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Seasonal CO_2 emission under different cropping systems on Histosols in southern Sweden

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ABSTRACT

Drained and cultivated organic soils contribute a substantial proportion of estimated anthropogenic greenhouse gas emissions in Sweden. According to rough estimates, different cropping systems give rise to different subsidence rates and, since some of this subsidence originates from oxidation of organic material, soil respiration may also vary with different crops. This field study investigated the possibility of mitigating carbon dioxide (CO_2) emissions from cultivated organic soils by using a specific cropping system. The CO_2 emission rates from soils under different crops in similar environmental conditions were measured at 11 field sites in southern Sweden representing different types of organic soils. The variation in emissions between the crops tested was low compared with total CO_2 emissions from the soil and differences between crops were not consistent. This shows that growing a particular crop cannot be recommended as a mitigation option for limiting CO_2 emissions from cultivated organic soils.

1. Introduction

Pristine peatlands represent a large store of carbon worldwide. Under natural conditions, most peatlands are accumulators of organic plant material and, at least in their early life, carbon sinks. Drainage and cultivation of peat soils increase soil aeration and reverse the carbon flux into net carbon dioxide (CO_2) emissions. During the past two centuries, large peatland areas in Sweden have been drained for agriculture and forestry purposes. Drained peatlands subside due to consolidation, shrinkage, compaction, erosion and oxidation of the organic material (Berglund, 1996). The soil respiration rate, i.e. oxidation of organic material, is mainly determined by temperature and soil moisture (Koizumi et al., 1999; Fang and Moncrieff, 2001). Vegetation type is another important factor. In Sweden, a rule of thumb, based on measurements of the subsidence in long-term field experiments on organic soils, states that different cropping systems give different subsidence rates, e.g. permanent grassland gives a lower rate than row crops (Berglund, 1989). Since part of the subsidence originates from degradation of organic material, i.e. CO_2 emissions, row crops are considered to emit more CO_2 than grassland (Kasimir-Klemedtsson et al., 1997). One problem with using subsidence as an estimate of organic matter decomposition is how to distinguish between the different processes causing the subsidence (Glenn et al., 1993). For example, arable soils are more prone to wind erosion than grasslands, where the peat is protected by the grass (Irwin, 1977; Lucas, 1982; Parent et al., 1982). The wind-transported material is deposited in another place (Parent et al., 1982), sometimes the adjacent grassland, but in this case the decomposition rate of the arable land is not increased, nor is it decreased on the grassland. Well-decomposed (sapric) peat soils are often used to produce high-value row crops and are also the most wind erodible (Kohake et al., 2010). Differing subsidence rates between cropping systems of different intensity may be due mainly to a combination of crop cover, differences in soil type and how prone the soil type is to wind erosion. Old data on subsidence measurements are very often used to upscale the effect of changing crops on CO_2 emissions from organic soils (Kasimir-Klemedtsson et al., 1997), but it is very important to measure the actual emission rates from a specific soil under different crops in similar environmental conditions in order to evaluate the true effect.

In a digital soil survey in 2003 (Berglund and Berglund, 2010), the area of agricultural organic soils in Sweden was estimated to be approx. 301,500 ha, with 202,400 ha of deep peat (>50 cm peat depth), 50,200 ha of shallow peat (<50 cm peat depth) and 49,000 ha of gyttja soils (gyttja, marl, marl-containing gyttja, clay gyttja and gyttja clay). This was equivalent to about 8% of Sweden's agricultural land at that time. Managed grasslands and pastures dominated the use of these cultivated organic soils and annual crops only occupied 25% (Berglund and Berglund, 2010). It has been estimated that 6–8% of total annual anthropogenic emissions of greenhouse gases in Sweden originate directly

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from farmed organic soils (Berglund and Berglund, 2010). When greenhouse gas emissions from cultivated organic soils are converted into CO_2-equivalents, it has been estimated that CO_2 contributes 85–95% of the Global Warming Potential (GWP), nitrous oxide (N_2O) contributes 5–15% and methane (CH_4) <1% (Maljanen et al., 2004; Grönlund et al., 2006). Therefore CO_2 should be the most important gas for which to find mitigation options.

There is a great need for development of management strategies on peat and other organic soils to reduce subsidence and emission rates. In many countries legislation or subsidy systems to regulate the management of cultivated organic soils, e.g. choice of crop, are currently being discussed. Previous studies regarding the effect of choice of cropping system on CO_2 emissions show contradictory results. For example, Maljanen et al. (2002) measured CO_2 emissions from drained organic soil with different vegetation types and found that barley (*Hordeum vulgare*) emitted slightly more than grassland, while bare soil and forest emitted less than agricultural crops. In other studies the opposite trend has been observed, with barley emitting less than grassland (Martikainen et al., 2002; Maljanen et al., 2004). Lohila et al. (2003) and Elsgaard et al. (2012) reported lower CO_2 emissions from potato fields than from grassland and arable fields. In a Nordic inventory of greenhouse gas emissions from peat soil, the emissions from perennial grassland were about the same as from barley (Maljanen et al., 2010). Kandel et al. (2013) concluded that a shift from annual spring barley to perennial reed canary grass (*Phalaris arundinacea*) did not change the greenhouse gas emission rates. These discrepancies between studies indicate that the crops grown on a particular field are not the decisive factor for CO_2 emissions. Other factors that can be of great importance include ground-water level (Petersen et al., 2012; Karki et al., 2014), soil properties (Maljanen et al., 2004; Berglund and Berglund, 2011) and spatial and temporal differences (Rochette et al., 1991; Camporese et al., 2008). For instance, the date/time of sampling are commonly reported to have significant effects on CO_2 emissions (Elder and Lal, 2008b; Regina and Alakukku, 2010). Moreover, crops require different kinds of management inputs, such as fertiliser, soil tillage, irrigation etc., leading to variations in soil physical and chemical conditions, creating different environments for greenhouse gas production.

