Soil carbon loss from managed peatlands along a land use gradient – a comparison of three different methods

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Abstract

Carbon (C) loss from managed organic soils is an important flux in the global carbon cycle. Different approaches exist to estimate greenhouse gas emissions and thus the C balance of these soils. Here we compare two methods using soil profiles and a method of greenhouse gas (GHG) flux measurements using closed chambers to quantify the net C loss from managed peatlands. We applied these methods to the well-studied peatland complex Ahlen-Falkenberger Moor near Cuxhaven in northern Germany. The peatland represents a land use gradient from near-natural wetland (NW) to extensively-used grassland (GE) (rewetted in 2003/2004) to intensively-used grassland (GI). The three methods are: (i) the so-called combined method which makes use of differences in bulk density and ash content between the upper and deeper parts of the profile (ii) the C accumulation method which uses peat accumulation rates derived from ^{14}C age-dated samples and their calculated C-stock in a certain depth and (iii) a method which gives the net ecosystem carbon balance (NECB) using closed chambers to quantify the GHG fluxes. Drainage at the Ahlen-Falkenberger Moor commenced at the beginning of the 20th century, and land use was intensified in the middle of the 20th century. For methods (i) and (ii), three peat cores down to approximately 100 cm at each site were taken in November 2012. These two profile-based methods give the C loss since the onset of drainage activities. Compared to this, the NECB represents the C balance (2007-2009) under present climate and management conditions.

According to the profile-based methods (i and ii), all three sites have lost C since the onset of drainage in the order NW<GE<GI. Calculated total C losses are, depending on the method, about 12 kg C m^{-2} for site NW, 19 to 38 kg C m^{-2} for site GE and 43 to 53 kg C m^{-2} for site GI. Based on chamber-derived GHG measurements, site NW currently accumulates C, site GE shows a neutral C balance and site GI is a C source. A comparison of these methods demonstrates that the historical C loss can be assessed by the two profile-based methods, but not by the flux measurements. By contrast, present changes in the C balance are captured by the flux measurements but not by the profile-based methods. Taken together, profile-based methods and flux measurements indicate that the C balance of these peatlands, since the beginning of drainage activities, has been changing over time.

Zusammenfassung

Kohlenstoffverluste von drainierten organischen Böden sind eine wichtige Grösse im globalen Kohlenstoffkreislauf. Es gibt verschiedene Methoden zur Bestimmung der Kohlenstoffverluste aus organischen Böden. Wir vergleichen hier zwei profilbasierte Methoden und Treibhausgasmessungen mittels Kammermessungen zur Bestimmung des Kohlenstoffverlustes aus dem Boden. Die Methoden wurden entlang eines Landnutzungsgradienten in dem Ahlen-Falken-berger Moor bei Cuxhaven, Deutschland, angewendet. Die Standorte waren ein naturnahes Moor (NW), ein extensiv genutztes Grasland (GE), sowie ein intensiv genutztes Grasland (GI). Die Kohlenstoffverlustberechnung basiert auf drei unterschiedlichen Ansätzen: (i) auf der kombinierten Methode, die Unterschiede in der Lagerungsdichte und im Aschegehalt zwischen dem Ober- und Unterboden berücksichtigt, (ii) auf der Kohlenstoffakkumulationsmethode, welche die berechneten Kohlenstoffakkumulationsraten, berechnet auf Grundlage von ^{14}C-Datierungen, zusammen mit dem Kohlenstoffvorrat in einer bestimmten Tiefe verwendet und (iii) auf einer Methode, welche die Kohlenstoffbilanz mittels Kammermessungen für die Netto Ökosystem Kohlenstoffbilanz (NECB) bestimmt. Die beiden erstgenannten Methoden (i und ii) geben den kumulierten Kohlenstoffverlust seit dem Beginn der Drainage wieder. Im Vergleich dazu repräsentiert die NECB (iii) den Kohlenstoffhaushalt unter den gegebenen und aktuellen klimatischen Bedingungen sowie der Landnutzungsart. Seit Anfang des 20. Jahrhunderts wurde das Moor drainiert und in der Mitte des 20. Jahrhunderts die Landnutzung intensiviert. Für die Analyse von verschiedenen biogeochemischen Bodenparametern wurden im November 2012 drei Bohrkerne bis etwa 100 cm Tiefe an jedem Standort entnommen.

