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# *In situ* incubations highlight the environmental constraints on soil organic carbon decomposition

David Risk, Lisa Kellman, Hugo Beltrami and Amanda Diochon

Environmental Sciences Research Centre, St Francis Xavier University, 1 West Street, Antigonish, NS, B2G 2W5, Canada

E-mail: [drisk@stfx.ca](mailto:drisk@stfx.ca)

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## Abstract

We use root exclusion plots, subsurface gas sampling and *in situ* diffusivity measurements to quantify *in situ* soil organic carbon (SOC) decomposition dynamics within separate depth-dependent soil pools (0 and 35 cm). We contrast these measurements with observations of temperature–decomposition potentials, generated from laboratory incubations of the same soils at optimal moisture levels and native temperatures. The decomposition–temperature response was similar at different depths in the field, but every gram of soil C at 35 cm was more than 100 times less active in decomposition than surface soil. These depth-related variations were not evident in decomposition potentials generated from aerobic laboratory incubations, highlighting the importance of environmental physical factors in constraining soil organic carbon decomposition. At depth, physical protection of SOC could match or even override the importance of quality and temperature in determining the future stability of deeper, recalcitrant pools.

**Keywords:** soil organic matter, soil carbon storage, SOC decomposition dynamics

## 1. Introduction

Evaluating soil organic matter (SOM) responses to perturbations in the physical and biological environment is critical to understanding how the terrestrial–atmospheric carbon balance may shift in the face of climate change. Increases in primary production are expected to increase SOM inputs: however, this will be offset by increases in the rates of SOM decomposition due to elevated soil temperatures [1–3]. Whether the balance will lie in a net gain or loss of soil carbon is a topic of current debate [3–6], especially the response of different soil pools to changes in soil temperature over the long term.

A variety of techniques are used to assess SOM decomposition as a function of temperature. Modeling studies have provided useful estimates of long-term SOM turnover processes [7] and contradictory results may be a result of assumptions about how different pools of SOM respond to temperature over time. Studies which assume a single soil

carbon pool and uniform turnover rate [5] are unlikely to produce results consistent with those which assume multiple pools with different turnover times [4]. Incubation experiments have also provided critical evidence [8, 9], but are conducted under non-native conditions which may explain differences in predicted temperature response [10]. In addition, the perturbation of soils in such experiments may alter soil structural properties that might otherwise play an important role in the temperature response [11, 12]. Laboratory incubations, therefore, may provide optimal decomposition responses at a given temperature, rather than an accurate representation of true rates of field decomposition.

A recurrent theme in this debate is the accurate representation of natural processes and conditions, pointing to a need for further clarification of temperature–decomposition relationships *in situ*, where soil physical properties and environment can be preserved. *In situ* approaches are valuable, because in addition to SOM quality, there are a suite of

environmental factors that contribute to the actual response of SOM to climate, vegetation and land use changes [1].

Soil profiles represent natural vertical gradients along which we might expect controlling environmental factors to impede potential rates of decomposition with increasing depth. It may be possible to quantify the role of environmental limitations on SOM decomposition along these gradients *in situ* by examining depth-specific decomposition rates [2] in soils where CO<sub>2</sub> is generated solely from microbial activity. Obtaining realistic estimates of subsurface microbial respiration rates through depth has, however, been hampered to date by issues surrounding the magnitude of gas diffusivity values used in calculation methods. The production of CO<sub>2</sub> at each depth is assumed to be the difference between the flux across soil layers. The flux (*F*) for each layer is determined from Fick's law in one dimension:

$$F = -D \frac{\partial C}{\partial z}, \quad (1)$$

where *D* is the diffusivity (m<sup>2</sup> s<sup>-1</sup>), *C* is the CO<sub>2</sub> concentration (g m<sup>-3</sup>) and *z* is depth (m). In temperate soils where soil volumetric water content is subject to large annual fluctuations (50% to <10%), *D* can vary annually by 100 or 1000 times [13]. In contrast, the annual variability in CO<sub>2</sub> concentration may only be a factor of 3 [14]. As a result, tightly constrained diffusivity values must be used to calculate within-soil CO<sub>2</sub> fluxes and production.

