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Dynamics of soil organic carbon fractions one year after the re-conversion of poplar and willow plantations to arable use and perennial grassland

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ABSTRACT

Due to the intensive soil tillage during the re-conversion of fast growing tree plantations back to agricultural use, high losses of accumulated soil organic matter are expected. A field trial was conducted at two former fast growing poplar plantations and one willow plantation in northern Germany to study the effects of different tillage depths and land use systems during such a re-conversion of the plantations on soil organic carbon (SOC) dynamics. Re-conversion was performed at tillage depths of 5, 15 and 30 cm and rye-grass and maize cropping, were established. Directly after re-conversion and again one year after re-conversion, bulk soil C, distribution of C within various soil fractions (microbial biomass, water-stable aggregates, free and occluded light fraction organic matter) and C amounts added with coarse harvest residues were determined at 0–30 cm soil depths. After re-conversion, the amount of C stored in the harvest residues was 17–39 t C ha^{-1}. One year after re-conversion, it had declined distinctly but rarely significantly, due to the high spatial variability of the harvest residues in the field. Nevertheless, C of the bulk soil did not change, but a decrease of microbial biomass C, macroaggregate (250–2000 μm) C and free light fraction organic matter indicate a loss of important fractions of soil organic C. More C was found in macroaggregates under rye-grass than under maize one year after re-conversion in loamy soils. Overall, one year after re-conversion yet no clear effects of tillage depth or land-use on SOC dynamics could be detected.

1. Introduction

Producing woody biomass as renewable raw material or an energy source in plantations with fast growing trees such as poplars (*Populus* spp.) or willow hybrids (*Salix* spp.) has become more and more popular. Such tree plantations on former arable land do not require tillage and have the potential to increase the soil organic carbon (SOC) in the long term (Nair et al., 2009; Kahle et al., 2010; Mao et al., 2010). After 20–30 years of plantation, the productivity of the trees generally decreases and the plantation has to be newly established or can be restored to either grass or arable production (Grogan and Matthews, 2002; Kahle et al., 2010). Until now, the effects of this re-conversion have rarely been examined, but more information on the impact of re-conversion on SOC dynamics is needed to quantify the C sequestration potential of fast growing tree plantations over a whole management cycle.

During re-conversion, intensive soil tillage is performed to break up roots and coarse harvest residues, affecting SOC in two contrasting ways: (1) the intensive soil tillage destroys soil aggregates and exposes organic colloids to decomposers (Post and Kwon, 2000), thus leading to an enhanced mineralization of soil organic matter. (2) The incorporation of harvest residues increases total soil C-stocks (Johnson and Curtis, 2001) and may mitigate SOC losses with progressive residue decomposition (Sanchez et al., 2007).

SOC losses after tillage events of former no-tilled soils are mainly caused by mineralization of labile SOC pools such as the macroaggregate-associated C, light fraction and particulate organic matter (Puget et al., 2000; Six et al., 2000; Chen et al., 2009). This has been reported after conversion of forest ecosystems into arable use by Motavalli et al. (2000) and Okore et al. (2007). In contrast, Abiven et al. (2009) and Chivenge et al. (2011) reported that the incorporation of low quality crop residues with CN ratios up to 41 improved aggregate stability and C-sequestration in agricultural soils, but little is known about the impact of incorporated woody harvest residues on soil aggregation with even lower qualities. Common methods applied to try and reduce organic matter decomposition

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Table 1
Biomass yields of different tree compartments of the three plantations before final harvest.

	Georgenhof willow	Georgenhof poplar	Wachtum poplar
	Yield dry mass (t ha^{-1})		
Crown		28	22
Stem	32[a]	117	78
Stump roots	1	9	4
Coarse roots > 5 mm	1	6	7
Fine roots < 5 mm	0.1	3	2

[a] Stem + shoots.

are to reduce the tillage depth (Kushwaha et al., 2001; Conant et al., 2007) or to cultivate perennial crops or grassland (Guo and Gifford, 2002; Grandy and Robertson, 2007). Tillage depth influences residue incorporation into soil profiles, thus affecting decomposition dynamics (Olchin et al., 2008). Residues will decompose more rapidly when incorporated uniformly throughout the soil profile during deep tillage, due to a better contact with the soil (Balesdent et al., 2000). In contrast, Olchin et al. (2008) suggested a slower decomposition of residues deeper in the profile, originating from less favourable conditions for the microorganisms.

In the current study, a field trial at three former tree plantations in northern Germany was conducted to investigate whether reduced tillage intensity during the re-conversion and subsequent rye-grass compared to maize use would reduce mineralization of organic C. The specific objectives were elucidate the effects of three different tillage depths and subsequent land use on (1) total organic C stocks of the bulk soil, (2) on labile soil organic C pools and (3) on the amount of C stored in the incorporated harvest residues one year after re-conversion of the tree plantations.