Anhand der profilbasierten Methoden (i und ii) konnte ermittelt werden, dass seit der Drainage alle drei Standorte Kohlenstoff in der Grössenordnung NW<GE<GI verloren haben. Die berechneten totalen Kohlenstoffverluste sind, je nach Methode, in der Grössenordnung von etwa 12 kg C m^{-2} für Standort NW, 19 bis 38 kg C m^{-2} für Standort GE und 43 bis 53 kg C m^{-2} für Standort GI. Die aktuellen Treibhausgasmessungen für die Jahre 2007 bis 2009 zeigen, dass NW Kohlenstoff akkumuliert, GE eine neutrale Kohlenstoffbilanz aufzeigt und GI eine Kohlenstoffquelle ist. Ein Vergleich der Methoden veranschaulicht, dass der historische Kohlenstoffverlust mittels der profilbasierten Methoden abgeschätzt werden kann, eine Information, welche nicht mit den aktuellen Treibhausgasmessungen erfasst wird. Aktuelle Veränderungen in der Kohlenstoffbilanz hingegen werden mit den Treibhausgasmessungen aufgezeigt, können aber nicht mit den profilbasierten Methoden festgestellt werden. Zusammengefasst zeigt die Kombination der Methoden, dass sich die Kohlenstoffbilanz dieser Moorböden seit dem Beginn der Drainageaktivitäten über die Zeit verändert hat.

Keywords: peatland, carbon loss, land use change, organic soil, land use gradient, grassland use, soil profiles, C balance

1. Introduction

Carbon (C) loss from managed organic soils is an important flux in the global carbon cycle (Yu et al., 2011; Jungkunst et al., 2012). Under natural conditions, peatlands are anoxic and accumulate organic matter as peat (Clymo, 1984). Management of peatlands for agriculture or forestry requires drainage. This induces aerobic decomposition of the soil organic matter and a net C emission to the atmosphere (Maljanen et al., 2010). Over the last century, more than 50% of the peatland area in Europe has been converted mainly to agriculture or forestry (Byrne et al., 2004). In Germany, 75% of the greenhouse gas (GHG) emissions from soils are attributed to agricultural use (Höper, 2007), and more than half of the GHG emissions from managed peatlands originate from sites managed as grasslands (Drösler et al., 2008). Together, GHG's from organic soils contribute 5.1% to Germany's national total emissions (Drösler et al., 2013). Average C loss rates from temperate peatlands under grassland use are 0.6 kg C m−2 yr−1 for deeply drained and 0.4 kg C m−2 yr−1 for shallowly drained peatlands (IPCC, 2013). Ranked by land use intensity, intensively-managed grasslands emit on average 2.8 kg CO2eq m−2 yr−1, extensively-managed grasslands between 0.2 and 2.0 kg CO2eq m−2 yr−1 (depending on the water table), near-natural bogs are almost climate-neutral, but dry bogs emit up to 1.0 kg CO2eq m−2 yr−1 (Drösler et al., 2013). The latter values include the N2O emissions, which can contribute significantly to the GHG emission at intensively-managed sites. Different approaches exist to estimate the C balance of peatland soils. Here we compare two soil profile-based methods with each other and with greenhouse gas flux measurements by closed chambers to assess the net C loss from managed peatlands.

2. Material and methods

We applied the different methods to the well-studied peatland complex Ahlen-Falkenberger Moor in north-western Germany. The peatland

