TEMPERATURE SENSITIVITY OF ORGANIC MATTER MINERALISATION IN SOILS WITH CONTRASTING MANAGEMENT HISTORIES

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Abstract
Temperature is a key regulator of the mineralisation of soil organic matter (SOM). Kinetic theory suggests that the temperature dependence of mineralisation is greater for recalcitrant than for labile forms of SOM, but little experimental evidence exists to support this hypothesis. A strong temperature-dependence for recalcitrant SOM, which makes up the bulk of the SOM in soils, would mean that the size of the feedback to global warming may be larger than predicted by current models. The purpose of this study was to quantify the impacts of temperature on mineralisation of SOM fractions in selected treatments from the Millennium Tillage Trial. Three size fractions (>50, 5-50 and <5 µm) were isolated using standard sieving and sedimentation methods after dispersion by overnight shaking with glass beads in deionised water. Carbon (C) mineralisation (respiration) was determined by incubating subsamples of the fractions at three temperatures (5, 15, 25°C) for 98 d (water potential adjusted to -60 kPa). The results confirmed that that the particulate organic matter (POM, i.e., >50 µm fraction) was most labile and the clay-associated (<5 µm) organic matter least labile. In all fractions, mineralisation increased exponentially with temperature (Q_{10} values ranged from 1.9 to 2.6). The temperature dependence of mineralisation (expressed as the absolute increase in CO_2-C evolution between 5 and 25°C) was large for POM, intermediate for the 5-50 µm fraction and low for clay-associated organic matter. This sequence is the reverse of what would be predicted by kinetic theory.

Introduction
Concern over climate change has stimulated interest in the temperature-dependence of SOM mineralisation. Loss of soil organic C induced by a warmer climate could provide a positive feedback and accelerate the rate of global warming (Schimel et al., 1994; Bond-Lamberty and Thomson, 2010). Temperature, as a main regulator of microbial processes, affects the rate of organic matter mineralisation (Lloyd and Taylor, 1994). Soil contains different types of organic matter (labile and recalcitrant SOM), each with its own kinetic properties that influence the temperature dependence of their mineralisation. Kinetic theory suggests that recalcitrant organic matter, which accounts for large proportion of SOM, may be especially sensitive to an increase in temperature. Thus, one could expect that soil could become a significant net source of CO_2 evolution in response to global warming. However, published evidence that recalcitrant organic matter has a greater temperature-dependent mineralization response than labile organic matter is inconclusive.

Fractionation techniques are widely used to quantify and characterize organic C dynamics in soils (Plante et al., 2010). Separation of organic matter into different fractions enables better understanding of the mineralisation process. Carbon associated with the sand fraction (particulate organic matter) is generally considered a labile SOM pool with a short turnover time (Cambardella and Elliot, 1992; Gregorich et al., 2006). The organic matter bound to the fine particle-size fraction (silt and clay) is usually considered to be less biologically active because it is more humified and protected through microaggregation, adsorption by strong ligand exchange and polyvalent cation bridging.

The objective of this study was to test the kinetic hypothesis that recalcitrant organic matter is particularly temperature sensitive, by quantifying the effect of temperature on mineralisation of SOM present in different particle size fractions.

Materials and Methods

Site description

The soils used in this study were taken from the Millennium Tillage Trial which was established in 2000 (on a Wakanui silt loam at Lincoln) to identify the effects of management (tillage type; winter cover crops) on SOM following the conversion of long-term pasture to arable cropping. The following treatments were sampled in 2011: (1) long-term ryegrass-clover pasture; (2) arable cropping rotation, managed using no-tillage; and (3) chemical fallow, plots maintained plant-free since 2000 using herbicides; not cultivated. The pasture treatment, which represents the pre-trial land use, was maintained within the trial as a control (it had not been cultivated for at least 15 years prior to the trial) (Figure 1).

Figure 1: Aerial view of the experimental plots at Lincoln.

Samples (0–7.5 cm) were collected from three replicate plots of each treatment. Field replicate samples were composited and passed through a 4 mm sieve. Visible root material was removed by hand picking during sieving. Samples were stored field-moist in a refrigerator prior to fractionation and incubation.

Soil fractionation methods

Three size fractions (>50, 5-50, and <5 µm) were separated by sieving and sedimentation after dispersion by overnight shaking with glass beads in water.

