Geoderma 157 (2010) 126–132

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

# The effect of warming on the $CO_2$ emissions of fresh and old organic soil from under a Sitka spruce plantation

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ARTICLE INFO

*Article history:*
Received 5 August 2009
Received in revised form 3 March 2010
Accepted 12 April 2010
Available online 18 May 2010

*Keywords:*
Incubation
Soil respiration
Temperature sensitivity
Organic carbon

ABSTRACT

Under strictly controlled conditions we investigated the medium-term response of heterotrophic soil respiration to temperature. Soil fractions from a Sitka spruce plantation were sampled to represent "fresh" (i.e. shallower and containing more labile substrates) and "old" (i.e. deeper and presumed to contain more recalcitrant substrates) carbon sources. $CO_2$ efflux and its isotopic ($\delta^{13}C$) signature were measured using a Tunable Diode Laser. "Fresh" soil showed substantially higher $CO_2$ effluxes and its soil respiration was more sensitive to temperature in the range 5–10 °C than "old". After a 56 day incubation at 20 °C the soils were re-tested. The $CO_2$ fluxes were now lower but the sensitivity to temperature had increased in both "fresh" and "old" soils. Moreover, after this 56 day incubation the $\delta^{13}C$ signal of the $CO_2$ from the "fresh" soil had declined, indicating a change in the substrate utilised for respiration.



## 1. Introduction

Soil organic matter plays a major role in the carbon cycle. The emission of $CO_2$ from the organic matter stored in soils is one of the largest fluxes in the global carbon cycle, so small changes in the size of this flux can have a large effect on atmospheric $CO_2$ concentrations (Schlesinger & Andrews, 2000) and potentially constitute a powerful positive feedback to the climate system. Approximately 1500 Gt of organic carbon is stored in the world's soils to a depth of 1 m, with a further 900 Gt between 1 and 3 m (Jobbágy & Jackson, 2000). Annual fluxes of $CO_2$ from soil respiration have been estimated at roughly 75 Gt of carbon per year, which is more than ten times the amount emitted through the use of fossil fuels (Schlesinger & Andrews, 2000; IPCC, 2007). Of particular concern is the fact that soils of high latitudes include many peatlands and other organic soils, and store approximately one third of soil carbon globally (Biasi et al., 2005), whilst global warming is expected to be more pronounced at these high latitudes (IPCC, 2007). Moreover, Bellamy et al. (2005) presented evidence that carbon is being lost from soils in England and Wales, presumed to be the outcome of climate warming, although a more recent study has cast some doubt on this conclusion (Emmett et al., 2010).

The temperature sensitivity of soil respiration has been a topic of intense debate over recent years, as summarised by Davidson and Janssens (2006). There is evidence to suggest that under higher temperatures soil carbon decomposition will increase, thus resulting in increased $CO_2$ emissions from heterotrophic respiration (Knorr et al., 2005). However there is a contrasting opinion that soil carbon decomposition will be rather insensitive to temperature (Giardina & Ryan, 2000), being mostly determined by the supply rate of substrate. Much of the debate considers the temperature sensitivity of the labile versus recalcitrant fractions of the soil carbon. It has been suggested that the "fresh" (i.e. younger) soil carbon is more sensitive to temperature changes, whilst the older fraction is not sensitive, as it includes hard-to-decompose materials and organic matter that is protected in the interior of soil particles (Giardina & Ryan, 2000; Thornley & Cannell, 2001; Davidson & Janssens, 2006). Fang et al. (2005) have however shown that the temperature sensitivity of the recalcitrant and labile pools does not differ significantly, implying that both of these pools in the soil organic matter (SOM) will respond similarly to global warming (Fang et al., 2005). As a large component of SOM is made up of such recalcitrant material, the temperature sensitivity and potential availability as a substrate for microbial respiration of this pool are of acute importance with respect to climate change (Biasi et al., 2005).

