JANUARY 2019

GETTING SOIL PH RIGHT - LIME QUALITY AND APPLICATION RATES

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KEY MESSAGES

- ✔ **Agricultural practices can contribute to soil acidification**
- ✔ **Fertilisers vary in their effect on soil pH**
- ✔ **Applying lime helps alleviate soil acidity**
- ✔ **Liming products vary in their neutralising value and particle size**
- ✔ **Soil texture affects the amount of lime required**
- ✔ **Lime contributes very little to plant available calcium levels**

SOIL ACIDIFICATION CAUSES

Soil acidification, the drop in soil pH, is due to several factors including leaching of nitrate nitrogen, nutrient uptake by crops and root exudates, build-up of soil organic matter and use of nitrogenous fertilisers containing ammonium and urea. Some phosphorus fertilisers and others containing sulphur will also contribute to acidification. High rainfall and excess irrigation can accelerate acidification. Drainage water can remove about 250 – 625 kg/ha of lime equivalent each year, depending on the soil texture and organic matter content.

Soil acidity effects

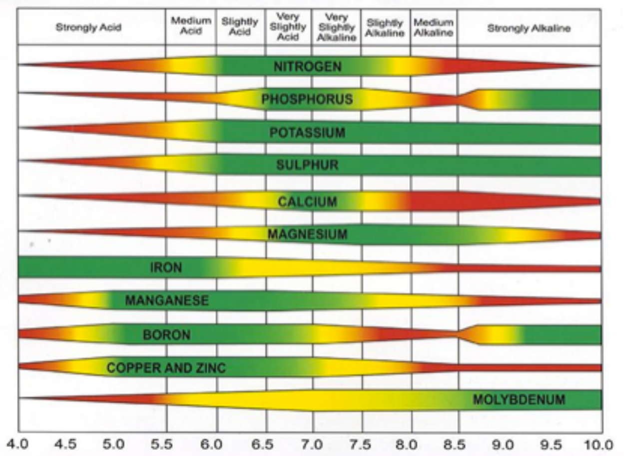
Soil acidity decreases the activity of beneficial soil microorganisms, and changes the solubility and availability of various nutrients (see Figure 1). The lower the pH, the lower the soil's reserves of beneficial cations i.e. calcium, potassium and magnesium. A pH below the optimum for a crop can have a marked effect on yield and quality due to nutrient imbalance and aluminium toxicity.

This project has been funded by Hort Innovation using the vegetable research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

LIMING AND SOIL PH
January 2019

Soil Wealth NURTURING CROPS
Integrated Crop Protection PROTECTING CROPS

Figure 1: How soil pH affects availability of plant nutrients



Liming can increase soil pH. When calculating how to increase the pH towards the desired value it is necessary to know:

- the target pH (pH 6.5 for most vegetable crops),
- the pH of the soil (via soil testing),
- the acidity or basicity of the fertiliser materials used
- the soil texture,
- the level of organic matter, and
- the type and quality of liming product to be used.

pH - logarithmic scale

pH is measured on a logarithmic scale, not a linear scale, i.e. the difference between each unit is not identical. To change the soil pH from pH 6 to pH 7 requires far less lime than to change the pH from 5 to 7 (see Table 1).

Table 1: pH as a logarithmic scale

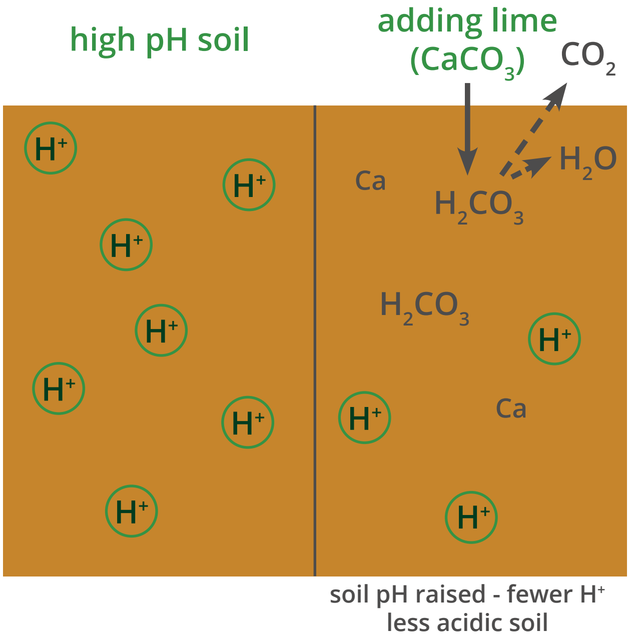
pH	
6	10 times the concentration of H^+ ions / acidity as pH 7
5	100 times the concentration of H^+ ions / acidity as pH 7
4	1,000 times the concentration of H^+ ions / acidity as pH 7

