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# Tillage-induced changes in the distribution of soil organic matter and the soil aggregate stability under a former short rotation coppice

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ABSTRACT

No-till, perennial cropping in short rotation coppice (SRC) can increase the contents of soil organic carbon (SOC) in arable soils. The return to annual crops will involve an intense tillage, which was hypothesised to accelerate the mineralisation. The impact of tillage on the contents of SOC and of total nitrogen ($N_t$) and the aggregate stability was investigated at a SRC with 17 years old stools of willows and poplar (*Salix* and *Populus* spp.), a tilled former SRC (TFC) and a continuously annually tilled arable soil (TS) at an Eutric Cambisol in Northern Germany in 2010. The contents of SOC and $N_t$ in the topsoil (0–30 cm soil depth) decreased in the following order: SOC: SRC ($9.1 \pm 1.21$ mg g$^{-1}$) > TFC ($8.2 \pm 0.41$ mg g$^{-1}$) > TS ($6.4 \pm 0.0$ mg g$^{-1}$) and $N_t$: SRC ($0.94 \pm 0.03$ mg g$^{-1}$) > TFC ($0.86 \pm 0.08$ mg g$^{-1}$) > TS ($0.78 \pm 0.07$ mg g$^{-1}$). SOC was relatively homogeneously distributed in the topsoil under TFC and TS, but concentrated close to the surface under SRC. The C/N ratio was significantly larger under SRC ($9.7 \pm 0.40$) and TFC ($9.5 \pm 0.36$) than under TS ($8.2 \pm 0.55$). The ratio of water-stable soil aggregates in the size of 2.00–3.15 mm decreased in the following order: SRC ($60 \pm 16$%) > TFC ($10 \pm 5$%) > TS ($3 \pm 1$%). Overall the study indicated that tillage of former SRC leads to a fast redistribution of SOC in the topsoil combined with a loss of aggregate stability. The pool size of SOC in the topsoil (SRC $36.7 \pm 4.7$ Mg ha$^{-1}$; TFC $38.1 \pm 2.4$ Mg ha$^{-1}$) remained unchanged after the first year of returned tillage and did not confirm an accelerated mineralisation in the short term. SRC and TFC exceed TS by about 6–8 Mg ha$^{-1}$ SOC (TS $30.2 \pm 0.0$ Mg ha$^{-1}$ SOC).



## 1. Introduction

Short rotation coppice (SRC) with willows and poplar (*Salix* and *Populus* spp.) can be an efficient and ecological option for high biomass production (Buonocore et al., 2012). SRC differ from common arable crops mainly by their no-till perennial use (10–25 years in 2–6 year rotations), the low need of pesticide applications and the remaining of the leaf litter due to harvest in late winter (Dimitriou et al., 2009). In consequence of these differences they can lead to carbon (C) sequestration in arable soils (Baum et al., 2009a).

In the long term, the chances of SRC on arable sites depend on their efficiency in biomass and energy production and on their ecological impact (Scholz and Ellerbrock, 2002; Rowe et al., 2009). The ecological impact of SRC was evaluated for C sequestration in the soil (Coleman et al., 2004; Lal, 2005; Dowell et al., 2009; Nair et al., 2009; Brandão et al., 2011; Sierra et al., 2013), for nutrient use efficiency (Berthelot et al., 2000; Mann and Tolbert, 2000) and for biodiversity (Baum et al., 2009b; Schulz et al., 2009; Fernando et al., 2010; Pellegrino et al., 2011). An increased accumulation of soil organic carbon (SOC) in the topsoil under SRC was explained by the large litter amounts from leaves and roots and the decreased mineralisation under no-till management (Bowman and Turnbull, 1997; Jug et al., 1999; Garten, 2002). Information on stocks of organic C in the deeper soil layers where most of the tree roots occur and that supply substantial amounts of C through root excudates and fine-root turnover is however lacking (Nair et al., 2009). Besides the impact of SRC on the C sequestration, also the aggregate stability can be affected (Barto et al., 2010). The intensity of the impact of SRC on soil properties depends on the initial site conditions and on the management (Nair et al., 2009).

