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AGRICULTURA USES OF LIME AND GYPSUM

ALAN MANSON & NICKY FINDLAY

Lime and gypsum are both naturally occurring, calcium-containing minerals that are used as soil amendments. Many land users believe that lime and gypsum can be used interchangeably. This is not so, however, as they have different functions in improving a soil's potential for agricultural use.

Lime

Lime, or calcium carbonate ($CaCO_3$), is used to reduce soil acidity and to add calcium and magnesium to the soil. Soil acidity is quantified using soil pH, exchangeable acidity and acid saturation; pH is a measure of the concentration of hydrogen ions in the soil water, and exchangeable acidity and acid saturation are related to the concentration of aluminium in soil water. A soil pH of 7 is neutral. Soils with a pH (measured in KCl) of between 5.0 and 7.0 (weakly acid) experience few pH-related problems. Where the pH is less than 5.0, aluminium solubility increases and plant growth may be affected (depending on acid saturation), particularly through restricted root growth. Poor root growth results in poor nutrient uptake and increased susceptibility to a variety of environmental stresses, including drought, disease and nutrient limitations.

Lime increases soil pH by reacting with some of the hydrogen ions in an acidic soil to produce water and carbon dioxide; it also precipitates soluble aluminium as aluminium hydroxide. The concentrations of both hydrogen ions and aluminium ions in soil solution are reduced and the soil pH increases (becomes less acidic). A number of factors determine the effectiveness of lime.

The neutralising value or purity of lime determines the amount of acid that a given quantity of lime will neutralise when added to that acid. It is expressed as a percentage relative to the neutralising value of pure calcium carbonate and is called the calcium carbonate equivalent (CCE).

TABLE 1 Calcium carbonate equivalent of some liming materials

Material	CCE (%)
Pure calcium carbonate	100
Calcitic agricultural limestone	70 - 100
Dolomitic agricultural limestone	70 - 109
Hydrated lime (slaked agricultural lime)	120 – 136
Burned lime (unslaked agricultural lime)	179

Particle fineness is important for lime effectiveness. The neutralization effect is greater with small particles because of increased total surface area exposed to soil acidity. Large particles or lumps of limestone (bigger than 1.7 mm) can remain unreacted in soils for many years.

Lime distribution and incorporation are also important because lime does not move through the soil. As the effect of a lime particle only extends about 3 mm from where that particle is placed, incorporation of lime into the soil is necessary for effective reduction of soil acidity. Also, lime takes time to neutralise soil acidity and should be incorporated at least two months before planting. This is particularly relevant when considering adopting a no-till system.

Acidity problems, in particular subsoil acidity, must be corrected before converting to a no-till system. If required, lime should be incorporated as deep as possible since there is negligible movement of lime down the soil profile, meaning subsoil acidity cannot be remedied once a no-till system has been established.

In established no-till systems, lime is surface applied and not incorporated into the soil. The activity of soil organisms (especially earthworms) slowly mixes the topsoil, and a small proportion of the lime is washed down cracks and large pores. The effect of surface-applied lime in a no-till system has been found to move downward at about 1.3 cm per year on fine-textured soils. Several years are required to neutralise acidity below a 5 cm depth. Therefore lime rates should be adjusted to 30 percent of the full rate since only the surface 5 to 8 cm of soil will be reacting with the lime (recommendations are given assuming incorporation to a depth of 20 cm). Soil sampling in the 0-5, 5-10 and 10-20 cm depth ranges is the most reliable method to determine pH changes and lime requirement over time for no-till systems.

Gypsum

Gypsum, or calcium sulfate ($CaSO_4$), is a naturally occurring, neutral salt (pH ~6.7). It contains approximately 20% calcium and 16% sulphur and thus can be used to improve soil calcium and sulphur levels. Gypsum is about 200 times more soluble than agricultural lime, allowing it to move readily down the soil profile where it can help to alleviate subsoil problems.

Calcium is an important plant nutrient that is essential throughout the soil for plant root growth. However, most soils have sufficient plant-available exchangeable calcium for good root growth, and most calcium "deficiencies" are actually induced by excessive levels of other elements such as aluminium, potassium, ammonium or sodium.