Incubation

Sub-samples of the fractions and whole soils were incubated at three temperature (5, 15, 25ºC) for 98 days (moisture potential -60 kPa). Carbon mineralisation (soil respiration) was measured by determining evolved CO_2 at intervals of 3-9 days. Measurements were made in triplicate.

Data analysis

We used the van't Hoff equation to describe the temperature dependence of C mineralisation:

$$y = De^{bt}$$

where y is the amount of C mineralized in 98 days, t is temperature in ^oC, D is the intercept (mineralisation at 0^oC) and b is a constant. The Q_{10} value, the factor by which mineralisation increases for a 10^oC increase in temperature, was calculated from the equation:

$$Q_{10}=e^{10b}$$

Temperature responses were also estimated by calculating the actual increase in mineralisation between 5 and 25^oC. Data were analysed using ANOVA (GenStat v.12) and Figures were created using SigmaPlot v.10.

Results and Discussion

Total organic C in whole soil ranged from 21.8 to 37.9 g/kg soil (Table 1). After 10 years, there were large decreases in C under arable cropping and, even more so, under chemical fallow.

Most (35.3-59%) of the C was present in the clay (< 5µm) fraction, followed by the silt fraction, with least in the sand fraction. This finding is consistent with previous reports (Gregorich et al., 1989; Bonde et al., 1992). The C losses under cropping and fallow were mainly from the sand size (i.e. particulate organic matter, POM) and silt size (5-50 µm) fractions. These results confirm that the POM is a labile form of organic matter and that the clay-bound organic matter is recalcitrant.

Table 1: Carbon in size fractions and whole soils.

Treatment	Carbon (g/kg soil)				
	Whole soil	Sand†	Silt	Clay	LSD (5%)
Pasture	37.9	8.9	14.1	13.4	0.64
Cropping	26.5 (30%)	5.4 (39%)	8.8 (37%)	11.2 (16%)	0.30
Fallow	21.8 (43%)	2.2 (76%)	5.7 (60%)	12.9 (4%)	0.60
LSD (5%)	2.3				

†Sand>50 µm; silt 5-50 µm; clay <5 µm.

Brackets indicate decrease relative to pasture.

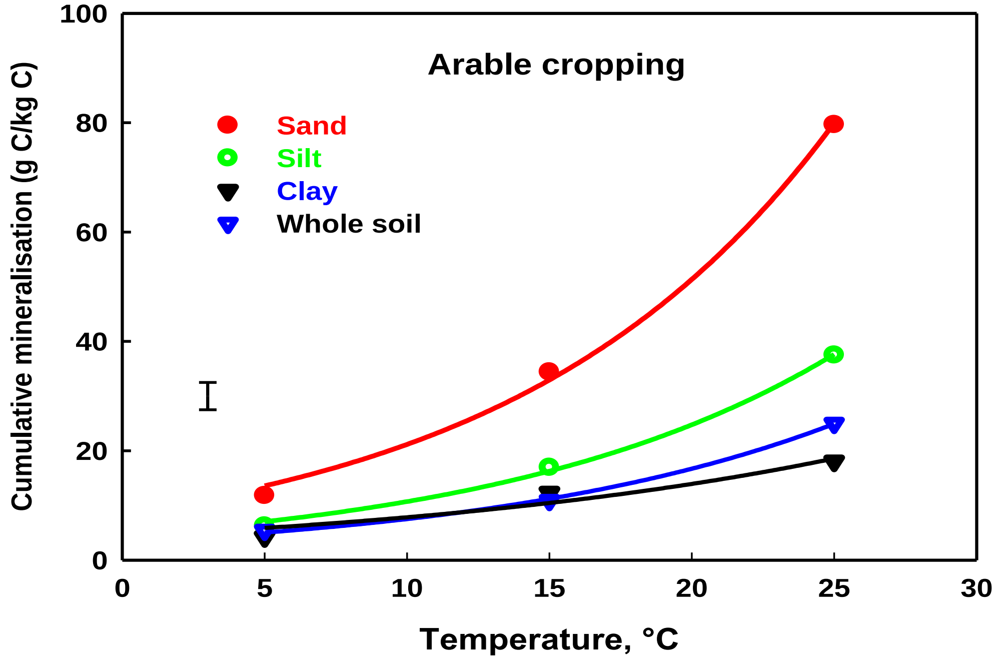

Figure 1: Effect of temperature on carbon (C) mineralisation (98 days) in soil fractions and whole soil. Error bar represents standard error of the mean (n=3).

