Biogeosciences Discussions

Biogeosciences Discussions is the access reviewed discussion forum of *Biogeosciences*

Sensitivity of microbial processes in Icelandic soils

R. Guicharnaud et al.

Title Page

Abstract	Introduction
Conclusions	References
Tables	Figures

|◄ | ►|
◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

The sensitivity of microbial processes in Icelandic soils to increasing temperatures

R. Guicharnaud[1,2,3], O. Arnalds[2], and G. I. Paton[3]

[1]Agricultural University of Iceland, Department of Land Resources, Iceland
[2]Agricultural University of Iceland, Department of Environmental Sciences, Iceland
[3]Institute of Biological and Environmental Sciences, Cruickshank Building,
University of Aberdeen, St. Machar Drive, Aberdeen AB24 3UU, UK

Correspondence to: R. Guicharnaud (rannveig@lbhi.is)

Abstract

Temperature change is acknowledged to have a significance effect on soil biological processes and the corresponding sequestration of carbon and the cycling of key nutrients. Soils at high latitudes are likely to be particularly impacted by increases in temperature. In this study, the response of a range of soil microbial parameters (respiration, nutrient availability, microbial biomass carbon, arylphosphatase and dehydrogenase activity) to temperature changes was measured in sub-arctic soils collected from across Iceland. Sample sites reflected two soil temperature regimes (cryic and frigid) and two land uses (pasture and arable). The soils were sampled from the field frozen, equilibrated at $-20°C$ and then incubated for two weeks at $-10°C$, $-2°C$, $+2°C$ and $+10°C$. Respiration and enzymatic activity were temperature dependent. Microbial biomass carbon and nitrogen mineralisation did not change with temperature. The main factor controlling soil respiration at $-10°C$ was the concentration of dissolved organic carbon. At $-10°C$, dissolved organic carbon accounted for 88% of the fraction of labile carbon which was significantly greater than that recorded at $+10°C$ when dissolved organic carbon accounted for as low as 42% of the labile carbon fraction. Heterotrophic microbial activity is governed by both substrate availability and the temperature and this has been described by the Q_{10} factor. Elevated temperatures in the short term may have little effect on the size of the microbial biomass but will have significant impacts on the release of carbon through respiration. These results demonstrate that gradual changes in temperature across large areas at higher latitudes will have considerable impacts in relation to global soil carbon dynamics.

1 Introduction

The Arctic contains about 11% of global soil organic matter (SOM) (Schimel and Mikan, 2005) while those areas referred to as "high-latitude ecosystems" may contain as much as 60% of global SOM (Hobbie et al., 2000). High latitude regions are experiencing the

most significant impacts of climate changes (Serreze et al., 2000; Schimel and Mikan, 2005) and this could result in the release of SOM in the future. It is acknowledged that the soil microbial biomass is active during sub-zero temperatures in winter months (e.g., Clein and Schimel, 1995; Mikan et al., 2002; Schimel and Mikan, 2005) because soil particles maintain liquid water films at temperatures down to $-10°C$ (Price and Sowers, 2004). Until now, most research has focussed on the high arctic environments (e.g., Mikan et al., 2002; Schimel and Mikan, 2005; Edwards et al., 2006) and the taiga (e.g., Schimel and Clein, 1996; Rodionow et al., 2006) where soils, impacted by permafrost, have limited pedological development. There has been little consideration of more mature soils or those at the margins of agricultural latitudes.

Controlled laboratory studies have frequently been used for studying the effect of temperature on soil biological parameters (e.g., Clein and Schimel, 1995; Schimel and Mikan, 2005; Panikov et al., 2006) as they enable experimental control with homogenised samples, thus removing some of the uncertainty associated with field conditions. Moreover, field measurements may not reflect the actual dependence of microbial respiration, as in the field, soil respiration is the product of both root and microbial respiration, which in turn have different temperature responses (Boone et al., 1998). Long-term incubation experiments have been criticized as they may not reflect the actual temperature dependence of microbial respiration and may underestimate the temperature dependence of rapidly depleted labile substrate pools (Boone et al., 1998; Reichstein et al., 2000). Furthermore mineral transformations in long term experiments may exaggerate measured microbial responses and experimental sensitivity may be compromised (Mikan et al., 2002). Short term incubations have been recommended for overcoming such effects (Boone et al., 1998; Reichstein et al., 2000; Mikan et al., 2002).

Iceland lies between 63 and 67° N and has a landmass of $103\,000\,km^2$. The climate is sub-arctic in the lowlands but arctic at higher elevations and the resultant soils are described as forming in cryic and frigid zones (Arnalds and Kimble, 2001). In Iceland, permafrost, is not wide spread, being found in isolated areas in the interior

(Thorhallsdottir, 1997). All soils, however, are exposed to annual freezing cycles between November and May. Iceland has the most extensive area of Andosols (volcanic soils) in Europe (Arnalds, 2004) and these soils have a propensity for high organic carbon and nitrogen sequestration (Palmason et al., 1996; Gudmundsson et al., 2004). Icelandic soils are estimated to store up to 2.1×10^9 t of soil organic carbon (Oskarsson et al., 2004). Despite the relative harshness of the Icelandic climate, these soils are highly fertile although their low bulk density and the need for land drainage makes effective soil management a considerable undertaking.

While there is a broad understanding of the physical and chemical attributes of Icelandic soils (Arnalds, 2004), there have been few biological investigations. Most soil studies have focussed on agronomical aspects and Gudmundsson et al. (2004) highlighted the inherent N limitation in these soils. Gudmundsson et al. (2004) and Ritter (2007) have postulated that these soils are associated with very significant N immobilization, but these observations have not been accompanied with empirical biological evidence.

Many techniques are available to study microbial size, activity and function in soils. In the case of this study a brief justification of selected methods can be made. The soil microbial biomass utilises the labile fraction of soil organic matter, transforming and cycling organic matter within the soil. Enzyme activities reflect the metabolic activity of key soil processes thus reflecting the responsiveness of the soil microbial biomass (mic_c) (Gianfreda et al., 2005). Soil respiration (C_{min}) is a measure of heterotrophic activity of the microbial biomass (Dawson et al., 2007). KCl extractable NH_4^+ and NO_3^- has been interpreted as a measure of soil exchangeable N (Bremner, 1965) and has frequently been used for estimating the net N mineralization, nitrification and ammonifications rates (Raison et al., 1987). While various assays have been developed for the measurement of net N_{min} (Keeny, 1982; Curtin and McCallum, 2004), workers have considered that the difference in initial versus final concentration of mineral N (NO_3^- and NH_4^+) can offer an adequate estimation of total N_{min} (Raison et al., 1987; Miller et al., 2007).

Such diverse measurements of soil microbial parameters require a degree of integration to place the measured values in a context. The widely adopted Q_{10} value is the factor by which a 10°C increase in temperature will increase the measured physiological response. The respiration coefficient Q_{10} is commonly used as an index of
5   temperature dependence (Mikan et al., 2002). The metabolic quotient (qCO_2) of the soil micro-flora (Odum, 1969) describes the ratio of respired C to assimilated biomass C and provides a comparative evaluation of the physiological condition of the soil microbial community. The soil qCO_2 has been used as an indicator of stress as soil microorganisms divert more energy from growth into maintenance as stress increases
10 (Killham, 1985). Anderson and Domsch (1993) used the qCO_2 while making an assessment of the effect of temperature on soil.

The primary aim of this study was to assess the response of soil microbial processes and nutrients dynamics in Icelandic soils to changes in temperatures. This was conducted by subjecting soils to increasing temperatures and measuring the total microbial
15 biomass and respiration, enzymatic activity and N mineralisation.

