Science of the Total Environment 599–600 (2017) 523–532

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Why does carbon increase in highly weathered soil under no-till upon lime and gypsum use?

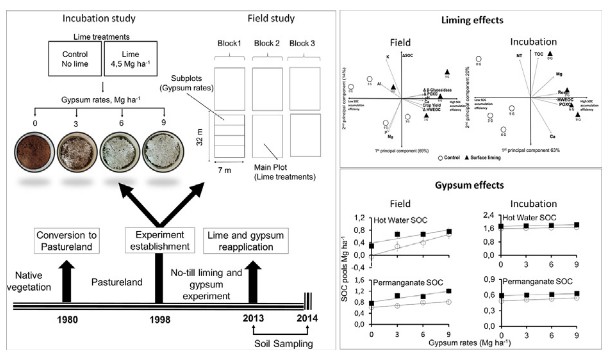
Thiago Massao Inagaki [a], João Carlos de Moraes Sá [b,*], Eduardo Fávero Caires [b], Daniel Ruiz Potma Gonçalves [b]

[a] Technical University of Munich, Chair of Soil Science, Institute for Advanced Study, Email-Ramann Str. 2, 85354 Freising, Bayern, Germany
[b] Department of Soil Science and Agricultural Engineering, State University of Ponta Grossa, Av. Carlos Cavalcanti 4748, Campus de Uvaranas, 84030-900, Ponta Grossa, Paraná, Brazil

HIGHLIGHTS

- Lime and gypsum use in field and incubation experiments increases soil C.
- Increase of calcium content and soil biological activity resulted in SOC gains.
- Calcium and labile SOC formed complex with mineral soil fractions.
- Associations between calcium and labile SOC can be the pathway to increase C sequestration.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 January 2017
Received in revised form 24 April 2017
Accepted 29 April 2017
Available online xxxx

Editor: Ajit Sarmah

Keywords:
Carbon sequestration
Soil biology
Acid soils
Soil organic matter
Soil correction
Incubation

ABSTRACT

Field experiments have been used to explain how soil organic carbon (SOC) dynamics is affected by lime and gypsum applications, however, how SOC storage occurs is still debatable. We hypothesized that although many studies conclude that Ca-based soil amendments such as lime and gypsum may lead to SOC depletion due to the enhancement of microbial activity, the same does not occur under conservation agriculture conditions. Thus, the objective of this study was to elucidate the effects of lime and gypsum applications on soil microbial activity and SOC stocks in a no-till field and in a laboratory incubation study simulating no-till conditions. The field experiment was established in 1998 in a clayey Oxisol in southern Brazil following a completely randomized blocks design with a split-plot arrangement and three replications. Lime and gypsum were surface applied in 1998 and reapplied in 2013. Undisturbed soil samples were collected before the treatments reapplications, and one year after. The incubation experiment was carried out during 16 months using these samples adding crop residues on the soil surface to simulate no-till field conditions. Lime and gypsum applications significantly increased the labile SOC stocks, microbial activity and soil fertility attributes in both field and laboratory experiments. Although the microbial activity was increased, no depletion of SOC stocks was observed in both experiments. Positive correlations were observed between microbial activity increase and SOC gains. Labile SOC and Ca^{2+} content increase leads to forming complex with mineral soil fractions. Gypsum applications performed a higher influence on labile SOC pools in the field than in the laboratory experiment, which may be related to the presence of active root system in the soil profile. We conclude that incubation experiments using lime and gypsum in undisturbed samples confirm that soil microbial activity increase does not deplete SOC stocks under conservation agriculture.

Abbreviations: SOC, Soil organic carbon; SL, Surface applied lime; HWEOC, Hot-water extractable organic C; POXC, Permanganate oxidizable organic carbon; TOC, Total organic carbon.

* Corresponding author.
E-mail address: jcmsa@uepg.br (J.C. de Moraes Sá).

http://dx.doi.org/10.1016/j.scitotenv.2017.04.234
0048-9697/

1. Introduction

The use of lime on agriculture has been reported as an effective practice to control soil acidity and minimize the toxicity of Al^{3+}, mainly in tropical and subtropical environments. Gypsum has also been recognized by its efficiency to reduce the Al^{3+} toxicity in deeper layers and to increase Ca^{2+} and SO_4^{2-} contents (Caires et al., 2015). Although the influence of both practices, especially lime, on soil organic carbon (SOC) dynamics has been intensively discussed, the factors and processes which govern their increases or decreases are not fully understood (Paradelo et al., 2015). Reports indicating increase (Briedis et al., 2012a, 2012b), decreases (Chan and Heenan, 1999; Fuentes et al., 2006; Aye et al., 2016) and no effect (Wyngaard et al., 2012) of lime applications on SOC stocks demonstrate the influence of several drivers such as climate, soil texture, soil management and biomass input. Gypsum effects on SOC although less studied than lime have demonstrated a significant effect to promote carbon sequestration, as demonstrated by Araújo (2016) in sugarcane fields and Inagaki et al. (2016) in long-term no-till field.

Higher biomass inputs from crop residues in soils resulting from the lime and gypsum applications have been pointed out as the main source of SOC increases in soils (Briedis et al., 2012a; Inagaki et al., 2016). In addition, the presence of Ca^{2+} ions are recognized to work as an ionic bridge between soil organic matter and clay particles, increasing soil aggregation and providing C protection (Briedis et al., 2012b). The increase of biomass input and the aggregating mechanisms of Ca^{2+} in soils work to increase carbon sequestration in long-term experiments when associated with conservation agriculture. In contrast, soil disturbance and low biomass input stand out as the main reasons for SOC depletions in liming experiments (Caires et al., 2006; Yagi et al., 2014; Aye et al., 2016). In a recent study, Aye et al. (2016) reported reduction of SOC stocks in long-term liming experiments, citing the fields low C-biomass inputs as the main reason for this depletion. According to the authors, the crop residue input was not enough to compensate the higher SOC mineralization caused by lime addition.

