CROPLAND

NUTRIENT MANAGEMENT

CHEMICAL AMENDMENTS

21. Liming Acidic Soils

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1. Description of the practice

Soil acidity (indicated by values of $pH_w < 5.5$) is a serious constraint to food production worldwide (FAO and ITPS, 2015). It occurs where hydrogen (H^+) ions are produced in large amounts and interact with clay particles, releasing aluminum which in turn produces more H^+ ions. The production of H^+ ions is a natural phenomenon caused by the reaction of CO_2 with water, absorption of excess cation over anion nutrients by plant roots and decomposition of organic matter, which is severe in Podzols and Histosols. Both hydrogen and aluminum are readily adsorbed by the clay minerals releasing Ca^{2+}, Mg^{2+} and K^+ ions, which may subsequently be leached from the soil by percolating water, leading to their deficiencies (Blum, Shad and Nortcliff, 2018).

Loss of cations is extensive in Ferralsols, Acrisols and Lixisols which cover approx. 2 185 Mha (million hectares) worldwide (IUSS-WRB, 2015). On agricultural lands, the use of ammonical fertilizers and urea are the most important cause of soil acidification, and besides plant nutrient deficiency the growth of many crop plants are impaired by the presence of high toxic levels of aluminum and low phosphorus availability as result of soil acidification (Bolan, Adriano and Curtin, 2003; Fageria and Baligar, 2008). As a result, biomass production and carbon sequestration are diminished despite fertilizer inputs.

Liming is therefore crucial and a common practice to ameliorate soil acidity in agricultural lands (Fageria and Baligar, 2008). It mostly consists of the application of ground limestone (calcium carbonate, lime or calcitic lime), dolomitic ground limestone (calcium magnesium carbonate or dolomite). Soil liming provides OH- ions to neutralize H^+ ions thereby decreasing aluminum toxicity with an increase in phosphorus availability and supply of Ca^{2+} and/or Mg^{2+} (Bolan *et al.,* 2003). Gypsum ($CaSO_4.H_2O$), which is more soluble than lime but does not change soil pH, may also be applied after liming reducing toxic levels of aluminum and to supply calcium in the subsoil (Caires, Joris and Churka, 2011).

2. Range of applicability

Worldwide, liming is the most common and effective practice to counteract soil acidification and it is a prerequisite for optimal nutrient use efficiency by crop plants growing on acid soils (FAO, 2017). The efficacy of liming in SOC sequestration is optimized if it is applied along with other management practices such as zero tillage, crop rotation with cover crops or green manure, soil mulching with crop residue retention and balanced fertilization. Combined management practices are key to increase crop biomass to offset faster C turnover, hence leading to C sequestration (Briedis *et al.,* 2012; Aye, Sale and Tang, 2016; Holland *et al.,* 2018). Reductions of soil organic carbon due to liming could be associated to increased mineralization parallel to the pH increase, but progressive reversion might happen due to the influence of the increased C inputs (Paradelo, Virto and Chenu, 2015).

3. Impact on soil organic carbon stocks

Liming contributes to soil organic carbon (SOC) sequestration mainly through increased biomass production resulting from improved soil health. Except for the natural ecosystems, plant growth is inhibited in acid soils due to toxicity of excessive H^+, Mn^{2+} and Al^{3+} concentration in soil solution, low microbial activity and poor nutrient cycling. Liming mitigates these soil constraints, thereby helping to achieve climate-driven genetic yield potential of agricultural crops (Table).

