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Research Article

The Effect of Liming on Carbon Mineralization in Acid Soils

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Abstract

Application of lime to acid soils is a common practice to ameliorate soil acidity, the short term and long-term effect of which has not been looked upon much. To study the short-term effect of liming on acid soils an incubation study was conducted with different doses of lime for 48 days in the soils of Raipur. Long-term effects were observed by studying the total organic carbon and computing carbon input in the long term fertilizer experiment (LTFE) samples of Ranchi. In both cases, it was observed that liming decreased carbon reserves in the soil by promoting carbon mineralization and microbial respiration. In the study incubation, cumulative carbon that was mineralized was maximum in higher doses of lime and in LTFE soils, 100% NPK and lime treated plots had lower total organic carbon compared to other treatments even though carbon input was high. This shows that liming promotes carbon mineralization and additional management practices are required to balance the losses.

Keywords: Lime; Acid Soils; Carbon Mineralization; Total Organic Carbon; Carbon Reserves

Introduction

Low pH significantly impairs soil capability, with acidic soils hindering plant growth in nearly 50% of the world's cultivable lands [1,2]. While soil acidification occurs naturally, human activities have substantially accelerated this process in recent decades. Current food production systems contribute to ongoing acidification as plant biomass removal depletes soil cations. Acidic soils are known to disrupt soil carbon and nutrient cycles, negatively impact plant and soil organism growth, and jeopardize ecosystem functions like net primary production and species diversity [3-5].

Liming, which has shown considerable potential for improving soil pH and crop yields, is widely employed as a common remedy for soil acidification [6,7]. The application of lime boosts plant growth by raising soil pH, which enhances nutrient availability while reducing aluminum toxicity [1,8]. Additionally, liming facilitates the immobilization of harmful heavy metals and modifies plant nutrient transformation and uptake, thereby influencing ecosystem productivity [9,10]. Nevertheless, conflicting outcomes regarding liming's effects on plant growth and yields have been documented. While some research has demonstrated significant improvements in crop yields [11,12], other studies have observed reductions in crop production, particularly when soils were limed or treated with excessive amounts [7,13]. Beyond its impact on plant productivity, pH changes induced by liming also affect soil microbial biomass, composition, and activity, as well as soil C and N availability. Furthermore, liming may influence soil organic C (SOC) concentrations and stocks.

Liming affects the preservation and breakdown of SOC. It can accelerate carbon depletion soil by increasing carbon solubility, microbial activity, and carbon decomposition rates [14,15]. However, lime-induced enhancements in plant growth, both above and below ground, and the resulting increase in organic matter input to the soil, may lead to observed SOC accumulation [16,17]. The overall change in total SOC content after liming depends on the balance between SOC gains and losses. Typically, liming is anticipated to boost soil microbial populations and their activities, thereby increasing organic matter mineralization. Consequently, researchers have observed increases in soil respiration and decreases in SOC stocks [18,19]. In addition to pH directly impacting soil microbial processes like denitrification [20], alterations in soil microbial parameters and substrate availability also influence the generation, consumption, and emission of greenhouse gases, specifically N_2O, methane, and carbon dioxide [7,21-23]. The worldwide rise in soil acidification and liming practices is expected to have a cumulative effect on the global carbon cycle [24]. On the other hand, the liming-induced enhancement of plant growth increases C inputs through litter and root exudation, which may surpass increased C losses due to SOC mineralization, ultimately resulting in SOC accumulation [25,26]. Assessing how liming impacts the mineralization of soil organic carbon (SOC) is crucial for anticipating shifts in soil carbon balance, emissions of greenhouse gases, and the long-term viability and economic benefits of agricultural crop systems [1].

The application of lime is recognized for its immediate impact on enhancing soil biological activity, while also potentially contributing to long-term increases in soil organic matter content. The short-term effects of liming on microbial activity in both field studies and laboratory experiments [27] has been reported. The temporary boost in microbial activity following lime addition to acidic soils is well-established [28]. Studies have shown that liming can enhance various soil properties, including microbial biomass content, soil respiration rate, the microbial metabolic quotient, soil enzyme activity (specifically dehydrogenase, sulphatase, and protease), and the net mineralization of organic N and S in soil [27].