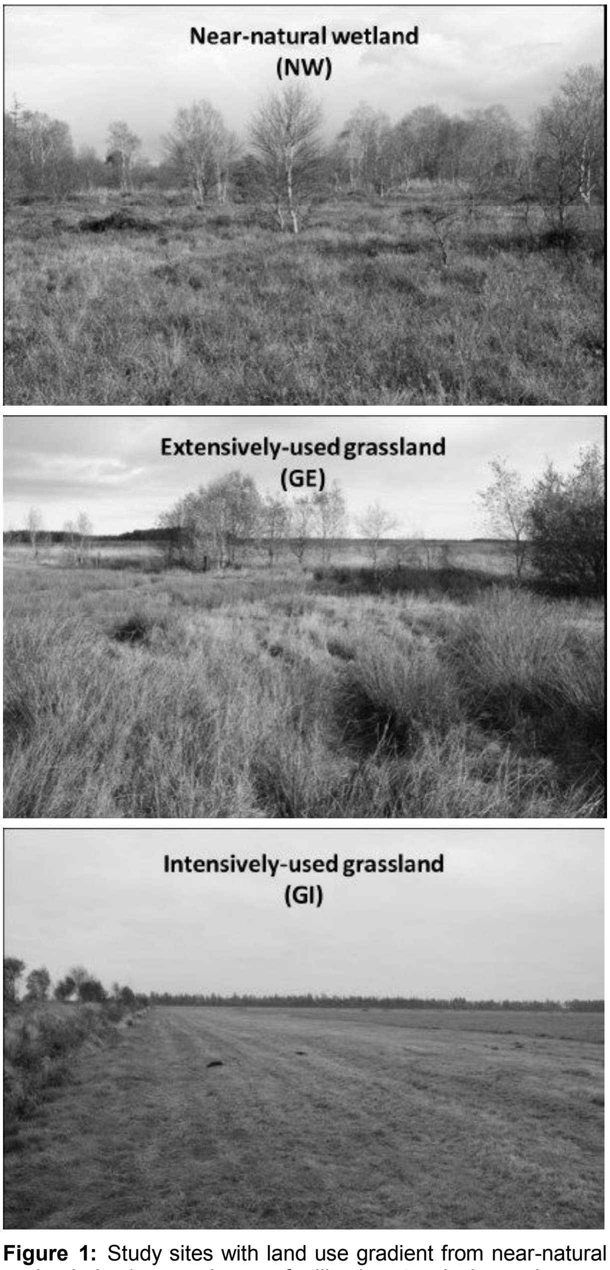

Figure 1: Study sites with land use gradient from near-natural wetland site (no mowing, no fertiliser), extensively-used grassland (cut once per year, no fertiliser) and intensively-used grassland site (cut 4-5 times per year, mineral and organic fertiliser).

complex represents a land use gradient (Fig. 1) from near-natural wetland (NW) to extensively-used grassland (GE) (which was rewetted in 2003/2004) to intensively-used grassland (GI). At both grassland sites, drainage started at the beginning of the 20th century, and land use was intensified in the middle of the 20th century. About 60% of the remaining area is currently used as grassland, and only a small area in the centre of the bog (approx. 5%) was never drained or cultivated and remains as a natural habitat today (Höper, 2007). Since the 1990s, the NW has been a nature conservation area. Detailed site descriptions can be found in Beetz et al. (2013) and Krüger et al. (2015). In November 2012, three peat cores down to approximately 100 cm were taken at each site, and various biogeochemical soil parameters were analysed.

The so-called combined method (Leifeld et al., 2014) estimates the physical primary subsidence due to the loss of pore water and peat shrinkage, and the chemical secondary subsidence due to the oxidative loss of organic matter. The integrated calculation of C loss from the peatland since the beginning of drainage is based on the simplified assumptions that the ratio of C to ash content during accumulation of peat has been constant and that the ash content before drainage was the same at all depths. After drainage, peat starts to oxidise and C is lost as CO_2 while the mineral parts remain as ash in the profile. Additionally, we assume that the ash content in the permanently water-saturated subsoil is not affected by drainage and that ash from the oxidised peat remains at the site and accumulates in the respective layer. See detailed method description in Krüger et al. (2015) and Leifeld et al. (2014).

In a second method (C accumulation method), the C loss is calculated based on ^{14}C age-dated samples from two different layers, with the assumption of linear C accumulation rates at the NW site (Fig. 2). Mean linear C accumulation rates at the NW site calculated by a linear regression of the age-dated samples are 0.046 kg C m^{-2} yr^{-1} (Fig. 2). The radiocarbon ages in a defined depth and the cumulative C-stock (Fig. 3) above the ^{14}C age-dated point are used to calculate the C balance of the peat soils under grassland. The difference between the calculated cumulative C stock above the ^{14}C age-dated point at the GE and GI sites (using the C accumulation rates of the NW site) and the measured cumulative C stock (Fig. 3) above the ^{14}C age-dated point of the peat core at GE and GI is the C loss of the soil. In detail, the C balance is calculated by the year (in years AD/BC) of sampling minus the age-dated sample (in years AD/BC) in the depth multiplied by the calculated yearly C accumulation rates of the NW site minus the cumulative C stock (kg C m^{-2}) above the corresponding depth of the respective site.

These two profile-based methods give the C loss since the onset of drainage. Carbon losses are displayed as kg C m^{-2} and loss rates as kg C m^{-2} yr^{-1} by dividing the C loss by the number of years passed since the peatland drainage was intensified.

In contrast to the profile-based methods, the net ecosystem C balance (NECB) (2007-2009) represents the current C loss or gain of the soil under given climate and management conditions including the C change by harvesting and fertiliser application. The measurements were performed by Beetz et al. (2013). CO_2 fluxes were measured using closed chambers (0.78 m x 0.78 m x 0.50 m) in flow -through dynamic mode. Opaque and transparent chambers were placed in turn to obtain data on combined autotrophic and heterotrophic respiration of the ecosystem (RECO) and net ecosystem exchange (NEE), respectively. See detailed description of this method in Beetz et al. (2013).