Table 95. Measured effects of liming acidic soils on soil organic carbon stocks

Location	Climate zone	Soil type	Baseline C stock (tC/ha)	Additional C storage (tC/ha/yr)	Duration (Years)	Depth (cm)	More information	Reference
South-Western Sweden	Cool Temperate Moist	Haplic Podzol	116.9; 35-year old Norway spruce forest (BAU)	1.60	10	0-40	Surface dolomite; one application of 8.8 t/ha. 1000 mm annual rainfall	Nilsson *et al.* (2001)
Hertfordshire, UK		Chromic Luvisol; silty clay loam	76; permanent grassland (t0)	0.14	129	0-23	Surface calcitic lime; 4 t/ha every 4 years followed by different lime amounts to reach pH 7. 704 mm average annual rainfall	Fornara *et al.* (2011)
Southern Brazil	Tropical Moist	Ferralsol; loamy	49.9; Zero till rainfed annual crop with NPK (BAU)	0.51	15	0-20	Surface dolomite + NPK; 6 t/ha in 1993 and 3 t/ha in 2000; 1545 mm annual rainfall	Briedis *et al.* (2012)
Central Brazil		Ferralsol; clayey	183; (BAU)	1.76	7	0-200	Incorporated dolomite; 7.08 t/ha and 5 t/ha gypsum ($CaSO_4.2H_2O$)	Araújo *et al.* (2019)
North-Eastern India		Alfisol; sandy loam	15.5; irrigated annual crop system (t0)	0.15	29	0-45	Incorporated dolomite + NPK at 10-cm depth; 2.5 t/ha dolomite every 4 years; 1450 mm average annual rainfall	Hati *et al.* (2008)

4. Other benefits of the practice

4.1. Improvement of soil properties

Physical properties

Dispersion or flocculation of soil colloid particles may be influenced by liming due to its effect on soil pH and Ca in the soil solution. Thus, liming weathered tropical soils such as Ferralsols, especially those cultivated under reduced tillage, leads to an improvement of soil physical properties, which in turn decrease in soil water erosion and favouring soil C sequestration (Castro and Logan, 1991; Bolan *and Hedley,* 2003)

Chemical properties

Adequate liming raises P availability and significantly reduces Al and Mn toxicity; results in more vacated sites in the soil adsorption complex to be occupied by Ca, Mg and K, thereby mitigating their losses by leaching. Bioavailability of micronutrients such as molybdenum and boron increases with increasing soil pH up to 7.5. However, liming needs to be done judiciously to avoid nutritional imbalances due to P-Ca immobilization and low activity of Zn leading to yield reductions (Cregan, Hirth and Conyers, 1989; Bailey and Laidlaw, 1999; Fageria and Baligar, 2008).

Biological properties

Activities of microbes such as rhizobia, which are beneficial because of the atmospheric N fixation or plant growth-promoting rhizobacteria such as *Azospirillum* or *Pseudomonas* are improved in limed soils. Additions of lime caused an increase of mites and decrease of enchytraeids worms while collembolans were unaffected. Groups of earthworms show changes in their population numbers in soils that are limed. Also, the enzyme nitrogenase and molybdenum availability are increased with liming, therefore affecting positively the symbiotic nitrogen fixation by legumes (Bailey and Laidlaw, 1999, Bolan, Hedley and White, 1991, Holland *et al.,* 2018).

Benefits of liming can be already observed 1 month after application, particularly on soil pH_{CaCl2} and exchangeable Ca + Mg (Quaggio *et al.*, 1995), but the positive effects can last up to 6 years and beyond depending on soil texture, nitrogen fertilizer and rainfall pattern (Pavan and Oliveira, 1997, Sime, 2001).

4.2. Minimization of threats to soil functions

Table 96. Soil threats

Soil threats	
Soil erosion	Losses by rainfall water in Ferralsols and Acrisols are a combination of bare soil prone to raindrop impact leading to soil crusting, reduced water infiltration and increased runoff. Soil liming, as part of soil and water conservation practices such as reduced tillage with crop rotation including cover crops and contour terracing to diminish water losses, improve soil structure which facilitates infiltrability of water (Castro Filho *et al.,* 1991; Haynes and Naidu, 1992).

