Soil acidity - its stratification and amelioration with lime

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Key words

acidity, lime, soil pH, stratification, acidification, sampling

Take home message

- Productive agriculture is acidifying
- Create strategies to monitor soil pH to understand the effects of productivity and amelioration strategies
- Sampling in 5 cm intervals to a depth of 20 cm identifies the presence of acidic subsurface layers. Testing at 10 cm intervals does not provide the level of detail needed for cost effective decision making
- Proactive maintenance of the pH is a good long-term strategy, especially on productive soils. If you wait to see clinical symptoms of soil acidity in plants, yield losses have already occurred.

Introduction

Research over the last 30-40 years has provided sound knowledge regarding soil acidity.

Soil acidity is measured as soil pH which is a negative logarithmic scale. The ‘negative’ means that the more acid (H^+) there is in the soil solution the lower the pH and the ‘logarithmic’ means with each decrease in pH unit, there is a 10-fold increase in acid concentration in the soil. That is, a soil at pH 5 has 10 times that acid of pH 6 and a soil at pH 4 has 100 times the acid of pH 6. This is important to understand when trying to manage acid soils.

Acidity is created during agricultural production via a number of processes. These include:

- The removal of products (wool, meat, grain, fodder) which are all alkaline, leaving the soil more acidic
- The use of legumes to fix nitrogen from the atmosphere. This causes acidity via several mechanisms indirectly but primarily because plants excrete more acid when plant N is fixed rather than taken up as nitrate from the soil
- The use of fertilisers that undergo nitrification (the biological process that forms nitrate) and create acid in the soil. These include sulfate of ammonia, MAP, DAP and urea
- The use of acidifying fertilisers such as elemental sulfur.

The rate that a soil acidifies (decreases soil pH) is a function of the magnitude of the processes occurring and the ability of the soil to resist pH change when acid is created. This is called the pH buffering capacity (pHBC) and is determined by the soil properties – clay content and type, organic matter content and exchangeable aluminium concentration.

Acidity impacts plant growth via toxicities of aluminium (Al) and manganese (Mn); deficiencies of molybdenum (Mo), phosphorus (P), magnesium (Mg) and calcium (Ca). Acidity can also disrupt the soil biology responsible for nutrient cycling and nitrogen (N) fixation by legumes. Whilst some crops are more tolerant or susceptible to conditions of acidity than others, and breeding programs exist to create more tolerant varieties, the fact remains that agriculture is acidifying and the negative impacts on the broader soil chemistry and biology will continue if acidity is not ameliorated.

The negative plant effects of acidic soils can be overcome with the use of agricultural lime. Superfine lime of high neutralising value (purity) mixed well into the soil can increase soil pH. The NSW DPI produced liming models that predicted pH change due to liming rates on soils of differing pHBC identified by their effective cation exchange capacity (ECEC). The ECEC was used as a surrogate for pHBC, as both relate to the same soil components. The output of these models was tabulated in the NSW Soil Acidity PrimeFact (Upjohn et al. 2005). However, the data that the model production used was based on well mixed, incorporated lime. This does not relate to no-till farming systems or systems where surface broadcasting only is used.

Stratification

Acidifying processes do not occur uniformly within agricultural soil profiles. They occur within different layers of the soil and as such, result in stratified soil pH profiles having higher pH in the surface few centimetres and relatively lower soil pH in the 5- 15 cm region (Figure 1). These lower pH layers are called acidic subsurface layers and have been shown to have significant impacts on plant and soil biological function. Though important, the presence of acidic subsurface layers is often not identified by land managers/advisors due to the standard practice of soil sampling in 10 cm depth intervals.

