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Impact of reduced tillage on carbon and nitrogen storage of two Haplic Luvisols after 40 years

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ABSTRACT

It is broadly accepted that reduced tillage increases soil organic carbon (C_{org}) and total nitrogen (N) concentrations in arable soils. However, the underlying processes of sequestration are not completely understood. Thus, our objectives were to investigate the impact of a minimum tillage (MT) system (to 5–8 cm depth) on aggregates, on particulate organic matter (POM), and on storage of C_{org} and N in two loamy Haplic Luvisols in contrast to conventional tillage (CT) (to 25 cm). Surface soils (0–5 cm) and subsoils (10–20 cm) of two experimental fields near Göttingen, Germany, were investigated. Each site (Garte-Süd and Hohes Feld) received both tillage treatments for 37 and 40 years, respectively. In the bulk soil of both sites C_{org}, N, microbial carbon (C_{mic}), and microbial N (N_{mic}) concentrations were elevated under MT in both depths. Likewise, water-stable macroaggregates (>0.25 mm) were on average 2.6 times more abundant under MT than under CT but differences in the subsoils were generally not significant. For surface soils under MT, all aggregate size classes <1 mm showed approx. 35% and 50% increased C_{org} concentrations at Garte-Süd and Hohes Feld, respectively. For greater macroaggregates (1–2, 2–10 mm), however, differences were inconsistent. Elevations of N concentrations were regular over all size classes reaching 61% and 52%, respectively. Density fractionation of the surface soils revealed that tillage system affected neither the yields of free POM nor occluded POM nor their C_{org} and N concentrations. Moreover, more C_{org} and N (15–238%) was associated within the mineral fractions investigated under MT in contrast to CT. Overall, similar to no-tillage, a long-term MT treatment of soil enhanced the stability of macroaggregates and thus was able to physically protect and to store more organic matter (OM) in the surface soil. The increased storage of C_{org} and N did not occur as POM, as reported for no-tillage, but as mineral-associated OM.

1. Introduction

The displacement of conventional tillage (CT) by practices which reduce the physical impact on the soil has been broadly reviewed in the context of energy saving, sustainable fertility and degradation of arable soils (Ahl et al., 1998; Kushwaha et al., 2001) as well as within the discourse of enhancing C sequestration in arable soils in order to reduce CO_2 emissions (Paustian et al., 2000).

The argument most frequently discussed for enhanced organic matter (OM) storage in no-tillage (NT) soils is the increase of aggregate stability (Kushwaha et al., 2001; Hernández-Hernández and López-Hernández, 2002; Denef et al., 2007; Zotarelli et al., 2007). In CT soils, the physical impact caused by the plough leads to a disruption of macroaggregates (>0.25 mm; Tisdall and Oades, 1982; Kushwaha et al., 2001; Six et al., 2000a; Bronick and Lal, 2005) and exposes microaggregates (<0.25 mm) and free OM to microbial decomposition (Six et al., 2000a; Zotarelli et al., 2007). This macroaggregate-turnover is supposed to be the primary mechanism leading to C-loss in cultivated soils (Jastrow, 1996; Six et al., 2000b). Nutrient sequestration is decreased in CT soils (Lupwayi et al., 1999) due to a loss of macroaggregates rich in OM (Six et al., 2000a,b). Thus, macroaggregates play an important role in protecting OM from degradation (Ashman et al., 2003). This leads to an accumulation of OM in NT systems (Oorts et al., 2007). For example, Six et al. (2000a) and Balota et al. (2004) found 38% and 45%, respectively, higher organic carbon (C_{org}) and total nitrogen (N) concentrations in the bulk soil (0–5 cm) of a NT treatment than in a CT soil whereas Oorts et al. (2007) measured an increase of 10–15% in C_{org} and N totals.