2   Methods

2.1   Sample preparation and selected soil measurements

Sample sites were selected to cover two soil temperature regimes and to include both grass (G) and barley (B) cultivation. Barley fields had been ploughed annually, while
20 grass fields were ploughed at five year intervals and reseeded with suitable sward. Sample locations were: Möðruvellir (Mö$_{cryic}$) and Glaumbær (Gl$_{cryic}$) in the North with a cryic soil temperature regime and Hvanneyri (Hv$_{frigid}$) and Korpa (Kor$_{frigid}$) in the West (Fig. 1) both from a frigid temperature regime. Sampling took place at the end of April while the soils were still frozen. From each site eight replicate 8 cm diameter stain-
25 less steel cores samplers were inserted into the frozen soil (through the turf) from 0–15 cm depth and the samples were maintained frozen during their transport to Ab-

Sensitivity of microbial processes in Icelandic soils

R. Guicharnaud et al.

erdeen, Scotland, where all preparatory work was conducted in a cooled laboratory. Field capacity was determined on thawed sub-samples as described by Kassel and Nielsen (1986). The eight replicate cores were hand mixed and bulked and sieved through a 3.75 mm sieve (discarding vegetative materials). All sample preparation was conducted in a cool room at +5°C to minimise biological activity. Thereafter soils were frozen at −20°C (Schimel and Mikan, 2005; Clein and Schimel, 1995) for two weeks (Mikan et al., 2002). After this two week period, the soils were transferred to the four separate incubators for 2 weeks at −10°C, −2°C, +2°C or +10°C. The soils were maintained at ambient moisture content (Schimel and Mikan, 2005) which ranged from 38–59% of field capacity. These values have been reported to be optimal for soils with Andic properties (Dahlgren et al., 2004). Subsamples were taken for routine analysis (bulk density (BD), organic C, N and pH (Blakemore et al., 1987).

2.2 Microbial biomass C (mic_c)

Soil microbial biomass carbon (mic_c) was determined by chloroform fumigation (Vance et al., 1987) on all soils and treatment temperatures after the 2 week incubation. Soils were placed frozen in desiccators and were allowed to thaw during the 24 h chloroform fumigation. Non-fumigated samples were extracted immediately with 25 ml $0.5 M K_2SO_4$. Dissolved organic carbon (DOC) was analysed by an aqueous carbon analyser (LABTOC Pollution and Process Monitoring) with UV digestion and infra-red detector. The K_{EC} factor used was 0.45 (Vance et al., 1987). The $0.5 M K_2SO_4$ extractable DOC from un-fumigated soils samples was used to characterize the labile carbon pool of these soils.

2.3 Soil respiration (C_{min})

Soil respiration was conducted as described by Dawson et al. (2007) by accurately weighing 1 g of field moist soil into 9 ml vacuettes. Triplicate destructive samples were maintained at −20°C for two weeks. Thereafter samples were removed from −20°C

to 4 different incubators set at temperatures -10, -2, $+2$ and $+10°C$. Thereafter soils were maintained in incubators for another two weeks prior to CO_2 analyses. During the 2 week experiment, soil respiration was measured after 4, 8 and 14 days. Twenty four hours prior to sampling, vials were sealed and sampled using a $250\,\mu l$ syringe. The CO_2 was measured using a gas chromatograph (Chrompack CP 9001) with a $2.0\,m \times 1/8'' \times 2.0\,mm$ column (Porapak QS) and N_2 carrier gas ($20\,ml\,min^{-1}$).

The Q_{10} value was calculated as a respiration coefficient based on cumulative CO_2 release over two weeks with a standard exponential rate equation over the defined temperature interval (van't Hoff, 1898):

$$Q_{10} = e^{(10 \times (\ln(R_2/R_1)/(T_2 - T_1)))}$$

where R_1 and R_2 are respiration rates at temperatures T_1 and T_2, respectively. The qCO_2 value was calculated by dividing the cumulative CO_2 respired ($\mu g\,CO_2$-C g_{OC}^{-1}) by the microbial biomass C (expressed as μg-C g_{OC}^{-1}; Odum, 1969).

2.4 Enzymatic activity measurements

Dehydrogenase activity was measured according to a modified method by Trevors (1984) at all temperatures except at $-10°C$ (reagents remained frozen). In summary, 1 g of field moist soil was placed into sterile darkened Universal bottles. Universal bottles with 1 g of soil were placed in incubator at $-20°C$ for two weeks. After the two week incubation at $-20°C$ Universal bottles were placed in 4 incubators at the four experimental temperatures ($2°C$, $+2°C$ and $+10°C$) for two weeks. After the 2 week incubation , 10 ml 0.1 M iodonitetrazolium chloride (with 0.5 M N-tris (hydroxymethyl) methyl 1-2 aminoethane-sulfonic acid (TES), adjusted to pH 7.8 with 5 M NaOH) and placed on an end-over shaker for 18 h in incubators at, $-10°C$, $-2°C$, $+2°C$ and $+10°C$. At $-10°C$ however, the added 10 ml of 0.1 M iodonitetrazolium chloride solution froze so dehydrogenase activity was not measured at that particular temperature. Thereafter 10 ml of ethanol were added and the solution centrifuged at 2750 G for 20 min.

Samples were analyzed at 490 nm on a spectrometer (Cecil Instruments CE373) and quantified against a linear calibration for iodonitetrazolium formazan (INTF).

Arylphosphatase activity was measured according to Tabatabai and Bremner (1969) at all incubation temperatures except −10°C. Prior to analyses 1g of soil was placed in Universal bottles and incubated at −20°C for tow weeks. Thereafter bottles were placed in four incubators at −2°C, +2°C, and +10°C for another two weeks. After the two week incubation at −2°C, +2°C, +10°C, 4 ml de-ionized water, 0.25 ml toluene and 1 ml 0.015 M p-nitrophenyl phosphate (substrate) was added to each bottle. Thereafter bottles were sealed with glass marbles and incubated at 37°C for 1 h, after which 1 ml 0.5 M CaCl$_2$ and 4 ml 0.5 M NaOH was added, samples were sealed with rubber bungs and then shaken for 30 s prior to filtration (Whatman No 1). Absorbance was measured at 400 nm (Cecil Instruments CE373) and concentrations were determined against a linear calibration using p-nitrophenol.

The Q_{10} coefficient was calculated as activity coefficient for dehydrogenase and aryl phosphatase activities for assessing both enzymes temperature dependence. Calculations Q_{10} coefficients were based on van't Hoff (1898) were R_1 and R_2 corresponded to enzyme activities at temperatures T_1 and T_2 respectively ($Q_{10}=e^{(10\times(\ln(R_2/R_1)/(T_2-T_1)))}$).

2.5 Extractable mineral N as an estimation of N mineralization (N$_{min}$)

Measurement of the extractable NH_4^+-N and NO_3^--N were made on soils before undergoing treatments and after the two week incubation. Five g of field moist samples were shaken in an over and under shaker for 2 h with 25 ml 2 M KCl solution, and then filtered through Whatman No 42 filter paper before quantification on a flow injection analyzer (FIAstar 5010 analyzer). All soils were extracted immediately after removal from incubators.

2.6 Data analysis

Statistical analyses were conducted using SAS 9.1 for Windows 2002–2003. After normality testing, One Way ANOVA was performed to test for significant differences between measured soil parameters, landuse systems and temperature treatments. All levels of significance are expressed as $p \leq 0.05$.

3 Results

3.1 Selected soil measurements

Soil temperature regimes and properties are summarised in Table 1. The pH values of all soils ranged from 4.3 to 6.8. BD ranged from 0.2 to 0.5 g/cm^3, soil total C from 5.1 to 25%, soil total N from 0.5 to 1.3% and soil C/N ratio from 10.2 to 14.4. There was no general relationship between measured soil properties and soil temperature regimes (Table 1).