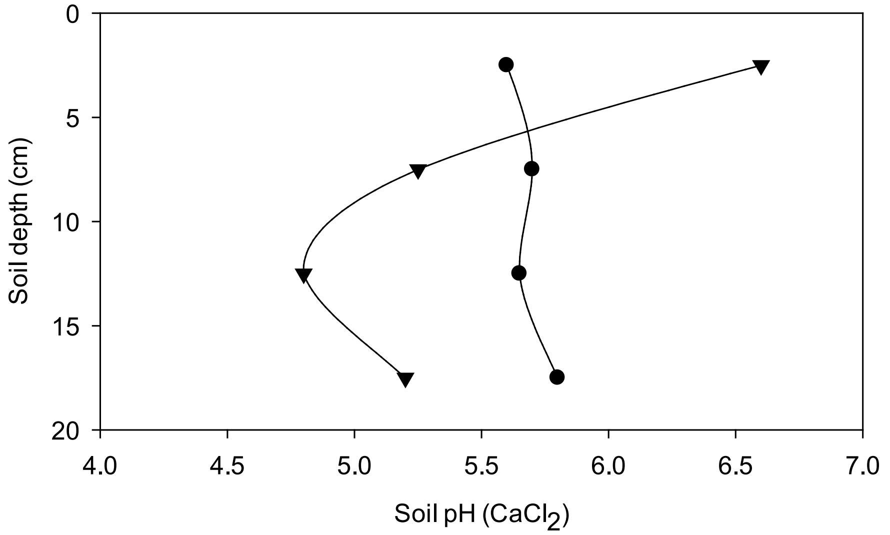

Figure 1. Soil pH_{Ca} profiles taken from the field 40 m apart on the same soil type. Soil pH stratification following approximately 90 years of agriculture (▼) compared to under native grass with no agricultural productivity (cemetery, ●), north of Canowindra, NSW.

The research program conducted by the authors utilises 2.5 cm sampling depth increments to track the movement of lime. Whilst such fine increments are commercially impractical, the data produced have identified that 5 cm increments successfully locate the presence of acidic layers within the soil. Figure 2 reports the soil test value as measured in 10 cm intervals (Figure 2a) and 5 cm intervals (Figure 2b) on the x-axes against the pH of the most acidic 2.5 cm interval of the sample presented on the x-axis. If the soil test value was able to find the acidity present within the interval the data points would fall on the dotted 1:1 line. Clearly, sampling in 10 cm intervals provides misleading results compared with those of 5 cm increment sampling. This change in sampling practice need to not be excessively expensive and only soil pH and perhaps CEC (including aluminium) need to be measured. It could easily be argued that failing to identify the presence of an acidic subsurface layer can produce the massive cost of crop failure compared to the small cost of 2 additional samples per sampling zone.

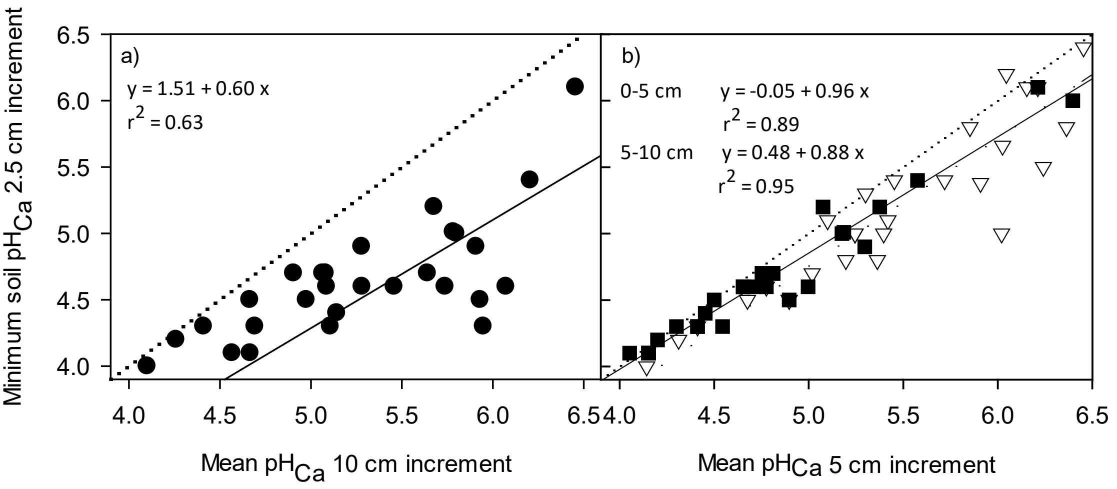

Figure 2. The relationship between mean soil pH_{Ca} of the a) 0-10 cm (●, regression solid line), b) 0-5 cm (▽, regression dashed line) and 5-10 cm (■, regression solid line) depth increments and the minimum soil pH of any 2.5 cm depth increment within those increment ranges for 31 soils between Albury and Cowra, NSW. Dotted line in a) and b) represents 1:1 isoline. (Source: Condon et al. 2020)