Detailed examinations of vertical *in situ* decomposition processes therefore require novel approaches in root-free soils that combine accurate estimates of diffusivity with corresponding vertical SOM-C concentration measurements, CO<sub>2</sub> concentration and soil climatic instrumentation—all at a single location. Soil plots where gas data, diffusivity data and corresponding temperature and moisture data are being measured collectively provide opportunities to develop and test hypotheses about how environmental factors ultimately control SOM decomposition processes in discrete subsurface soil layers.

Here we examine the temperature response of vertically distinct SOM decomposition at sites where root exclusion is made possible by trenching or removal of vegetation. We examine decomposition–temperature relationships in shallow and deep soil zones using a newly developed *in situ* diffusivity measurement system and a subsurface sampling approach [15], and compare these relationships to those developed for soils incubated under laboratory conditions in the range of native temperatures. Laboratory incubations can be considered to represent the temperature–decomposition dynamics under ideal conditions, and hence a potential, without the environmental constraints of factors that might otherwise limit decomposition rates. We use differences between the laboratory incubations (potential) and *in situ* field measurements (actual) as an indication of the role environmental controls play in decomposition dynamics at experimental plots located within a temperate zone forested soil. To our knowledge, this is the first study to combine field and laboratory estimates of subsurface CO<sub>2</sub> production to evaluate the relative control of substrate quality and environmental constraints on decomposition.

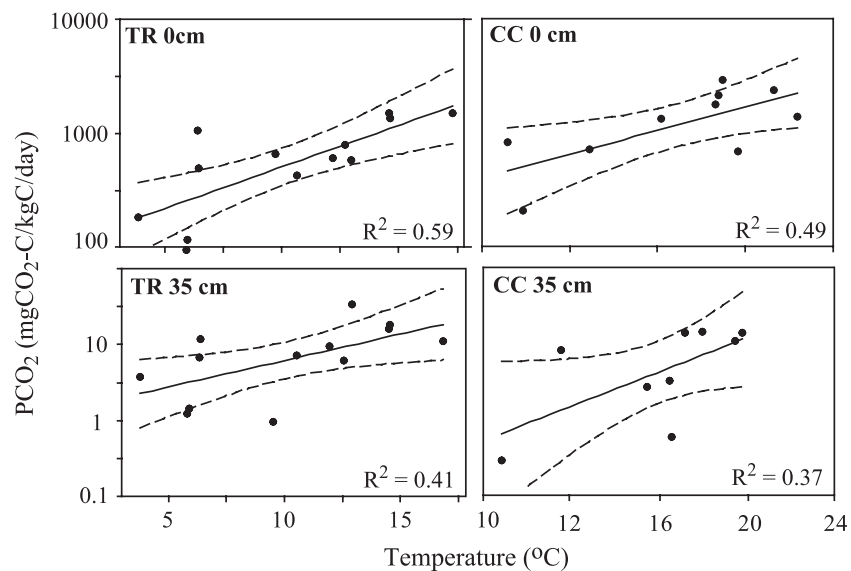
**Table 1.** Summary of soil characteristics for the intact mature forest (TR) and clearcut (CC) at 0 and 35 cm depth. Figures in parentheses represent 1 standard deviation of the mean (*N* = 3).

