EXTENSION OF BEST PRACTICE PRINCIPLES FOR IDENTIFYING AND MANAGING SOIL LIMITATIONS IN SOUTHERN AND CENTRAL NSW

Agriculture produces food and fibre products. The very nature of plant production causes the soil to become more acidic. Recent studies indicate that the rates of lime currently used in contemporary farming systems are generally too low to raise pH in the first instance, then maintain a desirable pH by neutralising acidification.

What is soil acidity?

The pH scale describes the acidity (H^+) or alkalinity (OH^-) in soil. It is a negative logarithmic scale: the more acid present, the lower the pH value. A soil with a pH of 5 is 10 times more acidic than a soil of pH 6; and pH 4 is 100 times more acidic

than pH 6. While the pH scale ranges from 1 to 14, the pH of soils in the field is between pH_{Ca} 3.8 and 9.5. Soil is generally classed as acidic at pH below 5.5. As pH declines, soil and plant function is generally affected.

Plant growth and the pH (CaCl₂) scale



Acidification

Acidification is the combined effect of processes that either add acid or remove alkali from the soil. The rate of pH decrease is the product of the rate that acid is produced in the soil, and the soil's ability to resist a change in pH due to that acid addition. This is known as pH buffering capacity (pHBC).

In most acid soils, there is a relationship between pHBC and the Cation Exchange Capacity (CEC), so CEC is used as a surrogate for pHBC. Soils with high CEC (clay soils, or soils with high organic matter content) will exhibit high pHBC. While the CEC and pHBC effect from the clay content is difficult to change, agricultural management – such as the use of pasture rotations and stubble retention – can influence organic matter content. Clays have a higher pHBC than sands, so to achieve a decrease of one pH unit, more acid would need to be applied to the clay than to the sand.

For example, an acidification rate resulting in a soil pH decline of one unit over a 30-year period in the surface 30 cm of a sandy clay loam soil, would take 120 years under the same farming system for clay soils (Helyar *et al.* 1990). It follows that the amount of lime (calcium carbonate; $CaCO_3$) required to increase the pH by one unit would also be more in the clay. Therefore pHBC is the quantity of lime required to increase 1 kg of soil by one pH unit.

The magnitude of acidification can be expressed as the equivalent mass of lime required to theoretically neutralise the acidity for an area (kg $CaCO_3/ha$).

Causes of acidification

Several important agricultural processes increase the rate of acidification.

Product removal

Agriculture produces food and fibre products. The very nature of plant production causes the soil to become more acidic. As plants grow, they take up more positively charged nutrients (cations) than negatively charged (anions). Plants must remain neutrally charged, so they excrete positively charged H⁺ (hydrogen ions; protons; acid), which acidifies the soil, especially around the roots (the rhizosphere). Because the plant has excreted acid, plant material is now alkaline (high pH). In a natural cycle, the plant would die where it grew and the alkali in the plant would be returned to the site of acid formation. The net effect would balance out, to start again with the next growth cycle. However, when plants are removed as agricultural products, either directly (hay, grain, silage) or indirectly (as wool or meat produced by animals grazing the plants) the acidity remains in the soil. The greater the product removal, the greater the acidification.

Fertilisers

For a fertiliser to directly cause acidification, acid (H⁺) must be produced. Several common fertilisers do this.

Elemental sulfur (S) fertilisers - microbes convert the sulfur to sulfate (plant-available S) and acid. While elemental S can be used on alkaline soils to decrease pH, its use on acid soils should be avoided, as it worsens soil acidity. The use of sulfate fertilisers is not acidifying, as the fertiliser is already in the sulfate form and the acidifying reaction does not take place in the soil.

Ammonium fertilisers - e.g. MAP, DAP, ammonium sulfate. Ammonium fertilisers will always result in acidification of the soil, however the magnitude will be less if the added nitrogen (N) is utilised by the plant. The main acidifying reaction of ammonium fertilisers is the microbial transformation of ammonium (NH⁴⁺) to produce nitrate (NO³⁻) and acid (two acids for every nitrate formed). Both ammonium and nitrate are plant available, but plants can more easily access and utilise nitrate. However, the positive charge on ammonium causes it to stick to clay and resist leaching, whereas nitrate is negatively charged, so can freely leach. This is important because once the acidifying reaction occurs, the nitrate can move to another location, leaving the acidity where the fertiliser was placed. When the nitrate is taken up by the plant, an alkali is released. (Uptake of nitrate can cause the plant to become negatively charged, so it releases alkaline OH⁻). This alkalinity can only ever neutralise some of the acidity formed and the leaching loss of the nitrate means that the full acidifying effect of the ammonium fertiliser will be exhibited in the soil.

The use of nitrate fertilisers can be alkaline due to the plant excreting alkali in response to nitrate uptake. However nitrate fertilisers are not a commercially viable management tool for acid soils due to the expense, and the inability to control the location of plant uptake once applied to the soil, as nitrate moves within the soil water. If nitrate fertilisers are lost by leaching, no pH change will occur in the soil.

Urea fertilisers - in theory, the processes that occur in soils following urea application should neutralise each other. The conversion of urea to ammonium adds alkali, and is followed by:

- gaseous loss as ammonia, which adds acid (net effect no pH change); or
- the ammonium is used by the plant and acid is excreted (net effect no pH change); or
- the ammonium is converted to nitrate (2 x acid) addition), which is then used by the plant and alkali excreted (net effect no pH change).

This theoretical understanding has led people to believe that urea does not cause acidification unless nitrate is lost via leaching. However, the process mentioned does not happen at the same site within the profile. Therefore, the reactions do not balance each other out, but rather cause pH changes (acid and alkaline) in different areas of soil profile. This becomes significant in controlled traffic, no-till systems where fertilisers are placed in the same area of the profile year after year.