Due to the elevated macroaggregate-turnover, a CT soil forms less occluded particulate organic matter (oPOM) than a NT soil (Six et al., 2000b). Moreover, tillage systems also have an effect on C_{org}- and

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N-concentrations in POM fractions: Wander and Bidart (2000), Oorts et al. (2007), and Zotarelli et al. (2007) proved that there are higher OM concentrations under NT systems than under CT for light free POM (fPOM) and oPOM. Six et al. (1999) reported that the C-concentration of fine (0.053–0.25 mm) oPOM decreased about 51% in CT soils. Zotarelli et al. (2007) found less mineral-associated C in CT than in NT systems after 14 years but no differences were detected after 4 years of diverging tillage systems.

In contrast to CT–NT comparisons, there has been less research into those systems which are ploughless but do not completely abandon tillage. Moreover, such reduced tillage systems vary largely in terms of machinery used and of tillage depth. In the following, those systems reaching a maximum depth of 10 cm are defined as minimum tillage (MT) systems. In several studies, C_{org}, N, and the microbial status of MT soils were reviewed: Compared to NT systems, MT soils among various soil types and climatic regions accumulate OM to a similar extent (Meyer et al., 1996; Salinas-Garcia et al., 1997; Ahl et al., 1998; Kandeler et al., 1999; Stockfisch et al., 1999; Wright et al., 2005). Also MT increased microbial C (C_{mic}) and microbial N (N_{mic}) (Kandeler et al., 1999; Stockfisch et al., 1999) and potential C and N mineralization (Salinas-Garcia et al., 1997; Wright et al., 2005). Kushwaha et al. (2001) studied aggregate stability in a MT system of an Inceptisol of a sandy loam texture revealing a trend that tillage reduction increased macroaggregate proportion.

Whether MT has similar impacts on aggregate stability and on POM fractions as described for NT remains still unclear. Thus, the aim of our study was to investigate the effect of a MT system (1) on C_{org} and N concentrations and (2) on aggregates and particulate organic matter (POM) in contrast to CT.

2. Materials and methods

2.1. Sites, treatments, and sampling design

Our study was conducted on two long-term experimental sites located near Göttingen, Germany: Garte-Süd and Hohes Feld. Mean annual precipitation is 645 mm and mean annual temperature is 8.7 °C (30-years' average 1961–1990 by Deutscher Wetterdienst, 2008). The soil type of both sites is a Haplic Luvisol (WRB) derived from loess (Ehlers et al., 2000; Reiter et al., 2002). A field-experiment was established in 1970 at Garte-Süd and in 1967 at Hohes Feld consisting of 4 and 3 field-replicates, respectively: Conventional tillage (CT) with a regular mouldboard plough to 25 cm depth and minimum tillage (MT) with a rotary harrow to 5–8 cm depth have been implemented. Before the start of the experiment soil had been mouldboard ploughed.

The soil texture (0–30 cm) at Garte-Süd consists of 15.1% clay, 72.7% silt, and 12.2% sand (Ehlers et al., 2000) and at Hohes Feld of 17.2% clay, 66.5% silt, 16.4% sand (De Mol, 1996). Table 1 shows some further site properties. C_{org} stocks at Garte-Süd were slightly higher under MT (0–5 cm: 10.2 t ha^{-1}; 10–20 cm: 17.6 t ha^{-1}) than under CT (0–5 cm: 9.0 t ha^{-1}; 10–20 cm: 15.1 t ha^{-1}). Further, N stocks were 0.78 and 1.66 t ha^{-1} at MT and 0.67 and 1.42 t ha^{-1} at CT plots, respectively. The same trends were detected for C_{org} stocks at Hohes Feld (0–5 cm: 12.2 t ha^{-1}; 10–20 cm: 19.3 t ha^{-1} under MT and 11.6 t ha^{-1}; 14.0 t ha^{-1} under CT, respectively). N stocks at Hohes Feld were 0.95 and 1.87 t ha^{-1} under MT and 0.67 and 1.53 t ha^{-1} under CT, respectively. The crop growing was the same on both sites and crops were in the last 5 years as follows: forage maize, winter wheat/mustard, pea, winter wheat and winter wheat. All residues were incorporated by the respective tillage operations.