Site	Depth (cm)	Soil C (%)	Soil C/N (g/g)	Mean moisture (cm <sup>3</sup> cm <sup>-3</sup> )
TR	0	3.49	37(2)	0.273
TR	35	1.54	19(1)	0.273
CC	0	5.67	21(3)	0.342
CC	35	2.58	16(3)	0.342

## 2. Methods

This study was conducted in sandy textured soils in a temperate mixed forest located in Lakevale, Nova Scotia, Canada 45°45'11N, 61°57'21W. In 2003, a 40 ha section of the forest was clearcut and in 2003 2 m<sup>2</sup> experimental plots were established in both the clearcut (CC) and mature intact forest (TR). Both sites are equipped with above-and below-ground instrumentation following Beltrami [16] to monitor temperature and moisture. The CC treatment was left free of slash, regrowth has been curtailed by regular weeding and we assume that fresh carbon inputs since harvesting are negligible. In the intact forest, we employed root exclusion techniques [17, 18] to mimic the absence of root activity of the CC soils. In 2003, a 50 cm deep trench was dug around the TR plot and lined with a vapor barrier to prevent root ingrowth and to minimize lateral CO<sub>2</sub> gradients. The plot was left for one year to allow for recovery from the respiratory burst initiated by the presence of freshly severed roots. In each plot, 50 cm long subsurface equilibration tubes [14] were installed horizontally in the mineral soil at 0, 2.5, 5, 10, 20, 35 and 50 cm from a temporary pit at the side of the plot. Soil samples were collected during installation of subsurface samplers for elemental analyses (C and N) using an elemental analyzer (Euro-vector). We assume that differences in soil profile C concentrations between sites (table 1) are the result of natural spatial variability.

In 2004, we sampled subsurface CO<sub>2</sub> concentrations weekly from May to August by drawing samples from the equilibration tubes for lab analysis using a LI-7000 gas analyzer, in continuous flow configuration. Carbon dioxide concentrations were used to construct CO<sub>2</sub> concentration–depth profiles to calculate heterotrophic subsurface CO<sub>2</sub> production at two depths (0 and 35 cm) using a simplistic multi-layered diffusion model based on Fick's law ([2] and references therein). Soil gas diffusivity was parameterized using *in situ* measurements collected under a wide range of soil moisture contents with a membrane probe and automated continuous flow system [15]. The total error in CO<sub>2</sub> production estimates is roughly 2%, expressed as the RMSE of all associated uncertainties including analysis (1%), sampling, handling (3–4%), diffusivity measurement (1%, [15]) and soil moisture reflectometers used for diffusivity–moisture curves (Campbell CS616, 1.5%). While soil CO<sub>2</sub> concentrations follow typical vertical patterns in soil profiles amongst plots at these sites, they are also spatially variable [14], a reflection of variability in both gas transport rates and CO<sub>2</sub> production. Nevertheless, typical variabilities in subsurface



**Figure 1.** Relationships between soil CO<sub>2</sub> production (PCO<sub>2</sub>) and soil temperature at surface (0 cm) and depth (35 cm) for the trenched plot at the mature intact forest (TR) and clearcut (CC) forest, with 95% confidence intervals indicated by the dotted lines.

gas concentration at a single plot, where moisture and other factors that affect transport are fixed, are estimated at 30% from the coefficient of variation for triplicate samplers installed within a single soil pit at these sites. An exponential best fit model was used to describe the relationship between temperature and microbial CO<sub>2</sub> production at both soil depths for each plot. From these models, estimates of production at 10 and 20 °C allowed us to directly compare actual respiration with respiration potentials from laboratory incubations.

To evaluate C respiration potential, we conducted short-term laboratory incubations of field soils under ideal conditions [19]. Soil samples were passed through a 2 mm sieve and a subsample was dried to constant weight and homogenized for elemental analysis (% C and N,  $n = 3$ ) using an elemental analyzer. Approximately 2.5 g dry weight of the sample was committed to a 12 mL Labco exetainer and samples were inoculated following [20]. The inoculum was added until the sample was at 60% of its field holding capacity. Samples were pre-incubated at room temperature for 5 d and then incubated simultaneously at 10 and 20 °C for 3 d to allow for temperature equilibration, after which time the vials were capped with Labco screw caps with pierceable rubber septums and purged with CO<sub>2</sub> free air. Concentrations of CO<sub>2</sub> in the headspace were measured after several hours using a Multiflow coupled with a CF-IRMS (GV-Isoprime) and converted to rates of respiration (mg C-CO<sub>2</sub> kg C<sup>-1</sup> d<sup>-1</sup>).