3.2 Microbial biomass C (mic$_c$)

For individual soils, there was no significant difference between mic$_c$ at each treatment temperature with the exception of GI$_{cryic}$ (barley) were mic$_c$ was higher at sub-zero temperatures. Moreover, generally mic$_c$ values did not differ statistically between grass and barley or for soil temperature regimes (cryic and frigid) (Fig. 2).

3.3 Respiration (C$_{min}$) and DOC

C$_{min}$ (cumulative CO$_2$ release) increased with temperatures. The highest value was at +10°C for all soils with the exception of Kor$_{frigid}$, (barley and grass) with rates higher at +2°C and −2°C respectively (Fig. 3). In contrast to C$_{min}$, DOC concentrations were generally highest at −10°C and lowest at +10°C (Fig. 3). Moreover, DOC accounted

for 88–96% of total C release (respiration+DOC) (Miller et al., 2007) for both land uses (barley and grass) and temperature regimes (Fig. 3) at $-10°C$ and 42–74% of total C release at $+10°C$.

Metabolic quotients ($q\mathrm{CO_2}$ values) for all soils (barley and grass) at all temperature treatments are shown in Fig. 4. Generally temperature did not affect the $q\mathrm{CO_2}$ values with no significant differences being detected between temperature treatments and $q\mathrm{CO_2}$ values.

Overall, respiration Q_{10} values differed significantly between temperature intervals. There was no trend between highest and lowest Q_{10} values for temperature treatments. On most occasions the highest or lowest Q_{10} values for each soil were detected at the temperature range between -2 to $+2°C$ (Table 2). There was not a significant difference between Q_{10} values and soil temperature regime or land use (grass and barley). Calculated Q_{10} values for $\mathrm{C_{min}}$ revealed that soils had lowest temperature dependencies at the coldest temperatures (-10 to $-2°C$) with mean Q_{10} values of 1.14. Q_{10} values between -2 to $+2°C$ had a mean value of 4, although mean Q_{10} values were calculated to be between 1 and 2 with the exception of $\mathrm{Hv_{frigid}}$ barley with a value of 17.5 (Table 2). Temperature dependencies in the range of $+2$ to $+10°C$ were not significant with a mean Q_{10} values being on average 2.16.

3.4 Enzymatic measurements

For dehydrogenase activity, highest values were measured at $+10°C$ in all soils (Figs. 5 and 6). In general, the lowest activity was measured at the lowest temperature, although in four soils ($\mathrm{Gl_{cryic}}$ barley, $\mathrm{Hv_{frigid}}$ grass $\mathrm{Kor_{frigid}}$ barley and $\mathrm{Mo_{cryic}}$ grass) activity was significantly higher at $-2°C$ than at $+2°C$ (Fig. 5). Dehydrogenase activity was greater in soils under grass compared to barley for both soil temperature regimes (Fig. 5).

Q_{10} values differed significantly between temperature intervals and were generally highest at $+2$ to $+10°C$ (Table 2). There was no trend between Q_{10} values and soil temperature regime or land use (Table 2).

Arylphosphatase activity was generally highest at +10°C and lowest at −2°C (Fig. 6). There was a significant difference in arylphosphatase activity at −2°C compared to +2°C but not in the range of +2°C to +10°C (Table 2). Arylphosphatase activity did not differ significantly between land use (barley and grass).

5   The arylphosphatase activity quotient Q_{10} differed significantly between temperature ranges (−2 to +2°C and +2 to 10°C). The Q_{10} was higher in the −2°C to +2°C range (except for Gl_{cryic} barley and Mo_{cryic} barley) compared to Q_{10} values in the +2°C to +10°C range (Table 2). This is contrary to Q_{10} values for dehydrogenase activity, which were generally higher at the +2 to +10°C.

10 3.5 Extractable mineral N as an estimation of N immobilisation, nitrification and mineralization (N_{min})

For each soil (except for Kor_{frigid}-grass), regardless of land use or soil temperature regime (cryic and frigid), net NH_4^+−N immobilisation was the dominant process when temperatures were above zero (Fig. 7a). Where net ammonification (NH_4^+−N produc-
15 tion) was occurring, this was recorded at sub-zero temperatures (Fig. 7a). In Gl_{cryic} barley and grass soils, net ammonification occurred at −2 and −10°C (Gl_{cryic} barley) and −10°C (Gl_{cryic} grass) respectively. In Kor_{frigid} barley and grass soils, net ammonification was occurring at −2°C and −10°C and −2°C respectively (Fig. 7a).

Net nitrification (NO_3^-−N production) was site specific and independent of soil tem-
20 perature regime or land use (Fig. 7b). For both Gl_{cryic} and Kor_{frigid} soil net nitrification was the dominant process at all temperatures with the exception of Gl_{cryic} grass which had net NO_3^-−N immobilisation at −10°C and −2°C. Net NO_3^- − N immobilisation was the dominant process in Hv_{frigid} and Mo_{cryic} soils. Gl_{cryic} barley and grass had net nitrification at −10°C and −2°C and −10°C, respectively.
25 Net N-mineralisation (NH_4^+−N+NO_3^-−N), was also site specific (Fig. 7c) with there was no relationship with soil regime, landuse or incubation temperature.

4 Discussion

The physicochemical properties of the soils were similar to those that typified Andosols of Iceland (Arnalds, 2004). For the duration of the incubation experiments, mic_c did not change significantly with temperature. Lipson et al. (2000) and Sjursen et al. (2005) reported that mic_c may be unaffected by single or multiple freeze – thaw events, particularly when the events are not extreme but frequent. This is likely to be the case in Iceland where temperatures within cultivated soils rarely drop below $-5°C$ in lowland agricultural soils (The Icelandic Meteorological Office, unpublished observations). During such temperature fluctuations, microorganisms associated with the mic_c could readily assimilate substrates in the soil which would in turn enhance activity (Schimel and Clein, 1996; Lipson et al., 2000).

Measurements of C_{min} (cumulative CO_2 over 2 weeks at $-10°C$, $-2°C$, $+2°C$ and $+10°C$) increased with increasing temperatures reflecting temperature dependent soil heterotrophic activity (Fig. 3). Measurable C_{min} at sub-zero temperatures has been widely reported in high arctic, arctic and sub-arctic soils and has mostly been attributed to unfrozen water films around soil particle. These are sufficient to maintain microbial activities even at low temperatures (e.g. Coxon and Parkinson, 1987; Clein and Schimel, 1995; Brooks et al., 1997; Mikan et al., 2002; Miller et al., 2007). Q_{10} values from this study were comparable with Q_{10} values from sub-alpine organic soils (Q_{10}, 2.5) (Reichstein et al., 2000), alpine soils (Q_{10}, 2.5 to 3.8) (Fierer et al., 2006) and sub-Antarctic soils (Q_{10}, 1.8 to 2.5) (Smith, 2003), but generally lower than Arctic tundra soils (Q_{10}, 4.6 to 9.4) (Mikan et al., 2002). Although calculated Q_{10} values were highest in the range of $-2°C$ to $+2°C$, Q_{10} values in this study could not be related specifically to temperature treatment, soil regime or landuse. This confirms the complexity of the soil environment when trying to draw conclusions from single measurements but it also highlights that nutrient cycling is maintained in cold environments (Koch et al., 2007). This is further confirmed when the qCO_2 values are considered as this could suggest that the microbial stress in relation to growth and maintenance was independent of the

BGD

6, 6749–6780, 2009

Sensitivity of microbial processes in Icelandic soils

R. Guicharnaud et al.

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

|◄ | ►|

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

treatments (Killham, 1985).

