Changes of Soil Organic Matter under Minimum Tillage in Different Soil-climatic Conditions

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Abstract: Quantitative and qualitative soil organic matter properties were observed in a specific large area experiment (Chernozem – Gross Enzersdorf, Austria) and in a medium-term field experiment (Cambisol – Studena, Czech Republic). Two technologies – minimum tillage (MT) and conventional tillage (CT) – were compared by means of the determination of quantitative and qualitative soil organic matter parameters of the soil samples in the years 2004–2005. Cambisol showed higher values of quantitative soil organic matter parameters in MT compared to those in CT over the whole soil profile. For Cambisol, the qualitative parameters were almost comparable for both technologies. Chernozem showed more favourable values of the quantitative parameters in the surface layer in MT, however, the values had rather a contrary trend in deeper soil layers. CT showed slightly more favourable values of the qualitative soil organic matter parameters in Chernozem. It can be said that Chernozem organic matter reaction to tillage technology changes is slower and of minor rate in comparison with that of Cambisol organic matter. The results of quantitative and qualitative parameters do not conform with the generally recognised values for the Chernozem soil type.

Keywords: Cambisol; Chernozem; humus content and quality; humus fractionation; minimum tillage

Permanent sustainable systems in arable lands require the maintenance of productive and unproductive soil functions. Using different no-tillage system modifications promotes this approach (Lal & Kimble 1997; Horáček & Liebhard 2004). No-tillage systems are being spread either in Austria or in the Czech Republic due to their prevailing benefits (Sprague & Triplett 1986; Liebhard 1997; Lal & Kimble 1997; Horáček *et al.* 2008) compared to their disadvantages (Alblas *et al.* 1994). The views of specialists and farmers are different. It has been stated that the costs reduction at no-tillage amounts to 20–45% (Liebhard 1997). Also, the environmental benefit of these technologies is significant (Blum 1990) though hard to calculate. No-tillage farming offers innumerable benefits to soil and water conservation (Chatterjee & Lal 2009).

Soil organic matter ensures a substantial part of the retentive soil capacity and regulation for energy and substance flux (Stevenson 1994; Horáček & Liebhard 2004).

The losses or accumulation of soil organic matter and its transformations especially are crucial

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for most of the soil properties (Berg *et al.* 2009). Primary soil organic matter transformations are most significant. They are affected by many factors, in particular the origin, characteristics, and chemistry of primary organic substances (Schulz 2004; Horáček *et al.* 2008). Soil physical properties limit the water-air and thermal soil conditions (Stevenson 1994). Soil chemistry, pH (Horáček *et al.* 2008), and nutrient mobility, especially that of available phosphorus, are important as well. Available phosphorus participates in energy transfers and influences edaphon activity (Angers *et al.* 1992; Horáček *et al.* 2008). Soil organic matter transformations are first of all a stand function (Lal & Kimble 1997), but are also affected by management including tillage systems (Lee *et al.* 2009) and its characteristics are mainly influenced by the tillage depth and intensity. Some profile differentiations happen during the time at both reduced and conventional tillage (Sprague & Triplett 1986; Horáček *et al.* 2008). It has been often stated that the soil organic matter accumulates in the surface layer in long-term no-tillage systems (Angers *et al.* 1992), and that organic fertilisers and postharvest remains are not transformed in genuine humus sufficiently (Horáček *et al.* 2008).

Usually only the changes in the surface layers are described, but not those in the deeper soil profile (Berg *et al.* 2009). Blanco-Canqui and Lal (2008) state that no-tillage farming potential for sequestering soil organic carbon in all environments as well as its impacts on soil profile organic carbon distribution are not well understood yet.

The aim of this study was to determine the soil profile distribution of carbon content and its fractions by comparison of minimum and conventional tillage systems in different soil-climatic conditions.

