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Impacts of elevated atmospheric ozone on peatland below-ground DOC characteristics

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ABSTRACT

Rising concentrations of tropospheric ozone are having detrimental impacts on the growth of crop and forest species and some studies have reported inhibition of the allocation of carbon below ground. The effects of ozone on peatland ecosystems have received relatively little attention, despite their importance within the global carbon cycle. During this study, cores from a Welsh minerotrophic fen and ombrotrophic bog were exposed to four ambient/elevated ozone concentration regimes representing current and predicted 2050 profiles. A large and significant reduction in the concentration of porewater dissolved organic carbon (DOC) was recorded in the fen cores exposed to the elevated ozone concentrations (up to −55%), with a concurrent shift to a higher molecular weight of the remaining soil carbon. No effects of ozone on DOC concentrations or characteristics were recorded for the bog cores. The data suggest higher ozone sensitivity of plants growing in the fen-type peatland, that the impacts on the vegetation may affect soil carbon characteristics through a reduction in root exudates and that there may have been a shift in the source of substrate DOC for microbial consumption from vegetation exudates to native soil carbon. There may also have been a direct effect of ozone molecules reacting with soil organic matter after being transported into the soil through the aerenchyma tissue of the overlying vegetation. These qualitative changes in the soil carbon in response to elevated ozone may have important implications for carbon cycling in peatland ecosystems, and therefore climate change.

1. Introduction

Concentrations of tropospheric ozone (O_3) have more than doubled during the past century; typical surface measurements today are 30–40 ppb compared with 10–15 ppb during the pre-industrial era (Volz and Kley, 1988). The rate of increase in annual mean concentrations during the last three decades has been approximately 0.5–2% (Vingarzan, 2004). The dominant factor behind the increasing background concentration is the global increase in ozone precursor emissions associated with the extraction and use of fossil fuels, which has greatly elevated the concentrations of VOCs and NO_x in the atmosphere (Finlayson-Pitts and Pitts, 1997). In the last decade, a clear signal has also emerged that background concentrations are rising, but peak ozone concentrations in Europe and North America are declining, as controls on precursor emissions take effect (NEGTAP, 2001; Oltmans et al., 1998). This changing profile is expected to continue, with IPCC modelling data

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indicating that mean surface ozone concentrations are predicted to continue to rise throughout the 21st century. For example, predictions for eight sites in the UK indicate increases in annual mean concentration of 13% by 2030, 29% by 2060 and 55% by 2100 (Coyle and Fowler, 2003).

Studies have shown that ozone can have a number of detrimental impacts on vegetation and it is regarded as the most potent phytotoxic regional-scale air pollutant (Krupa and Kickert, 1989; Runeckles and Krupa, 1994; Fuhrer et al., 1997; Andersen, 2003; Ashmore, 2005). Even low concentrations of ozone can induce physiological toxicity in some plants (Karnosky et al., 1996). The primary impacts of ozone occur in the leaves, as the molecules are taken up directly by the plant's open stomata. Some studies have reported decreased photosynthesis and reproductive functioning in a range of plants after ozone exposure (Krupa and Kickert, 1989; Black et al., 2000) and others have recorded reduced leaf conductance, leaf area and carbon assimilation, reduced water use efficiency and flowering, and loss of stomatal control (Runeckles and Krupa, 1994; Andersen, 2003). Ozone has been identified as a contributing factor in the long-term decline of forest growth in areas of high exposure (Peterson et al., 1995). It is thought that the impacts of ozone worldwide today are considerable, and with background concentrations of ozone likely to increase during this century, it is envisaged that ozone may seriously impair food production and ecosystem function in the future (Ashmore, 2005).