Dehydrogenase and arylphosphatase activity were measured at sub-zero temperatures and this observation is in agreement with previous workers (Bremner and Zantua, 1975). The existence of unfrozen water films at sub-zero temperatures in Icelandic soils is likely due to the high relative water holding capacity and low bulk density associated with volcanic soils (Arnalds, 2004). Dehydrogenase activity correlated with the measured C_{min} ($r=0.86$, $P<0.05$). Highest dehydrogenase enzyme activity was measured at the highest temperatures. The Q_{10} values were greater in the range of $+2°C$ to $+10°C$ compared to $-2°C$ to $+2°C$ (Table 2). The Q_{10} values in the range $-2°C$ to $+2°C$ were below 2, indicating that dehydrogenase activity was less temperature dependent within that range as previously reported (Browman and Tabatabai, 1978; Tabatabai, 1982). Dehydrogenase activity was greater in grassland soils compared to barley soils and such observations are well documented as disturbance through ploughing may reduce activity (Mijangos et al., 2006).

Arylphosphatase activity has also been measured at sub-zero temperatures (Bremner and Zantua, 1975). The greatest arylphosphatase increase was observed between $-2°C$ to $+2°C$ rather than from $+2°C$ to $+10°C$, which had been the case for dehydrogenase activity. As a consequence, arylphosphatase activity coefficients (Q_{10}) were higher in the range $-2°C–+2°C$ compared to $+2–+10°C$ (Table 2). Arylphosphatase activity was more sensitive to temperature around the freezing point than dehydrogenase activity (Browman and Tabatabai, 1978).

When all carbon pools, mic_c, DOC and C_{min}, have been combined (Fig. 8), a pattern is revealed. The biomass pool remains constant throughout all temperature treatments, but as temperature rises there is a commensurate rise in respiration because the DOC pool is being metabolised. This results in lower DOC concentrations when soil respiration is highest and corresponding highest measured DOC concentrations when respiration is lowest (Fig. 8). No difference was observed in all three carbon pools at temperatures in the range $-2°C$ and $+2°C$ (Fig. 8), hence the soils have been conditioned to perform around these temperatures. The soils of Iceland experience

BGD

6, 6749–6780, 2009

Sensitivity of microbial processes in Icelandic soils

R. Guicharnaud et al.

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◄ | ►►

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

unusually frequent freeze and thaw cycles, indeed more than any other sub-arctic region (Orradottir, 2002). Hence it would be expected that the soils would be responsive around such critical temperatures.

At $-10°C$, DOC accounted for 88% of the total measured C released (respiration+DOC), but at $+10°C$ this was only 65%. This response is similar to the temperature dependent observations of Miller et al. (2007) in sub-arctic soils. Hobbie et al. (2000) stated that cold season respiration may be mediated by DOC and that this in turn would regulate microbial biomass size and activity. It has been reported that during the cold season, microbial biomass switches from processing plant detritus and SOM to relying more heavily on recycled microbial biomass and dissolved organic matter (DOM) in unfrozen water films (Schimel and Mikan, 2005; Sharma et al., 2006). These results confirm the conservative microbial dynamics of such soils and highlight that DOC is a major component of C released in the coldest temperature treatment ($-10°C$). It should though be noted that the DOC pool contains a complex mix of C compounds, some of which are more labile and will cycle fast while other might be more recalcitrant (Schimel and Mikan, 2005; Boddy et al., 2008). It has also been discussed that the more resistant fraction of DOC might have different temperature dependencies than the more labile fraction (Knorr et al., 2005; Bauer et al., 2008). Soil warming experiments have demonstrated that increased carbon efflux rates by increasing temperatures returns eventually to similar rates as before the temperature increase. This was believed to demonstrate that the response pattern was not due to acclimation response of soil microorganisms but due to depletion of readily decomposable substrate (Davidson et al., 2000; Ågren and Bosatta, 2002; Kirschbaum, 2004; Bauer et al., 2008). This study was conducted on a short time scale (2 weeks) and measured the initial breakdown of the labile fraction of DOC and it can not be excluded that if the experiment would have been conducted on a larger time scale that the response pattern would have yielded different carbon efflux rates. It is however believed that availability of labile C compounds may be a major component in controlling soil respiration of high latitude systems (Boddy et al., 2008) and studying the short term

response of the more labile fraction of DOC merits investigation.

In terms of the nitrogen dynamics, the system behaves in a more complex way than authors have reported for soils of the high Arctic (Schimel and Clein, 1996; Schimel and Mikan, 2005) and sub-arctic (Miller et al., 2007). This is not surprising as despite
5 Iceland's high latitude, these soils are productively cultivated. The soils are more mature than soils in the high arctic with a significantly larger microbial biomass, greater concentration of labile carbon and considerably more C_{min}. In each of the soils studied there was evidence of considerable ammonification as temperatures rose from $-10°C$. N_{min} occurred in certain soils simultaneously both above and below the freezing point
10 which is consistent with previous studies in the arctic and sub-arctic (e.g., Schimel and Clein, 1996; Schimel and Mikan, 2005; Oquist et al., 2004; Miller et al., 2007). There is little doubt that ammonification is more active as the temperature rises but so is the immobilisation of resultant NH_4^+ as activity per unit of microbial biomass increases. The resultant NH_4^+–N in the soils is being utilised by the microbial biomass, and this
15 can be seen by the close correlation between C_{min} (cumulative CO_2) and soil NH_4^+–N concentration (Fig. 9). At the highest NH_4^+–N concentrations, there is the lowest cumulative respiration (C_{min}) while those soils with highest microbial activity have negligible NH_4^+–N, suggesting the N limitation of these soils. These results are in agreement with other studies of sub-arctic soils that acknowledge that NH_4^+–N production is temper-
20 ature dependent and enhanced during thawed conditions (Müller et al., 2002; Miller et al., 2007). Hobbie and Chapin (1996) suggested that N limitation in arctic soils was due to decomposing litter during the cold season, while Schimel et al. (2004) stated that these ecosystems were fundamentally N limited. These results support the findings of Palmasson et al. (1996) and Gudmundsson et al. (2004) that N is the constraining fac-
25 tor in Icelandic soils. Nitrogen limitation in these soils has been attributed to three main factors (Ritter, 2007): Andic soil properties which slow down organic N turnover, low N mineralisation rates (Palmason et al., 1996) and low atmospheric N deposition (Ritter, 2007). Overall N_{min} was not temperature dependant nor was there an association with soil temperature regimes or landuse. N_{min} in cryic and frigid soils is determined by

site specific aspects such as microbial biomass composition rather than temperature. It may be further considered that N_{min} in Icelandic soils will be little affected with increasing temperatures in the Arctic but rather controlled by soil microbial activity and substrate form and availability (Koch et al., 2007).

The soils for this study were selected to reflect managed Icelandic land uses in different temperature regimes. It is acknowledged that they have a considerable carbon binding capacity and the release of carbon from these environments as a consequence of climate change could have significant global impacts. While these soils may have evolved to become conditioned to continual freeze-thaw episodes elevated temperatures could dramatically alter the microbial dynamics.

5 Conclusions

Microbial biomass size does not seem to be effected by temperature, but the resultant activity was. By selecting a range of activity measurements a better understanding of the dynamics can be developed. In this study, nitrogen dynamics seem to reflect site specific criteria rather than temperature treatments. The response of labile carbon in these soils is governed by temperature and there is a careful balance between DOC and carbon mineralisation.

Dissolved organic carbon is a complex mixture of C compounds with low molecular weight compounds being reported to be a major component in controlling soil respiration of high latitude systems. Moreover low and high molecular compounds are believed to have different temperature dependencies. A study of characterising C compounds of DOC and their temperature dependencies would be a valuable addition to understanding what mediates microbial activity in Icelandic soils.