MATERIALS AND METHODS

Environmental setting

The exact field experiment takes place at Gross Enzersdorf (GE) in Austria. The field is situated approximately 10 km to the east of Vienna in the altitude of 153 m a.s.l. The average annual temperature is 9.6°C, the average annual precipitation is 572 mm. The soil type is Chernozem with the particle size of 400–450 g/kg of particles < 0.01 mm, pH 7.5–7.6 (carbonate content 216–269 g/kg, humus content in Ap horizon 30.5 g/kg). Two crop rotations with five different tillage systems are established in parallel on the plots: conventional tillage, direct drilling, partly soil loosening with organic fertiliser placement on to the stubble, direct drilling with the disc the treatment to the depth of seedbed and retaining of 2/3 of mulch, and integrated or combined reduced tillage; all variants four-replicated. The crop varieties, fertilisation and crop protection are equal on all the plots, only the approaches to the weed regulation are different. For this study, conventional tillage system (CT) samples and samples from the variant of direct drilling with the disc treatment to the depth of seedbed and retaining of 2/3 of mulch (MT) were chosen. The soil samples were taken from the depths of 0.00–0.10; 0.10–0.20; 0.20–0.30 and 0.30–0.40 m (Table 1) by means of dug holes, four-replicated.

Table 1. Summary of designations of soil samples depths, plots and variants

Variant	Soil samples depth (m)	
	Studena (S)	Gross Enzersdorf (GE)
CT 5/MT 5	0.05–0.10	0.00–0.10
CT 10/MT 10		0.10–0.20
CT 15/MT 15	0.15–0.20	
CT 20/MT 20		0.20–0.30
CT 25/MT 25	0.25–0.30	
CT 35/MT 35		0.30–0.40

CT – conventional tillage; MT – minimum tillage

The field experiment in relatively severe soil-climatic conditions takes place at Studena in the Czech Republic in the altitude of 600 m a.s.l. The average annual precipitation is 650 mm, the average precipitation during the vegetation period is 413 mm. The soil type is Cambisol with the particle size of 250–300 g/kg of particles < 0.01 mm. A zone of approximately 30 m wide track on the experimental field is ploughed (CT). Other parts of the field had been for 12 years continually unploughed and just shallowly tilled (MT). The cultivation was first performed by a SE 3 Horsch seed exactor and then by Concord ploughshare cultivators. The common cropping pattern, fertilisation and protection of the plants were identical on the both parts of the field. The experimental pattern was the same as in Gross Enzersdorf (selected variants). The soil samples were taken from the variant of conventional tillage system (CT) and the variant of minimum tillage system (MT) from the depths of 0.05–0.10; 0.15–0.20 and 0.25–0.30 m (Table 1) by means of dug holes, four-replicated.

Soil analysis

Air-dried soil samples were pulverised (Pulverisette 8; Fritsch, Germany) to < 2 mm. The subsamples were further pulverised to < 0.25 mm (Laborete 27; Fritsch, Germany) to determine total carbon and humic substance fractions. Soil organic matter was characterised by total oxidisable carbon content (C_t), humic substances oxidisable carbon content ($C_{HS} = \Sigma\ C_{HA} + C_{FA}$), hot water-soluble carbon content (C_{hws}), humic acids to fulvic acids ratio (HA/FA), and the absorbance at 400 nm to that at 600 nm ratio (colour quotient Q 4/6). Konovova and Bělčikova (1965) fractionation method modified in accordance to Horáček (1995) was used as follows: the soil fraction below than 0.25 mm was used instead of that below than 2 mm, and the extracts were obtained by centrifugation instead of filtration. Before the chemical oxygen demand (COD) determination, the C_{HS}, C_{HA}, and C_{FA} extracts were exposed to evaporation at 60°C. Carbon analyses were performed as chemical oxygen demand (COD) with acid potassium dichromate method (0.0667M $K_2Cr_2O_7$ at 125°C for 45 min) with 0.1M Fe^{2+} retitration on the automatic titrator (DL 50 Mettler-Toledo, Switzerland). Labile carbon as a sensitive measurement for determining the impacts of fertilisation and cultivation (Ghani *et al.* 2003) was determined according to Weigel *et al.* (1998).

The program STATISTICA (Stat Soft, Inc.) was used for the statistical processing of the data ($LSD_{0.05}$).