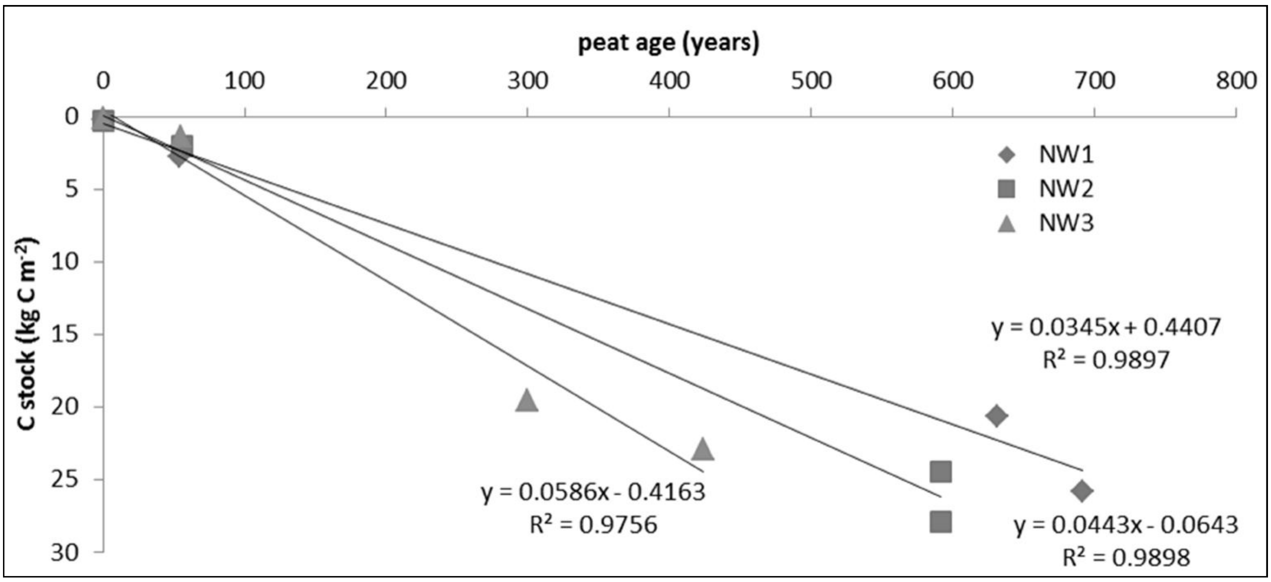

Figure 2: Calculated C accumulation rates by peat age vs. C stock for the near-natural wetland site.

3. Results and discussion

According to the profile-based methods, all three sites have lost C since the onset of drainage (Tab. 1). The total C loss, calculated by the two profile-based methods, is in the order NW<GE<GI. Based on the chamber-derived NECB, site NW accumulates C, site GE shows a neutral C balance and GI is still a C source in 2007 to 2009 (Beetz et al., 2013).

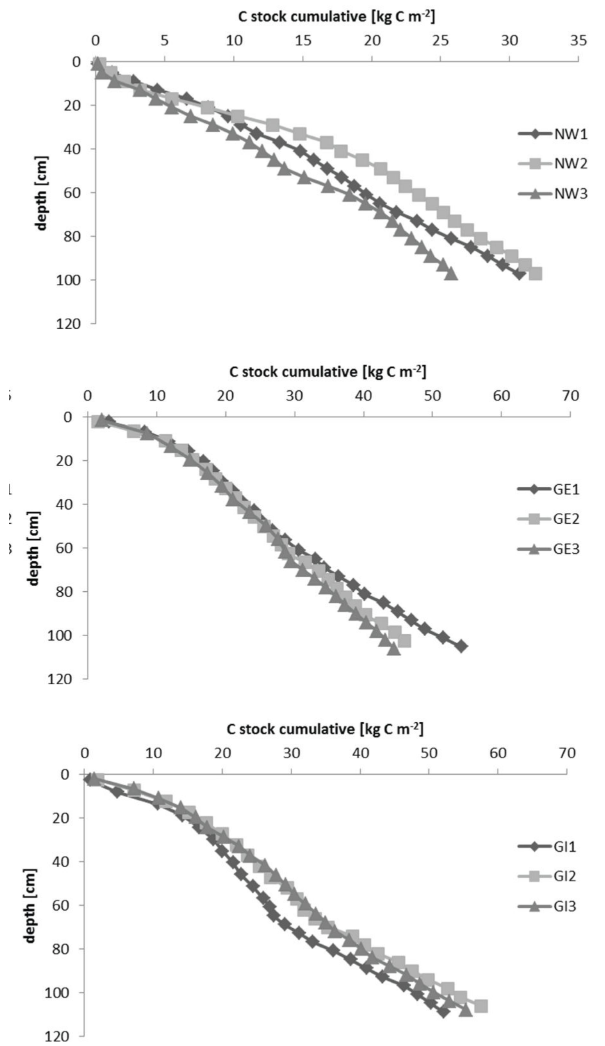

Figure 3: Cumulative C stock (kg C m−2) of each soil core for the three sites.

