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Effect of water table management and elevated CO_2 on radish productivity and on CH_4 and CO_2 fluxes from peatlands converted to agriculture

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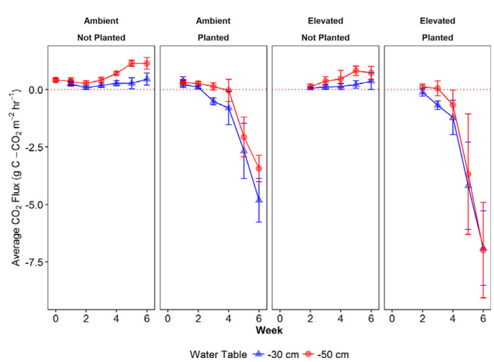
HIGHLIGHTS

- Peat loss is a major issue affecting farmers in Europe, including the UK.
- A more sustainable farming should prevent peat loss while maintaining productivity.
- This experiment tested the impact of water table on productivity and peat loss.
- Raising the water table from −50 cm to −30 cm increases radish productivity.
- Increasing water table to −30 cm reduces peat loss.

GRAPHICAL ABSTRACT



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ABSTRACT

Anthropogenic activity is affecting the global climate through the release of greenhouse gases (GHGs) e.g. CO_2 and CH_4. About a third of anthropogenic GHGs are produced from agriculture, including livestock farming and horticulture. A large proportion of the UK's horticultural farming takes place on drained lowland peatlands, which are a source of significant amounts of CO_2 into the atmosphere. This study set out to establish whether raising the water table from the currently used −50 cm to −30 cm could reduce GHGs emissions from agricultural peatlands, while simultaneously maintaining the current levels of horticultural productivity. A factorial design experiment used agricultural peat soil collected from the Norfolk Fens (among the largest of the UK's lowland peatlands under intensive cultivation) to assess the effects of water table levels, elevated CO_2, and agricultural production on GHG fluxes and crop productivity of radish, one of the most economically important fenland crops. The results of this study show that a water table of −30 cm can increase the productivity of the radish crop while also reducing soil CO_2 emissions but without a resultant loss of CH_4 to the atmosphere, under both ambient and elevated CO_2 concentrations. Elevated CO_2 increased dry shoot biomass, but not bulb biomass nor root biomass, suggesting no immediate advantage of future CO_2 levels to horticultural farming on peat soils.

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Overall, increasing the water table could make an important contribution to global warming mitigation while not having a detrimental impact on crop yield.

1. Introduction

Anthropogenically produced greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) represent the principle contributors to global warming (IPCC, 2013). CO_2 has been identified as the dominant greenhouse gas (GHG) driving climate change, while CH_4 is the second most potent GHG and has a radiative forcing 28 times greater than that of CO_2 over a hundred years (IPCC, 2013). Globally atmospheric concentration of CO_2 has risen from pre-industrial levels of ~260 ppm to over 400 ppm currently (Wigley, 1983; IPCC, 2014a, b), while atmospheric CH_4 have increased 150% over the same time period (IPCC, 2013). A significant proportion of these anthropogenic GHG emissions come from all aspects of agriculture (Foresight, 2011; Gilbert, 2012). The reduction of GHG emissions from agriculture is fraught with enormous challenges. Given the ever-increasing human population, which is estimated to reach around 10 billion in 30 years' time, it is important that any GHGs emission mitigation measures should not negatively affect food production and therefore food security (Godfray et al., 2010). On a global scale, close to 20% of the worlds' peatlands are exploited for agricultural use (Strack, 2008).

Drainage of peatlands for agriculture increases the oxygen content of the soil, promoting organic matter decomposition (Strack, 2008; Regina et al., 2015), which ultimately increases CO_2 emissions. A recent study by Evans et al. (2016) (SP1210) measured GHGs fluxes from both cultivated fen peat soils and a near intact peat fen in East Anglia, finding the cultivated soils to be a source of 25.34–28.45 t CO_2 ha^{-1} yr^{-1} while the near intact fen was a sink measuring −5.13 t CO_2 ha^{-1} yr^{-1}. Peatlands cover 11% of England (14,185 km^2) but they are estimated to store more than half of total soil C in England (Natural England, 2015). While peatland drainage increases CO_2 loss into the atmosphere, natural peatlands are sources of CH_4 due to methanogenic activity under their prevalent waterlogged anoxic soil conditions. Consequently, while drainage increases CO_2 emissions, it reduces CH_4 losses (Petrescu et al., 2015) and can eventually lead to CH_4 consumption (Conrad, 1996).