At present, the sustainability of the impact of SRC on soil properties, especially the proportion of SOC and the aggregate stability, is hardly known. It was hypothesised that tillage-induced mineralisation under former SRC will cause a loss of SOC, $N_t$ and aggregate stability.

Therefore, the objectives of the present study were to evaluate the impact of tillage on the contents of SOC, total nitrogen ($N_t$) in the soil, the C/N ratio and the aggregate stability in a tilled former

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rotation coppice (TFC) compared to a no-till SRC and an adjacent arable reference with tilled annual crops (TS).

## 2. Materials and methods

### 2.1. Test site and soil sampling

The test site Gülzow (12°04′05″ E, 53°49′20″ N) is situated in Northern Germany and is characterised by an average annual temperature of 8.6 °C and an average annual precipitation of 578 mm year$^{-1}$ (1980–2011). The monthly means of the air temperature and the monthly sum of precipitation for the period (1980–2011) and for investigated period 2010 are presented in Fig. 1.

The monthly means of the air temperature varied from −8.4 °C to 22.3 °C (1980–2011). The precipitation varied from 0 mm to 203 mm month$^{-1}$ (1980–2011). Eutric Cambisols (World Reference Base for Soil Resources; IUSS, 2007) were the dominating soil types (Bailly et al., 1998). The texture of the topsoil was sandy, characterised by 56 g kg$^{-1}$ clay (<0.002 mm), 238 g kg$^{-1}$ silt (0.002–0.063 mm) and 706 g kg$^{-1}$ sand (0.063–2.0 mm). At the time of establishment of the SRC in spring 1993 the arable topsoil contained 7.3 mg g$^{-1}$ SOC and 0.86 mg g$^{-1}$ $N_t$, the C/N ratio was 8.5. The initial concentrations of plant available P, K and Mg, extracted with the Doppel-lactat method (VDLUFA, 1997), accounted in the topsoil for 66 mg g$^{-1}$ P, 151 mg g$^{-1}$ K and 26 mg g$^{-1}$ Mg. Based on the German nutrient classes "very low," "low," "medium," "high" and "very high," the plant nutrient supply was medium for Mg and P and high for K. The pH of the topsoil was 5.1 (Kahle et al., 2005).

The SRC was established with a randomised block design with three replicates and a total size of 1.4 ha. Each plot has a total size of 135 m$^2$. The SRC consists of 28 clones of willow and poplar (three rows of 30 m length each). The distance between the rows was 1.50 m and within the row 0.50 m (13,300 cuttings ha$^{-1}$). No fertiliser or pesticides were applied so far. Poplar and willows were harvested in the winters (January or February) of 1996, 1999, 2002, 2005, 2008, and 2011 (3-year rotation).

In March 2010 one replicate per clone of the SRC with 17 years old stools was harvested and returned to annual tilled crops. The return was managed with a rotary hoe and a field cultivator in up to −40 cm and up to −30 cm soil depth, respectively. In April 2010 summer barley (*Hordeum vulgare* L.) was sown and harvested in August 2010. Subsequently Italian Ryegrass (*Lolium multiflorum* LAM.) was sown.

An adjacent arable site, which was continuously cultivated with tilled annual crops, was used as reference (TS) with three replicates of the same size. At the reference site annual fertilisation comprised 140–200 kg ha$^{-1}$N (Kahle et al., 2010). P and K fertilisers were applied in each third year, the last time in 2009.

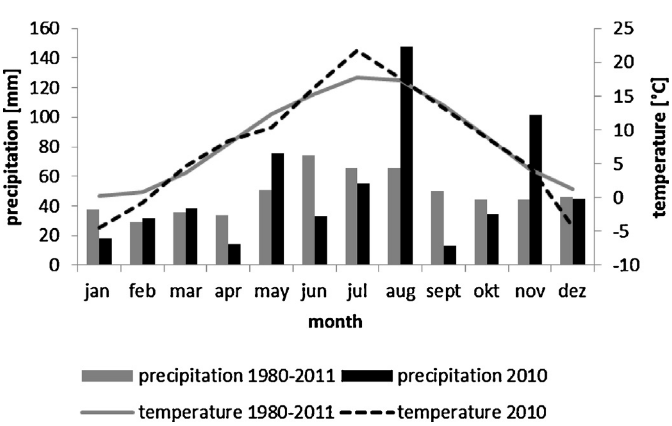


**Fig. 1.** Temperature (monthly mean) and precipitation (monthly sum) at the test site Gülzow from 1980 to 2011 and in the investigation period 2010.