According to the combined method, the NW site has lost 11.5 kg C m−2. According to the NECB, it is now a C sink of about 0.063 kg C m−2 yr−1 (Beetz et al., 2013) (Tab. 1). The calculated C loss, integrated over the period since drainage intensification, could be due to the effect of drainage activities in the surrounding area that also influenced the hydrology at the NW site (Krüger et al., 2015). Since the 1990s, the NW site is located in a nature conservation area; this may have recovered water tables, resulting in a negative C balance (C sink) today (Beetz et al., 2013).

The GE site has lost 18.8 kg C m−2 according to the combined method and 38.2 kg C m−2 according to the C accumulation method since drainage intensification. The rewetting of the GE site is reflected in the current NECB, indicating a currently neutral C balance of the soil. However, since drainage intensification, the GE site has lost 0.313 kg C m−2 yr−1 (combined method) to 0.636 kg C m−2 yr−1 (C accumulation method) (Tab. 1). An increase in water table depth may have changed the C balance at this site from a C source into a C neutral status.

The calculated C loss was highest at GI site (42.9 kg C m−2 by the combined method and 52.8 kg C m−2 by the C accumulation method). The current annual C emissions at this site (0.683 kg C m−2 yr−1 (NECB 2007-2009)) are in the same order of magnitude of annual C losses integrated over the whole period since drainage intensification (0.716-0.880 kg C m−2 yr−1) (Tab. 1).

For both grasslands, our calculated annual C loss as revealed from the profile-based methods (Tab. 1), based on an assumption of 60 years of intensive drainage, is in the range of previously reported C loss rates from temperate peatlands under grassland use (IPCC, 2013). Independent of the applied method, C loss from the GI site is the highest. Furthermore, the NW site shows the lowest C loss or even a C uptake. A higher calculated C loss at GE as revealed by the C accumulation method may be attributed to the high C accumulation rates calculated for the NW site. In future studies, estimates using the C accumulation method could be improved by using a natural site without any anthropogenic influence. Higher calculated C losses by the C accumulation method com-

Table 1: Annual C balance in kg C m−2 yr−1 (mean with SD) calculated by three different methods along the land use gradient. Positive values indicate a C gain and negative values a C loss of the soil.

	Near-natural wetland (NW)	**Extensively-used grassland (GE)**	**Intensively-used grassland (GI)**
Combined method (Krüger et al., 2015)*	-0.191 (±0.105)	-0.313 (±0.047)	-0.716 (±0.181)
C accumulation method*	-	-0.636 (±0.026)	-0.880 (±0.074)
NECB (2007-2009) (Beetz et al., 2013)	0.063 (±0.086)	0.030 (±0.166)	-0.683 (±0.190)

*Integrated C loss since drainage intensification (60 years) with annual C losses calculated by the total C loss divided by the years.

pared with the combined method at the GE site also may be due to the high radiocarbon ages of peat at this site in the deeper parts of the profile (Krüger et al., 2015), resulting in high calculated C losses by this method. At the GI site, high radiocarbon ages in deeper parts and high ash contents in the upper part lead to high calculated C losses by both profile-based methods. The results of annual C losses at the GI site are in the same range as the calculated NECB. The three applied methods use different assumptions and give results for the two managed sites in the same range as C losses from managed peatlands in the temperate region (IPCC, 2013).

4. Conclusions

The profile-based methods assess an average C balance over the last several decades or hundreds of years since the peatland drainage began, whereas GHG measurements capture short defined measurement periods of only a few years. Thus, GHG measurements present the year-to-year variation due to temperature, water table and precipitation fluctuation. Profile-based methods, however, integrate C losses during the first years of drainage activities, which are presumably higher than the average over the declining emissions in advanced years (Leifeld et al., 2012). The profile-based methods give long-term soil C changes of drained and managed peatlands.

Independent of the method, a clear distinction between the three sites with respect to their C balance can be derived. Furthermore, changes in land use alter the soil C balance of peatlands; in our case, the rewetting and the designation as a nature conservation area lead to reduced C losses or, in the recent years, to a C uptake. This change in soil C balance due to land use change can be detected by a combination of profile-based methods and flux measurements.

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