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Amount and stability of recent and aged plant residues in degrading peatland soils

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ABSTRACT

Peatlands store large amounts of soil organic carbon (SOC). Drainage, required for agriculture, aerates these organic soils and triggers rapid peat decomposition. In turn, cultivation of organic soils is also accompanied by input of young organic carbon (YOC) from plant residues. The extent to which YOC inputs compensate for oxidative peat loss is unknown. Furthermore, the lability of YOC in organic soils introduced by cultivation has never been examined. Here we studied the amount and lability of YOC in two adjacent drained organic soils by a combined ^{13}C and ^{14}C approach. Soils have been under intensive arable use for several decades and were both cultivated, inter alia, with corn, a C4 plant. In 1995, one soil was converted from annual cropping to permanent cultivation with *Miscanthus x giganteus*, another C4 plant, while the other was converted to permanent C3 grassland in 2009. Using $\delta^{13}C$ signatures, we analysed the fractions of C4 derived carbon in the soil and in CO_2, during one month of soil incubation. This enabled us i) to estimate C4-C accumulation in both soils, and ii) to assess the lability of C4-C carbon that accumulated either at least five years prior to sampling (current grassland soil) or until sampling (current *Miscanthus soil*). The fraction of C4-C derived SOC in the *Miscanthus* soil was 0.19 ± 0.024 in the top 30 cm, corresponding to an accumulation rate of 1.6 ± 0.2 t C4-C ha^{-1} yr^{-1}. This accumulation rate is in the range of rates found for fertile mineral soils cultivated with *Miscanthus*. Yet, this C4-C accumulation rate is below average C-losses of agriculturally used organic soils. The grassland soil contained a smaller fraction of 0.08 ± 0.002 C4-C in SOC. The rates of total CO_2 emitted from the two soils did not differ, but the fraction of CO_2 derived from C4-C was significantly higher in the *Miscanthus* soil (0.53 ± 0.05) than in the grassland (0.29 ± 0.04) soil. Hence, in both soils YOC was more labile than bulk SOC. The ratio between the fraction of decomposing C4-C and C4-C in SOC was the same for both soils indicating a similar lability of currently accumulated and aged C4-C. In both soils, the ^{14}C age of emitted CO_2 was younger than that of SOC, confirming an increased lability of YOC over old SOC.

1. Introduction

Intact peatlands represent a major global sink for atmospheric carbon. They cover more than 4×10^6 km^2 (3%) of the earth's terrestrial surface (Joosten, 2004) and store up to 30% of global soil organic carbon (Parish et al., 2008). Many peatlands have been and are still drained to make them usable for agriculture, grassland or forestry. Drainage provides oxygen to the roots and triggers rapid decomposition of peat, transforming the former sink into a source of atmospheric carbon dioxide (CO_2) (Freeman et al., 2004). The rates of CO_2 emission from drained organic soils range between 0.4 and 11.2 t C ha^{-1} yr^{-1} and add up to around 0.35 Gt C globally (Byrne et al., 2004; Höper, 2007; Joosten, 2010; Couwenberg et al., 2011).

Cultivated organic soils receive young organic carbon (YOC) via recent plant residues. It is unclear to which extent these YOC inputs accumulate in soil and counterbalance C loss from peat decomposition. The differences between the stable carbon isotopic signatures ($\delta^{13}C$) of C3 plants (Calvin cycle during photosynthesis) and C4 plants (Hatch-Slack pathway during photosynthesis) can be used to differentiate YOC inputs from SOC previously cropped with C3 vegetation (Balesdent et al., 1987). While the $\delta^{13}C$ values of C3

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plants range from −32 to −20‰, those of C4 plants range from −17 to −9‰ (Glaser, 2005). Thus, after a land-use conversion from C3 to C4 vegetation, the rate of YOC accumulation can be estimated by studying the shift towards more positive δ^{13}C values of SOC.

Using this approach, several authors (Kahle et al., 1999; Hansen et al., 2004; Dondini et al., 2009a, 2009b; Felten and Emmerling, 2012; Zimmermann et al., 2012; Poeplau and Don, 2014) found that in mineral soil, cultivation of *Miscanthus x giganteus*, a bioenergy crop and C4 plant, increases SOC storage by 0.97–1.95 t C ha^{-1} yr^{-1} in central and northern Europe. Carbon sequestration in soils under *Miscanthus* cultivation is related to the huge root system, introducing substantial amounts of carbon below ground, senescence of plant litter throughout the year that accumulates on the soil surface, and absence of tillage and fertilisation that otherwise could enhance decomposition of SOC through aeration and nutrient input (Schneckenberger and Kuzyakov, 2007). Accumulation of *Miscanthus* derived SOC is highest on former croplands, presumably because croplands tend to be more fertile than e.g. grasslands. Further, croplands are more depleted in SOC compared to land-uses with permanent vegetation cover and absence of tillage (Leifeld et al., 2005; Don et al., 2012; Zimmermann et al., 2012).

