GLOBAL SYMPOSIUM ON SOIL ORGANIC CARBON, Rome, Italy, 21-23 March 2017

Effects of a raised water table on CO_2 and CH_4 soil emissions and celery yield from agricultural peat under climate warming conditions

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Abstract

Peatlands are globally important areas for carbon preservation: covering only 3% of world's land, they store 30% of total soil carbon. At the same time, peat soils are widely utilised in agriculture: 40% of UK peatlands have been drained for agricultural use and 24% of deep peat area in England is being farmed. One of the most important regions for crop production on lowland peats in the UK are the East Anglian Fenlands (the Fens): an area of drained peatlands in East England. This study was conducted on peat cores excavated from a field in the Fens and focused on the following objectives:

1. To examine effects of climate change-induced temperature rises on celery productivity and peat CO_2 and CH_4 emissions.
2. To find the field water table level that reduces peat emissions of CO_2 and CH_4 while maintaining celery productivity.

The research found higher CO_2 emissions from the elevated (+5°C) temperature treatment and lower CO_2 emissions from the higher (-30cm) water table level, however, noted no effect on CH_4 emissions of any of the treatments. The higher water table decreased aboveground celery biomass. There was no effect of increased temperature on aboveground celery yield.

Keywords: peat; agriculture; greenhouse gases; drainage; climate change

Introduction, scope and main objectives

Peatlands are globally important areas for carbon preservation: covering only 3% of world's land, they store 30% of total soil carbon (Global Environmental Centre, 2008). At the same time, peat soils are widely utilised in agriculture: in Europe 14% of peatland area is under cultivation (Global Environmental Centre, 2008), 40% of UK peatlands have been drained for agricultural use (Dixon et al., 2014) and 24% of deep peat area in England is being farmed (Natural England, 2015).

One of the most important regions for crop production on lowland peats in the UK are the East Anglian Fenlands (the Fens): an area (1,500 square miles) of drained peatlands in East England covering Cambridgeshire, Norfolk, West Suffolk and Lincolnshire (Darby, 1956). Eighty eight percent of the Fenland area is cultivated, sustaining around 4000 farms and supplying 37% of total vegetable production in England (NFU, 2008). The soils of the area are fertile (89% of agricultural land being classified as grade 1 or 2: the highest scores on a six grade scale which describes soil suitability for cultivation in England and Wales) and so crops with high nutritional demands (such as vegetables) tend to dominate (NFU, 2008). It is estimated that Fenland peats store 41 Tg of Carbon, which is lost from the ecosystem at a rate of 0.4 Tg C/yr (Holman, 2009). Despite their economic and environmental importance, Fens are at risk due to continued drainage-induced volume loss of the peat layer via shrinkage, compaction and oxidation, which are estimated to result in wastage rate of 2.1 cm/yr (Holman, 2009).

Manipulation of the water table has the potential to extend the lifespan of the fertile soil of the Fens. The position of water table is often credited to be of key importance in determining the rate of mineralisation of organic matter. The majority of studies on temperate and Northern peatlands demonstrate that a rise in the position of the water table decreases emissions of CO_2 and increases release of CH_4 (Nykanen et al., 1995, Dinsmore et al., 2009, Wilson et al., 2016, Karki et al., 2010, Strack et al., 2004, Hou et al., 2013, Poyda et al., 2016, Regina et al., 2015, Yrjala et al., 2011), although in many instances no link is found between the water table level and emissions of greenhouse gases (Regina et al., 2007, Schrier-Uijl et al., 2010, Muhr et al., 2011) or a drawdown of the water table results in smaller release of CO_2 Dirks et al, 2000). Despite the importance of preservation of agricultural peats, there is a lack of studies which attempt to find water table level that strikes a balance between crop yield and GHG production. Renger et al. (2002) found that while a water table of -40 cm to -50 cm maximised grass yield on a fen, keeping it at -30 cm is the optimal solution as 90% of productivity is kept and mineralisation is lowered by 30-40% of the maximal value. A similar pattern was reported by Regina et al. (2015) on organic soils cultivated for grass in Finland: they noted a decline of CO_2 and N_2O emissions when water table was raised from -70 cm to -30 cm, although they do not provide biomass data. Nevertheless, the relationship between the position of water table and peat oxidation is not always clear: water table level was found to have no effect on CO_2 emissions (Lafleur et al., 2005) and its lowering from -40 cm to -80 cm resulted in a decreased CO_2 loss (Berglund and Berglund, 2011).

