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Response of peat decomposition to corn straw addition in managed organic soils

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ABSTRACT

Drainage and land-use are key factors that trigger CO_2 emissions from cultivated organic soils. Drainage enhances aeration, and land-use might affect peat decomposition due to the input of fresh organic matter (FOM). The effect of FOM addition on peat decomposition of agriculturally used organic soils has seldom been quantified experimentally. In this study, we i) incubated soil samples taken from three adjacent former peatland sites that were drained and managed as cropland, perennial grassland and forest, respectively, and measured CO_2 release over 16 months at 20 °C. In a second experiment, ii) we incubated soil samples from the same three sites with and without adding corn straw as FOM (2% w/w) at 20 °C over three weeks. The ^{13}C and ^{14}C signatures of soil organic carbon (SOC) and emitted CO_2 enabled us to apportion the amount of decomposed corn, as well as to estimate relative effects of corn addition on the decomposition of SOC from old peat (SOC_{old}) and from young soil organic carbon (SOC_{young}). In the first experiment, samples lost between 0.03 and 0.09 mg CO_2-C mg SOC^{-1} in the order forest > grassland > cropland. The higher ^{14}C values of the emitted CO_2 vs. that of SOC indicated that SOC_{young} was more easily decomposable. FOM addition induced negative ($-14.8 \pm 5.2\%$), positive ($+14.9 \pm 4.6\%$) and neutral priming ($-14.2 \pm 30.0\%$) of SOC decomposition in the forest, grassland and cropland samples, respectively. Most importantly, we find that the relative contribution of SOC_{old} to the overall CO_2 release consistently decreased after FOM application, whereas decomposition of SOC_{young} was rather stimulated. The latter finding is in line with previous studies on intact peat. Our results show that young and old C pools in managed organic soils respond differently to the addition of fresh plant residues, and FOM addition can effectively reduce the decomposition of old peat. Hitherto negative priming was never reported for agriculturally used organic soils and it might be caused by the overall poor decomposability of old peat.

1. Introduction

Peatland soils represent a major global sink for atmospheric carbon (C). They cover $> 4 \times 10^6$ km^2 of the earth's surface (Joosten, 2004) and store up to 30% of global soil organic carbon (SOC) (Parish et al., 2008). Making peatlands usable for intensive agriculture, grassland or forestry requires that their groundwater table is lowered to a level at which the soil provides sufficient aeration to the roots of the cultivated plants. The entry of oxygen, however, also 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 CO_2–C ha^{-1} yr^{-1} and add up globally to c. 0.35 Gt C (Byrne et al., 2004; Couwenberg et al., 2011; Höper, 2007; Joosten, 2010).

Peat decomposition in drained organic soils depends on depth, density and functionality of the drains, soil hydraulic properties and water regime, climate and land-use, as well as the structure and composition of the peat (Höper et al., 2008; Kasimir-Klemedtsson et al., 1997; Reiche et al., 2010). Peat decomposition is fastest with groundwater tables of 80–120 cm below the soil surface, as typically found for arable use of organic soils (Höper, 2002). Intensive land-use and deep drainage fosters peat decomposition more than shallow drainage and permanent vegetation cover (Byrne et al., 2004; Höper, 2007; Kasimir-Klemedtsson et al., 1997; Mundel, 1976).

Soil organic carbon (SOC) in managed organic soils is understood as a mixture of old organic carbon that had accumulated as peat (SOC_{old}) and young organic carbon (SOC_{young}) originating from recent inputs of organic residues. Compared to SOC_{young}, SOC_{old} is richer in oxygen-depleted compounds such as lignin, other phenols, and aliphatics,

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because oxygen-rich compounds like polysaccharides become rapidly decomposed during peat formation. Due to the enrichment of recalcitrant organic matter, SOC_{old} is thought to be less decomposable in degraded organic soils than SOC_{young} (Leifeld et al., 2012).

In organic soils, ^{14}C ages typically increase with soil depth up to ages of 10,000 years (Shotyk et al., 1998). On newly cultivated former peat extraction sites, where the uppermost young peat was removed, this age gradient was used to determine how much of the decomposed SOC originated from old organic matter, e.g. peat, and how much from SOC_{young} (Biasi et al., 2011). However, in organic soils that have been under arable use for longer times, determination of peat age is challenging, because the decomposing SOC is a mixture of SOC_{old} and SOC_{young} amounts of unknown shares (Bader et al., 2017a). Still, the higher age of that mixture as compared to the signature of the contemporary vegetation allows identifying relative contributions of old vs. young carbon to the CO_2 that is released from those soils.

Input of fresh organic matter (FOM) to soil can provoke a priming effect (PE), i.e. a change in the decomposition rate of native SOC (Blagodatskaya and Kuzyakov, 2008; Kuzyakov et al., 2000). Positive priming increases decomposition, negative priming decreases decomposition rates after incorporation of an exogenous substrate. One explanation for positive priming is that easily decomposable FOM acts as an energy source for decomposers, stimulating their growth and enhancing the release of exoenzymes, which promote the breakdown of more recalcitrant SOC compounds (Blagodatskaya and Kuzyakov, 2008; Fontaine et al., 2003). Another explanation is that nutrients are immobilized more quickly with accelerated microbial growth, which, together with the depletion of FOM, induces enhanced decomposition of N-rich native soil organic matter (SOM). Negative priming might be caused by soil microbes switching their nutrition preference from SOM to more easily decomposable FOM (Kuzyakov et al., 2000).