pH is an indication of how many hydrogen ions (H^+) are available.

The more hydrogen, the lower the pH.

When adding lime (e.g. calcium carbonate) to soils, it is the carbonate, not the calcium that changes the pH because the carbonate reacts with the hydrogen ions (H+) to form water and carbon dioxide. So the hydrogen ions that were in the soil become chemically bound in the soil water (see Figure 2).

Figure 2: How adding lime affects soil pH



Fertiliser acidity / basicity

All chemicals have an inherent pH. When adding fertiliser to soil, the chemicals that are added have the potential to change the soil's pH. Those that are more acidic can be counteracted by liming. Table 2 lists fertilisers and their acidity or alkalinity.

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Table 2: Average composition and equivalent acidity or basicity of fertiliser materials

Fertiliser materials	Chemical Formula	Total Nitrogen (N)	Available Phosphoric Acid (P_2O_5)	Combined Sulphur (S)	kg to neutralise (per 100 kgs of fertiliser material applied)	
		Percent			Lime (NV=100)	Acid*
Nitrogen materials						
Ammonium nitrate	NH_4NO_3	33.5–34			62	
Monoammonium phosphate (MAP)	$NH_4H_2PO_4$	11	48		58	
Ammonium phosphate-sulphate	$NH_4H_2PO_4.(NH_4)_2SO_4$	13	39	7	69	
Ammonium phosphate-sulphate	$NH_4H_2PO_4.(NH_4)_2SO_4$	16	20	15	88	
Ammonium phosphate-nitrate	$NH_4H_2PO_4.NH_4NO_3$	27	12	4.5	75	
Diammonium phosphate (DAP)	$(NH_4)_2HPO_4$	16–18	46–48		70	
Ammonium sulphate	$(NH_4)_2SO_4$	21		24	110	
Anhydrous ammonia	NH_3	82			147	
Aqua ammonia	NH_4OH	20			36	
Calcium ammonium nitrate solution	$Ca(NO_3)_2.NH_4NO_3$	17			9	
Calcium nitrate	$Ca(NO_3)_2$	15.5				20*
Calcium cyanamide	$CaCN_2$	20–22				63*
Sodium nitrate	$NaNO_3$	16				29*
Urea	$CO(NH_2)_2$	45–46			71	
Urea formaldehyde / ureaform		38			60	
Urea ammonium nitrate solution	$NH_4NO_3.CO(NH_2)_2$	32			57	
Phosphate materials						
Single superphosphate (SSP)	$Ca(H_2PO_4)_2$		18–20	12		neutral
Triple superphosphate (TSP)	$Ca(H_2PO_4)_2$		45–46	1		neutral
Phosphoric acid	H_3PO_4		52–54		110	
Superphosphoric acid (ammonium polyphosphate [APP])	H_3PO_4, $H_4P_2O_7$, $H_6P_4O_{13}$ and other higher forms		76–83		160	
Potash materials						
Potassium chloride	KCl					neutral
Potassium nitrate	KNO_3	13			23	
Potassium sulphate	K_2SO_4			18		neutral
Sulphate of potash magnesia	$K_2SO_4.2MgSO_4$			15		neutral

*included to give an indication of relative alkanity of the applied fertiliser

Adapted from Ayers and Westcot (1985)

Soil texture

Soil texture, the size of soil particles, has an effect on lime requirements. Table 3 shows an example of the amount of 100% neutralising value lime required for different soil textures to lift the pH in the top 10 cm of soil by 1.0 pH unit. This does not apply to very acid or already alkaline soils.