The future of the Fens is overshadowed by another uncertainty: increases in temperature brought by climate change. It is estimated that average global temperature increase expected by the end of this century (relative to 1986-2005) would be within the range of 0.3-4.8°C (IPCC, 2014). Rising temperatures should accelerate the rate of organic matter mineralisation, which will lead to higher emissions of greenhouse gases as well as enhanced plant growth due to better availability of nutrients (Rustad et al., 2001). The effects of higher temperatures on crop growth and greenhouse gas emission have not been properly investigated in the context of peatlands utilised in agriculture.

This study was conducted on peat cores excavated from a field in the Fens and focused on the following objectives:

3. To examine effects of climate change-induced temperature rises on celery productivity and peat CO_2 and CH_4 emissions.
4. To find the field water table level that reduces peat emissions of CO_2 and CH_4 while maintaining celery productivity.

Methodology

A total of 64 soil cores were collected from a farm in Methwold Hythe, Norfolk. This was done by inserting PVC pipes with a diameter of 11 cm to a depth 60 cm. The PVC pipes were excavated out of the ground, preserving the existing soil structure. The cores (half planted and half unplanted) were subjected to a multifactorial manipulation of:

- Water table at two levels: -30 cm and -50 cm
- Fertilisation: fertilisation with ammonium polyphosphate and lack of fertilisation
- Temperature: ambient and elevated (+5°C).

In order to regulate temperature conditions, the cores were placed in two growth chambers. To simulate the field conditions, the chamber temperature was raised each week from the base temperature of 17°C (22°C in the elevated temperature treatment) until it reached 20°C (25°C in the elevated temperature treatment) in week 6. The temperature, air humidity and PAR settings of this experiment are based on June, July and August readings from the field in years 2013, 2014 and 2015.

CO_2 and CH_4 measurements were taken once a week in weeks 1-11 with an LGR Ultra Portable Gas Analyser GGA-30p. Two custom-made PVC chambers: a transparent (to record fluxes in light) and an opaque (for dark respiration) chamber (both with a volume of 2.8 l) were used to collect soil gas emissions and transfered to the LGR in real time. Each measurement lasted 2 minutes. The fluxes of CO_2 and CH_4 were calculated as described in McEwing et al. (2015).

Statistical analysis was performed using the open source programme R (R Core Team 2016). Linear models and mixed effects models were used to test the effects of water table level, temperature and fertiliser use on celery biomass and emissions of CO_2 and CH_4. The analysis was done in the lme4 package (Bates, Maechler & Bolker, 2014), so as to avoid temporal and spatial pseudoreplication.

Results

The weight of the aboveground fresh biomass was 19% lower from the -30 cm water table treatment as compared with the -50cm water table. Aboveground fresh biomass was not significantly affected by temperature. Dry root biomass was lower in the -30 cm water table treatment by 33% and remained unaffected by temperature.

The CO_2 flux from unplanted cores was 25% higher from the elevated temperature treatment and also 31% higher form the -50 cm water table treatment. CH_4 fluxes were not affected by any of the treatments.

Discussion

Higher CO_2 emissions from the elevated (+5°C) temperature treatment may point to increased rates of organic matter oxidation by soil microorganisms. Temperature increases may enhance the decomposition of organic matter, among other factors, through positive effects on microbial metabolic rate (Ziegler et al., 2013). A number of studies demonstrate that in the agricultural context a water table of -20cm or lower is enough for complete oxidation of methane by methanotrophs (Regina et al., 2015; Karki et al., 2016; Poyda et al., 2016, Renou-Wilson, 2014). The absence of a relationship between water table fluctuations and methane emissions at low water table levels is likely due to the fact that low water tables have no or negligible effect on topsoil water content (Juszczak et a., 2012), which is the key factor in determining methanotrophic activity (Tiemeyer et al., 2016). The lack of response of CH_4 emission to the elevated temperature treatment could be because the difference of 5°C was not enough to significantly affect the production and consumption of CH_4, especially for the values close to the optimal temperature (25°C).

Conclusions

Raising the water table from -50 cm to -30 cm would depress celery yields, however, it would also decrease the rate of peat wastage. Global warming is likely to increase peat loss via oxidation and unlikely to improve celery yields.