Iceland has unique soils that have adapted to the climatic conditions, but if temperatures are to rise significantly then there is likely to be a dramatic change in soil carbon dynamics.

References

Ågren, G. I. and Bosatta, E.: Reconciling differences in predictions of tempereture responce of soil organic matter, Soil Biol. Biochem., 34, 129–132, 2002.

Anderson, T. H. and Domsch, K. H.: The metabolic quotient for CO_2 (qCO_2) as a specific activity parameter to assess the effects of environmental-conditions, such as pH, on the microbial biomass of forest soils, Soil Biol. Biochem., 25, 393–395, 1993.

Arnalds, O.: Volcanic soils of Iceland, Catena, 56, 3–20, 2004.

Arnalds, O. and Kimble, J.: Andisols of deserts in Iceland, Soil Sci. Soc. Am. J., 65, 1778–1786, 2001.

Bauer, J., Kirschbaum, M. U. F., Weilhermüller, L., Huisman, J. A., Herbst, M., and Vereecken, H.: Temperature dependence of wheat decomposition is more complex than the common approaches of most multi-pool models, Soil Biol. Biochem., 40, 2780–2786, 2008.

Blakemore, L. C., Searle, P. L., and Daly, B. K.: Methods of chemical analysis of soils, New Zealand Soil Bureau Science Report, 80, 1–103, 1987.

Boddy, E., Roberts, P., Hill, W. H., Farrar, J., and Jones, D.: Turnover of low molecular rates dissolved organic C (DOC) and microbial C exhibit different temperature sensitivities in Arctic tundra soils, Soil Biol. Biochem., 40, 1557–1566, 2008.

Boone, R. D., Nadelhoffer, K. J., Canary, J. D., and Kaye, J. P.: Roots exert a strong influence on the temperature sensitivity of soil respiration, Nature, 396, 570–572, 1998.

Bremner, J. M.: Inorganic Forms of Nitrogen, in: American Society of Agronomy, edited by: Black, C. A., Madison, Wisconsin, 1179–1237, 1965.

Bremner, J. M. and Zantua, M. I.: Enzyme activity in soils at subzero temperatures, Soil Biol. Biochem., 7, 383–387, 1975.

Brooks, P. D., Schmidt, S. K., and Williams, M. W.: Winter production of CO2 and N2O from alpine tundra: Environmental controls and relationship to inter-system C and N fluxes, Oecologia, 110, 403–413, 1997.

Browman, M. G. and Tabatabai, M. A.: Phosphatase activity in soils, Soil Sci. Soc. Am. J., 42, 284–290, 1978.

Sensitivity of microbial processes in Icelandic soils

R. Guicharnaud et al.

Title Page

Abstract	Introduction
Conclusions	References
Tables	Figures

|◀ | ▶|

◀ | ▶

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Clein, J. S. and Schimel, J. P.: Microbial activity of tundra and taiga soils at subzero temperatures, Soil Biol. Biochem., 27, 1231–1234, 1995.

Coxon, D. S. and Parkinson, D.: Winter respiratory activity in aspen woodland forest litter and soils, Soil Biol. Biochem., 19, 49–59, 1987.

Dahlgren, R. A., Saigusa, M., and Ugolini, F. C.: The nature, properties and management of volcanic soils, Adv. Agron., 82, 113–182, 2004.

Davidson, E. A., Trumbore, S. E., and Amundson, R.: Soil warming and organic carbon content, Nature, 408, 789–790, 2000.

Dawson, J. J. C., Godsiffe, E. J., Thompson, I. P., Ralebitso-Senior, T. K., Killham, K. S., and Paton, G. I.: Application of biological indicators to assess recovery of hydrocarbon impacted soils, Soil Biol. Biochem., 39, 164–177, 2007.

Edwards, K. A., McCulloch, J., Kershaw, G. P., and Jefferies, R. L.: Soil microbial and nutrient dynamics in a wet arctic sedge meadow in late winter and early spring, Soil Biol. Biochem., 38, 2843–2851, 2006.

Fierer, N., Colman, B. P., Schimel, J. P., and Jackson, R. B.: Predicting the temperature dependence of microbial respiration in soil: A continental scale analyses, Global Biogeochem. Cy., 20, GB3026, doi:10.1029/2005GB002644, 2006.

Gianfreda, L., Rao, M. A., Piotrowska, A., Palumbo, G., and Colombo, C.: Soil enzyme activities as affected by anthropogenic alterations: Intensive agricultural practices and organic pollution, Sci. Total Environ., 341, 265–279, 2005.

Gudmundsson, T., Bjornsson, H., and Thorvaldsson, G.: Organic carbon accumulation and pH changes in an andic Gleysol under a long-term fertilizer experiment in Iceland, Catena, 56, 213–224, 2004.

Hobbie, S. E. and Chapin, F. S.: Winter regulation of tundra litter carbon and nitrogen dynamics, Biogeochemistry, 35, 327–338, 1996.

Hobbie, S. E., Schimel, J. P., Trumbore, S. E., and Randerson, J. R.: Controls over carbon storage and turnover in high-latitude soils, Glob. Change Biol., 6, 196–210, 2000.

Kassel, D. K. and Nielsen, D. R. (Eds.): Methods of Soil Analysis, Part 1, Field Capacity and Available Water Capacity, 901–926, 1986.

Killham, K.: A physiological determination of the impact of environmental-stress on the activity of microbial biomass, Environ. Pollut. A, 38, 283–294, 1985.

Kirschbaum, M. U. F.: Soil respiration under prolonged soil warming: are rate reductions caused by acclimation or substrate loss?, Glob. Change Biol., 10, 1870–1877, 2004.

Sensitivity of microbial processes in Icelandic soils

R. Guicharnaud et al.

Knorr, W., Prentice, I. C., House, J. I., and Holland, E. A.: Long-term sensitivity of soil carbon turnover to warming, Nature, 433, 298–301, 2005.

Koch, O., Tscherko, D., and Kandeler, E.: Temperature sensitivity of microbial respiration, nitrogen mineralization, and potential soil enzyme activities in organic alpine soils, Global Biogeochem. Cy., 21, GB4017, doi:10.1029/2007GB002983, 2007.

Lipson, D. A., Schmidt, S. K., and Monson, R. K.: Carbon availability and temperature control the post-snowmelt decline in alpine soil microbial biomass, Soil Biol. Biochem., 32, 441–448, 2000.

Mijangos, I., Perez, R., Albizu, I., and Garbisu, C.: Effects of fertilization and tillage on soil biological parameters, Enzyme Microb. Tech., 40, 100–106, 2006.

Mikan, C. J., Schimel, J. P., and Doyle, A. P.: Temperature controls of microbial respiration in arctic tundra soils above and below freezing, Soil Biol. Biochem., 34, 1785–1795, 2002.

Miller, A. E., Schimel, J. P., Sickman, J.O., Meixner, T., Doyle, A. P., and Melack, J. M.: Mineralization responses at near-zero temperatures in three alpine soils, Biogeochemistry 84, 233–245, 2007.

Odum, E. P.: The strategy of ecosystem development. An understanding of ecological succession provides a basis for resolving man's conflict with nature, Science, 164, 262–270, 1969.

Oquist, M. G., Nilsson, M., Sorensson, F., Kasimir-Klemedtsson, A., Persson, T., Weslien, P., and Klemedtsson, L.: Nitrous oxide production in a forest soil at low temperatures - processes and environmental controls, FEMS Microbial. Ecol., 49, 371–378, 2004.

