ELSEVIER

Soil Biology & Biochemistry 38 (2006) 3130–3140

Soil Biology & Biochemistry

www.elsevier.com/locate/soilbio

Carbon, nitrogen and temperature controls on microbial activity in soils from an Antarctic dry valley

D.W. Hopkins[a,*], A.D. Sparrow[b], B. Elberling[c], E.G. Gregorich[d], P.M. Novis[e], L.G. Greenfield[f], E.L. Tilston[a,1]

[a]*School of Biological & Environmental Sciences, University of Stirling, Stirling FK9 4LA, Scotland, UK*
[b]*Department of Natural Resources and Environmental Sciences, University of Nevada, 1000 Valley Rd, Reno, NV 89512, USA*
[c]*Institute of Geography, University of Copenhagen, Øster Voldgade 10, DK-1350, Copenhagen K, Denmark*
[d]*Agriculture Canada, Central Experimental Farm, Ottawa, Canada K1A 0C6*
[e]*Manaaki Whenua – Landcare Research, P.O. Box 69, Lincoln 8152, New Zealand*
[f]*School of Biological Sciences, University of Canterbury, Private Bag 4800, Christchurch, New Zealand*

Received 2 September 2005; received in revised form 31 December 2005; accepted 17 January 2006
Available online 24 March 2006

Abstract

The Antarctic dry valleys are characterized by extremely low temperatures, dry conditions and lack of conspicuous terrestrial autotrophs, but the soils contain organic C, emit CO_2 and support communities of heterotrophic soil organisms. We have examined the role of modern lacustrine detritus as a driver of soil respiration in the Garwood Valley, Antarctica, by characterizing the composition and mineralization of both lacustrine detritus and soil organic matter, and relating these properties to soil respiration and the abiotic controls on soil respiration. Laboratory mineralization of organic C in soils from different, geomorphically defined, landscape elements at 10 °C was comparable with decomposition of lacustrine detritus (mean residence times between 115 and 345 d for the detritus and 410 and 1670 d for soil organic matter). The chemical composition of the detritus (C-to-N ratio = 9:1–12:1 and low alkyl-C-to-*O*-alkyl-C ratio in solid-state ^{13}C nuclear magnetic resonance spectroscopy) indicated that it was a labile, high quality resource for micro-organisms. Initial (0–6 d at 10 °C) respiratory responses to glucose, glycine and NH_4Cl addition were positive in all the soils tested, indicating both C and N limitations on soil respiration. However, over the longer term (up to 48 d at 10 °C) differential responses occurred. Glucose addition led to net C mineralization in most of the soils. In the lake shore soils, which contained accumulated lacustrine organic matter, glucose led to substantial priming of the decomposition of the indigenous organic matter, indicating a C or energetic limitation to mineralization in that soil. By contrast, over 48 d, glycine addition led to no net C mineralization in all soils except stream edge and lake shore soils, indicating either substantial assimilation of the added C (and N), or no detectable utilization of the glycine. The Q_{10} values for basal respiration over the −0.5–20 °C temperature range were between 1.4 and 3.3 for the different soils, increasing to between 3.4 and 6.9 for glucose-induced respiration, and showed a temperature dependence with Q_{10} increasing with declining temperature. Taken together, our results strongly support contemporaneous lacustrine detritus, blown from the lake shore, as an important driver of soil respiration in the Antarctic dry valley soils.

Keywords: ^{13}C nuclear magnetic resonance; Activation energy; Carbon mineralization; Decomposition; Glucose; Glycine; Lacustrine detritus; Microbial mat; Ammonium; Polar desert; Q_{10}

1. Introduction

Despite the extremely low temperatures, dry conditions and scarcity of conspicuous terrestrial autotrophs (Bargagli et al., 1999; Thomas, 2005), the soils of the Antarctic dry valleys contain organic C (Burkins et al., 2000; Barrett

---

[*] Corresponding author. Tel.: +44 1786 467755; fax: +44 1786 467843.
E-mail address: d.w.hopkins@stir.ac.uk (D.W. Hopkins).

[1] Present address: Department of Forest Ecology, Swedish University of Agricultural Sciences (SLU), 901 83 Umeå, Sweden.

0038-0717/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2006.01.012

et al., 2005; Elberling et al., 2006), emit CO_2 (Burkins et al., 2001; Parsons et al., 2004; Elberling et al., 2006) and support communities of heterotrophic soil organisms (Friedmann, 1982; Treonis et al., 1999; Stevens and Hogg, 2002). The invertebrates, notably the microbivorous and detritivorous nematodes, in the dry valley soils have been most widely studied (Freckman and Virginia, 1997; Virginia and Wall, 1999; Treonis et al., 1999; Courtright et al., 2001; Doran et al., 2002). These are detritivorous and microbivorous consumers which form the highest trophic layer in the terrestrial community (“McMurdo’s equivalent of elephants and tigers”; Wilson, 2002), and they are, therefore, indicative of the presence of micro-organisms and inputs of detritus. However, relatively little is known about the size, diversity and activity (beyond CO_2 emissions) of the micro-organisms and the resources available to them in dry valley soils.