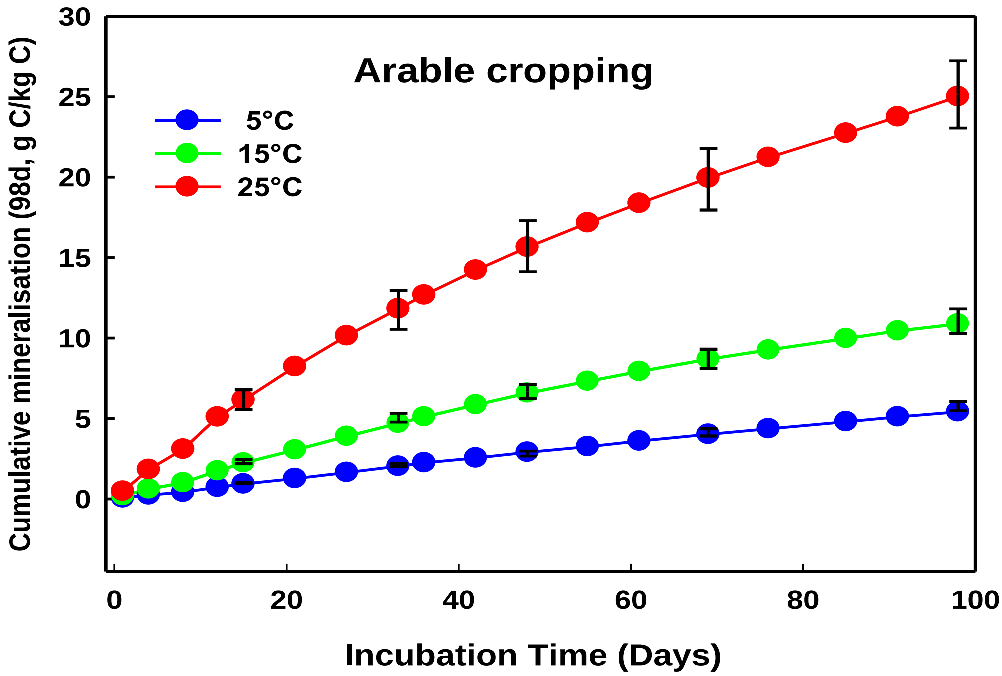

Figure 2: Cumulative mineralisation of carbon (C) in arable soil at three temperatures during 98-day incubation. Error bars represent standard error of the mean (n=3).

Over the 98-day incubation, the cumulative C mineralized differed (P<0.001) among particle size fractions and temperatures (Figures 1 and 2). Mineralisation (the amount of C mineralized per unit of C in each fraction) was substantially higher for POM and the silt-associated organic matter than for the clay-bound organic matter. The high C mineralisation rate of POM may be attributed to weak bonding of partly decomposed plant debris to sand-size particles. Strong bonding to clay minerals limits microbial access to organic C in the clay fraction, resulting in low rates of decomposition.