Orradottir, B.: The influence of vegetation on frost dynamics, infiltration rate and surface stability in Icelandic Andisolic Rangelands, MS thesis, Department of Rangeland Ecology and Management, Texas A&M University, USA, 2002.

Oskarsson, H., Arnalds, O., Gudmundsson, J., and Gudbergsson, G.: Organic carbon in Icelandic Andosols: Geographical variation and impact of erosion, Catena, 56, 225–238, 2004.

Palmason, F., Thorgeirsson, H., Sigurdardottir, H., Bjornsson, H., and Arnalds, O.: Nítratlosun í jarðvegi (in icelandic), Icelandic Agricultural Sciences, 10, 185–208, 1996.

Panikov, N. S., Flanagan, P. W., Oechel, W. C., Mastepanov, M. A., and Christensen, T. R.: Microbial activity in soils frozen to below −39 degrees C, Soil Biol. Biochem., 38, 3520–3520, 2006.

Price, P. B. and Sowers, T.: Temperature dependence of metabolic rates for microbial growth, maintenance, and survival, . Natl. Acad. Sci. USA, 101, 4631–4636, 2004.

Sensitivity of microbial processes in Icelandic soils

R. Guicharnaud et al.

Raison, R. J., Connell, M. J., and Khanna, P. K.: Methodology for studying fluxes of soil mineral-N in situ, Soil Biol. Biochem., 19, 521–530, 1987.

Reichstein, M., Bednorz, F., Broll, G., and Katterer, T.: Temperature dependence of carbon mineralisation: Conclusions from a long-term incubation of subalpine soil samples, Soil Biol. Biochem., 32, 947–958, 2000.

Ritter, E.: Carbon, nitrogen and phosphorus in volcanic soils following afforestation with native birch (*betula pubescens*) and introduced larch (*larix sibirica*) in Iceland, Plant Soil, 295, 239–251, 2007.

Rodionow, A., Flessa, H., Kazansky, O., and Guggenberger, G.: Organic matter composition and potential trace gas production of permafrost soils in the forest tundra in northern Siberia, Geoderma, 135, 49–62, 2006.

Schimel, J. P., Bilbrough, C., and Welker, J. A.: Increased snow depth affects microbial activity and nitrogen mineralization in two arctic tundra communities, Soil Biol. Biochem., 36, 217–227, 2004.

Schimel, J. P. and Clein, J. S.: Microbial response to freeze-thaw cycles in tundra and taiga soils, Soil Biol. Biochem., 28, 1061–1066, 1996.

Schimel, J. P. and Mikan, C.: Changing microbial substrate use in arctic tundra soils through a freeze-thaw cycle, Soil Biol. Biochem., 37, 1411–1418, 2005.

Serreze, M. C., Walsh, J. E., Chapin, F. S., Osterkamp, T., Dyurgerov, M., Romanovsky, V., Oechel, W. C., Morison, J., Zhang, T., and Barry, R. G.: Observational evidence of recent change in the northern high-latitude environment, Climatic Change, 46, 159–207, 2000.

Sharma, S., Szele, Z., Schilling, R., Munch, J. C., and Schloter, M.: Influence of freeze-thaw stress on the structure and function of microbial communities and denitrifying populations in soil, Appl. Environ. Microbiol., 72, 2148–2154, 2006.

Sjursen, H. S., Michelsen, A., and Holmstrup, M.: Effects of freeze-thaw cycles on microarthropods and nutrient availability in a sub-arctic soil, Appl. Soil Ecol., 28, 79–93, 2005.

Smith, V. R.: Soil respiration and its determinants on a sub-Antarctic island, Soil Biol. Biochem., 35, 77–91, 2003.

Tabatabai, M. A.: Soil enzymes, in: Methods of Soil Analysis, edited by: Page, A. L., Miller, R. H., and Keeney, D. R., American Society of Agronomy, Madison, Wisconsin, 775–833, 1982.

Tabatabai, M. A. and Bremner, J. M.: The use of p-nitrophenyl phosphate for assay of soil phosphatase activity, Soil Biol. Biochem., 1, 301–307, 1969.

Thorhallsdottir, T. E.: Tundra Ecosystems of Iceland, in: Polar and Alpine Tundra, edited by:

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◄ | ►

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Wiegolaski, F. E., Elsevier, Amsterdam, The Netherlands, 85–96, 1997.

Trevors, J. T.: Dehydrogenase-activity in soil - a comparison between the INT and TTC assay, Soil Biol. Biochem., 16, 673–674, 1984.

Van't Hoff, J. H.: Lectures on Theoretical and Physical Chemistry, Part 1, Chemical Dynamics, Edwards Arnold, London, UK, 1898.

Vance, E. D., Brookes, P. C., and Jenkinson, D. S.: An extraction method for measuring soil microbial biomass-C, Soil Biol. Biochem., 19, 703–707, 1987.

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

I◄ | ►I

◄ | ►

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table 1. Selected soil properties and temperature regimes for all soils, land use (barley, grass) and temperature regime (cryic, frigid). C_{tot} denotes soil total organic carbon, N_{tot} denotes soil total organic nitrogen and BD denotes soil bulk density.

Soil temperature regime	Land use	pH H_2O	C_{total} %	N_{total} %	C:N	BD $g\,cm^{-3}$	Moisture %
Gl_{cryic}	Barley	6.6	9.15	0.77	10.2	0.50	48.6
Gl_{cryic}	Grass	6.4	9.03	0.90	11.5	0.50	50.3
Hv_{frigid}	Barley	4.5	20.0	1.3	14.4	0.30	63.0
Hv_{frigid}	Grass	4.3	25.0	1.06	13.7	0.20	60.1
Kor_{frigid}	Barley	5.4	8.65	0.77	11.2	0.50	53.5
Kor_{frigid}	Grass	5.9	9.90	0.90	11.0	0.50	53.7
$Mö_{cryic}$	Barley	6.4	5.95	0.44	11.8	0.50	53.6
$Mö_{cryic}$	Grass	7.0	5.14	0.51	11.6	0.40	65.2

Table 2. Q_{10} values for cumulative C_{min}, dehydrogenase and arylphosphatase activity two weeks of incubation at $-10°C$, $-2°C$, $+2°C$ and $+10°C$. Q_{10} values are means of 3 replicates ($n=3$).