Estimates of C turnover in the dry valleys are in the range 20–130 years (Burkins et al., 2001; Elberling et al., 2006), and Barrett et al. (2005) reported that large proportions of the organic C and N in dry valley soils are potentially mineralizable within a relatively short period (90 d) under optimal conditions. These observations indicate the presence of regular inputs of relatively labile organic residues, consistent with the hypothesis that particulate (modern) matter is transported from productive to low-productivity sites. Observations of aeolian transport of lacustrine microbial mats and endolithic communities (Parker et al., 1982; Nienow and Friedmann, 1993; Greenfield, 1998; Moorhead et al., 2003), and both increases in soil respiration along transects towards a lake and the greater concentrations of organic C at the soil surface (Elberling et al., 2006) all support this hypothesis. Under some circumstances organic C deposits originating from ancient lake sediments may also contribute to the soil C stocks in the dry valleys (Burkins et al., 2000). This is the so-called “legacy” C, the principal evidence for which comes from Taylor Valley which contained the paleaolake Washburn (~10,000–23,000 yr BP; Burkins et al., 2000). It is not, however, clear what contribution, if any, legacy C makes to contemporary C turnover. The implications of relatively fast turnover times of soil organic C in the dry valleys (Burkins et al., 2001; Barrett et al., 2005; Elberling et al., 2006) are either that legacy C deposits may be about to be exhausted, or that the legacy C is either so stable or protected that it contributes little to contemporary C cycling. If the latter is true, contemporary C cycling in dry valleys soils must be sustained largely, if not exclusively, by modern sources of organic matter.

In this paper, we examine the role of modern lacustrine detritus as a driver of soil respiration in the Garwood Valley, a small and relatively sheltered Antarctic dry valley, by characterizing the composition and mineralization of lacustrine detritus and soil organic matter and relating these to soil respiration and the controls on soil respiration.

2. Materials and methods

2.1. Site and soils

This research was conducted with soils collected in the Garwood Valley (78°01′S, 163°53′E), southern Victoria Land (Ross Sea region), Antarctica in January 2002 and 2003 (i.e. the austral summer). The Garwood Valley is a U-shaped glacial valley characterized by calcareous sandy aeolian and fluvial sediments, glacial moraines, and bedrock dominated by dolomite, granite and metamorphosed rocks. The valley runs approximately from east to west and is nearly bisected by the Garwood Glacier which divides the valley into an upper and a lower (closer to the Ross Sea) basin. The sites we used were in the upper part of the valley, bounded by the Joyce Glacier to the east and the Garwood Glacier to the west. This area is approximately 3 km long (east to west) and about approximately 4 km wide (north to south), and contains a small lake (variously referred to as Lake Colleen Foam Lake) fed by seasonal melt streams and drained in the summer, when it is partly ice-free, by a single stream running eastwards to the Ross Sea. In the summer there is regularly a moat (zone) of open water at the lake edge, and substantial amounts of foam and microbial mat that accumulate at the shore. The site is about 40 km south of the McMurdo Dry Valleys Long-Term Ecological Research site in the much larger Taylor Valley.

The land surface of the upper Garwood Valley was categorized according to topography, geomorphic features, distance from the lake shore, and soil type to give eight distinct landscape elements, further details of which are provided by Elberling et al. (2006) and summarized in Table 1. Five replicate samples of soil were collected from the 0 to 1 cm depths within each landscape element. Stones >1 cm were removed from the soils by sieving and the soils were double-wrapped in air-filled polythene bags, stored and transported to New Zealand at a temperature below 0 °C before air-freight to Stirling under refrigeration to Stirling, which took 4 d.

2.2. Lacustrine detritus

Samples of lacustrine detritus were collected from the shallow water (<10 cm deep) in the ice-free moat at the lake shore in January 2002. Two types of detritus were collected: microbial mat and foam floating on the lake surface. The microbial mat was predominantly composed of fresh bacterial, particularly cyanobacterial (*Nostoc* sp. Vaucher and *Phormidium* sp. Kützing) biomass and, presumably, recently dead micro-organisms. The foam is believed to derive from soluble compounds in the water released during microbial metabolism and degradation. Water was drained from these materials for approximately 30 min and they were stored in air-filled polythene bags for 7 d under ice in the field until refrigeration. The detritus was air-dried (50 °C), sub-samples were acid-treated (three