Each tillage system and each field-replicate was sampled on the 20th of March (Garte-Süd) and the 26th of March (Hohes Feld) 2007. For each field-replicate a composite sample out of three sub-plots was taken from 0 to 5 cm (surface soil) and from 10 to 20 cm (subsoil). This sampling approach was chosen in order to distinguish accurately between those layers which were affected by MT and those which were not. After sampling, the samples were soon stored in plastic bags at 4 °C. To avoid any influence of preparation on microbial biomass parameters and on aggregates, all samples were gently mixed by hand, large chunks were broken and large plant material was picked out.

2.2. Separation of water-stable aggregates

Water-stable aggregates were separated according to John et al. (2005) prior to analysis of C_{org} and N. Briefly, field-moist composite samples were gently passed through a 10 mm mesh and dried at 40 °C for 48 h. One hundred grams of dry soil were placed on a 2 mm sieve and submerged into distilled water for 10 min to allow slaking. Thereafter, the sieve was moved up and down into the water with 50 repetitions. Water-stable aggregates remaining on the mesh (large macroaggregates: 2–10 mm) were collected, vacuum filtered (<0.45 μm) to remove water, dried at 40 °C for 48 h on the filter, and weighed. Aggregates which passed the 2 mm-sieve were poured onto the next smaller mesh size and the fractionation-procedure was continued as described above. Mesh-sizes used were: 1 mm for medium macroaggregates, 0.25 mm for small macroaggregates, and 0.053 mm for microaggregates. Finally, the supernatant (silt and clay together with finest microaggregates <0.053 mm) was precipitated with 0.5 M $AlCl_3$ (5 ml on 2 l of supernatant). To recover the <0.053 mm-fraction after precipitation, the water was siphoned off and the deposit was dried at 40 °C for 48 h. All fractions were ball-milled (Retsch, Haan, Germany) and stored.

Table 1
Site properties (bulk soil <2 mm) of Garte-Süd and Hohes Feld for different tillage systems and depths; mean values and standard errors (n = 4 for Garte-Süd, n = 3 for Hohes Feld).

Site	Depth (cm)	Tillage system	C_{org} (g kg^{-1})	N (g kg^{-1})	C_{mic} (mg kg^{-1})	N_{mic} (mg kg^{-1})	C_{mic}:C_{org} (%)	Bulk density (g cm^{-3})	pH (H_2O)	CEC (mmol$_c$ kg^{-1})
Garte Süd	0–5	Conventional	13.3 (2.4)	0.98 (0.03)^a	147 (15)^a	24.0 (2.3)^a	1.19 (0.21)	1.36 (0.09)	7.0 (0.1)	151 (26)
	10–20		10.2 (0.9)	0.95 (0.04)	183 (7)	31.5 (1.8)	1.70 (0.10)	1.49 (0.01)^a	7.0 (0.1)	156 (28)
	0–5	Minimum	16.3 (1.1)	1.24 (0.07)^b	357 (47)^b	62.0 (5.1)^b	2.23 (0.37)	1.25 (0.04)	6.9 (0.1)	149 (21)
	10–20		11.5 (0.4)	1.08 (0.10)	234 (32)	41.5 (5.4)	2.03 (0.21)	1.54 (0.01)^b	7.1 (0.1)	159 (20)
Hohes Feld	0–5	Conventional	16.9 (4.9)	1.00 (0.09)^a	201 (28)	37.5 (2.5)^a	1.31 (0.26)	1.32 (0.08)	7.0 (0.1)	163 (13)
	10–20		9.9 (0.8)	1.07 (0.03)	206 (7)	35.0 (2.7)	2.12 (0.26)	1.42 (0.05)	7.0 (0.1)	171 (12)
	0–5	Minimum	17.4 (0.5)	1.36 (0.08)^b	359 (73)	77.3 (3.2)^b	2.08 (0.44)	1.40 (0.04)	6.7 (0.1)	173 (8)
	10–20		12.4 (0.6)	1.20 (0.82)	249 (17)	42.8 (3.5)	2.01 (0.14)	1.56 (0.02)	7.1 (0.0)	176 (6)

Letters indicate comparison among tillage systems; exclusively those values which are significantly different at $P \leq 0.05$ are followed by different letters.