Carbon fraction concentrations in a haplic Luvisol as affected by tillage

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ABSTRACT

Changes of soil organic matter (SOM) parameters were investigated in a haplic Luvisol with medium-heavy texture. Soil samples were taken from several layers at minimum (MT) and conventional (CT) tillage plots of a field experiment in Sitzenhof (Germany). All cultural practices except for tillage (crop rotation, fertilizing, protection measures, etc.) were identical over the whole time of the experiment. The concentrations of oxidizable carbon C_{ox} and its constituents (humic acids (HA), fulvic acids (FA), and hot-water soluble carbon) are comparable in layers 15–20 cm in both variants. In 0–15 cm and 30–55 cm layers, these concentrations were higher in the MT variant. A similar trend was observed in the colour quotient values of humic substances Q4/6, which indicates increasing condensation of humus substances (HS) at deeper layers in both variants, and it is also confirmed by a humic to fulvic acids ratio HA:FA. Concentrations of SOM fractions were higher (except 15–20 cm layers) in the MT than CT treatment throughout the profile, especially below the 30 cm depth. The SOM did not accumulate markedly in the surface layer of long-term MT treatment.

Keywords: carbon fractionation; profile distribution; minimum tillage

Minimum (conservation) tillage systems with their different modifications are increasingly used under economical pressure in Central and Eastern Europe (in Czech Republic, too). Michalson et al. (1999) report ca. 60% of farm land under this system in production regions of the USA and Canada in total.

The minimum tillage systems influence on properties of the soil profile, affecting potential productivity of the site (Sprague and Triplett 1986, Steiner et al. 1999, Mikanová et al. 2012). Van den Putte et al. (2010) reviewed and assessed the effect of soil tillage on crop yields, using 47 studies from 75 sites all over Europe. On average, for deep minimum tillage (MT), the yields are even somewhat higher than for the conventional tillage (CT) systems, except for maize. The breakdown of the primary soil organic matter (SOM) in soil is an important and frequently discussed problem of MT systems. Concentrations and transformations of the SOM in systems with shallow MT are important elements controlling soil fertility

(Stevenson 1994), but it is a complicated process (Gosling et al. 2013).

Soil organic matter is a very complicated complex of the inanimate organic substances of various origins and various degrees of change (Stevenson 1994). Humified part – humus substances (HS) of the SOM is priced the most (Horáček et al. 2008), recently the decomposable part of SOM is priced, too (Kolář et al. 2009). There is a lot of effort for its better definition (Kleber 2010) or precise determination of its components (Williams et al. 2005, Matějková and Šimon 2012, Baum et al. 2013). A new review of the physical characteristic and analytical methods of SOM present de Freitas Maia et al. (2013). The transformation of soil organic matter is a complicated process in MT systems. Shallow tillage limits incorporation of post-harvest residues and organic manure near the soil surface cause organic matter accumulation in the surface layer after long-term minimum tillage (Angers et al. 1993) and insufficient transformation of shallow-incorporated organic

residues to humus. Most studies focused on the content of soil SOM and concentrations of soil oxidizable carbon (SOC – C_t, C_{ox}) in the surface layer or topsoil (Sprague and Triplett 1986, Guo and Wang 3013) including their soil sequestration (Comeau et al. 2013). Few studies focused on other depths (Horáček et al. 2008). A higher content of SOC in the MT than in CT soil was usually recorded, particularly to a depth of 10 cm. The similar results were summarised by Lal and Kimble (1997), who suggested the possibility of land evaluation based on temporal changes in the SOC content. Grant (1997) used modelling of the SOC content in MT systems and found a good correspondence between the model-computed and experimentally determined SOC (the content of SOC in MT soil was also higher than in CT).

The aim of this study was to determine the profile distribution of quantitative and qualitative parameters of SOM in a haplic Luvisol and their relationships under a long-term MT and CT systems in a field experiment.