For economic and geographical reasons, fewer studies have investigated the potential impacts of elevated ozone on natural and semi-natural vegetation compared to crop and tree species. So far, dose–response functions for ozone have only been derived for 80 species of natural vegetation exposed singularly (Hayes et al., 2006), with very few dose–response functions available for intact communities. Recent evidence has shown that the highest numbers of potentially ozone-sensitive communities are found in grasslands, heathlands and mire, fens and bogs (Mills et al., 2007), but these predictions have yet to be tested on whole ecosystems. Thus, the potential impact of atmospheric ozone on peatland ecosystems is an under-researched topic. This is despite the crucial role peatlands play in the global carbon cycle and their relative sensitivity to processes associated with climate change (Gorham, 1991; Freeman et al., 2001, 2004). Peatlands in the boreal and subarctic zone of the northern hemisphere are estimated to contain 455 Pg of carbon, or slightly less than that already contained in the atmosphere (Gorham, 1991); any disturbances to soil carbon cycling processes by elevated ozone could have profound implications for climate change.

There is limited understanding of how ozone-induced impacts on vegetation might affect the soil carbon cycle (Andersen, 2003; Ashmore, 2005). Plant roots are not exposed to ozone directly (Blum and Tingey, 1977), but there is potential for an upset in the normal soil carbon flux because ozone can reduce carbon acquisition and alter carbon partitioning within vegetation (Cooley and Manning, 1987). A number of studies have reported reduced allocation of carbon below ground for many different vegetation types (McCool and Menge, 1997; Edwards, 1991; Yoshida et al., 2001), but there are also results to the contrary (Duckmanton and Widden, 1994; Nouchi et al., 1995; McCrady and Andersen, 2000). Similarly, there are mixed results of the impacts on root respiration (Edwards, 1991; Nouchi et al., 1995; Scagel and Andersen, 1997). However, the general consensus is that exposure to ozone will increase the carbon demand and sink strength in leaves, leading to a reduced allocation of carbon below ground (Andersen, 2003).

A reduction in the quantity of root exudates can suppress microbial activity and therefore the rate of decomposition of soil organic matter. For example, in a forest soil, ozone-induced changes in substrate quality and soil microbial activity led to reduced decomposition (Kim et al., 1998). A long-term study into the impacts of ozone on enzymes within a forest soil measured a significant 25% reduction in the activity of the carbon cycling enzyme 1,4-β-glucosidase (Chung et al., 2006).

Although there is a degree of disparity in the results obtained for assessing below-ground responses, there is sufficient evidence to suggest that ozone can have an important impact on carbon cycling above and below ground and alterations to these processes could have serious implications for the quantity and quality of soil organic matter. These effects are of special concern given the rising background concentration of tropospheric ozone and the dearth of knowledge on impacts of ozone in the 20–50 ppb range on semi-natural ecosystems (Coyle and Fowler, 2003).

Here we report the results of a short-term fumigation experiment where mesocosms of fen and bog peat-supporting intact vegetation were exposed to elevated concentrations of ozone. The primary objective was to investigate whether increasing the concentration of atmospheric ozone to levels expected during the middle of this century can affect the quantity or quality of dissolved organic carbon (DOC) contained within the porewaters of carbon-rich peat soil.

2. Methods

2.1. Site descriptions and peat microcosm collection

Twenty peat microcosms were collected from each of two contrasting peatlands in north Wales; Cors Goch fen (UK National Grid Ref. SH 501 813), and an acidic bog within Snowdonia's Nant Francon valley (UK National Grid Ref. SH 641 616). Cors Goch is a typical minerotrophic fen, with the vegetation dominated by *Festuca rubra* and *Juncus acutiflorus* with only a small presence of *Sphagnum* mosses (<5%). The peatland within the Nant Ffrancon valley is a typical acidic bog and is dominated completely by *Sphagnum* species. The cores were collected in PVC drainpipes measuring 10 cm diameter × 40 cm depth. Surface vegetation was kept intact and as uniform as possible between the cores. For the fen samples, approximately 70% of the core surface was vegetation, with the remaining 30% as bare soil. The surface of the bog cores was 100% coverage of *Sphagnum* moss. Five replicate cores were collected for each of the four treatments. The cores were sealed and capped and placed at random into plastic boxes which were filled with deionised water. Holes in the side of each drainpipe ensured the water-table was maintained to a level just below the soil surface.