Soil location and treatment	Cumulative CO$_2$ −10 to −2°C	−2 to +2°C	+2 to +10°C	Dehydrogenase −2 to +2°C	+2 to +10°C	Phosphatase −2 to +2°C	+2 to +10°C
Gl-barley, cryic	2.8	1.3	3.5	0.2	2.0	0.3	2.0
Gl-grass, cryic	1.9	1.5	2.7	3.4	1.5	1.6	1.1
Hv-barley, frigid	0.3	17.5	2.5	1.9	1.2	218.5	0.4
Hv-grass, frigid	1.3	4.6	1.9	0.7	1.8	11.9	0.6
Kor-barley, frigid	1.1	1.6	0.9	0.4	1.6	46.3	1.2
Kor-grass, frigid	1.7	0.6	0.8	3.4	1.1	647.4	1.2
Mö-barley, cryic	1.4	0.6	3.5	1.1	1.7	0.1	1.3
Mö-grass, cryic	0.8	4.3	1.5	0.3	1.8	12.1	1.3
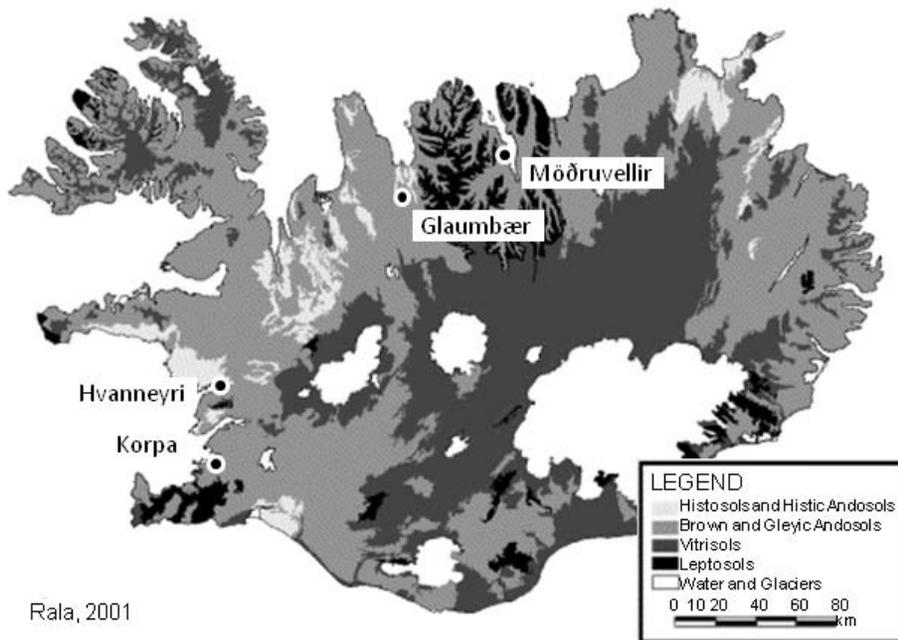
Fig. 1. A simplified soil map of Iceland with sampling locations (Modified from Arnalds and Gretarsson, 2001).

Full Screen / Esc

Printer-friendly Version

Interactive Discussion
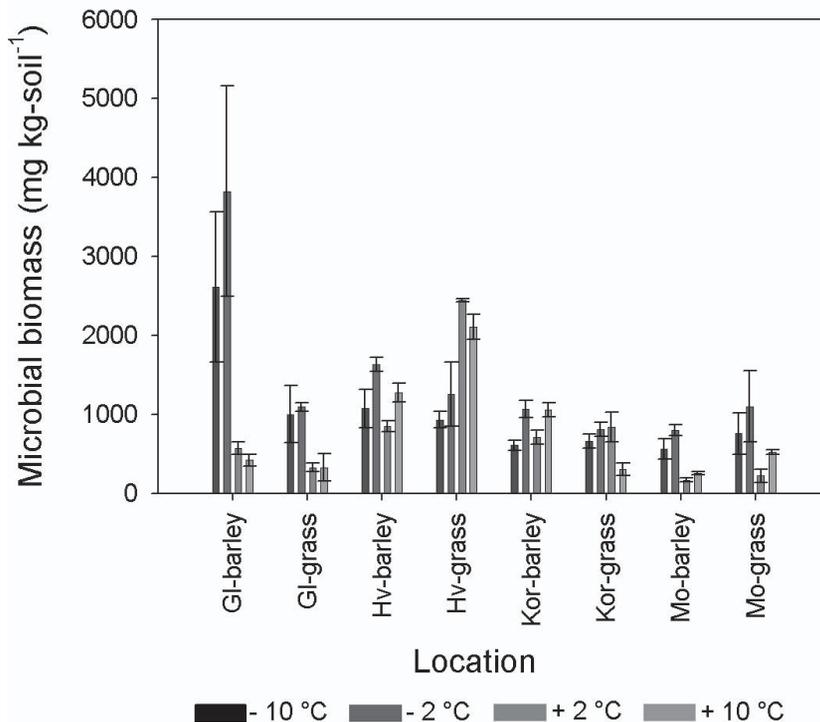
Fig. 2. Microbial biomass for all soils, land use systems and soil temperature regime after 2 weeks incubations at −10°C, −2°C, +2°C and +10°C. Columns represent mean ±1 SE (n=3). GI=Glaumbær, Hv=Hvanneyri, Kor=Korpa, Mo=Möðruvellir.
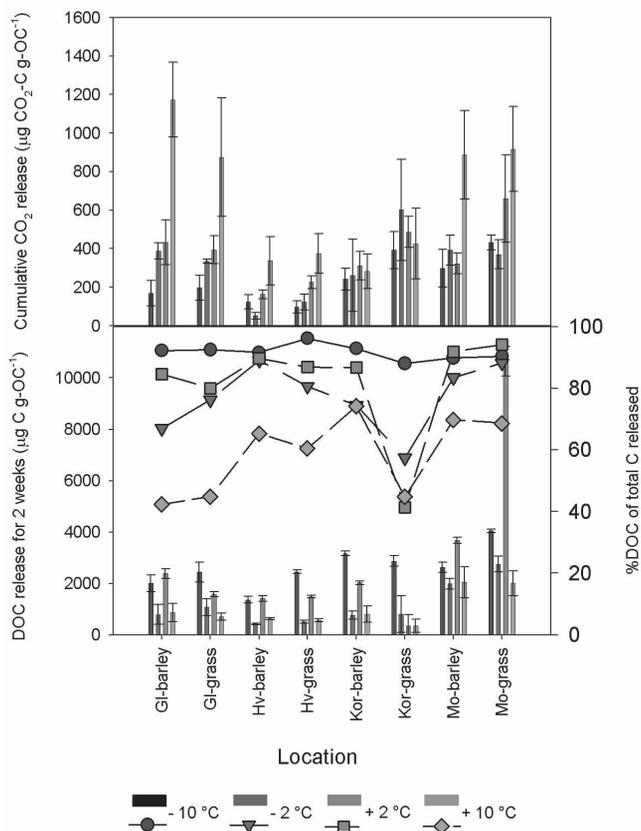
Fig. 3. Cumulative CO_2 release and DOC (from un-fumigated soil samples) after 2 weeks of incubation at $-10°C$, $-2°C$, $+2°C$ and $+10°C$. Columns represent mean ± 1 SE ($n=3$) of all soils, land use and soil temperature regime. Note the difference in scale between mineralized CO_2 and extractable DOC. Gl=Glaumbær, Hv=Hvanneyri, Kor=Korpa, Mo=Möðruvellir.
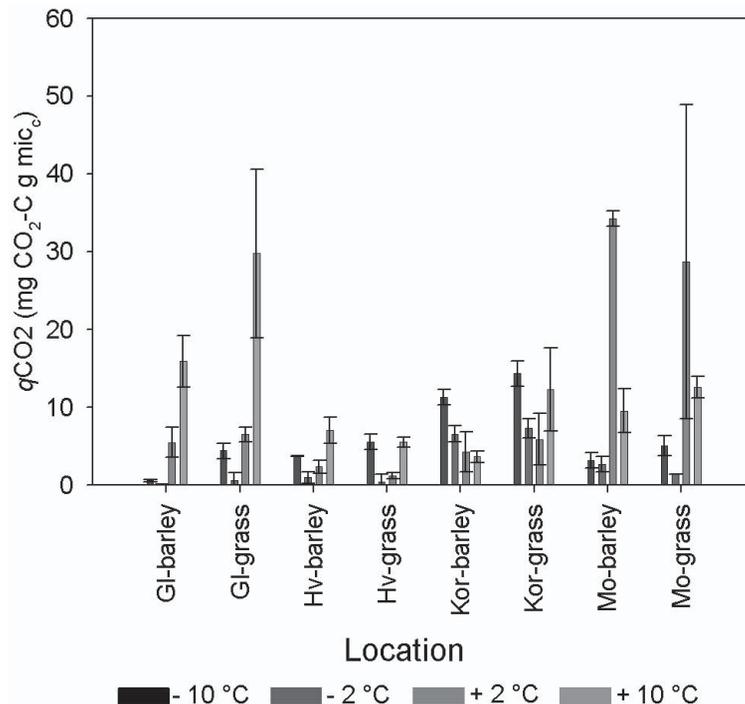
Fig. 4. qCO_2 for all soils, land use systems and soil temperature regime after 2 weeks incubation at $-10°C$, $-2°C$, $+2°C$ and $+10°C$. Columns represent mean ± 1 SE ($n=3$). Gl=Glaumbær, Hv=Hvanneyri, Kor=Korpa, Mo=Möðruvellir.