Hamer and Marschner (2002) found that application of various amino acids and other compounds commonly found in root exudates increased the decomposition of peat, and also Basiliko et al. (2012) reported a positive, albeit weak PE of root exudates on peat decomposition. In contrast, Linkosalmi et al. (2015) found no PE after root exudate application in a drained fen and bog soil under forestry. Walker et al. (2016) reported accelerated peat decomposition on organic soil plots vegetated by dwarf-shrubs or graminoids. Using isotopically labelled sheep feces as FOM input, Leiber-Sauheitel et al. (2015) reported no PE on peat decomposition in an organic soil used for grazing. In summary, the available evidence suggests that priming either does not occur in organic soils or is positive. All of the studies above utilized peat that was not or little affected by drainage or agricultural practices. With long lasting conversion to cropland, grassland or forest, substantial amounts of young organic matter enter the decomposing SOC_{old} i.e. peat pool. These young inputs change the ^{14}C signature of SOC, the chemical composition of SOM and probably SOM decomposability. However, little is known how this additional built-up of younger, soil organic matter impacts on decomposability and possible PE of the original peat.

Here we first incubated samples from three adjacent organic soils that had been converted to different types of land use (forest, grassland, cropland) after drainage decades ago to evaluate SOC decomposability over more than one year. To investigate PEs, we performed a second, shorter soil incubation experiment with and without the application of corn straw as FOM. The stable carbon isotope signature allowed us to quantify CO_2 derived from FOM, whereas differences in radiocarbon contents between SOC and decomposing SOC (i.e. emitted CO_2) allowed to determine the relative decomposition of SOC_{old} and SOC_{young}. We assessed peat quality by the elemental composition of soil organic matter, as well as the specific CO_2 emissions and their radiocarbon composition. The experiments allowed us to test the following hypothesis:

1. SOC_{young} in drained, managed organic soils is more easily decomposable than SOC_{old}.
2. The addition of FOM increases the relative contribution of SOC_{old} towards decomposition.

2. Methods

2.1. Sampling site

We performed the study with soil samples taken from a drained former peatland site at Gals (47.0399° N, 7.0648° E) in the so-called "Grosses Moos" area. This area, which is located between the lakes of Biel, Neuchatel and Morat in western Switzerland, was a large fen of 770 km^2 until large parts of it were first drained around 150 years ago through watershed-wide lowering of the groundwater table by 2.5 m. The fen had formed on alluvial and aeolian deposits and lake sediments in the early post glacial time after the retreat of the Rhône Glacier. Gals has a mean annual temperature of 10 °C and a mean annual precipitation of 1145 mm. Following drainage, the study site was at first used for peat extraction until around 1900, when it was converted to cropland. In the 1940s, a forest consisting mainly of common ash (*Fraxinus excelsior*) and sycamore maple (*Acer pseudoplatanus*) was planted as wind barrier in the eastern part of the sampling site. In the 1960s the groundwater table was further lowered by another 1.1–2.5 m in response to continuing soil subsidence (Dubler, 2010; Presler and Gysi, 1989). In 1999, a contiguous 4 m wide strip of the arable cropland west of the forest was converted to permanent grassland. In the years before our sampling, the grass was cut 1 or 2 times per year after the 15th of June on this strip. The cropland was cultivated with corn in 2013 followed by wheat in 2014.

2.2. Soil sampling

We classified the soil of our study site as a murshic limnic histosol (WRB 2014). The degree of peat decomposition was above 8 for the whole histic horizon, according to the von Post index (Carter and Gregorich, 2006). In October 2013, a first set of soil samples was collected by extracting soil cores at four different locations (A-D) on each of the three sites, one core per location on the forest and the cropland site and two soil cores at each location on the grassland site. The soil cores were 1 m long. We extracted cores using a Belorussian peat corer in the forest and on the cropland, and a motorized Humax corer on the grassland, because the soil was too dry at the time of sampling to be penetrated by the Belorussian corer. Until analysis, the samples were stored at 5 °C for one week. We used the method of Rogiers et al. (2008) to account for soil compaction during sampling, and divided the cores into sections corresponding to 5 cm depth increments of the soil profile. The cores included both, the organic soil layers on the top and the mineral sediment below. Some cores were interlayered by mineral sediment. We used the samples taken in October 2013 for the long-term incubation experiment and to determine soil properties. In May 2014, we collected a second set of soil samples from a depth of 20–30 cm at locations B-D from each site. We measured PEs on those samples.

2.3. Analysis of soil samples

Sub-samples from a profile depth of 0–5 and 20–30 cm, were suspended at a 1:2.5 ratio by mass in deionized water and shaken at 250 cycles min^{-1} for 15 min, to be measured for pH with a flat surface electrode (pH 100, Extech Instruments, USA). An aliquot of all soil samples was dried at 105 °C and ground in a ball mill (Retsch MM400) for 2 min at 25 rotations s^{-1}. We measured total carbon (Ctot), hydrogen and nitrogen after dry combustion of milled subsamples in an elemental analyzer (Hekatech, Germany). To determine SOC contents, we treated aliquots with 36% HCl (acid fumigation) in a desiccator to remove carbonates before we analyzed them for carbon content. Soil carbon stocks (t C ha^{-1}) refer to the histic horizons summed over the entire depth of each profile, excluding the sediment layers.