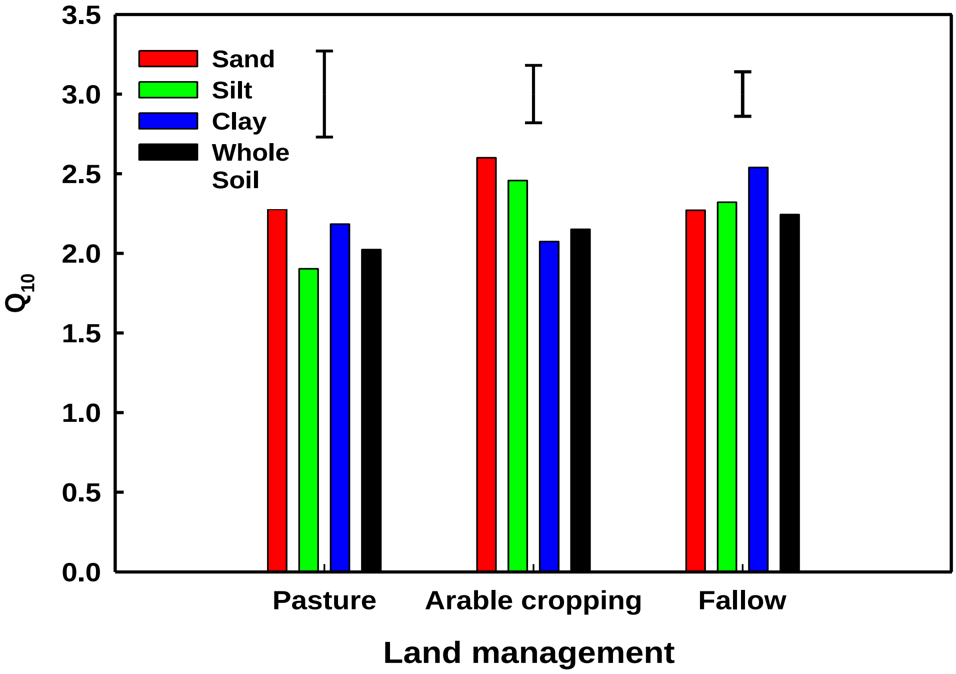

Figure 3: Q_{10} value for soil fractions and whole soils under different managements.

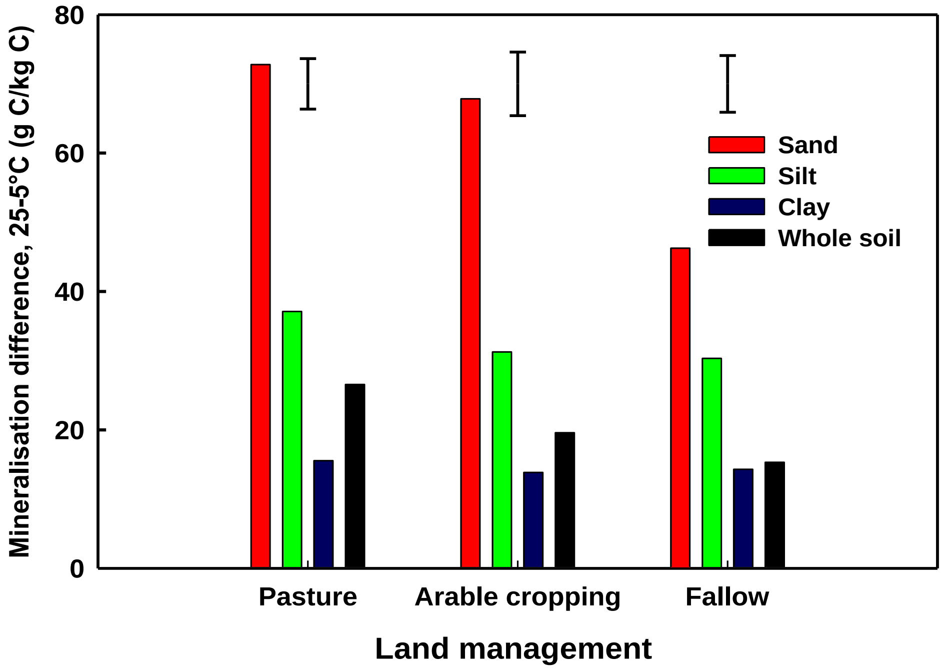

Figure 4: Carbon mineralisation temperature response (i.e., mineralisation at 25ºC minus mineralisation at 5ºC) of soil fractions and whole soils. Error bars represent standard error of the mean (n=3).

The temperature response of C mineralisation was exponential in all cases (Figure 1). The soil fractions (and whole soils) had similar Q_{10} values and did not show a significant difference (Q_{10} ranged from 1.9 to 2.6; Figure 3). Thus, mineralisation approximately doubled for each 10°C increase in temperature. However, the absolute response to temperature was greatest for the labile fractions (POM > silt > clay; Figure 4) because they had much higher “basal” mineralisation rates. Our results are consistent with those of Plante et al. (2010), who suggested that recalcitrant SOM was less temperature sensitive.

Conclusions

After 10 years of continuous management, the soils investigated provided a clear gradient of organic matter: pasture > arable cropping > fallow. Sand (POM) and silt-size fractions accounted for most of the C loss in the arable and fallow treatments. Carbon mineralisation exhibited exponential responses to temperature in all fractions. No significant difference of Q_{10} values between fractions was found. Absolute temperature response (increase in mineralisation between 5 and 25°C) was greater for labile fractions (POM > silt > clay). We conclude that recalcitrant SOM will be less affected by increases in temperature than the labile SOM.

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