The aim of this study was to investigate whether addition of lime in acid soil affects carbon mineralization. It was hypothesized that liming promotes carbon mineralization. The study revealed that addition of lime in acid soil has an impact on carbon mineralization in long term fertilizer experiments as well as in short lab incubation studies.

Materials and Method

Soil samples were collected from different sites i.e. from Raipur and the farm of the Birsa Agricultural University, Ranchi, India (23°17′ N, 85°19′ E and 625 m above mean sea level) under the All India Coordinated Research Project on Long-term Fertilizer Experiments (AICRP-LTFE) of the Indian Council of Agricultural Research. The experiment was initiated in 1972. The major cropping system followed here is soybean- wheat. The treatment details are as follows: control, 50% NPK, 100% NPK, 100% NP, 100% N, 100% NPK+FYM, 100% NPK + Lime. The soil of the study site is Typic Haplustalf with pH of 5.3 (soil: water, 1:2). Total carbon was determined using a TOC analyser.

A short term laboratory incubation study was conducted with the samples collected from Raipur for a period of 48 days. The pH of the sample was 4.5 (soil: water, 1:2). An experiment was conducted using 100g of soil kept at 70% field capacity. Various lime rates (0, 0.25, 0.50, and 1.0 g per 100 g of soil) were applied, and the samples were incubated at room temperature. The study was replicated three times. Additionally, a separate sample with only 0.5g of lime was incubated to examine CO2 efflux solely from lime. Carbon mineralization, measured as CO2, was assessed using the NaOH trap method at specific intervals (1, 4, 7, 14, 28, 34, 41, and 48 days). Excess NaOH was back-titrated with 0.5 N HCl, using saturated BaCl2 and phenolphthalein as indicators. After each titration, the vials were replenished with fresh NaOH and sealed with parafilm to prevent CO2 loss. To determine the exact strength of the acid, the HCl was standardized using 0.5 N sodium carbonate with methyl red as an indicator [29].

The amount of C evolved was calculated using the formula

*C evolved (mg/100 g soil) = (B-S)*N*6(equivalent wt of C)*

Where B is the amount of HCl consumed in blank sample, S is the amount of HCl consumed in each sample and N is the normality of HCl.

Statistical analysis

One way ANOVA analysis was carried out on the data to study the effect of liming.

Results and Discussion

The results from the incubation of Raipur soil indicate that during the incubation period, carbon mineralization was higher in lime amended soils compared to non-amended soils. The cumulative carbon dioxide evolved from 1.0 g lime treated soil was found to be significantly higher compared to other treatments (Figure 1). The carbon dioxide emanating from the control and only lime added samples were low throughout the incubation. The cumulative carbon dioxide released was in the order 1.0 g lime > 0.5g lime> 0.25g lime > blank> lime blank.

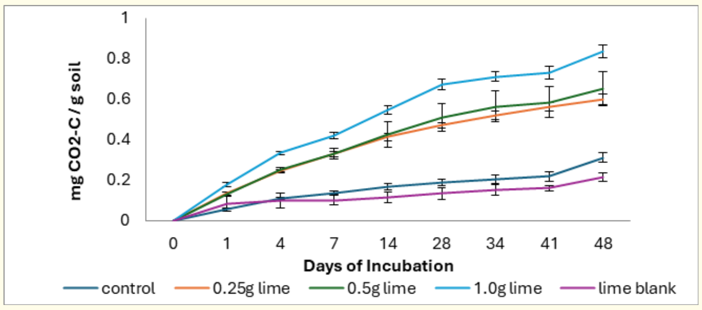

Figure 1: Cumulative carbon mineralized from soils of Raipur with different doses of lime.