### 3. Results and discussion

#### 3.1. In situ temperature response of SOC pools

The temperature dependence of SOC decomposition for different depths (figure 1) indicated no apparent difference in the temperature response of surface pools at either site, with overlapping 95% confidence intervals on exponential regressions. At depth, we observed sluggish CO<sub>2</sub> production

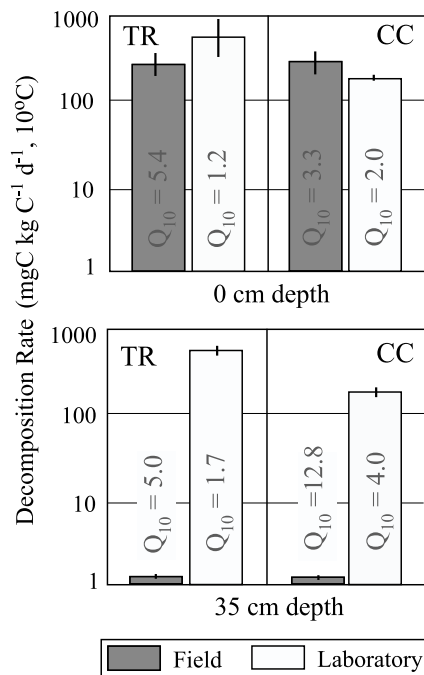
rates overall, and, at the CC site, a high temperature dependence. We expected that any observed depth differences would be linked to SOM quality or to *in situ* differences in microbial community dynamics, and subsequent sections address their possible underlying causes.

#### 3.2. Field in situ rates of SOC decomposition

The decomposition rate per unit kg of soil C, observed and normalized for soil temperature (10 °C), allows comparison of the activity of each gram of soil C, in shallow and deep pools, and for plots where environmental factors, including soil temperature, may differ as a consequence of clearcutting (figure 2). Respiration of TR and CC deep layers are comparable, and every gram of soil C is >100 times less active in decomposition than at the surface, indicating high recalcitrance, and/or the importance of conditions that limit microbial activity (or access to substrate) at this depth. While within-plot variabilities in CO<sub>2</sub> concentrations were high, and prevent differentiation of observed temperature-dependent decomposition rates between sites at a given depth, these data highlight the depth-dependent differences in decomposition rates at both sites.

#### 3.3. Potential decomposition versus observed field decomposition

Decomposition rates of surface soils are of similar magnitudes in the field and under laboratory conditions (figure 2). Most interestingly, though, while we observe decomposition rates in the deep soil profile that are many times (>100×) slower than at the surface, incubation of these soils yield contrasting results (figure 2), even after correcting for differences in carbon content. Incubation of these soils in the range of native temperatures and under optimal conditions of moisture suggest the soils have the potential to respire at much greater rates than



**Figure 2.** Observed decomposition rates of SOM in the field and laboratory at 0 and 35 cm depth, standardized for soil C content and temperature. Error bars for lab data show variability between replicate samples, and for field data represent the known coefficient of variability (30%) in subsurface CO<sub>2</sub> between replicate gas samplers at a study site. TR and CC denote intact forest and clearcut sites, respectively.

observed in the field, and in fact at rates that are comparable on a per gram of carbon basis to the surface measurements. Rates of decomposition are in the reported range for surface (0–10 cm, 600–900 mg C–CO<sub>2</sub> g C<sup>-1</sup> d<sup>-1</sup>) and subsurface (35–50 cm, 120–800 mg C–CO<sub>2</sub> g C<sup>-1</sup> d<sup>-1</sup>) mineral soils incubated around 20 °C [21–23] and our laboratory incubation results are consistent with incubation studies such as Fang *et al* [6] that have shown far smaller differences (~2–4×) between surface and deep soil decomposition rates. Incubations did not show the dramatic differences in decomposition rates between depths, or the wide range of Q<sub>10</sub>s that we observed *in situ* (figure 2), suggesting that SOM quality differences may, in fact, be negligible relative to differences imposed by environmental conditions in the field.