RESULTS AND DISCUSSION

Soil organic matter quantity

In Cambisol in Studena, we have recorded a relative decrease of total carbon (C_t) content steadily with the depth in both CT and MT variants (Figure 1a). MT variant shows a slightly higher total amount in the whole soil profile than ploughing

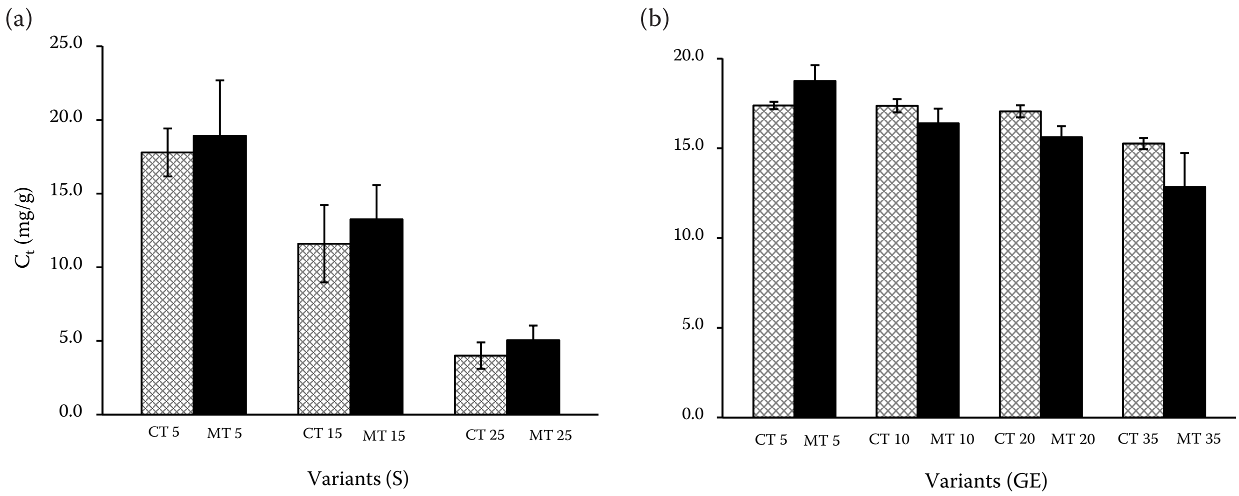

Figure 1. Depth distribution of C_t content as affected by different medium-term tillage systems (a) Studena (S), Czech Republic and (b) Gross Enzersdorf (GE), Austria

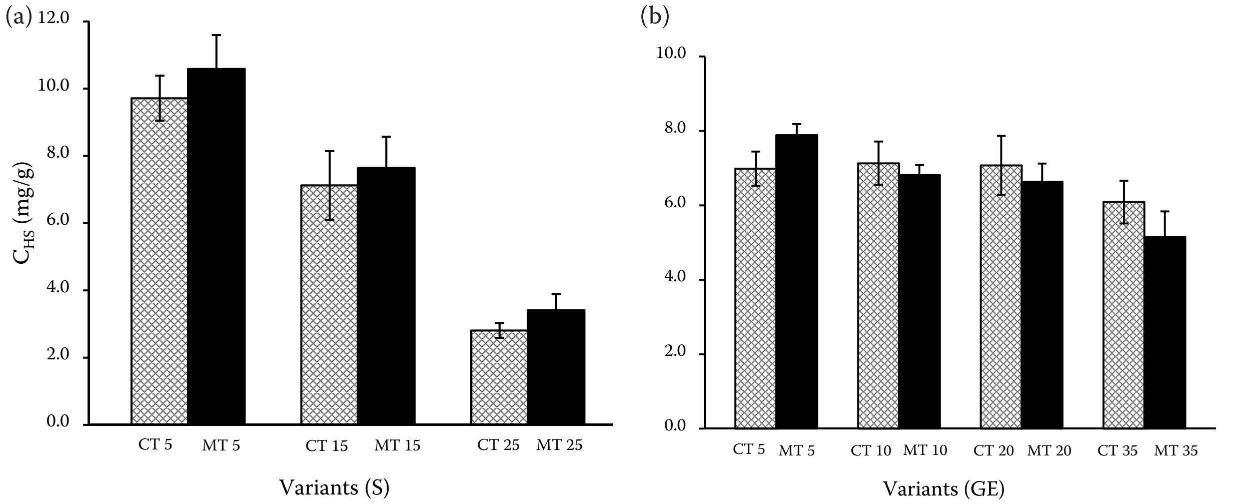

Figure 2. Depth distribution of humus substances carbon (C_{HS}) content as affected by different medium-term tillage systems (a) Studena (S), Czech Republic and (b) Gross Enzersdorf (GE), Austria

simultaneously. This difference is important in the depth of 0.25–0.30 m, which is in contrast to the previously established values of the long-term experiment (Horáček *et al.* 2008).

