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Review

Net effect of liming on soil organic carbon stocks: A review

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ABSTRACT

Liming is a common agricultural practice worldwide, used for increasing productivity in acid agricultural soils. Liming reduces Al saturation and toxicity and/or increases pH up to values where the availability of nutrients is higher. The effect of this practice on soil properties has been extensively studied, with focus of most studies upon pH, exchangeable cations and productivity. In turn, the effects of liming on soil organic C (SOC) stocks still remain poorly known. The net effect on SOC can be the result of several factors: first, liming increases the soil biological activity, thus favoring the mineralization of organic matter, which should result in CO_2 losses and a decrease of the SOC stocks. Second, liming ameliorates soil structure, increasing the stability of clay assemblages and clay-organic matter bonds, which should bring an increase in SOC physical and physicochemical protection. Finally, as liming ameliorates soil conditions to plant growth, plant productivity increases and also the return of C inputs to soil, thus potentially increasing SOC concentrations. The net effect of these processes is not well understood yet. Still, some overall trends can be deduced from data currently available in the literature. Liming does modify SOC stocks, increasing them in most cases, what seems to be caused by higher C inputs to limed soils due to increased productivity. Reductions in SOC have also been reported, probably in connexion with increased mineralization, whereas the role of improved soil structure remains unclear. Overall, these insights are deduced from published data which are still scarce, so we encourage the scientific community to synthesize unpublished SOC data from existing in situ experiments, in order to enlarge the span of experimental conditions and gain knowledge about the role of such a widespread agricultural practice on SOC stocks.

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1. Introduction

Considerable effort is dedicated nowadays to determine the effect of agricultural practices, such as fertilization or tillage, on fluxes and stocks of soil organic carbon (SOC). Abundant literature exist about this issue, addressing different tillage practices, such as organic farming, no-till, reduced, or conventional tillage, as well as mineral or organic fertilization (e.g. Paustian et al., 1998; West and Post, 2002; Conant et al., 2007). However, the effect of a widely extended practice such as liming still remains poorly known.

Liming is widely used for increasing productivity in acid agricultural soils (Haynes and Naidu, 1998), which are present in extensive areas of the world, especially in the tropics, and to counteract the acidification of forest soils in the Northern regions of the globe (Lundström et al., 2003). This is so because most extensive catch crops are not adapted to acid soils (Brady and Weil, 1996). Liming is most usually applied as calcium carbonate (lime), calcium/magnesium carbonate (dolomitic lime), calcium oxide, or calcium hydroxide (Tisdale et al., 1985; Meriño-Gergichevich et al., 2010). The processes going on in the matrix of an acid soil when lime is applied are complex, but can be summarized as follows: Ca salts increase Ca content in the exchange complex, which results in higher base saturation. Simultaneously, Al ions being released from the exchange complex as they are replaced by Ca are neutralized by OH groups (in the case of hydrated lime application). As a consequence, there is an increase in the soil pH as the acid hydrolysis of Al is greatly reduced when lime is applied, and there is less spaces for protons in the exchange complex. The increment in the soil pH also means that Al forms become less soluble and therefore less reactive. As a result of these processes, liming increases the pH of acid soils up to values where the availability of nutrients is maximal (i.e., in a range of pH near 6), reduces Al saturation and toxicity (sometimes also Mn toxicity), alleviates Ca deficiency and reduces the positive charge in soils with variable charge components, thus increasing P availability by decreasing P sorption (Tisdale et al., 1985; Haynes and Naidu, 1998; Osman, 2013).

Since the main purpose of liming is to modify soil pH and the composition of the exchange complex, most of the scientific studies in this field are focused on soil pH, Al saturation, exchangeable cations or plant productivity. The long-term effects of liming on SOC have been more rarely studied on their own, and only recently more attention is being paid to the parallel evolution of SOC in limed and unlimed soils (Fornara et al., 2011; Briedis et al., 2012a; Srámek et al., 2012).

According to present knowledge, the net effect of liming on SOC will be the result of a number of processes that take place simultaneously (Fig. 1):

(1) Increased plant productivity resulting in larger OM inputs. As liming ameliorates soil conditions to plant growth, an increase of plant productivity is expected. The higher yields resulting from lime applications will produce increased returns of organic matter to the soil in the form of dying roots and decaying crop residues, and consequently, higher SOC stocks than where no lime is applied (Haynes and Naidu, 1998).

(2) Increased OM mineralization due to a more favorable pH. Lime applications are known to have short-term stimulating effects on soil biological activity (Edmeades et al., 1981; Haynes, 1984; Haynes and Swift, 1988; Badalucco et al., 1992), thus favoring organic matter mineralization and very likely accelerating organic matter turnover rates in soil. This flush of microbial activity will likely result in smaller SOC stocks, if all other factors remain constant, and if the flush persists. As an example, Leifeld et al. (2013) have observed decreasing mean residence times of soil organic carbon with increasing pH in a natural acidity gradient in grassland alpine soils.

(3) Amelioration of soil structure, that will reduce mineralization by means of a better physical protection of SOC. Liming is known to ameliorate soil structure, as high Ca^{2+} concentrations and high ionic strength in the soil solution enhance the flocculation of clay minerals and thus the formation of stable aggregates. Direct positive effects of liming on soil structure are also ascribed to the cementing actions of carbonates (Doner and Lynn, 1989; Haynes and Naidu, 1998). Increasing the stability of soil structure improves the efficiency of SOC physical protection and hence decrease mineralization rates. Besides, changing the nature of exchangeable cations may also impact the adsorption of organic matter and thereby its protection by this mechanism.

These processes are not fully independent. For example, increased OM mineralization due to liming will also deplete labile soil organic matter having an aggregating action (Puget et al., 1999) and will thus affect negatively aggregate stability. But in turn, increased microbial activity can also increase aggregate stability, since microorganisms produce extracellular polysaccharides which act as binding agents (Burns and Davies, 1986; Chenu, 1989, 1995; Cheshire and Hayes, 1990).

The relative extent and net effect on SOC of these interdependent processes will certainly depend on a number of factors, such as initial soil pH, liming rate, clay content and mineralogy, soil use, climate, and others. Also, lime applications are usually discontinuous, so different short- and long-term effects may exist. The many processes affected by liming may explain why, although evidence of the impact of liming on some soil properties is well established, its net effect on SOC is not entirely understood yet. The aim of this paper is to assess the effect of liming on soil organic carbon stocks by reviewing and analyzing the available scientific literature.

2. Materials and methods

2.1. Literature survey selection criteria

We applied several criteria to our analysis. First, we focused on mineral horizons and discarded studies on peat soils and organic

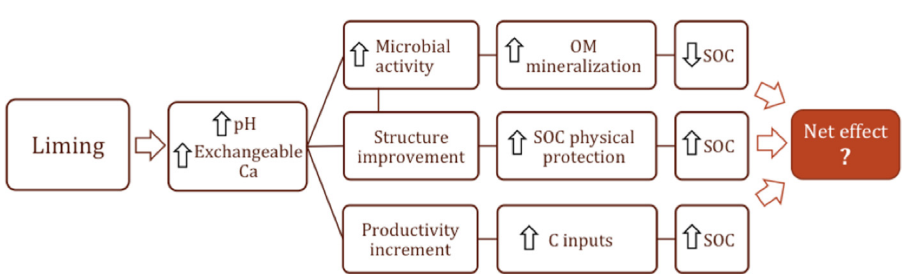

Fig. 1. Potential effects of liming on soil organic carbon (SOC). The schema summarizes results from several papers reviewed by Haynes and Naidu (1998).