Incubation experiments in soils have been widely used, mainly because of their capacity to create ideal experimental conditions, eliminating interference of humidity and temperature on soil microbial activity (Curtin et al., 2012). However, incubation experiments performed to assess the lime and gypsum influence on SOC usually make use of disturbed samples with no crop residue addition (Fuentes et al., 2006; Wong et al., 2009), which commonly results in SOC depletion as a consequence of the microbial biomass activity increase. Therefore, the use of new methods to evaluate the lime and gypsum activity in laboratory studies is necessary to better understand its influence on SOC dynamics in conservation agriculture conditions.

We hypothesized that although many studies conclude that Ca-based soil amendments such as lime and gypsum may lead to SOC depletion due to the enhancement of microbial activity, the same does not occur under conservation agriculture conditions. Thus, the objective of this study was to evaluate the effects of lime and gypsum applications on SOC pools, microbial activity and soil fertility in a no-till field and in a pilot incubation experiment using undisturbed soil with crop residue additions to simulate conservation agriculture conditions.

2. Material and methods

2.1. Site description and soil

The experiment was performed in a no-till crop field area in Ponta Grossa PR, southern Brazil (25°10′S, 50°05′W). The annual precipitation is approximately 1550 mm with average maximum and minimum temperatures of 22 and 13 °C, respectively. According to Köppen–Geiger System (Peel et al., 2007), the climate is described as Cfb type (mesothermal, humid, subtropical), with mild summer and frequent frosts during the winter. The average altitude is 970 m above sea level. The soil is classified as red Latosol (Brazilian classification, Embrapa (2013)) equivalent to a clayey, kaolinitic, thermic Rhodic Hapludox (Soil Survey Staff, 2010), with 610 g kg^{-1} of clay.

2.2. Soil sampling and field experimental design

The experimental area was previously used as a pastureland with no historical of lime and gypsum applications. In 1998, the lime and gypsum experiment was established in a completely randomized design with three replicates. The plots sizes were 224 m^2 (32 × 7 m) and the subplots sizes were 56 m^2 (8 × 7 m). In the main plots, the treatments were assigned as follow: 1) control, no lime application; and 2) Surface lime application (SL) of 4.5 Mg ha^{-1}, divided in three yearly applications of 1.5 Mg ha^{-1} from the establishment of the experiment (Fig. 1). The lime rate was calculated to raise the base saturation in the topsoil (0–20 cm) to 70%. In the subplots, four rates of gypsum were surface-applied: 0, 3, 6, and 9 Mg ha^{-1}. Further information about the experimental site was described by Inagaki et al. (2016).

In 2013, the lime treatment was reapplied in a full surface application of 4 Mg ha^{-1}. Gypsum treatments were also reapplied on soil surface at the same rates of 0, 3, 6 and 9 Mg ha^{-1}. Soil samples were collected in August 2013 at the depths of 0–0.05, 0.05–0.10, 0.10–0.20, 0.20–0.40 and 0.40–0.60 m before the lime and gypsum reapplications, and in August 2014, one year after. During the crop season, the soil was cultivated with soybean crop (*Glycine* max) during the summer and let under fallow during the winter. All the soil analyses were performed in both years to calculate the short-term gains. 4.5, 20 and 37 kg ha^{-1} of NPK at sowing in band application were used in the area for soybean crop.

2.3. Pilot incubation experiment

For this experiment, we have developed a pilot incubation trial using undisturbed soil samples with addition of crop residues on soil surface, in order to mimic the conditions of a no-till field. No study, in our knowledge, has examined the lime and gypsum effects under these conditions. We collected 24 undisturbed samples (5 × 5 cm steel rings) randomly from a control plot (i.e. no lime and no gypsum application) in the 0–0.05 m layer in 2013.

The experimental design used was completely randomized with factorial 2 × 4, with three replicates. The factors evaluated in the experiment were: a) two liming treatments: Control (no lime) and surface lime application of a rate equivalent to 4 Mg ha^{-1}; and b) Gypsum applied in the rates equivalent to 0, 3, 6 and 9 Mg ha^{-1} (Fig. 2). The rates were the same applied on the field experiment. Both lime and gypsum treatments were manually applied over the top of each undisturbed sample. Before the samples incubation, we added an equivalent of 10 Mg ha^{-1} of maize residues (*Zea mays* – 448 g kg^{-1} of C content) on the surface of each sample in order to simulate the C-biomass input in no-till system. Twelve months after, we added the equivalent of 4 Mg ha^{-1} of soybean residue (*Glycine* max – 389 g kg^{-1} of C content), simulating a corn-soybean crop rotation.

The samples were inside of hermetic closed glass flasks, maintained in a dark chamber under controlled temperature of 28 °C ± 2 °C, and approximately on 50% of the maximum water retention capacity. Samples moisture was maintained constant through water weekly additions. After 480 days of incubation (16 months), the remaining crop residues were manually removed from the surface and the soil was collected, dried under 40 °C and passed by a 2 mm sieve.

2.4. Soil basal respiration

The determination of soil basal respiration followed the methodology described by Jenkinson and Powlson (1976). Briefly, each