The total carbon content in Chernozem in Gross Enzersdorf shows the expected profile curve which means that it slightly decreases with the depth (Figure 1b). The greatest decrease is in the depth of 0.30–0.40 m, where A_1 horizon terminates. However, the effects of the compared tillage technologies on total carbon content are different. The conventional tillage (CT) shows lower total carbon content in the surface layer of 0.00–0.10 m than the minimum tillage (MT), but the other soil depths taken show a converse trend.

The humus substances carbon content in the soil profile mostly closely correlates with total carbon content in the processed land (Lal & Kimble 1997). This means that the values in Cambisol evenly decrease with the depth, but the average content values over the whole soil profile are slightly higher for MT than for CT, although not significantly (Figure 2a). Chernozem shows more favorable values only in the surface layer in MT, while in CT more favourable values appear in the undermost layer (Figure 2b), but not statistically significant.

The hot water carbon (C_{hws}) content represents a labile component of soil organic matter. This parameter has very often been cited

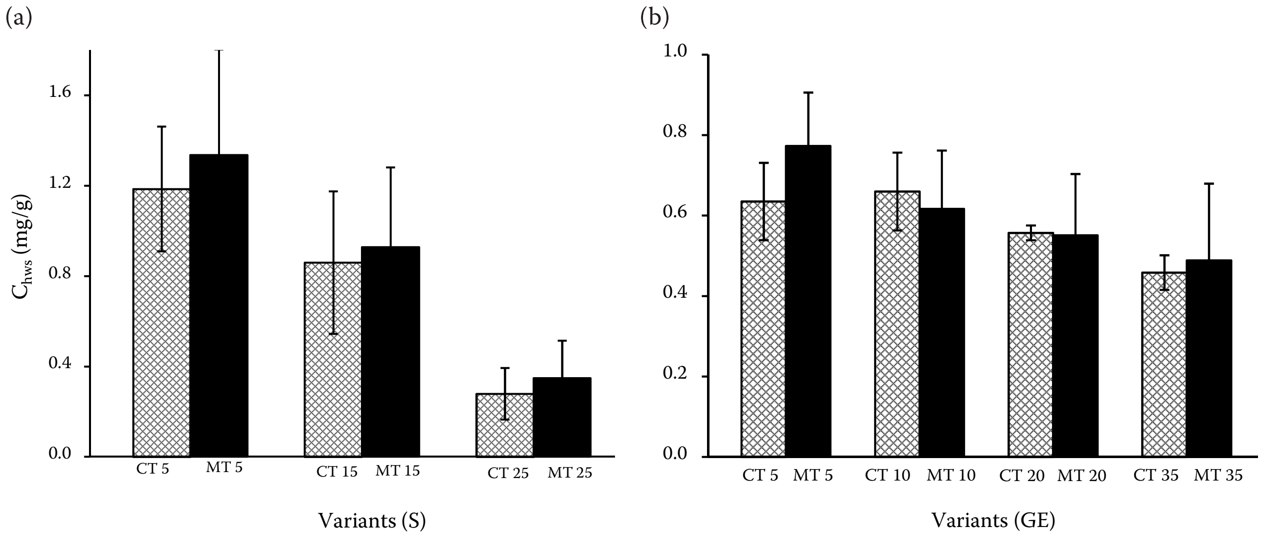

Figure 3. Depth distribution of hot water soluble carbon (C_{hws}) content as affected by different medium-term tillage systems (a) Studena (S), Czech Republic and (b) Gross Enzersdorf (GE), Austria