Stable isotope analysis offers further insight into soil carbon dynamics, as it helps to identify the substrates for microbial respiration (Andrews et al., 2000). The different chemical components of SOM are a relic of aboveground processes used to manufacture biochemical compounds. Fractionation of carbon isotopes occurs during photosynthesis, and to a lesser extent during the biosynthesis of organic compounds from glucose. Plant materials which become incorporated into SOM then retain a depleted $^{13}C$ content, for example the signature of lignin can be depleted in $^{13}C$ by ~4–7‰ relative to cellulose (Blair et al., 1985, Benner et al., 1987). Fractionation during the subsequent oxidation of these compounds by soil microbes is a

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doi:10.1016/j.geoderma.2010.04.003

further determinant of the carbon isotope ratio of respired $CO_2$. It has been conversely shown that $\delta^{13}C$ values of SOM generally increase, or become more enriched with depth (Amundson et al., 1998). This enrichment with depth can vary in magnitude from ~1.7‰ up to 4‰ for $\delta^{13}C$ (Nadelhoffer & Fry, 1988; Quideau et al., 2003; Boström et al., 2007). It is therefore apparent that the $\delta^{13}C$ value of the respired signal can be significantly affected by the magnitude of decomposition at different depths in the soil profile.

The objectives of this study were:

1) To observe the effect of temperature on $CO_2$ flux from soil gathered at two depths in a profile of organic soil, representing "fresh" versus "old" organic matter.
2) To re-measure the samples after a period of several weeks incubation at 20 °C to evaluate the effect of depleting the most labile components of soil organic matter.
3) To explore the isotopic signatures of the fluxes, to see whether it is possible to distinguish different processes involved in the decomposition of "fresh" and "old" organic matter.

These objectives were achieved by measurement of $CO_2$ fluxes from soil samples brought in from the forest and incubated at controlled temperatures and moisture contents. A tunable diode laser was used to continuously measure the $CO_2$ flux, offering the possibility of isotopic analysis of the $CO_2$.

## 2. Materials and methods

### 2.1. Site description and soil sampling

Samples for incubation were collected within Harwood Forest, Northumberland, England (55° 12′ 59″ N, 2° 1′ 28″ W). Harwood Forest consists of mainly even-aged stands of Sitka spruce (*Picea sitchensis* (Bong.) Carr.). The size of the forest is approximately 4000 ha, with an elevation of approximately 300 m. The mean annual temperature of the site is 7.6 °C, with a minimum and maximum temperature in 2008 of −6.2 and 22.6 °C respectively (S. Dengel, pers comm.), whilst average annual precipitation is 950 mm (Zerva & Mencuccini, 2005; Ball et al., 2007). The dominant soil type found in Harwood forest is peaty gley, a soil that is seasonally waterlogged (Zerva et al., 2005). The forest was established on ericaceous moorland in the 1930's, through the planting of trees on top of small ridges following ploughing (Ball et al., 2007). This practice led to a peculiar structure of the soil profile, where the organic horizon is often absent in the furrows, whilst on the ridges an inversion of the usual horizon arrangement occurs (Zerva & Mencuccini, 2005). Care was taken during soil sampling to avoid such structural anomalies, by sampling in those furrows where inversion due to ploughing had not occurred.

Soil sampling took place during November 2006. Soils were sampled randomly at three sites within a single, 30 year old 2nd rotation forest stand. Previous research (Zerva & Mencuccini, 2005) at Harwood Forest has shown that most variability of soil C stocks occurs within, rather than among stands. Soils were separated into shallow ("fresh") (5–15 cm, $O_L$ layer) and deep ("old") (20–30 cm, A layer) samples and transported back to the laboratory where they were stored at 4 °C until preparation for incubations began. "Fresh" in this context does not mean newly-produced, however it did contain easily recognisable organic debris. Average soil C content was 39.1% in the "fresh" samples, and 21.7% in the "old" samples (Table 2).