More than half of European peatlands are no longer storing carbon (Zeitz and Velty, 2002) while in the UK about 1.3 million ha (40%) of peatland has been drained for farming purposes and only 20% (660,000 ha) is considered to be nearly natural, i.e. with minimal anthropogenic interference (Dixon et al., 2014). In combination with oxidation, peat is lost from drained peatlands due to physical changes in the soil structure (compression and compaction) and also wind erosion from the drained top layer of the peat soil (Levanon et al., 1987). A clear example of dramatic peat loss can be observed at the Holme Fen Post in Huntingdonshire, in southern England, where soil oxidation and compaction has resulted in subsidence of 4 m since 1848 (Eyre, 1968; Berglund and Berglund, 2011)

To reduce this C loss, it is necessary to raise the water table of cultivated peatlands, but excess water in the plant rooting zone and the associated anoxic soil conditions can negatively affecting root growth resulting in lower crop yields (Wang et al., 2004). Furthermore, a high water table can interfere with the use of heavy farm machinery and can encourage the prevalence of plant fungal diseases such as *Aphanomyces* (water mould), *Pythium*, and *Phytophthora* (Katan, 2000) further reducing crop yield. Only a few studies (e.g. Stanley and Harbaugh, 2002; Berglund and Berglund, 2011) have examined the effects of peatland water table manipulation on agricultural crop yield, especially of commercially important crops. The effect of water table depth on yields dependents on plant species, e.g. maize and sorghum under waterlogged conditions presented reduced yields compared to when soil was more aerated (Kahlown et al., 2005), and grasslands present a 10% loss in yield when water table is raised from −50 to −30 cm (Renger et al., 2002). On the other hand, an increase of water table could be beneficial for plant growth, especially for shallow rooting crops (Lambers et al., 2013), ryegrass (*Lolium perenne*) (Berglund and Berglund, 2011) and caladium (*Caladium xhortulanum*) tuber yields (Stanley and Harbaugh, 2002), and crop tuber yields (Stanley and Harbaugh, 2002). In the UK, farmers regularly use a rather cautious water table depth of −50 cm below the surface, and are concerned that a water table higher than −50 cm will negatively affect crop production (Martin Hammond - Manager at Rosedene Farm, one of the largest fenland farms in the UK, 2017). Overall, raising water table level should slow down peatland degradation and reduce GHGs emissions significantly improve the protection of the peat soil and reduce C loss (e.g. Renger et al., 2002), supporting more sustainable agricultural practices.

Increased atmospheric CO_2 affects plants by increasing their growth rate as the photosynthetic rate and water use efficiency are improved, leading to an increase in biomass (Idso et al., 1987; Poorter, 1993). Photosynthetic rate increases under elevated CO_2 levels (Sage et al., 1989; Poorter, 1993; Ainsworth and Long, 2005). To date, few studies have explored the impact that elevated CO_2 in combination with water table management has on crop productivity (Ainsworth and Long, 2005) and on the net CO_2 and CH_4 release from soil (Dijkstra et al., 2012), and thereby on the impact that agricultural practices will have on the climate.

In consultation with the farm manager of one of the largest farming groups in the UK, in eastern England, we undertook a multifactorial manipulation of water table and CO_2 concentration on peat cores collected from their field to test the response of CO_2 and CH_4 fluxes to current and future conditions. The final goal of this study was to explore the possibility of significantly reducing the rate of peat C loss by increasing the soil water table from a current position of −50 cm to a water table of −30 cm while maintaining a commercially acceptable crop yield. We hypothesised that increasing the water table to −30 cm from the currently adopted −50 cm would reduce CO_2 emissions but increase CH_4 emissions, and increase radish productivity. Finally, we expected that radish productivity would be higher with elevated CO_2.

2. Materials and methods

2.1. Study site

The soil samples used in the experiment were collected from Rosedene Farm in the East Anglian fens, west Norfolk (Fig. 1). The soils are formed from nutrient-rich fen peat, established after extensive post-war drainage that was ushered in by a large-scale agricultural expansion programme during the late 1930s and the early 1940s (Short, 2007). The core sampling was performed on the 24th September 2015, when no crops was present in the field. The different fields were separated by dykes, used for water table management separate all the fields, and these dykes are connected to water reservoirs used to manage the water table over the entire farm.

2.2. Experimental design

A total of 46 cores were successfully collected from the site and transported to the Sir David Read Controlled Environment Facility at the University of Sheffield, United Kingdom. The cores were collected using PVC pipes of 11 cm inner diameter and 50 cm depth. In order to preserve the soil structure, i.e. avoid compaction and horizons, the