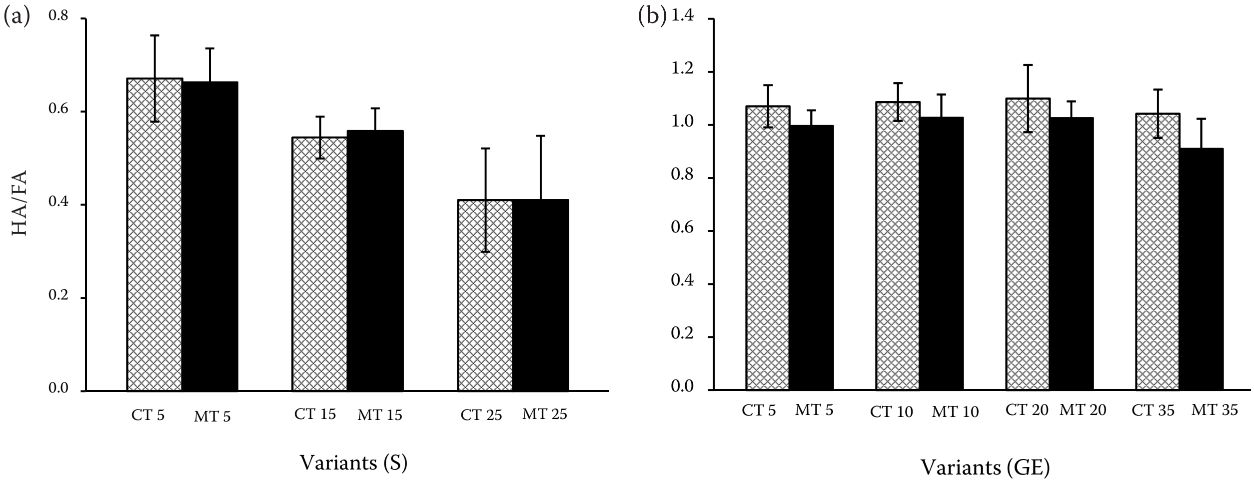

Figure 4. Depth distribution of humic acids to fulvic acids ratio (HA/FA) as affected by different medium-term tillage systems (a) Studena (S), Czech Republic and (b) Gross Enzersdorf (GE), Austria

recently (Ghani *et al.* 2003), because it should very closely correlate with lightly mineralisable nitrogen (Weigel *et al.* 1998). It is possible to state that in Cambisol C_{hws} correlates with C_t contents in particular soil depths, the profile curves are being similar (Figures 1a and 3a). There is a more markedly higher C_{hws} content in the surface layer of Chernozem in MT than in CT, and a slightly higher content is found also in the depth of 0.30–0.40 m in MT (Figure 3b). In other depths, CT shows slightly higher values in comparison to MT. Total C_{hws} contents in Chernozem are deep below the expected values. However, C_{hws} content differences between the versions are not statistically significant.

Soil organic matter quality

The humic acids (HA) to fulvic acids (FA) ratio is probably the most widely used indicator of soil organic matter quality. It indicates the preponderance or lack of more favourable humus substances (humic acids) over less favourable humus substances (fulvic acids) (Stevenson 1994). The HA/FA ratio is more or less constant in the first three depths of Chernozem. The decrease occurs in the depth of 0.30–0.40 m in MT. CT shows an imperceptible decrease (Figure 4b). CT compared to MT shows more favourable values (not statistically significant) of this indicator, thereby showing a higher humus quality for this soil type. However, it should be