### 2.2. Incubation experiment

Before the incubation experiment began, all soils were sieved to 4 mm and roots were carefully removed. For the initial incubation experiment, soils were maintained at field moisture content (75 and 62% gravimetric water content, or 91 and 88% water holding capacity for "fresh" and "old" samples respectively). They were weighed and placed into modified Erlenmeyer flasks where they were compacted to near their original field bulk density. A total of six flasks were used for the experiment (split between "fresh" and "old" soil samples). The flask lids were then sealed with grease (Apiezon N Grade vacuum grease, Apiezon Products, Manchester, U.K.). The soils were then incubated in the dark in a temperature-controlled water bath (Grant Instruments, Cambridge, U.K.). The initial incubation temperature was 5 °C, and once respiration rates had stabilised at this temperature for ~48 h the temperature was increased incrementally (from 5 °C to 10 °C to 16 °C to 22 °C) up to a maximum of 30 °C. The temperatures were chosen to be representative of temperatures found at the site, and although sustained temperatures of 30 °C are unknown at this site, this temperature was chosen so as to estimate the maximum possible effect of warming on the utilisation of soil carbon compounds. At each temperature step, respiration was measured for ~48 h after rates had stabilised. The total time course of the initial incubation experiment was 22 days. When the initial incubation was completed, all soils were adjusted to a water holding capacity (WHC) of 65%, supposedly the WHC at which microbial respiration occurs most efficiently (Howard & Howard, 1993). 100% WHC was determined as the gravimetric water content of water-saturated soil that had been allowed to drain over 6 h in a filter funnel. Once 65% WHC had been attained across all samples, the flasks containing the soils were placed in an incubator set to 20 °C for 8 weeks. The flasks were then placed back in the waterbath and respiration rates were measured over the same temperature range as per the initial incubation experiment.

### 2.3. Respiration measurements

Total heterotrophic soil respiration, and the $\delta^{13}C$ of the soil respiration were determined using a tunable diode laser absorption spectrometer (TGA 100A, Campbell Scientific Inc., Logan, Utah, U.S.A.), using methods described in detail in Bowling et al. (2003). Tubing (Decabon™ 6 mm) was used to route atmospheric air into a 100 l buffer volume, which was used to dampen rapid changes in $CO_2$. Immediately downstream of the buffer volume were the "sample" (containing soil) and "reference" (empty) flasks in the water bath. Air was continually flushed through the sample and reference flasks at approximately 0.25 l/min by a bypass pump (Busch R5 series vacuum pump, Busch UK Ltd, Shropshire, U.K.). The flow was controlled upstream of each flask by a critical flow orifice (O'Keefe Controls Co., Trumbull, Connecticut, U.S.A.), which was positioned before a heated filter which prevented condensation building up in the tubing. The sample (outlet) and reference (inlet) flasks were then individually selected and diverted through a series of manifolds, a Nafion-based drying assembly (PD 1000, Campbell Scientific Inc., Logan, Utah, U.S.A.), and mass flow controller before going into the TGA. Low pressure within the TGA (~16 mb) was maintained using a vacuum pump (XDS5, BOC Edwards, Crawley, West Sussex, U.K.).

The sample and reference lines were sampled alternately for 30 s, over a total period of 15 min for each individual sample flask. At intervals of 5 min during sampling, two calibration gases were sampled for 30 s each. Calibration gases were routed directly through a manifold into the TGA, while a standard reference gas was routed directly into the TGA.

### 2.4. Calibration gases and procedure

The two calibration gases used during the course of the experiment had total $CO_2$ concentrations of 330 ppm and 600 ppm. The TGA measures absolute $CO_2$ rather than simply their ratio, and therefore values for mole fractions of each isotope were required for each tank. The $\delta^{13}C$ of the calibration gases was measured at the Scottish Universities Environmental Research Centre (SUERC) using