



Temperature sensitivity and carbon release in an acidic soil amended with lime and mulch



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ABSTRACT

Lime is commonly applied on agricultural lands for ameliorating soil acidity. However, lime dissolution and its concomitant contribution to carbon dioxide (CO₂) fluxes with the addition of organic residues at varying temperatures in acidic soils are not well known. We conducted laboratory incubation experiments for 96 days (20 ± 1 °C and 40 ± 1 °C) to quantify the priming effects of lime (0.46 and 0.92% w/w) and mulch (0.5% w/w) additions on carbon (C) release in a Chromic Luvisol. The C released from lime (δ¹³C of −8.67‰), mulch (−13.02‰) and soil (−25.2‰) was quantified using their distinct δ¹³C values. Total lime derived C in soils without mulch constituted approximately 32% and 17% of the total C fluxes at 20 °C and 40 °C, respectively. During the 96-day incubation period, in the absence of mulch addition between 64% and 100% of the applied lime C was released as CO₂ at both incubation temperatures. Furthermore, lime derived, mulch derived and soil derived C increased by 59, 48 and 284% respectively, when the incubation temperature was increased from 20 °C to 40 °C. These results suggest that mineralization of native soil C was more sensitive to temperature than the C released by lime dissolution and mulch mineralization. Temperature sensitivity of soil derived C was lower in treatments with mulch and lime addition compared to soil without C amendments. We obtained a Q₁₀ value of 2.41 ± 0.06 for the C released by the lime dissolution in the acidic soil. These findings are important for modelling the contribution of different C sources to atmospheric CO₂ concentrations in soils, such as the acidic limed and mulched soils.

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1. Introduction

Liming represents a common management practice for agricultural production on acidic soils, which occupy about 3950 Mha of land worldwide (Von Uexküll and Mutert, 1995). In the United States alone, nearly 30 Mt, and in Australia about 2.5 Mt of lime is applied annually to the agricultural fields (Page et al., 2009; West and McBride, 2005). However, the rate of lime application is being considerably increased on such soils for better crop production. Lime addition promotes CO₂-C fluxes through the dissolution of carbonates (inorganic carbon) and by changed bacterial population and increased microbial activities as a result of increased soil pH (Biasi et al., 2008; Fornara et al., 2011). An increased mineralization of soil organic carbon (SOC) after liming may particularly occur in soils high in particulate organic carbon (POC), such as those amended with

organic residues. These amended soils are highly sensitive to disturbance and land management (Haynes, 2005; Leifeld and Fuhrer, 2009; Six et al., 1998). The decomposition of POC may temporarily reduce the stability of macro-aggregates (Baldock et al., 1994; Castro and Logan, 1991; Chan and Heenan, 1999) that could further enhance the priming effect on the decomposition of native soil C (Ahmad et al., 2013; Dumale et al., 2011).

The dissolution of carbonates in limed acidic soils can substantially contribute to CO₂-C fluxes (Bertrand et al., 2007; Page et al., 2009). In limed acidic soils, the lime derived CO₂-C fluxes (inorganic) could constitute up to 77% of the total CO₂-C fluxes under controlled temperature conditions (Dumale et al., 2011). Nevertheless, liming effect could be variably short-lived under field conditions. Biasi et al. (2008) reported that the lime derived CO₂-C fluxes were much lower in the field, and not observed after 4 months of its application. However, considering the extent of acidic soils and current volume of lime utilization; there is a potential risk of overestimating the heterotrophic microbial activity in limed acidic soils by measuring the total CO₂-C fluxes without separating the lime derived and biogenic CO₂-C fluxes. The dissolution of carbonates in soils could also lead to the overestimation of total CO₂-C fluxes (Biasi et al., 2008; Tamir et al., 2011).

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The application of organic residues and their composts in agriculture is increasingly being proposed as a strategy for enhancing soil fertility and C sequestration (Khalil et al., 2005). The use of organic residues as an amendment has variable effects in the soil, which depend on the quality and quantity of the organic matter, the redox potential, pH, moisture conditions and soil microbial population (Carrington et al., 2012; Schwendener et al., 2005; Tian et al., 1992). Organic residues can also have liming effects in acidic soils; the magnitude of liming effects induced by organic residues varies depending on the type of residue, their rates of application and the buffering capacity of the soil (Haynes and Mokolobate, 2001). Similar to lime, the application of organic residues could increase the decomposition of native soil C (Bertrand et al., 2007; Liang et al., 1999; Malosso et al., 2004; Rasse et al., 2005). However, the native SOC mineralization, lime dissolution and its concomitant contribution to CO₂ fluxes with the addition of organic residues in acidic soils are largely unknown.

Global warming is considered to promote the decomposition of SOM and subsequent increase in soil CO₂-C fluxes (Cox et al., 2000; IPCC, 2007). SOM is decomposed by heterotrophic microorganisms, which are one of the key players of the global C cycle due to the CO₂-C fluxes they generate (Schindlbacher et al., 2011). With increase in temperature the heterotrophic microorganisms can rapidly decompose significant amounts of SOM and accelerate soil CO₂-C fluxes (Haddix et al., 2011). Non-biological dissolution of lime and its temperature dependence is important to accurately account for the lime contribution to greenhouse gases from liming of acidic soils. However, the temperature dependency of lime dissolution in limed acidic soils is yet to be explored. Further, there is lack of research on the temperature dependency of total soil respiration and soil derived C with the addition of lime and in the presence and/or the absence of organic residues in acidic soils. Since a large area under agriculture is continuously limed and mulch application is also increasing for enhancing soil fertility and C sequestration; a small change in the C dynamics of these limed or mulched soils can have significant impacts on the global atmospheric CO₂-C fluxes.