Soil threats	
Nutrient imbalance and cycles	Liming increases the availability of nutrients through favouring processes such as nitrification that govern N availability to crop plants. Also, liming reduces P adsorption, resulting in an increase in P agronomic efficiency in many Sub-Saharan countries (Vanlawe *et al.,* 2015).
Soil salinization and alkalinization	Although liming materials are not used for ameliorating soil salinity, calcium containing compounds will help to reduce sodium levels, which is a major constraint in these soils (Mukhopadhyay *et al.,* 2020).
Soil contamination / pollution	There are well established studies demonstrating the potential value of liming as immobilizing agent in reducing the bioavailability of a range of heavy metals in soils such as cadmium and arsenic (Bolan *et al.,* 2003; Hong *et al.,* 2014).
Soil biodiversity loss	Despite considerable variation in response of soil biota to acidity, liming has been shown to have a positive impacts on the abundance of bacteria and earthworms, important in the nutrient cycling, and of fungi in recalcitrant decomposition (C storage); abundance of soil pathogens decreased through liming with subsequent disease regulation (Robson and Abbott, 1989; Holland *et al.,* 2018).
Soil compaction	It has been found that liming a sandy clay loam Ferralsol combined with gypsum application resulted in a better organization of soil particles, increasing macroporosity and reducing soil bulk density and penetration resistance (Carmeis *et al,* 2016). Soil aggregates break down during wetting cycle, then set to a hard, structureless mass during drying, leading to hardsetting and soil surface sealing. Liming improves soil structure, thereby helps to mitigate soil sealing and hardsetting (Roth and Pavan, 1991).
Soil water management	The addition of lime to a sandy loam Acrisol (pH 4.1) in Brazil has increased by 60 percent the gross water use efficiency in maize/cowpea intercropping system compared to sole application of NPK fertilizer (Gaiser *et al.,* 2004). In Australia, application of 2.9 t/ha of lime maximized the ability of pastures to utilize scarce available water reserves of an acidic (pH 4.1) Ferralsol (Hayes *et al.,* 2016).

4.3. Increases in production (e.g. food/fuel/feed/timber/fibre)

The application of an appropriate rate of lime brings several chemical and biological changes in the soil and increases root growth, which are beneficial or helpful in improving food, feed or fuel crop yields on acid soils. Optimum base saturation in soil is very critical to achieve climate-driven genetic yield potential of agricultural crops, which is both soil and crop dependent. For Ferralsols, the desired optimum base saturation for most cereals is in the range of 50 - 60 percent, and for legumes it is in the range of 60-70 percent, which, when reached, places the productivity of these crops among the highest in the world (Sanchez and Salinas, 1981; Fageria and Baligar, 2001).

With regard to Al saturation, about 90 percent of maximum maize yield was obtained at 29 percent Al saturation in Ferralsols and Acrisols. In Rwandan Ferralsols, yields of wheat, beans and potatoes were significantly increased by liming (Yamoah, Burleigh and Eylands, 1992). Sandy Cambisols in Zimbabwe when limed produced large increase in groundnut (*Arachis hypogaea*) yield, an important component in the diet of the rural population (Murata *et al.,* 2002). In the central highlands of Ethiopia, combined applications of 1.65 t/ha lime and 30 kg/ha P fertilizer increased barley yield of an acid ($pH < 5.0$) Nitisol (Desalegn *et al.,* 2017).

4.4. Mitigation of and adaptation to climate change

Liming can be a source or sink for CO_2, depending on whether reaction occurs with strong acids or carbonic acid (Kunhikrishnan *et al.,* 2016). On the other hand, particularly under zero tillage, liming provides an opportunity for N_2O and CH_4 mitigation (Baggs, Smales and Bateman, 2010; García-Marco *et al.*, 2016). The strategy of soil C sequestration involves return of the biomass to the soil in excess of the mineralization capacity and to enhance formation of organo-mineral complexes or stable micro- and macroaggregates (Lal, 2003). Agricultural lands showing chemical degradation by processes such as increasing soil acidity can be restored through liming, when in combination with other best management practices. Compared to acidic soils, limed soils contain more biomass above- and belowground and therefore they have higher soil C stocks. From a perspective of adaptation to climate change, regular liming applications with zero tillage and integrated crop-livestock maintain soil surface permanently covered (soil mulching) keeping soil moisture for several days whenever a dry spell of up to 20 days happens.