Table 3: Liming requirements for different soil textures (from Nicholson)

Soil texture	Lime (t/ha)
Clay	9
Clay loam	7
Loam to clay loam	5
Sandy loam	4
Sand	2.5

The soil texture effect is due to differences in cation exchange capacity (CEC). Clay has a very high CEC, sand a very low one. The higher the CEC, the more of the positively charged cations (e.g. Mg^{2+}, Ca^{2+}, K^{+}, Al^{3+}, H^{+}) a soil can hold. In an acidic soil, the proportion of hydrogen (H^{+}) and aluminium (Al^{3+}) on exchange sites and in the soil solution are high. This means that, at the same low pH, clay soils contain more acidifying H^{+} and Al^{3+} than sandy soils because they can hold more (see Figure 3).

Given the same pH to start with, sandy soils acidify more quickly. Therefore they require liming more frequently to maintin the same pH because $CaCO_3$ leaches more easily from sandy soils (lower buffering capacity/CEC).

When lime (e.g. calcium carbonate, $CaCO_3$) is added to a soil, the calcium replaces hydrogen and aluminium on exchange sites, so they go into solution. The remaining carbonate 'bonds' with hydrogen in the soil solution and, together, are ultimately transformed into water and carbon dioxide, a gas (see Figure 2). The H ions (H^{+}) are thus 'neutralised' and the exchange sites hold more calcium than before.

Lifting the pH also reduces toxic aluminium levels in the soil. The higher the pH is above 5.5 the greater the reduction in the availability of Al to non-toxic levels, as it is less soluable.

The reason for the greater lime requirement of clay compared to sand is that it contains more of the acidifying cations H and Al at low pH and therefore needs more lime to 'deactivate' them.

Soil acidity and organic matter

Soil organic matter has a CEC greater than clay - it holds and attracts a lot of positively charged ions. If your soil is high in organic matter, you will require even more lime to raise the pH.

Lime neutralising value (NV)

The neutralising value (NV) is calculated in comparison to pure calcium carbonate ($CaCO_3$). $CaCO_3$ is given an arbitrary value of 100. Less lime is required if the NV of a liming product is greater than 100 and more is required if the NV is less than 100. For example, a poor grade agricultural lime with an NV of 60 will have to be applied at approximately twice the rate of a good quality hydrated lime (NV of 110 to 120). Table 4 lists liming products and their neutralising values.

Figure 3: Relationship between soil texture and soil pH

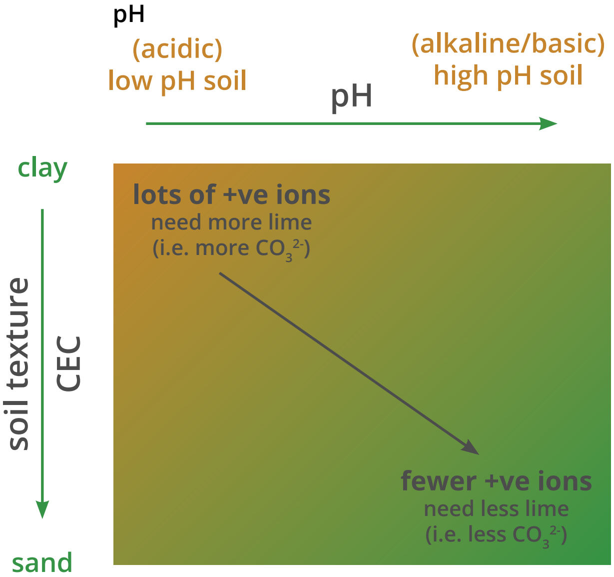


Table 4: Chemical analyses[a] of pure and commercial grades of the principal liming materials

Liming material	Chemical formula	Neutralising value		
		Pure product	Commercial grades[a]	
			Good	Poor to fair
Agricultural lime (calcium carbonate)	$CaCO_3$	100	95–98	60–75
Hydrated (slaked) lime (calcium hydroxide)	$Ca(OH)_2$	135	110–120	<105
Burnt lime / Quicklime (calcium oxide)	CaO	179	128–150b	<120
Dolomite (calcium/magnesium carbonate)		109	92–102	60–75
Burnt dolomite (calcium/magnesium oxide)		214	110–160b	80–100
Magnesite (magnesium carbonate)	$MgCO_3$	119	95–105	–
Burnt magnesite (magnesium oxide)	MgO	250	180–220[b]	–

[a] Analyses of commercial grades of materials based on NSW DPI records.
[b] High values can be expected only from freshly burnt products. Burnt and hydrated lime, dolomite and magnesite readily react with carbon dioxide and moisture in the atmosphere to revert to hydrated and carbonate forms, causing their neutralising values and calcium and magnesium analyses to fall with time and exposure to air.