Soil organic matter (SOM) derived from *Miscanthus* is assumed to have a similar resistance to decomposition as SOM derived from grass residues (Foereid et al., 2004; Schneckenberger and Kuzyakov, 2007). However, YOC inputs are mainly stored as particulate organic matter, and are thus considered rather labile (Hansen et al., 2004; Zimmermann et al., 2012). In agricultural organic soils, not only the amounts of YOC inputs are largely unknown, but also their stability. In contrast to mineral soils, organic soils largely lack pedogenic minerals that stabilise YOC inputs (Jobbágy and Jackson, 2000; von Luetzow et al., 2006). Compared to YOC, peat is rich in oxygen-depleted compounds such as lignin, other phenols, and aliphatics, whereas oxygen-rich compounds such as polysaccharides are preferentially decomposed during peat formation. Due to the enrichment of such recalcitrant organic matter during formation and humification, old peat derived SOC is assumed to be less decomposable in drained organic soils than YOC (Leifeld et al., 2012).

Whereas the stable C isotope approach can be applied in almost all soils, peatland soils are unique in terms of their radiocarbon signature considering the fact that peat formation often began thousands of years ago (Loisel et al., 2010). Biasi et al. (2011) related the radiocarbon content of SOC to that of the CO_2 emitted during decomposition in order to compare the lability of YOC and peat derived organic matter in a drained organic soil following peat extraction. They exploited the sharp gradient in radiocarbon age between the underlying old peat and newly formed YOC. Their approach is not directly applicable to most other agricultural organic soils, because without removal of the younger, uppermost peat, SOC in degrading organic soils comprises a mixture of peat and YOC whose mixing ratio and radiocarbon signatures are uncertain. However, a comparison of radiocarbon signatures between SOC and emitted CO_2 can still give insights into the relative stabilities between old and young SOC.

To our knowledge, no study to date has addressed the lability of YOC in organic soils that have been under agricultural use for decades by either of these approaches. Here we used δ^{13}C and radiocarbon measurements to study the accumulation of YOC introduced as C4-C into a drained organic soil over the course of 20 years of cultivation with *Miscanthus x giganteus*. In addition, we studied the decomposability of the accumulated YOC, by relating the fraction of C4-C in the SOC to the fraction of C4-C in the CO_2 emitted during an incubation experiment. In the same way, we also determined the lability of older YOC in an adjacent soil that experienced a land use conversion 5 years prior to sampling from periodic C4 cultivation to perennial C3 grassland cultivation. We validated our δ^{13}C results using radiocarbon measurements of SOC and emitted CO_2, in order to assess the relative lability of YOC and peat.

This study aims to determine:

1. How much C4-C, i.e. YOC, accumulated in a drained organic soil cultivated with *Miscanthus x giganteus* (C4-plant) during 20 years and how much aged C4-C remained in an adjacent organic soil where periodical C4-plant cultivation has been terminated five years prior to sampling?
2. How stable is YOC that accumulates in degrading organic soil relative to peat?
   a. How stable is recently accumulated YOC?
   b. How stable is YOC that has aged in the field prior to sampling?

2. Methods

2.1. Site description

The samples were taken from two neighbouring sites on a drained peatland at Cressier (47.0449° N, 7.0438° E) in the region "Grosses Moos" of western Switzerland. The former peat soils of the two sites had formed on alluvial and aeolian deposits and lake sediments after the retreat of the Rhône Glacier in the early post-glacial period. The area was first drained in 1864. Intensive agricultural use with arable ley rotation started around 1930, corn was included into the crop rotation after 1960. According to aerial photographs and maps, the land-use of the two soils was the same between 1935 and 1995 (Swiss Topo, URL).

Since 1995 one of the two sites was cultivated with *Miscanthus x giganteus*. Since land-use conversion to *Miscanthus*, the site did not receive any fertilizer. In 2009 the other site was converted from arable cropland to extensively used perennial grassland. Thus, in contrast to the other site, no new C4-C entered the grassland soil for at least five years prior to the sampling in 2014. The grassland soil is cut once per year after the 15th of June. The two study sites are hereafter referred to as their last land-use before sampling, i.e. *Miscanthus* site and grassland site.

As a reference site, we used peat samples from an organic soil located in immediate vicinity (within 1.3 km) of the two study sites. The reference site is a forest since 1940 and thus did not accumulate C4-C. More information about the forest soil and sample treatment are provided in Bader et al. (submitted).

2.2. Soil sampling

The soil of the two study sites was classified as murshic limnic histosol (WRB, 2014). The decomposition ranged between 7 and 10 according to the von Post index (Carter and Gregorich, 2006). The grassland soil was sampled in April 2014 and the *Miscanthus* soil three weeks later, after harvest. Volumetric soil samples were taken down to 1 m depth using a Humax corer (Martin Burch AG, Switzerland). At each site two soil cores were taken. The distance between the two cores at each location was 60 m. Cores were extracted in four segments measuring 25 cm in length and 5 cm in diameter. The segments were further divided into longitudinal sections representing 5 cm depth increments of the undisturbed soil, following the method of Rogiers et al. (2008).