4.5. Socio-economic benefits

Unlike many fertilizers, lime has a strong carryover. In western Kenya, lime at 2, 4 and 6 t/ha maintained $pH \geq 5.5$ of an Acrisol for 2, 3 and 4 years, respectively. It has been observed in a clayey Ferralsol in Central region of Brazil, that after 4 years with eight crop cycles (rice (*Oryza spp.*) , common bean , maize (*Zea mays*), and soybean (*Glycine max*)), the soil pH and the levels of Ca and Mg were still adequate to maintain crop yields at an optimal level. From an economic perspective, liming is a capital investment rather than an operating input because of its long-term benefits (Lukin and Epplin, 2003; Fageria and Baligar, 2008; Kisinyo *et al.,* 2014).

4.6. Other benefits of the practice

Lime requirement

Methods to assess lime requirement are based on soil pH, base saturation, and aluminum saturation adjustments at appropriate levels according to the crop demands and expected yields. Care should be taken, however, on lime requirement based only on exchangeable aluminum, since it is controlled by the soil-specific relationship between exchangeable aluminum and the non-aluminum toxicity and mineralogical soil properties. For many Ferralsols and Acrisols, exchangeable aluminum accounts for a small part of the total soil acidity (Cregan, Hirth and Conyers, 1989; Cantarella, van Raij and Quaggio, 1998; Fageria and Baligar, 2008).

Lime quality

The quality of a liming material is determined by its neutralizing value (NV) and its particle size. Fine particle limestone with an NV of 98 percent has high ability to neutralise acidity. However, coarse lime material react slower than fine particle lime and the need to repeat soil liming may be extended.

Timing of application

Soil moisture is critical to the reaction of limestone, thus rainfall patterns in the area should be monitored and used as a guide. As limestone shows lower solubility compared to some fertilizers, allow several weeks for reaction in the acidic soil, particularly Ferralsol and Acrisol before sowing time and NPK fertilizer application.

5. Potential drawbacks to the practice

5.1. Tradeoffs with other threats to soil functions

A common tradeoff is observed when lime is unevenly broadcasted, especially at large rates (> 4 t/ha) on the soil surface (overliming) leading to pH higher than 6.5.

Table 97. Soil threats

Soil threats	
Nutrient imbalance and cycles	Overliming can cause P deficiency due to high levels of Ca and also significantly reduce the plant availability of micronutrients (Zn, Cu, Fe, and Mn), which decreases with increasing pH, particularly over 6.5 (Bolan *et al.,* 2008)
Soil contamination / pollution	In some soils with high levels of molybdenum, overliming may increase Mo uptake by crop plants causing Mo toxicity, especially in ruminants (molybdenosis) (Bolan *et al.,* 2003).
Soil acidification	Aluminum solubility is minimal in the pH range of 5.5-6.5, but when pH is close to 7.0 it becomes increasingly soluble as the negatively charged aluminate form and can be taken up by crop plants decreasing crop yield (Fageria and Baligar, 2008).

5.2. Increases in greenhouse gas emissions

Mitigation of N_2O emissions from soils are optimized if the soil moisture of the limed soils is kept around the field capacity. On the other hand, liming shows variable effects on soil CH_4 uptake rate (Kunhikrishnan *et al.*, 2016).

5.3. Conflict with other practice(s)

Liming is most commonly practiced to overcome the impact of soil acidification on crop yield. However, an integrated approach involving liming, management practices such as use of less-acidifying fertilizers, improved nutrient use efficiency, reduced nutrient losses by leaching or product removal by harvest, and increased plant tolerance will probably be necessary, particularly where the acidification potential is high and acidification is likely to extend into the subsoil (Bolan and Hedley, 2003).

5.4. Decreases in production (e.g. food/fuel/feed/timber/fibre)

Overliming can cause nutrient deficiencies, leading to a reduction in crop production (e.g, lime-induced iron chlorosis) (Bolan *et al.,* 2008).