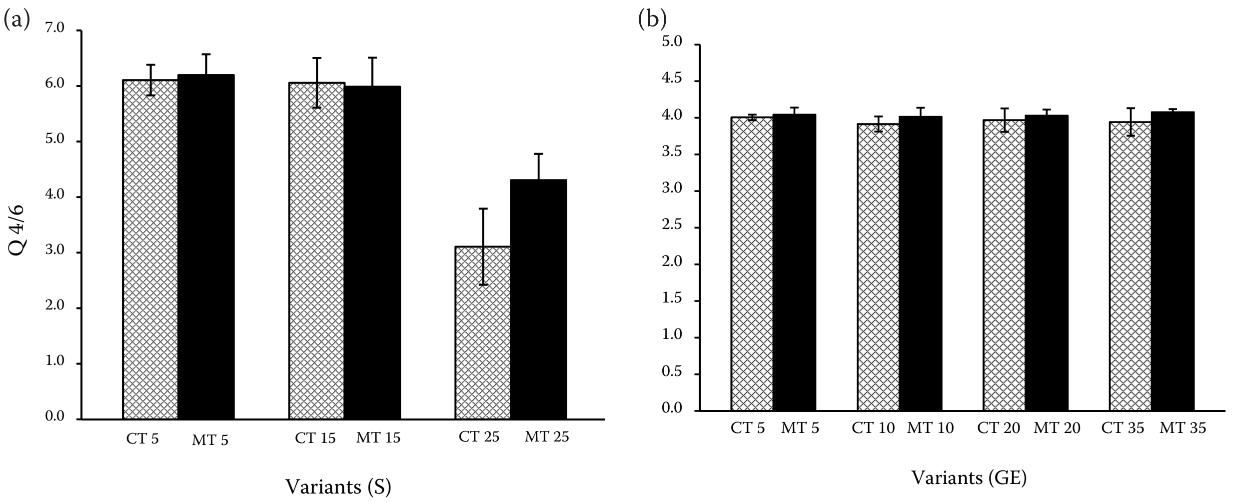

Figure 5. Depth distribution of coloured quotient (Q 4/6) as affected by different medium- term tillage systems (a) Studena (S), Czech Republic and (b) Gross Enzersdorf (GE), Austria

noted that the HA/FA ratio is on average for all the values too low for this soil type.

In Cambisol, the HA/FA ratio values correspond to this soil type and have an expected profile curve as well. Here, this parameter values are not in whatever way affected by the tillage technology (Figure 4a).

The coloured quotient (Q 4/6) shows the expected profile curve in Cambisol. The first two soil depths show approximately the same and higher values (Figure 5a), which generally indicates worse humus quality. The value of Q 4/6 in the depth of 0.25–0.30 m is significantly lower than that in the first two depths. This would also indicated significantly higher humus quality, which does not correspond to the HA/FA ratio in this depth. This means that the evaluation parameter Q 4/6 has to be approached differently in greater depths of the soil profile (Horáček *et al.* 2008).

For Chernozem, the values are similar for both technologies in the whole soil profile (Figure 5b); it is possible to state that they are slightly lower (more favourable) in CT than in MT – analogous to the HA/FA ratio. It should be again noted that Q 4/6 values in Chernozem do not correspond with the data stated in the literature for this soil type (Němeček *et al.* 2001), however, a partial explanation can be found in the work by Kubát *et al.* (2008) or Kasozi *et al.* (2009). This means that these more recent works cite wider range parameter values Q 4/6 for the Chernozem soil type.

CONCLUSIONS

The effects of minimum and conventional medium-term tillage systems on soil organic matter in different soil-climatic conditions (Chernozem – Gross Enzersdorf, Austria; Cambisol – Studena, Czech Republic) have been evaluated by means of the determination of the selected qualitative and quantitative parameters.

The total carbon content and two other carbon fractions contents determined (C_{HS} and C_{hws}) are higher, but not significantly, in the surface layer of Chernozem in MT compared to CT. It is rather reverse in the deeper soil profile. Humus substances show a lower quality in the whole soil profile in MT depending on their composition (Q 4/6, HA/FA). Nevertheless, both some quantitative and all the qualitative parameters show lower values than are the usual values previously reported in the literature for the Chernozem soil type.

All the quantitative parameters are slightly better in MT compared to CT in the whole profile of Cambisol. Their values correspond to this soil type. The qualitative parameters show comparable values for both technologies in A-horizon (0.00–0.25 m). In the deeper soil profile of Cambisol, CT shows more favourable Q 4/6 values, while HA/FA values remain comparable for both technologies.

It is possible to summarise that Cambisol responds to tillage changes by slightly increased contents of the observed carbon fractions in MT at comparable soil organic matter quality. Chernozem responds to tillage changes rather in the surface layer. All the parameters of this Chernozem organic matter are much worse in absolute values in comparison with the usual values for this soil type (Němeček *et al.* 2001; IUSS Working Group WRB 2006).

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