MATERIAL AND METHODS

Environmental setting. The field experiment was performed in Sitzenhof (Germany). The experimental and control sites were situated in a ~200 ha field at an elevation of 430 m a.s.l. The average annual air temperature is 7°C and average annual precipitation is 670 mm. The soil type is haplic Luvisol (WRB 2007) of medium up to heavy texture (clay loam – clay at depth to 0.2 m, clay to deeper depths (about 250 g/kg particles < 0.01 mm). The control site (~40 m wide and ~800 m long, situated in the middle of field) was annually tilled by plough to ~26–28 cm depth. In contrast, a shallow (4 cm to 15 cm) minimum tillage was used on the experimental site (the rest of field) since 1987. The deeper aeration process (app. 15 cm), including organic fertilization – cattle (mostly) and pig slurry in dose 300–400 t/ha, was used once in 4–5 years. The seed exactors were used in the start of the experiment, later skived seed machines were used, too. This experiment was carried out since 1997. The field experiment was established as a rotation of winter pea (*Pisum sativum* L.), winter wheat (*Triticum aestivum* L.), maize on silage (*Zea mays* L.) and winter wheat. The yields of winter pea in the sampling year were comparable; 4.1 t/ha for MT and 4.2 t/ha for CT

and yields of winter wheat were 7.4 t/ha for MT and 7.2 t/ha for CT in the next year. The other cultural practices (fertilisation type and rate, rotation of crops, pesticide application, etc.) except for tillage were the same in both plots.

Soil analyses. Soil samples were taken from four soil pits at 5 cm layers to a depth of 55 cm in each of the MT and CT sites, for each pit and each layer separately; they were not mixed to make composite samples.

Soil samples were pulverised (Pulverisette 8; Fritsch, Germany) to < 2 mm after air-drying. Subsamples were further pulverised to < 0.25 mm (Laborette 27; Fritsch, Germany) for determination of oxidizable carbon (C_{ox}) and fractionation of humic substances.

Soil organic matter was characterised by the following fractions: oxidizable carbon content in soil, oxidizable carbon of humic substances ($C_{HS} = C_{HA} + C_{FA}$), humic acids (C_{HA}) and fulvic acids (C_{FA}) in the alkaline extracts (0.1 mol/L sodium pyrophosphate in sodium hydroxide) and hot-water soluble carbon (C_{hws}) according to Weigel et al. (1998). Carbon analyses were performed as chemical oxygen demand (COD) with acid potassium dichromate method (0.0667 mol/L $K_2Cr_2O_7$ at 125°C during 45 min) with 0.1 mol/L $FeII+$ retitration on the automatic titrator (DL 50 Mettler-Toledo GmbH, Greifensee, Switzerland). The usual procedure of humic fractionation was modified (Horáček 1995) as follows: < 0.25 mm soil fraction was used instead of < 2 mm fraction and the extracts were obtained by centrifugation instead of filtration. Before the COD determination the C_{HS}, C_{HA}, C_{FA} and C_{hws} extracts were evaporated at 60°C. The Q4/6 values were established using a Jenway 6 100 spectrophotometer (Bibby Scientific Limited, Staffordshire, UK) in stabilized alkaline extracts at 465 nm and 665 nm. The HS concentrations were treated prior to the measurements in extracting solutions so that their absorbance at 465 nm ranged around 0.7.