The cumulative CO_2 efflux observed at the end of incubation was 0.84 mg CO_2-C/g soil for 1.0 g lime amended soils, 0.65 mg CO_2-C/g soil for 0.5g lime, 0.59 mg CO_2-C/g soil for 0.25g lime, 0.31 mg CO_2-C/g soil for control and 0.21 mg CO_2-C/g soil for control samples with 0.5g lime. The cumulative CO_2 efflux from 1.0g lime treated soils was significantly higher than 0.5g and 0.25g lime amended soils. There was no significant difference between 0.5g and 0.25g lime amended soils. The CO_2 efflux from only lime added samples show that lime does contribute to CO_2 evolution from the samples studied, though it was marginal compared to control samples.

The Total Organic Carbon (TOC) (%) and C input (kg C/ha/yr) of the soils of Ranchi under different treatments are given in table 1. The TOC under different treatment in 0-15 cm depth varied from 0.64 to 0.94 and in 15-30 cm depth varied from 0.57 to 0.73. The carbon input ranged from 602 (kg C/ha/yr) in control plots to 6094 (kg C/ha/yr) in 100% NPK + FYM treated plots. The TOC was found to be highest in 100 % NPK + FYM treated plots corresponding to the highest C input. The C input in lime treated plots was found to be higher than in other treatments excluding FYM treated plots, but no corresponding increase in TOC was observed in this treatment. Liming typically yields beneficial outcomes by mitigating aluminum and occasionally manganese toxicity, and/or addressing calcium deficiency. The primary symptom of aluminum toxicity is stunted growth, particularly in roots and shoots. The application of lime can significantly enhance root and shoot development, leading to increased carbon return to the soil via decaying roots and plant residues. Over time, these effects may contribute to enhanced soil structure [28] due to the resulting increase in soil organic matter [30]. The total organic carbon (TOC) in lime-treated plots was measured at 0.74%, which was lower compared to other treatments. Comparable findings were observed in 34-year-old low-input and cultivated trial plots, where liming reduced soil organic carbon (SOC) in both bulk soil and aggregates [31]. It was noted that total SOC in the 0-10 cm layer either decreased or remained constant following long-term lime application [32]. The study also found that changes in each carbon type were influenced by alterations in TOC, with lower content of each carbon type in limed soils compared to unlimed soils.

This indicates that even though addition of lime promotes increase in carbon input to the soil, the carbon sequestered in the soil is less as it drives carbon mineralization.

Treatments	TOC (%)		
	0-15 cm	15-30 cm	C input (kg C/ha/yr)*
50% NPK	0.76	0.71	1530
100% NPK	0.78	0.65	1944
100% NP	0.78	0.68	1377
100% N	0.74	0.62	294
100% NPK+ FYM	0.94	0.73	6094
100% NPK+LIME	0.74	0.64	2231
Control	0.64	0.57	602

Table 1: Effect of different treatments on total organic carbon concentration (%) and carbon input under LTFE of Ranchi soil.

The decrease in soil organic carbon (SOC) caused by liming is primarily attributed to increased carbon mineralization, which results from higher carbon solubility, enhanced microbial activity, or a combination of both factors [14,15,18,33]. The growth in microbial biomass and activity in limed soils may have contributed to greater SOC mineralization. The reduction in SOC content following liming could be linked to increased microbial breakdown of SOC at optimal soil pH levels [34], which in turn speeds up SOC turnover rates. However, if the rise in biomass inputs due to liming is insufficient to counterbalance the resulting accelerated SOC turnover rate, a net loss of carbon would occur. The positive effects of liming acidic soil on above- and below-ground plant biomass production have been well-established in scientific literature [35,36].

Conclusion

This study demonstrated that short term (48 days incubation) as well as long term liming decreased SOC and promoted carbon mineralization in acid soils. Carbon mineralization increased with increase in dosage of lime (maximum at 1.0g lime/100g soil). In long term fertilizer experiments, supplementation of lime increased plant biomass and carbon input to the soil, but there was no corresponding increase in TOC in these soils. The results indicate that impact of liming on carbon reserves depends on the balance between the carbon input and the rate of carbon mineralization and microbial respiration. Thus, amelioration of soil acidity with liming should be carried out with additional management practices to maintain the carbon reserves in the soil.

Conflict of Interest

The authors have no conflict of interest to declare.

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