In the present study, we used sugarcane biomass derived mulch (0.5% w/w, a relatively labile source of C compared to native SOM) in combination with lime (0.46 and 0.92% w/w) to determine the priming effects on organic C in an acidic soil. SOM in coarse-textured soils is more vulnerable to environmental disturbances due to the reduced potential for SOC stabilization in aggregates or organo-mineral complexes (Creamer et al., 2013). We incubated mulch and lime in a coarse-textured soil to incorporate the influence of temperature. We tried to decipher temperature dependency by imposing a 20 °C increase on the C addition treatments. Here we examined the rates of C release in an acidic soil in the presence and/or absence of lime and mulch (organic residue) at two constant temperatures i.e., 20 °C and 40 °C. The hypotheses of this study were: (i) lime dissolution and C mineralization in an acidic soil would be regulated by the synergistic effects of mulch, and (ii) all C sources would be equally sensitive to changed temperature conditions.

2. Materials and methods

2.1. Soil, lime and mulch

Sub-surface soil (10–20 cm) was collected from a long term acidification trial site at the Agricultural Research Institute, Wagga Wagga (147°20'E, 35°05'S). The site had been under pasture for 2 years prior to the acidification trial which consisted of 13 treatments. Of those treatments, the most acidified treatment i.e. treatment 10 (wheat–wheat rotation with nitrogen application rate of 100 kg ha⁻¹ as urea) was selected for sampling. The pH of the surface soil (in 0.01 M CaCl₂) was 4.93 when the trial commenced with cultivations in April 1979, and it dropped to 4.21 (0–5 cm) after 12 years of continuous wheat (*Triticum aestivum* L.) cropping.

Also, the site remained under wheat cropping from 1979 to 2005. Further detailed information on the effects of treatments for soil profile acidification was given by Conyers et al. (1996). Since the trial ended (2006–2011), the site was under failed crop (drought). At the time of sampling in April, 2011, it was under barley (*Hordeum vulgare* L.) cultivation. The soil is classified as a Chromic Luvisol (FAO-UNSECO, 1974) and a Red Kandosol according to the Australian Soil Classification System (Isbell, 2002). The soil was air-dried, passed through a 2 mm sieve, and analyzed for soil reaction (pH), particle size distribution, cation exchange capacity, exchangeable acidity and exchangeable cations (Rayment and Lyons, 2010). Soil water holding capacity (WHC) was gravimetrically estimated. Lime requirement (LR) of the soil to raise the soil pH to 6.0 was estimated using the method described by Shoemaker et al. (1961). Sugarcane biomass derived mulch, obtained from a local nursery, was used in the incubation experiments. The dried mulch was ground using a pestle and mortar and sieved to obtain <2 mm fraction before mixing with the soil and lime. Total C and nitrogen contents of the soil (1.40% C and 0.11% N) and mulch (42% C and 0.70% N) were determined using a Vario Max CNS analyzer (Elementar Analysensysteme GmbH, Hanau, Germany). The δ¹³C of soil (−25.2‰), lime (−8.67‰) and mulch (−13.02‰) was also analyzed, using an isotope ratio mass spectrometer (IRMS Delta V Thermo Finnigan, Bremen, Germany). Other important soil properties (pH, total exchangeable acidity (mmol_c kg⁻¹), cation exchange capacity, lime requirement (g kg⁻¹) and particle size analysis) have been earlier described (Ahmad et al., 2013).

2.2. Experimental design

We conducted incubation experiments at two constant temperatures i.e. 20 ± 1 °C and 40 ± 1 °C. The treatments consisted of soil only (S), soil + lime (S + L), soil + mulch (S + M), soil + mulch + lime (S + M + L) and soil + mulch + 2lime (S + M + 2 L). Analytical grade lime was applied at the rate of 0.46 (L) and 0.92% (2 L) (w/w); these rates were 2 and 4 times, respectively, of the estimated LR to raise the soil pH to 6.0. Mulch was applied at the rate of 0.5% (w/w). The soil (200 g oven-dried basis) was homogeneously mixed with the C amendments and all treatments were replicated three times.

Basal nutrients dissolved in deionized (DI) water were added to all treatments at the start of the experiment. The nutrient solution (mg kg⁻¹) contained N (30.3); P (91); K (114.9); S (1.3); B (0.1); Cu (1.2); Zn (1.7); Mn (0.8) and Mo (0.1). We added the nutrient solution to ensure that microbial activity was not nutrient limited (Chapman, 1997). The soil water content was maintained at 60% of WHC at the onset of the experiment and this level was maintained by periodically weighing the containers (at each sampling day). The moist soil mixtures were transferred into plastic containers, tapped and patted to produce a consistent bulk density (~1.2 g cm⁻³) across the C addition treatments. We set up each experimental unit in 1.2 L sealed plastic containers, which held three small containers: a 200 mL container with the soil mixtures, a 70 mL jar containing NaOH (2.5 M) to capture CO₂ emanating from soil mixtures and a 70 mL jar with 40 mL of DI water as a humidity control.

2.3. Sampling and measurements

2.3.1. Sampling

The NaOH traps were changed at 1, 2, 3, 4, 5, 6, 7, 8, 11, 19, 33, 54, 75 and 96 days after incubation (DAI) to determine the CO₂ evolved during the incubation period. At each sampling day, three blanks without soil but with the sealed jars were also set up to account for the atmospheric CO₂ present in the headspace of the incubation chambers. The NaOH jars were immediately sealed upon removal from the incubation containers and subsequently replaced with new ones. The NaOH jars were stored until analyses in sealed containers along with an open NaOH jar to absorb CO₂ in the enclosed atmosphere.

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