TFC and TS were managed with identical crop rotation, fertilisation and pesticide application since 2010. In 2010 120 kg ha$^{-1}$ N were applied to barley and 90 kg ha$^{-1}$N to grass. The soils under two poplar clones (*Populus nigra* × *Populus maximowiczii* clone Max 4 and *P. maximowiczii* × *Populus trichocarpa* clone 10/85(49)) and one willow clone (*Salix dasyclados*) were investigated in SRC and TFC. Soil samples were taken in SRC, TFC and TS with a soil corer up down – 90 cm soil depth with five replicates per plot in February 2011. The plot size was 4.5 m × 30 m. The soil cores were divided into 10 cm sections to investigate the vertical differences. The soil samples were air-dried, sieved < 2 mm and grounded < 0.1 mm before the soil chemical analyses.

### 2.2. Soil chemical analyses

The total carbon ($C_t$) and nitrogen ($N_t$) on whole soils were determined by dry combustion using a VARIO EL analyser (Elementar Analysensysteme GmbH, Hanau, Germany). The content of soil organic C (SOC) was quantified by deducting the separately determined inorganic C (dissolution with HCl and volumetric $CO_2$-determination) from the content of total carbon.

The pool sizes of SOC and $N_t$ were calculated per 10 cm-section and summarised for the topsoil (the three upper 10 cm-sections; 0–30 cm).

$$\text{Pool size of SOC (Mg ha}^{-1}) = \text{SOC (mg g}^{-1}) \times \rho_d(\text{g cm}^{-3}) \times \text{depth (cm)} \times 10$$

$$\text{Pool size of N}_t \text{ (Mg ha}^{-1}) = \text{N}_t(\text{mg g}^{-1}) \times \rho_d(\text{g cm}^{-3}) \times \text{depth (cm)} \times 10$$

where $\rho_d$ is the bulk density (g cm$^{-3}$).

### 2.3. Soil physical analyses

The bulk density ($\rho_d$) was analysed using soil cores (250 cm$^3$) with four replicates in the three soil depths 0–10 cm, 10–20 cm and 20–30 cm.

Soil samples for the investigation of aggregate stability were taken from 0 to 10 cm soil depth in March 2011. Six replicated soil cores (250 cm$^3$) were taken per plot. The soil aggregate stability was measured with a wet-sieving method according to DIN 19683-16 (2009). In advance the soil samples were air-dried and aggregates of 2.00–3.15 mm were separated by sieving. About 20–30 g of this fraction were placed on a round-hole sieve (mesh size: 1.0 mm) and dipped gently into water for 2 min with 72 vertical lifts of 8 cm high. The soil aggregates (AS) remaining on the sieve were dried at 105 °C and weighted. The dried remaining aggregates were re-watered and crushed to determine the proportion of sand (1.0–2.0 mm). The sand (S) was dried at 105 °C and weighted. The water-stable aggregates (%) were calculated as difference between AS and S fraction.

### 2.4. Statistical analyses

The effect of tillage and soil depth on the soil properties was tested by ANOVA and Scheffé test. Pearson correlation tests were done for contents of SOC and $N_t$ in different soil depths. All statistics were computed using SPSS Statistics 20 with a level of significance of $P < 0.05$. The results are presented as mean with standard deviation (SD).

## 3. Results

The content of SOC ($y$) was correlated with the soil depth ($x$) with $r = 0.90$ (SRC $y = -0.2x + 1.11$), $r = 0.96$ (TFC $y = -0.11x + 0.99$)