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

RESULTS AND DISCUSSION

Soil organic matter quantity. The C_{ox} concentrations varied between 15.5 and 2 g/kg in the surface (0–5 cm) and the deepest layer, of the MT
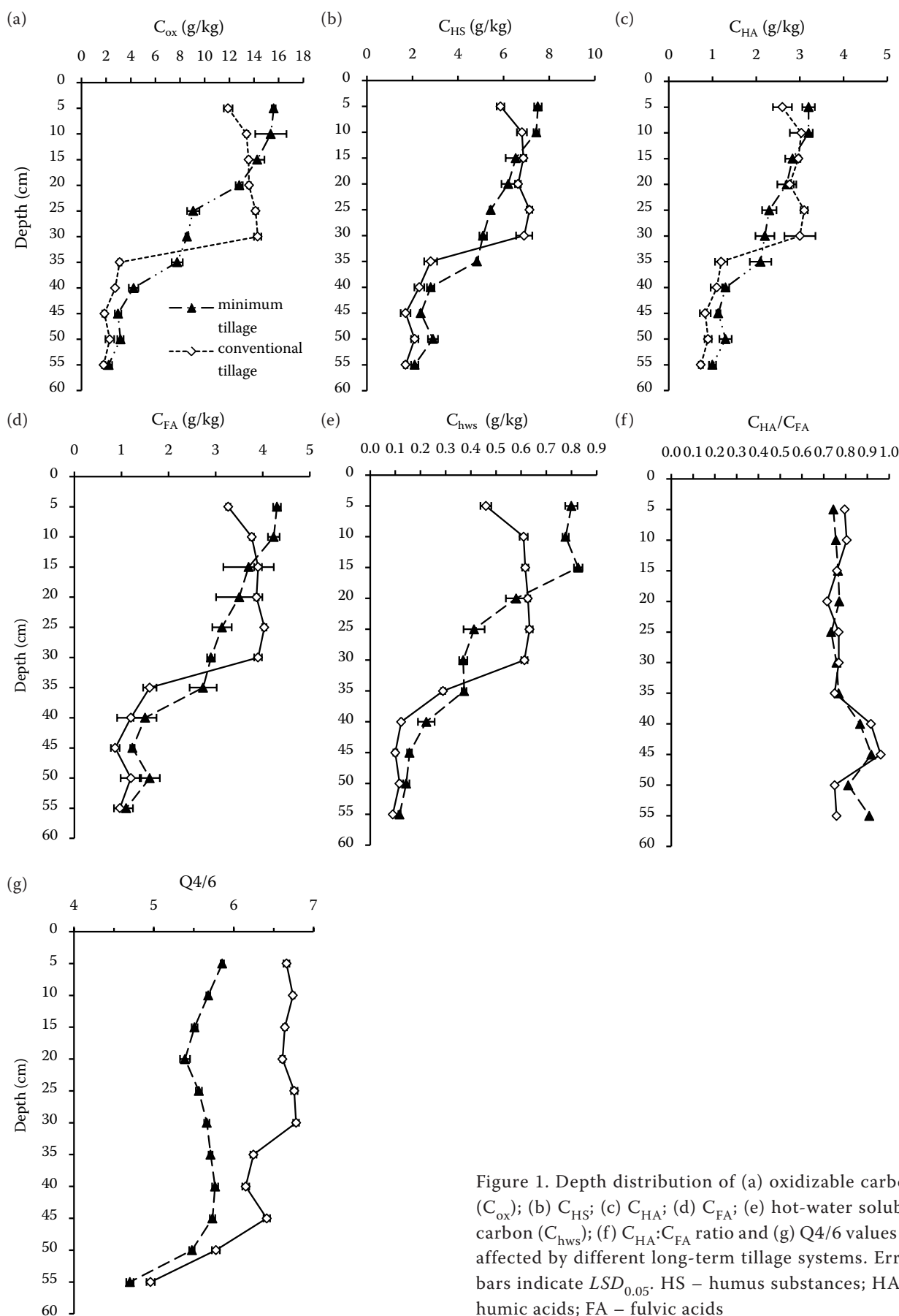
Figure 1. Depth distribution of (a) oxidizable carbon (C_{ox}); (b) C_{HS}; (c) C_{HA}; (d) C_{FA}; (e) hot-water soluble carbon (C_{hws}); (f) C_{HA}:C_{FA} ratio and (g) Q4/6 values as affected by different long-term tillage systems. Error bars indicate $LSD_{0.05}$. HS – humus substances; HA – humic acids; FA – fulvic acids

soil profile, respectively, and decreased steadily with depth (Figure 1a). In the CT plots, the C_{ox} concentration was ~13 g/kg in the 0–30 cm layer and then steeply declined < 2 g/kg in the deepest layer. The C_{ox} concentrations were comparable in both treatments to the 15–20 cm depth only, while higher C_{ox} values were found in the 0–15 cm depth and all deeper (30–55 cm) layers in the MT treatment, too. Our results suggested that neither primary nor secondary organic matters were accumulated in the surface layer during the long-term uninterrupted system of MT in this field experiment so markedly, which is in contrast to observations by Lal and Kimble (1997), Gosling et al. (2013). The data of C_{ox} and its components (see below) suggested that the plough system was performed deeper than is declaration, as well. The low C_{ox} content in 0–10 cm layer of CT variant documented 'base' up to topsoil pronouncement.