Amelioration

The lime use recommendations of the 1990s have been found inadequate in modern agriculture which is more productive, has greater use of N fertilisers and is based on no-till cropping systems that no not mix lime and soil together. The consequence of these changes is the formation of acidic subsurface layers, even where lime has been applied (Figure 3). The ineffectiveness of historic lime recommendations has been masked by 0-10 cm soil sampling. The pH stratified profiles shown in Figure 3 have 0-10 cm soil test values of pH 4.6 and 5.3, yet both have layers of greater acidity than reported in the soil test. The latter may result in a grower reporting no response to lime as the soil test value (0-10 cm) indicates lime has been effective, yet the acidic subsurface layer remains.

Higher rates of acidification and lack of soil mixing results in the alkali of added lime, at rates sufficient to remove aluminium (pH 5), being consumed within the soil surface thereby having no impact on acidity below 10 cm. This is of particular importance given the findings of Conyers and Scott (1989) and Li et al. (2019) which demonstrated that downward movement of the liming effect is facilitated when the soil pH is maintained above pH 5.5.

Shifting to a liming target of greater than 5.5 with a re-liming trigger of pH 5.5 theoretically provides the best long-term outcome for soil pH and associated soil function. The authors have implemented a series of trials that test this under a range of agricultural enterprises, soil type, and rainfall zones. Whilst the higher pH target invokes a concern of greater costs to ameliorate to that level, it is worth remembering that as pH is logarithmic, it takes less lime to move from pH 5 to pH 5.6 than it does to move from 4 to pH 4.6. Therefore, it is more cost effective to maintain pH before the acidity drops to a level that causes production losses. The history of acid soil research and the extension of liming application research has resulted in the industry seeking significant yield response to lime application. Therefore, the norm has become to wait for the illness to become apparent before providing the treatment rather than be proactive in our management so that we do not suffer the illness.

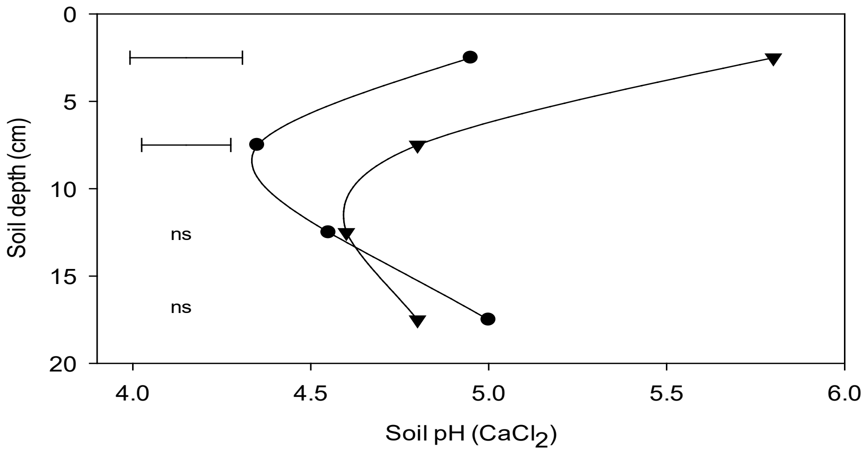

Figure 3. Soil pH$_{Ca}$ stratification following lime application within 5 years (▼, n =33) or more than 5 years (●, n=15) of sampling from locations between Albury and Cowra, NSW. Horizontal bars represent LSD (*P*=0.05), ns = no significant difference. (Adapted from Burns and Norton 2018).

Conclusion

Despite years of research, soil acidity remains a limitation to agricultural production. Left unchecked, agriculture is an acidifying enterprise. The acid soil management practices of the past are not keeping pace with today's agriculture. More focused research is required to find the most efficient methods of acid soil management within various agricultural systems. Proactive acid soil management should provide long term benefits to the productivity, sustainability and resilience of agricultural systems. The first step of effective acid soil management is monitoring soil pH. Sampling in 5 cm intervals to 20 cm is an effective method to identify the extent of subsurface acidity, to track the effectiveness of liming and track the rate of acidification.

Further reading

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