*In situ*, many physical mechanisms of SOM protection such as texture, aggregation/occlusion, soil moisture, oxygen availability and compaction [1] act to limit potential respiration rates observed in laboratory incubations. On an individual basis, it is not well understood how these factors might manifest themselves in the microbial community with respect to decomposition rates and the temperature sensitivity of decomposition. In addition, soil parameters may co-vary with temperature to obscure the pure temperature response. For example, at our sites temperature and moisture are strongly coupled and early season saturation strongly inhibits soil respiration, but when temperatures rise, soils dry, pores become aerobic and high soil gas diffusivities help replenish consumed oxygen. Together, these factors boost decomposition rates over short time and temperature intervals,

as reflected in the field Q<sub>10</sub>s (figure 2) and are unlikely to represent a pure temperature response. While the CC plot experienced higher temperatures (see figure 1), mean moisture values for the study period were also higher for this plot, due to reduced transpiration rates associated with harvesting of the vegetation.

Although *in situ* SOM decomposition studies must be approached and interpreted carefully, they should assume an important role in questions pertaining to future soil organic carbon stability, providing contrast and context to the decomposition potentials and climatic responses observed during laboratory incubation. These results suggest that *in situ* depth-dependent environmental factors may match or even override the importance of carbon quality in determining SOM stability, and that these effects could be disproportionately important for slower cycling pools which dominate at greater depths.

#### 4. Conclusions

The goal of this study was to examine decomposition rates and temperature responses in vertically distinct, root-free soils both *in situ* and in the laboratory in order to quantitatively evaluate the role environmental limitations may play in SOM decomposition dynamics.

Deep soil layers (35 cm) at these sites produced >100 times less CO<sub>2</sub> per gram of organic C than surface (0 cm) layers, suggesting critical differences in controls on decomposition through depth. Contrasting results from laboratory incubations lead us to question the role of SOM quality as a major control on *in situ* decomposition rates, and confirm that real-world dynamics are complex and unique to the *in situ* environment. Of particular importance may be physical mechanisms of protection that limit microbial activity and/or substrate availability. We propose that these factors could match or even override the importance of SOM quality in determining the future stability of deep, recalcitrant carbon pools at these and other study sites. While past soil carbon research has been overwhelmingly focused on biochemical processes, generating realistic predictions of C sequestration or C loss will require that new research also targets soil physical factors as a critical determinant of decomposition rate.

Although covariant factors can make the interpretation of data more complicated, *in situ* studies provide the only hope of capturing true decomposition–climate responses. We recommend that *in situ* and laboratory research be conducted in tandem to (1) confirm that measured potential laboratory responses are in fact observed in the field and (2) determine the extent to which additional physical factors influence organic matter pool stability.

