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Short communication

Interactive effects of liming and nitrogen management on carbon mineralization in grassland soils

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ABSTRACT

Grassland management has the potential to modify soil carbon (C) mineralization, but the relative importance of combined soil improvers or fertilizers and land use intensity on C mineralization remains unclear. We used laboratory incubations to examine the interactive effects of lime addition, mineral N inputs and grassland management intensity on soil C mineralization potential over 84 days. Monitoring of CO_2 production and O_2 consumption was coupled with measurements of soil pH and microbial biomass for soils obtained from grasslands with contrasting levels of land management intensity (extensive versus intensive N management) at each of three upland sites. Lime addition increased soil pH, cumulative CO_2 production and O_2 consumption across all N treatments and soils. These positive effects of liming either partly or fully compensated the observed negative effects of N on CO_2 and O_2 fluxes. Responses to combined liming and N addition varied depending on management intensity; N addition had no effect on liming response ratios for O_2 consumption at intensively-managed sites, but increased the magnitude of positive liming response ratios for O_2 consumption at extensively-managed sites. Overall, our results suggest that the magnitude of liming-induced increases in C mineralization is mediated by effects of both past and present N management on the soil microbial community. This highlights the importance of considering agricultural practices when assessing the net contribution of agricultural liming to soil-atmosphere feedbacks on climate change.

1. Introduction

Soil organic carbon (C) mineralization is a key biogeochemical process with the potential to regulate global atmospheric CO_2 concentrations. In agroecosystems, management practices modify both biotic and abiotic soil properties, which may influence the dynamics of soil organic matter. However, the impact of simultaneous management practices on C mineralization in different soils remains unclear. Improved understanding of the drivers of soil C mineralization is critical for the development of sustainable agricultural practices and effective climate mitigation strategies (Lal, 2004; Fornara et al., 2011).

Lime and inorganic nitrogen fertilizers are commonly added to agricultural soils to improve plant productivity (Haynes and Naidu, 1998). In temperate grasslands, the aim of liming is to increase soil pH and offset soil acidity, providing optimum conditions for plant growth and improving plant nutrient-use efficiency. Liming-induced increases in pH generally promote microbial activity, and are often considered to stimulate C mineralization (Curtin et al., 1998; Paradelo et al., 2015), although lime-derived carbon also contributes to CO_2 emissions and may lead to overestimations of soil organic C mineralization from soils (Bertrand et al., 2007; Biasi et al., 2008). Conversely, nitrogen addition typically decreases soil respiration and microbial biomass in grassland soils (Geisseler et al., 2016; Ramirez et al., 2012). In practice, liming and N inputs may both be applied to managed grasslands since N fertilization and NH_4^+ accumulation promote soil acidification (Bolan and Hedley, 2003). Indeed, neutralizing effects of lime may counteract the acidifying effects of N on soil pH and microbial biomass (Kennedy et al., 2004). Moreover, site management history could also influence the net effect of soil improvers on soil C dynamics via changes in the soil microbial community (Grayston et al., 2004; Tardy et al., 2015). For example, extensively-managed sites are characterized by soil with a higher fungal: biomass ratio and slower nutrient turnover compared with intensively-managed sites (De Deyn et al., 2008; Wardle et al., 2004). To date, few studies have investigated the interactions between liming and N inputs on C mineralization, and the influence of management intensity on these interactions remains unknown.

Here we investigate the interactive effects of lime addition, mineral N inputs and management intensity on soil C mineralization potential

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Table 1
Land use and soil characteristics of study sites (based on analyses carried out immediately prior to the experiment).