2. Materials and methods

2.1. Site description

The study was conducted at three experimental sites in northern Germany. At the site Georgenhof (51°27′ N, 9°0′ E, 320 m a.s.l.), the experiments were performed on a willow plantation and an adjacent poplar plantation. The mean annual precipitation and mean annual temperature are 740 mm and 7.9 °C, respectively. Soil type is a Stagno-Gleyic Cambisol derived from loess (FAO-WRB, 2006). Soil texture (0–30 cm) at the Georgenhof willow site is a sandy loamy silt (28% sand, 61% silt, 11% clay). The mean SOC content in 0–30 cm depths is 18 mg C g^{-1} and the mean CN ratio 12. At the poplar site soil texture is a silty loam (19% sand, 64% silt, 17% clay) with a SOC content of 22 mg C g^{-1} and a CN ratio of 13. The poplar plantation at the third site Wachtum (52°47′ N, 7°44′ E, 22 m a.s.l.) has a mean annual precipitation and temperature of 815 mm and 9.0 °C, respectively. Soil type is a deep-ploughed Gleyic Podzol (FAO-WRB, 2006) and soil texture is a silty sand (76% sand, 20% silt, 4% clay). SOC is 31 mg g^{-1} soil and the CN ratio 17. The plantations were established on former arable land in 1987 (Georgenhof) and 1989 (Wachtum) for the testing of fast growing willow (*Salix minimalis* and *Salix dasyclados*) and poplar (*Populus maximowiczii* × *Populus trichocarpa* and *Populus nigra* × *P. trichocarpa*) clones. From 1998 to the final harvest in 2010, no fertilization or harvest was carried out at any site, as the plantations were managed for raw material use. The initial plant density at the Georgenhof willow site was 15,385 trees ha^{-1} (1.3 m × 0.5 m), at the Georgenhof poplar site 10,000 trees ha^{-1} (1 m × 1 m). At the Wachtum poplar site, clones were planted with a spacing between 2.2 m × 1.2 m (3788 trees ha^{-1}) and 3 m × 1.2 m (2777 trees ha^{-1}). Due to thinning and high plant mortality, the tree density before the final harvest was 1296 trees ha^{-1} at the Georgenhof willow site, 1905 trees ha^{-1} at the Georgenhof poplar site and 1942 trees ha^{-1} at the Wachtum poplar site. Table 1 gives an overview over the biomass yields of the plantations before the final harvest of the three sites. More detailed information about the soil properties and plantations management of the study sites is presented in Toenshoff et al. (2012).

2.2. Tree harvesting and soil sampling

The trees were manually harvested in spring 2010 with a chain saw at the willow site and with a harvester at the two poplar sites. The harvester delimbed the trees on-site, so that the entire crown material remained at the poplar sites, while the trunks were directly moved off the sites. For restoring the sites, tree stumps and harvest residues were first mulched with a wood mulcher (FAE, UMH-225, Fondo, Italy and Class Xerion 3800, Harsewinkel, Germany), before the mulched debris, root stumps and coarse roots were ground and tilled with a rotary cultivator (FAE, SSM-225, Fondo, Italy and Class Xerion 3800, Harsewinkel, Germany) into soil. This was carried out in three strips, each with a width of 6 m at the two Georgenhof sites and 4 m at Wachtum, with tillage depths of 5 cm (shallow), 15 cm (medium) and 30 cm (deep), respectively. Soil was levelled with a rotary harrow and maize (*Zea mays* L.) and rye grass (*Lolium perenne* L.) were sown in three replicates per tillage depth in strips of 12 m.

Directly after rotary harrowing, the soil was sampled in three replicates per tillage treatment and again one year after re-conversion in three replicates per tillage treatment and land use at 0–5, 5–10, 10–15, and 15–30 cm depth in the shallow, at 0–15 and 15–30 cm in the medium and at 0–30 cm in the deep tillage treatment with a 10 cm diameter corer. Before the sampling one year after re-conversion, soil of the maize treatments was tilled with a rotary harrow according to the three different tillage depths. Two samples of each depth were combined per replicate. At both dates, bulk density was determined gravimetrically in 5 cm steps, using a steel corer (diameter 4 cm). All soil samples were sieved (<2 mm) and harvest residues > 2 mm were collected from the sieve, washed and dried at 60 °C. Sub-samples of harvest residues were dried at 105 °C to constant weight for determination of the dry matter content. As residue sampling was done along with the soil sampling, harvest residues larger 10 cm were not collected.

2.3. Soil analysis

Soil pH was determined in 0.01 M $CaCl_2$ at a soil/solution ratio of 1:2.5. For estimating microbial biomass C, two portions of 15 g field-moist sieved soil, stored at 4 °C until analysis, were extracted with and without $CHCl_3$ fumigation with 60 mL 0.5 M K_2SO_4. Organic C and total N in the extracts were measured after combustion using a Dimatoc 100 + Dima-N automatic analyzer (Dimatec, Essen, Germany). Microbial biomass C and N were calculated as the difference between fumigated and non-fumigated samples using a k_{EC} value of 0.45 (Wu et al., 1990) and a k_{EN} value of 0.54 (Brookes et al., 1985) to account for the non-extractable part.

Water stable aggregate fractions were determined at both sampling dates by wet sieving, using the method described by John et al. (2005). As a high proportion of macroaggregates was expected, dried soil (40 °C) of 100 g (<2 mm) was separated into two portions of 50 g and soaked in distilled water for 10 min to allow slaking. Each mixture was poured onto a 250 μm sieve, which was moved up and down in water with 50 repetitions, taking care that the screen broke the water surface every time. The fraction > 250 μm was collected, the two mixtures were combined and the sieving was repeated using a 53 μm sieve. Fine particles < 53 μm in the supernatant were precipitated with 0.5 M $AlCl_3$. All size classes were dried at 40 °C and ball-milled for C and N analysis.

With density fractionation according to John et al. (2005), the mineral-associated heavy SOC was separated from the free light