The C_{HS} concentrations decreased steadily from soil surface to deeper layers in the MT (Figure 1b). The C_{HS} concentration was relatively stable in 0–30 cm layers (consistently with C_{ox}) in the CT and then it decreased dramatically to low values, which were significantly lower than in the MT soil. Such a pattern suggested that humus substances were more uniformly distributed along the MT than CT profile. Sprague and Triplett (1986) or Kinsella (1998) reported similar results, even though some authors (e.g., Stevenson 1994, Comeau et al. 2013) believed that the C_{HS} concentration should be hardly influenced by soil tillage.

The C_{HA} concentrations (Figure 1c) showed a continually decreasing trend in the MT profile with a marked decrease in the 35–40 cm depth and a slight increase in the 45–55 cm layer (similarly to C_{HS} and C_{FA}). In the CT below 30 cm C_{HA} dramatically decreased from nearly stable to extremely low values by comparison with the MT soil.

The content of fulvic acids (Figure 1d) showed a similar trend in the soil profile as C_{HA}.

The C_{hws} values usually represent a characteristic part of soil organic matter (Weigel et al. 1998, Kolář et al. 2009). The highest concentrations of C_{hws} were determined in the first three layers of MT then they steadily decreased from the surface to depth (Figure 1e). The stable concentration of C_{hws} in topsoil steeply decreased to low values below 35 cm in the CT variant and was lower than in the MT in all depths. It suggested not only the better soil aggregate stability (Milanovskiy et al. 2013) but also the higher amount of potentially miner-

alizable nitrogen (Weigel et al. 1998) in topsoil, as well as in the deeper layers of MT treatment.

The components of the soil organic carbon C_{HS}, C_{FK}, C_{HK}, C_{hws} indicated generally higher concentrations and steadier distribution along the soil profile in the MT than in the CT. It means that many chemical properties in the MT profile, including soil structure (Franzlubers and Arshad 1996) and microbial activity (Wang et al. 2013), are influenced more positively than in the CT profile. It is very important for the soil edaphon that there is a sufficient amount of primary organic matter at relatively low depths of the MT profile as an energy source (Horáček et al. 2008).

Soil organic matter quality. Profile evaluation of a humic to fulvic acids ratio HA:FA as the most frequently used quality criterion of SOM and/or HS is rather complicated in this case. The value of HA:FA ratio (Figure 1f) increases at deeper layers both in the MT and CT variant, which would demonstrate an improvement of humus quality. But the actual reason is that there are hardly any primary organic matters at deeper layers and the reaming HS present at a relatively small amount are condensed to a lager extent. If the soil tillage systems are compared, better quality of HS is indicated by an HA:FA ratio for conventional tillage to 45 cm layer where this trend turns in favour of MT variant, but neither of the trends is statistically significant.

The values of colour quotients Q4/6 shown (Figure 1g) confirm higher condensation of aromatic nuclei of HS at deeper layers in both variants that was demonstrated by the HA:FA ratio, as well. In general, the values are relatively high and/or higher (especially in the topsoil) than those usually reported for the soil type concerned (Stevenson 1994). So, they indicate the lower quality of HS in both variants, and lowest in CT variant, which was confirmed also statistically. This seeming contradiction can be explained by generally low quality of SOM, which does not correspond to the given soil type.

It is possible to declare, that the quality of SOM expressed by the HA:FA ratio evaluated in total is comparable in both tillage systems. The quality of SOM expressed by the Q4/6 evaluated is better for the CT plot.

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