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## References

- [1] Davidson E A and Janssens I 2006 Temperature sensitivity of soil carbon decomposition and feedbacks to climate change *Nature* **440** 165–73
- [2] Risk D, Kellman L and Beltrami H 2002 Soil CO<sub>2</sub> production and surface flux at four climate observatories in eastern Canada *Global Biogeochem. Cycles* **16** 1122
- [3] Kirschbaum M U F 2000 Will changes in soil organic carbon act as a positive or negative feedback on global warming? *Biogeochemistry* **48** 21–51
- [4] Knorr W, Prentice I C, House J I and Holland E A 2005 Long-term sensitivity of soil carbon turnover to warming *Nature* **433** 298–301
- [5] Giardina C P and Ryan M G 2000 Evidence that decomposition rates of organic carbon in mineral soil do not vary with temperature *Nature* **404** 858–61
- [6] Fang C, Smith P, Moncrieff J B and Smith J U 2005 Similar response of labile and resistant SOM pools to changes in temperature *Nature* **433** 57–9
- [7] Torn M S, Vitousek P M and Trumbore S E 2005 The influence of nutrient availability on SOM turnover estimated by incubations and radiocarbon modeling *Ecosystems* **8** 352–72
- [8] Fierer N, Craine J M, McLauchlan K and Schimel J P 2005 Litter quality and the temperature sensitivity of decomposition *Ecology* **86** 320–6
- [9] Reichstein M, Bednorz F, Broll G and Katterer T 2000 Temperature dependence of carbon mineralisation: conclusions from a long-term incubation of subalpine soil samples *Soil Biol. Biochem.* **32** 947–58
- [10] Agren G I and Bosatta E 2002 Reconciling differences in predictions of temperature response of SOM *Soil Biol. Biochem.* **34** 129–32
- [11] McNerney M and Bolger T 2000 Temperature, wetting cycles and soil texture effects on carbon and nitrogen dynamics in stabilized earthworm casts *Soil Biol. Biochem.* **32** 335–49
- [12] Schjonning P, Thomsen I K, Moberg J P, de Jonge H, Kristensen K and Christensen B T 1999 Turnover of organic matter in differently textured soils—I. Physical characteristics of structurally disturbed and intact soils *Geoderma* **89** 177–98
- [13] Millington R J 1959 Gas diffusion in porous media *Science* **130** 100–2
- [14] Bekele A, Kellman L and Beltrami H 2007 Soil profile CO<sub>2</sub> concentrations in forested and clear cut sites in Nova Scotia, Canada *For. Ecol. Manag.* **242** 587–97
- [15] Risk D, Beltrami H and Kellman L 2008 A new method for *in situ* soil gas diffusivity measurement and applications in the monitoring of subsurface CO<sub>2</sub> production *J. Geophys. Res.* **113** G02018
- [16] Beltrami H 2001 On the relationship between ground temperature histories and meteorological records: a report on the Pomquet station *Global Planet. Change* **29** 327–52
- [17] Bond-Lamberty B, Wang C K and Gower S T 2004 Contribution of root respiration to soil surface CO<sub>2</sub> flux in a boreal black spruce chronosequence *Tree Physiol.* **24** 1387–95
- [18] Lavigne M B, Boutin R, Foster R J, Goodine G, Bernier P Y and Robitaille G 2003 Soil respiration responses to temperature are controlled more by roots than by decomposition in balsam fir ecosystems *Can. J. For. Res.* **33** 1744–53
- [19] Robertson G P, Blair J M, Groffman P M, Harris D, Holland E, Nadelhoffer K and Wedin D 1999 Soil carbon and nitrogen availability: nitrogen mineralization, nitrification, and soil respiration potentials *Standard Soil Methods for Long-Term Ecological Research* ed G P Robertson, C S Bledso, D C Coleman and P Sollins (New York: Oxford University Press) pp 258–71
- [20] Swanston C W, Caldwell B A, Homann P S, Ganio L and Sollins P 2002 Carbon dynamics during a long-term incubation of separate and recombined density fractions from seven forest soils *Soil Biol. Biochem.* **34** 1121–30
- [21] Cote L, Brown S, Pare D, Fyles J and Bauhus J 2000 Dynamics of carbon and nitrogen mineralization in relation to stand type, stand age and soil texture in the boreal mixedwood *Soil Biol. Biochem.* **32** 1079–90
- [22] Fierer N, Schimel J P and Holden P A 2003 Controls on microbial CO<sub>2</sub> production in surface and subsurface soil horizons of a California grassland *Global Change Biol.* **9** 1322–32
- [23] Fang C and Moncrieff J B 2005 The variation of soil microbial respiration with depth in relation to soil carbon composition *Plant Soil* **268** 243–53