5.5. Limitation of the practice

Acid sulfate soils are a natural soil type existing as a result of the oxidation process of metal sulphides such as pyrite (FeS_n) (Andriesse and van Mensvoort, 2006). These soils have a sulfuric horizon or a sulfidic material occurring in the coastal lowlands of Southeast Asia (Indonesia, Thailand, Vietnam), West Africa (Senegal, The Gambia, Guinea Bissau, Sierra Leone, Liberia) and along the north-eastern coast of South America (the Bolivarian Republic of Venezuela, the Guianas). The world extent of both coastal and inland acid sulfate soils is, however, not yet well quantified. In Australia it is estimated at ~22 Mha (IUSS-WRB, 2015; Fanning, Rabenhorst and Fitzpatrick, 2017). It is generally not easy and cost-effective to neutralize acid sulfate soils using liming materials mainly because of the continuous release of sulfuric acid. Normally, acid sulfate soils are managed by keeping them submerged thereby not allowing them to get exposed to air. Reducing the oxidisation potential of metal sulfides in soils to form acid sulfate soils zones is the current preferred mitigation strategy (Gurung *et al.,* 2017). If sufficient water and substantial investment for its management is available, rice can be cultivated on these problem soils. About 3.0 Mha of rice is cultivated on acid sulfate soils in Asia (2.9 Mha), Africa (0.5 Mha) and Americas (0.4), which are closely associated with deepwater/mangrove environments and rainfed lowlands (Haefele, Nelson and Hijmans, 2014). In Malaysia, the several steps of amelioration for rice cultivation include correct water management to prevent pyrite oxidation by maintaining water table level above the pyrite layers, liming at appropriate rate (~2.5 $t.ha^{-1}$), adequate fertilizer/organic matter application and keeping the soil submerged as long as possible before transplanting (Suswanto *et al.,* 2007).

6. Recommendations before implementing the practice

Before any application of lime to acid soils, it is strongly recommended to have the soil sampled and analyzed according to recommendations provided by the local/regional extension agent or a soil expert familiar with the soil properties of the region. Also, lime specifications must comply with local/regional regulations.

7. Potential barriers for adoption

Table 98. Potential barriers to adoption

Barrier	YES/NO	
Biophysical	Yes	Lime application can lead to release of CO_2 resulting from the dissolution of lime (Kunhikrishnan *et al.* 2016).
Cultural	Yes	There is still a poor understanding of the values of regular liming of soils that are subjected to continuous acidification such as legume-based grazed pastures (Bolan *et al.*, 1991).
Social	No	In the Zambian farming districts of Mkushi and Sowezi although smallholding farmers knew the benefits of using lime and that uptake of agricultural lime could be encouraged, the main constraints on the use of lime were the absence of soil testing and a lack of cash in the rural economy (Mitchell, 2005).
Economic	Yes	Although lime deposits are available in most countries affected by soil acidity in Sub-Saharan Africa, the cost effectiveness of liming, especially in relation to transport and the commonly required high application rates, is likely to negatively affect the adoption of this practice (Vanlawe *et al.*, 2015).
Institutional	Yes	The lack of soil testing facilities is a barrier for adoption of the practice in many regions. Additionally, developing lime supply chains from scratch is difficult and costly (Mitchell, 2005; Bossuet, Chamberlin and Warner, 2019).
Knowledge	Yes	There is still a lack of knowledge on the beneficial effects of regular liming on soil health and productivity, including constraints of estimating lime requirement (Bolan *et al.*, 2003).
Natural resource	Yes	The main source of agricultural lime is limestone deposit, whose frequency varies and quality-grade dolomite may be scarce (DMRE, 2003).

Photos of the practice

Photo 28. Liming acidic Ferralsol under grass pasture and annual crop in Brazil.

Table 99. Related cases studies available in volumes 3 and 5.

Title	Region	Duration of study (Years)	Volume	Case-study No.
Increasing Yield and Carbon Sequestration in a Signalgrass Pasture by Liming and Fertilization in Sao Carlos (SP, Brazil)	Latin America and the Caribbean	6	3	32

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