Manganese toxicity Photo: Dr Sergio Moroni, Charles Sturt University,

Identification of acidity

The main impact of acidity in agricultural systems is impaired plant growth. The poor growth observed is the product of the combined influences of soil pH on plants, microbes and nutrients. Measuring soil pH is the first step in diagnosing the underlying problem. Use of a commercial pH indicator kit may be useful in the field to identify the severity and location of acidity in a profile, and this may inform the depth to which samples should be taken for accurate labbased analysis of soil pH and associated nutrients.

Soil acidity influences nutrient availability. This commonly manifests as aluminium toxicity, which causes stunting and/or deformation of the root and reduced root hair development. This then limits the plant's access to water and nutrients and decreases nodulation in legumes. Depending on the soil parent material, the risk of aluminium toxicity can increase rapidly as pH_{Ca} declines below 4.8.

Manganese toxicity can occur at pH_{Ca}<5 and will stunt shoot growth and cause discolouration on the edges of young/ new leaves.

Acidity can also cause plant nutrient deficiencies. The high aluminium and iron concentrations present in acid soils can bind to some nutrients, making them unavailable to plants and microbes. Examples include phosphate and molybdenum (Mo). A Mo deficiency may result in less N fixation by legumes due to the presence of ineffective (white or green inside) nodules. Acidity also affects the soil organisms' ability to cycle nutrients from organic matter back to the plant. For example, acidity can decrease the rate of formation of plant available nitrogen.

Diagnosing soil acidity by observing plant symptoms is not an effective management tool. A variety of factors could cause symptoms and once observed, production loss has already occurred. The best method to diagnose and monitor soil acidity is to establish a periodic soil sampling strategy (every two to four years).

Because the processes that affect soil pH occur in different layers, soil pH changes with depth in the profile. The surface centimetres are often higher in pH than the subsurface layers from 5-15 cm. This is due to excessive cation uptake by plant roots from the subsurface, where roots tend to be concentrated, and the return of alkaline plant residue to the soil surface. Management practices such as surface application of lime without incorporation, or placing ammonium fertilisers in the seeding zone can also exacerbate a high pH at the soil surface. The result is 'pH stratification'. This is problematic because standard 0-10 cm and 10-20 cm soil testing fails to detect its presence.

While management can influence the soil acidification rate to some extent, it is an unavoidable consequence of agricultural production. The addition of liming materials (e.g. lime, dolomite or other carbonate sources) needs to occur to maintain soil pH and avoid acidity degrading the production system.



Use of a commercial pH indicator kit may be useful in the field to identify the severity and location of acidity in a profile, and this may inform the depth to which samples should be taken for accurate lab-based analysis of soil pH and associated nutrients. Photo: Helen Burns NSW DPI



Aluminium toxicity causing stunting and/or deformation of the root and reduced root hair development. Photo: Helen Burns NSW DPI



Figure 1 shows the pH CaCl² of field soil sampled in 2.5 cm increments (solid line), 5 cm increments (dotted line) or 10 cm increments (dashed line). The 10 cm increment effectively averages the pH in that region, recording a pH of 5.2 in the 0-10 cm sample that fails to identify the severe acidity that exists at 7-15 cm. Based on this example, the best recommendation for measurement and monitoring soil pH would be depth increments of 5 cm.

Figure 1: Price, T., Condon, J., McCormick, J., Burns, H. (2020). The Amelioration of Subsurface Acidity Stratification by Contrasting Liming Methods. In Proceedings of the 2020 Wagga Wagga GRDC Grains Research Update

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SOILS

Acidification rates under contemporary farming systems

Recent studies indicate that the rates of lime currently used in contemporary farming systems are generally too low to raise pH in the first instance, then maintain a desirable pH by neutralising acidification. For example, the lime required to balance acidification under an annual crop/annual pasture system east of Wagga (producing an average wheat yield of 2.8t/ha, sown with 80 kg/ha of MAP fertiliser) is estimated to be between 290 and 400 kg lime/ha per year. A lucerne hay production system that cuts 10 t/ha of hay would require 700 kg lime per year to balance product removal alone.

Management of acidity

The product most commonly used to ameliorate soil acidity is agricultural lime. It is mined from geologic deposits of varying quality. The quality of lime is reported by its neutralising value (NV%), which is a scale relative to pure calcium carbonate (NV=100%). Dissolving lime in soil is a slow process because a lime particle neutralises only the pH of the soil surrounding that particle. As the lime dissolves the soil becomes less acidic, so there is less acid present to dissolve the lime. Therefore, the effectiveness of lime is also related to the particle size: finer particles have a greater surface area per unit mass and therefore have greater soilto-lime contact for neutralising reactions to occur.

Broadcasting lime onto the soil surface is the most cost-effective method of application. Incorporation into the soil by tillage speeds up the amelioration process and increases its depth. The effects of lime move down the profile very slowly. Incorporation provides a 'head start' to deeper amelioration.

The rate of lime required to ameliorate acidity is influenced by the initial pH, the depth of soil to be influenced by the application, the target pH, the lime NV and the pHBC of the soil, which is estimated based on the CEC of the soil.



More information

https://communities.grdc.com.au/cropnutrition/acid-layers-topsoil-hurting-yield

This factsheet was written by Dr Jason Condon, Helen Burns and Abigail Jenkins from NSW DPI as part of the Extension of best practice principles for identifying and managing soil limitations in southern and central NSW (GRDC Project code FLR1909-001SAX).

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