One method for measuring the respiration originating from soil organic matter (SOM) and the influence of plants is to compare measurements on plots with a crop and plots with the crop removed (Berglund et al., 2011; Karki et al., 2015). Plots with a crop represent the total CO_2 emissions from soil, which can be divided into plant-derived CO_2 and SOM-derived CO_2. Kuzyakov (2006) suggests three different sources of plant-derived CO_2, namely root respiration, rhizomicrobial respiration and microbial respiration of dead plant residues, and two different sources of SOM-derived CO_2, namely microbial decomposition of SOM in root-free soil and microbial decomposition of SOM in root-affected soil, i.e. the priming effect. The priming effect can be described as a change in SOM decomposition caused by rhizodeposition. Plots with the crop removed only represent SOM-derived CO_2 in root-free soil. Our interest in this study was SOM (i.e. peat) decomposition in soil covered with different crops. The difference in CO_2 emissions between plots with a crop and plots with the crop removed represents the plant-derived CO_2, including the priming effect. The priming effect in nutrient-rich soils (e.g. peats and peaty marls) is most likely low (Fontaine et al., 2003). However, different crops can generate different levels of priming effect, both positive and negative (Kuzyakov, 2002; Cheng et al., 2003).

In the present study, soil CO_2 emissions were measured from peat and peaty marls under different cropping systems in similar conditions. Peaty marls defined as marls with a topsoil with organic matter content mainly originating from peat. Study sites on farms distributed throughout the southern half of Sweden were selected, in order to give a diverse set of soil types. Two cropping systems were compared at each site, cropping system being defined as the crop and the management practices associated with that crop. The variation in soil CO_2 emissions between sites and over growing seasons was determined. The main aim was to determine whether it is possible for farmers to mitigate the CO_2 emissions from organic soils by changing the crop grown.

2. Materials and methods

In 2009 the study started with CO_2 measurements at four sites on four different farms, in 2010 it was extended to seven sites and in 2011 it was reduced to three sites (Table 1). The sites cover a wide range of soil types and cropping system intensities (Tables 1–4). The soil types (Tables 2–4) at the sites can be divided into two main groups; peat soils (sites 1–7) and peaty marls (sites 8–11). The crops grown (Table 1) can be divided into three main groups; cereals (oats, barley, rape seed, spring wheat and spring triticale), row crops (potato, carrot and parsnip) and grassland (for fodder production and for lawn grass production). Every second year the lawn grass was tilled and resown, in year 1 the lawn grass was in its second year and in year 2 in its first year. Mowing was performed weekly. Grassland was renewed every third or fourth year and cut 2–3 times a year for fodder production. In this study they were all in their first or second year of growth. At site 1 the grassland was used for grazing in year 1. Row crops and cereals were spring sown annual crops with tillage every year.

2.1. Climate

The climate at the different sites varies slightly. At sites 1–2, mean annual rainfall is 539 mm and mean annual temperature 6.0 °C. At sites 3–4, mean annual rainfall is 625 mm and mean annual temperature 5.6 °C. At sites 5–11, mean annual rainfall is 513 mm and mean annual temperature 6.6 °C. All these values are 30-year averages,1961–90 (SMHI, 2015).

Spring 2009 was warmer and drier than normal, followed by normal weather until after midsummer, when a period of warm, dry weather occurred. July was rainy throughout, followed by a warm, dry August. The spring of 2010 and 2011 was dominated by the previous long, snow-rich winter. Although April was warmer and drier than normal, there was still much water on the fields from snow melt. In 2010, May and June were rainy, which led to difficulties with tillage at some sites. July was dry and warm, with exceptionally hot weather at sites 5–11. The last part of the season had normal rainfall and temperature and finished with an early autumn at the end of September. In 2011, May and June were less rainy than in 2010, which gave farmers a better start to the growing season. July was dominated by changeable weather, followed by a rainy August and September. The growing season of 2011 was colder throughout than that of 2009 and 2010.

2.2. Experimental design

A comparison was made between two different crops grown in the same field or adjacent fields (Fig. 1). The soil type (parent material of the organic soil), peat depth, drainage intensity (same distance from drainage ditch) and weather conditions were the same for both crops, and only the crop and its associated management differed. Ten study plots (approx. 1 m^2) were laid out in a transect along the crop border, about 5 m inward from the border at most sites (maximum 15 m). For the row crops, the study plots (2 m long) were placed along one row. The study plots consisted of five subplots with a crop and five with the crop manually removed (bare soil) in the beginning of the season and the surface was kept bare thereafter by manual weeding once a month. For grassland plots a spade was initially used to remove the vegetation. Measurements of CO_2 emissions were made on plots both with and without crop. Within 1 h prior to gas measurement, 0.25 m^2 of the plot with crop (0.5 m row length for row crops) was cut to facilitate measurements and to reduce the above-ground biomass part of the CO_2 flux. This area was then used for the gas flux measurements. On each measuring occasion, a new square/area of the study plot was