Adapted from Upjohn, Fenton, and Conyers (2005)

Lime quality

The quality of the liming product depends on its fineness (particle size) and its neutralising value. Lime with a smaller particle size can be more easily incorporated into the soil and has a greater surface area per unit volume and so will act faster (neutralise the acidity more quickly).

Calculating amount of lime to apply

Figure 4 provides a formula that will give an approximate level of the amount of lime to apply to change the pH by the required amount.

Figure 4: A formula to provide an approximation of the amount of lime required to raise the soil pH

Calculation for approximate amount of lime to apply

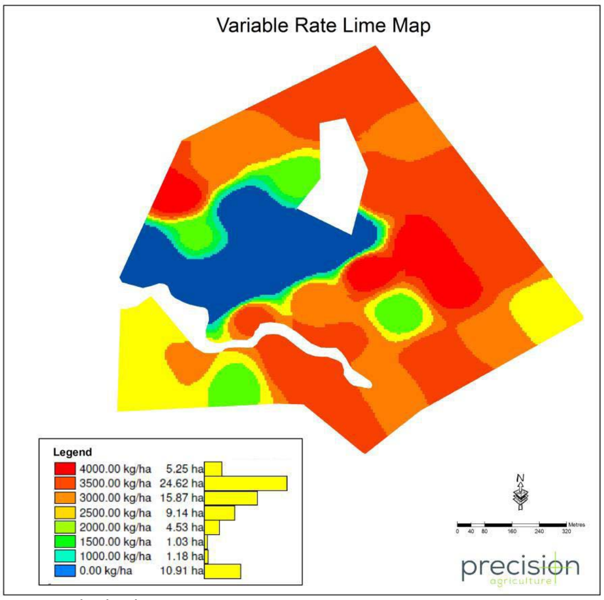
$$\frac{100}{\text{neutralising value of liming product (from Table 4)}} \times \text{soil texture lime requirement (t/ha) (from Table 3)} \times (\text{target pH} - \text{current soil pH}) = \text{lime (t/ha)}$$

adapted from Nicholson

Paddock variability

Across a paddock there may be considerable variability in pH. It is worth taking multiple soil samples and then zoning according to pH and applying different amounts of lime as appropriate to each zone (see Figure 5). This can be more economic, efficient and effective - it can save fertiliser and produce more even crops.

Figure 5: Paddock variable lime rate application



From Whitlock (2018)

Online calculators

There are range of online calculators, these ones may be useful to get started.

Soil Amelioration Calculator (and instructions) - these spreadsheets may not work with every version of MS Excel - - http://www.liebegroup.org.au/liebe-group-publications/lime-profit-calculator/

A simple liming rate calculator from the UK Agricultural Lime Association - https://aglime.org.uk/lime_calculator.php

This calculator allows you to compare particle size, NV and costs of lime products - http://soilquality.org.au/calculators/lime_comparison

Lime, soil calcium & plant availability

An acidic soil typically has low calcium availability as well as low levels of K and Mg. A large proportion of the exchange sites are occupied by H and Al. Applying lime will increase the Ca proportion on exchange sites. However, Ca from lime is not immediately plant available; it is not suitable to alleviate plant calcium deficiency in the short term. To improve calcium uptake in the short term, Ca will need to be applied via a fertiliser containing calcium that rapidly increases the Ca concentration of the soil solution (e.g. calcium nitrate, $Ca(NO_3)_2$). Applying foliar fertilisers is also possible. However, given Ca only travels upwards in the plant, any deficiencies in tubers or roots will not be improved via foliar applications.

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