L.M., Rosales-Robles E. (2002): Tillage effects on microbial biomass and nutrient distribution in soils under rain-fed corn production in central-western Mexico. Soil and Tillage Research, 66: 143–152.

Sims J.R., Haby V.A. (1971): Simplified colorimetric determination of soil organic matter. Soil Science, 112: 137–141.

Van den Putte A., Govers G., Diels J., Gillijns K., Demuzere M. (2010): Assessing the effect of soil tillage on crop growth: A meta-regression analysis on European crop yields under conservation agriculture. European Journal of Agronomy, 33: 231–241.

Vance E.D., Brookes P.C., Jenkinson D.S. (1987): An extraction method for measuring microbial biomass C. Soil Biology and Biochemistry, 19: 703–707.

Received on September 10, 2015
Accepted on November 3, 2015

Corresponding author:

Ing. Gabriela Mühlbachová, Ph.D., Výzkumný ústav rostlinné výroby, v.v.i., Drnovská 507, 161 06 Praha 6 – Ruzyně, Česká republika; e-mail: muhlbachova@vurv.cz