Site	Texture	Management Intensity	Soil code	Nitrogen fertilisation (kg N ha^{-1} yr^{-1})	Clay content (%)	Silt content (%)	Organic Matter (%)	Organic C (g kg^{-1} dry soil)	Total N (g kg^{-1} dry soil)	CEC Metson (Cmol + kg^{-1} dry soil)	Water Content at −80 kPa (%)
Laqueuille	Silt Loam	Extensive	L.Ext	0	14.3	60.1	18.3	106.0	10.2	30.8	74.6
		Intensive	L.Int	210	17.4	61.1	20.3	118.0	11.5	32.6	85.6
Blatiere	Sandy clay loam	Extensive	B.Ext	0	22.1	22.4	7.4	42.9	4.2	21.4	50.8
		Intensive	B.Int	240	22.2	24.7	6.9	40.0	3.9	20.5	55.5
Moine	Clay loam	Extensive	M.Ext	0	29.2	28.0	9.0	51.8	5.2	27.0	46.1
		Intensive	M.Int	240	30.4	31.1	9.1	52.5	5.2	29.0	47.7

using a three-month laboratory incubation study. Incubations are a useful tool for comparing soil C mineralization under standardized conditions (Zhou et al., 2012). We hypothesize that lime addition will increase soil O_2 consumption and CO_2 emissions via changes in pH, and test whether N inputs modify the impact of liming on potential C mineralization rates. We also predict that effects of liming and N inputs on potential C mineralization rates are modified by management intensity due to management-induced changes in microbial biomass and/or activity.

2. Material and methods

2.1. Soil sampling

Three upland grassland sites were selected from a long-term grassland management trial in Central France (Theix-Laqueuille, http://www.soere-acbb.com): Laqueuille (L), Blatière (B) and Moine (M). At each site, we selected a pair of grasslands with contrasting levels of management intensity: 0 versus 210–240 kg N ha^{-1} yr^{-1}, 'extensive' (Ext) and 'intensive' (Int) management respectively, giving a total of six experimental soils (Table 1). One soil sample (0–10 cm depth) was taken for each experimental soil in November 2016, and all soil samples were kept for one month at 4 °C prior to analysis. The soil was then homogenized by sieving (2 mm mesh), and pre-incubated for ten days in the dark at 20 °C, at a water potential corresponding to -80 kPa (moisture content from 46.1% to 85.6% on a dry weight basis depending on site).

2.2. Experimental design and incubations

Lime treatments (control, $CaCO_3$) were crossed with N treatments (control, NH_4NO_3) and management intensity (Ext, Int) in order to investigate interactive effects of $CaCO_3$, N fertilization and management. All eight treatment combinations were replicated three times (three independent sites), and soils for each treatment and replicate combination were incubated in quadruplet (or triplicate for one site). This resulted in 92 soil samples for incubation.

All soil samples (15 g dry weight equivalent, adjusted to -80 kPa water potential) were incubated aerobically for 84 days in the dark at 20 °C in 125 ml air-tight glass jars. Lime was mixed into soil at a rate of 4 T ha^{-1} immediately prior to incubation (31.5 mg $CaCO_3$ per jar), whereas N was mixed into soil at a rate of 85 kg ha^{-1} equivalent (2 mg NH_4NO_3 per jar). Both lime and N were added to the soil in powder form (Analytical grade products).

2.3. Measurements during soil incubation

Evolved CO_2 and O_2 consumption were determined at 13 dates during the incubation period (2, 4, 7, 9, 11, 14, 18, 25, 36, 46, 56, 70, 84 days). Values of O_2 consumption were used as an indicator of soil organic carbon mineralization, whereas CO_2 measurements represent total CO_2 emissions from organic and inorganic (lime) sources. At each sampling date, 3 ml of air was taken from each jar and injected into a gas chromatograph (PerkinElmer – Clarus 480). After measuring gas concentrations, all the jars were ventilated with moist CO_2-free air to prevent soil drying. Gas concentrations were corrected for both the volume of air available in each flask and the air pressure on the day of measurement/ventilation. Consumption of O_2 at each date was calculated as the difference between the O_2 concentration of CO_2-free air used for ventilation (20.5%) minus the actual O_2 concentration in sample jars, and expressed as mg O-O_2 kg^{-1} dry soil. Cumulative CO_2 production was calculated as the sum of C-CO_2 evolved at each measurement interval per kg dry soil. During the experiment, the average CO_2 concentration in the flask headspace was 2.65% (standard error = 0.29).

At the end of the incubation period, soils in the jars were sampled in

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