Fig. 5. Dehydrogenase activity for all soils, land use systems and soil temperature regime after 2 weeks incubation at −2°C, +2°C and +10°C. Columns represent mean ±1 SE (*n*=3). Gl=Glaumbær, Hv=Hvanneyri, Kor=Korpa, Mo=Möðruvellir.

Fig. 6. Aryl-phosphatase activity for all soils, land use systems and soil temperature regime after 2 weeks incubation at −2°C, +2°C and +10°C. Columns represent mean ±1 SE (*n*=3). Gl=Glaumbær, Hv=Hvanneyri, Kor=Korpa, Mo=Möðruvellir.
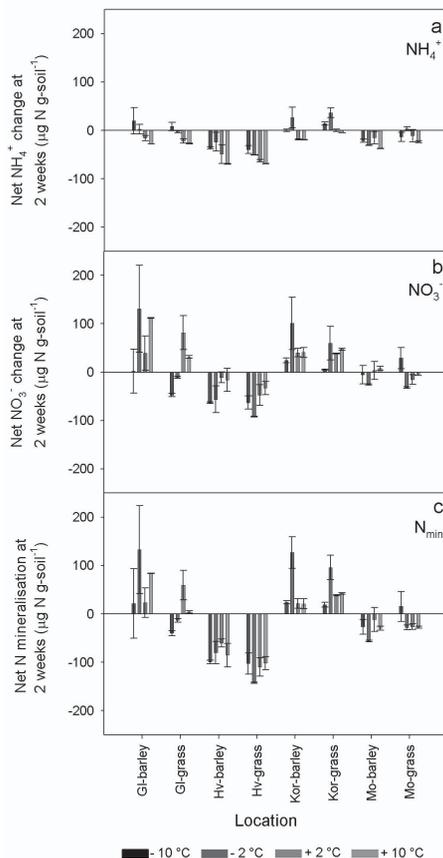
Fig. 7. Net Ammonification, nitrification and N $_{min}$ for all soils, land use systems and soil temperature regime after 2 weeks incubation at –10°C, –2°C, +2°C and +10°C. Columns represent mean ±1 SE (*n*=3). Gl=Glaumbær, Hv=Hvanneyri, Kor=Korpa, Mo=Möðruvellir.
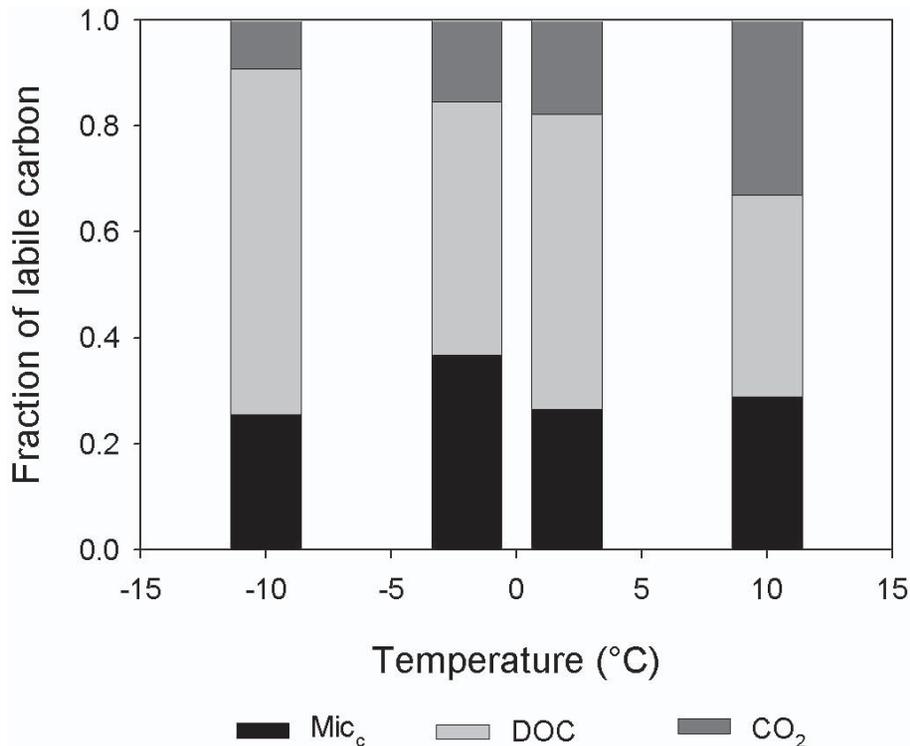
Fig. 8. C_{min} (cumulative CO_2 release) versus ammonium for all soils, land use systems and soil temperature regime after 2 weeks incubation $-10°C$, $-2°C$, $+2°C$ and $+10°C$. Columns represent mean ± 1 SE (n=3). Gl=Glaumbær, Hv=Hvanneyri, Kor=Korpa, Mo=Möðruvellir.
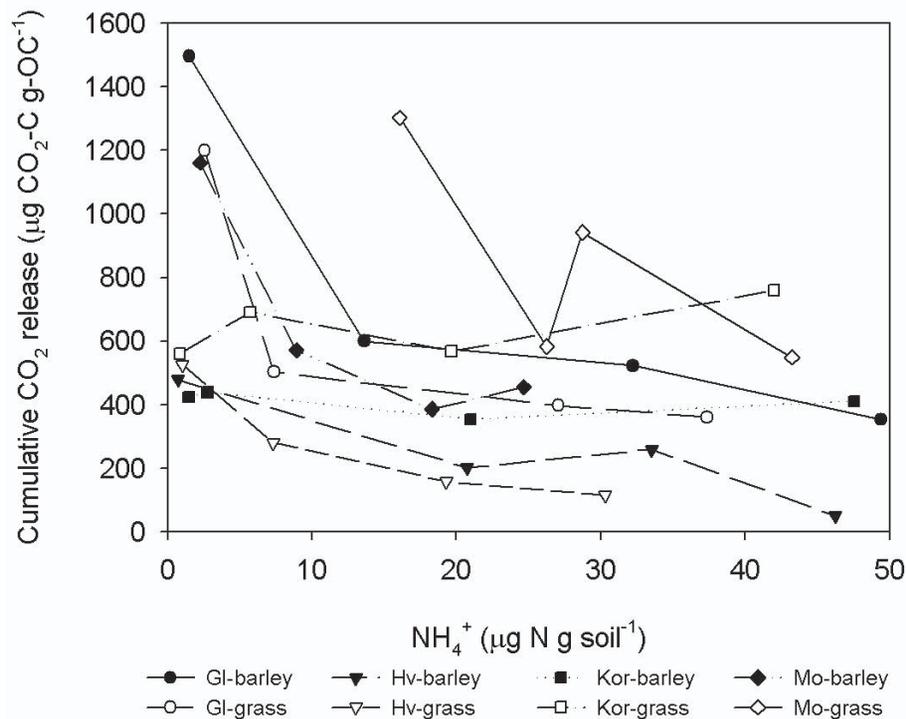
Fig. 9. Fractions of labile carbon for all soils, land use systems and soil temperature regime after 2 weeks incubation at $-10°C$, $-2°C$, $+2°C$ and $+10°C$. Columns represent mean ± 1 SE ($n=3$).