Where additional calcium is required, studies have shown that gypsum is more effective than lime at meeting plant calcium requirements. The calcium in gypsum is soluble, even when the soil pH is greater than 7; this enhances its plant availability and its mobility. Calcium applied as gypsum will be leached into the subsoil more rapidly than calcium applied as lime. The sulphur in gypsum is in the sulphate (SO_4^{2-}) form, which is plant available. Increasing sulphur deficiencies in crops have been noted as fertiliser use has shifted away from incidental sulphur supply in phosphorus fertilizers (most farmers now use MAP or DAP rather than superphosphate to supply P). This has increased the importance of gypsum as a sulphur fertilizer.

Gypsum can help to mitigate the problems caused by excessive sodium levels in sodic soils. The calcium replaces sodium on exchange sites and the sulphate enhances its removal by leaching (as soluble sodium sulphate). The lower sodium-calcium ratio and higher sulphate concentration in soil solution increases clay flocculation and improves aggregate stability (soil structure). Soils erode more easily when they lack structure. A lack of stable aggregates also means fewer pore spaces for water to move through. This results in rapid waterlogging and poor infiltration during rainfall and increased surface-crusting and soil compaction when soils dry out.

In some acid soils, gypsum can be used to ameliorate **subsoil** aluminium toxicity. Gypsum should not be used instead of lime to correct **topsoil** acidity as it has little effect on soil pH. Where it can be mixed in the soil, lime is much more effective at neutralizing soil acidity, increasing soil pH and decreasing acid saturation. Lime is also more effective than gypsum in the top 10 cm in no-till systems because earthworms and other organisms mix the lime into the soil. However, lime cannot be mixed into acid subsoils unless expensive deep tillage is done. It is in these situations that the use of gypsum can be effective.

In the high-rainfall parts of the KZN interior, aluminium toxicity due to subsoil acidity can severely restrict root development. Both the calcium and the sulphate in gypsum help to improve root growth in acid subsoils.

The sulphate ion ameliorates aluminium toxicity by:

- precipitating aluminium- and sulphate-containing minerals;
- exchanging with hydroxyl ions on iron- and aluminium-oxide surfaces; the hydroxide ions then precipitate aluminium as aluminium hydroxide
- complexing with aluminium in the soil solution to form aluminium sulphate, which is less toxic and more capable of being leached away

The calcium ions:
compete with the aluminium ions for uptake by the root; and

- displace aluminium ions from the soil's exchange sites
- decrease acid saturation of the soil.

Gypsum is most effective at reducing subsoil aluminium toxicity in highly weathered clays and sandy clay loams; effective application rates range from 2 to 10 t ha^{-1}. It does not effectively reduce aluminium toxicity in sandy soils and less-weathered soils (those with low concentrations of iron and aluminium oxides).

TABLE 2 Summary of differences between lime and gypsum

Lime	Gypsum
Lime is a carbonate, oxide or hydroxide of calcium	Gypsum is a sulphate of calcium
Lime has alkaline properties	Gypsum is a neutral salt in water (neither alkaline nor acid)
Lime raises the pH of soils by neutralizing hydrogen ions.	Gypsum will not neutralise acid soils or effectively raise pH.
Lime may be used as a source of Ca in low-Ca soils.	Gypsum may be used as a source of Ca and of S.
Lime won't effectively reclaim sodic soils unless elemental sulphur or sulphuric acid is added.	Gypsum reclaims sodic soils by replacing Na with Ca.
Lime may slightly improve water penetration in some soils – improvement decreases as pH rises.	Gypsum may improve water penetration when very pure (low salt) water is used for irrigation. Gypsum won't improve the drainage of a poorly drained soil. It has no effect on plough pans, clay pans or hardpans.

Contact

Dr Alan Manson or Nicky Findlay
Professional Scientists
Tel: 033 355 9464 or 9644
alan.manson@kzndard.gov.za
nicky.findlay@kzndard.gov.za

KZN Department of Agriculture & Rural Development
Soil Fertility Research, Analytical Services,
Cedara

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