Interim results for deep insertion of lime into acid organic soils

Jeff D MORTON[1*], Bob LONGHURST[2], Shane ROZEBOOM[3], Harry E SNELL[3]

[1] *MortonAg, 8 Deacon St, Christchurch*
[2] *Pastoral Nutrient Management, Hamilton*
[3] *JD and RD Wallace Partnership*
[*]Corresponding author: mortonag1@gmail.com

Abstract
Organic (peat) soils are inherently acid in their natural state with soil pH levels that decline from 4.5 – 5.0 in the surface layer of 0 – 75 mm to 4.0 - 4.5 at a depth of 400 mm. Traditionally lime has been surface-applied and incorporated into the lower soil layers by cultivation. An alternative method of inserting 3 - 4 t/ha of lime down to 400 mm soil depth was tested on a developing Waikato deep Moanatuatua Organic soil. When two-thirds of the lime was placed within the 300 - 400 mm layer and one-third within the 200 - 300 mm layer in summer 2021, soil pH in the 200 - 300 mm layer decreased from 5.6 in 2021 to 5.3 in 2023 and significantly increased from 4.2 to 4.9 in the 300 – 400 mm layer over the same time period. Reversing the ratio of the lime rate into the two layers resulted in a significant increase in soil pH from 4.5 to 5.3 in the 200 – 300 mm layer and a non-significant increase from 4.2 to 4.6 in the 300 – 400 mm layer. Generally, there were corresponding decreases in soil exchangeable aluminium (Al) concentration in those layers. The ratio of lime insertion rate had no significant effect on rooting depth between years. There was a moderate correlation between soil pH and exchangeable Al when measured at depths of 0 – 400 mm. These interim results indicate that the deep insertion of lime into an acid Organic soil was effective in increasing soil pH and reducing soil Al concentration in the lower soil layers in the two years after the lime was inserted.

Keywords: aluminium, lime insertion, Organic soils, root depth, soil pH

Introduction

Organic soils formed on low-lying land mainly occur in the Waikato but are also present in Southland and the west coast of the South Island. The highly acidic nature of these soils is a by-product of microbial decay processes, cation exchange and input of acids from the environment (Crum 1988). A highly acidic soil restricts root growth which reduces their ability to potentially extract water from the water table during dry summers.

From the original research and experience, van der Elst (1962) recommended an application of 2.5 - 5.0 t/ha of lime pre-cultivation followed by a further 2.5 t/ha of lime pre-sowing for undeveloped peats. These rates of lime were assessed to maintain soil pH until pasture renewal when 0.5 t/ha of lime pre-cultivation and 0.5 t/ha of lime pre-sowing was applied. Further research showed that to establish and grow improved pastures, the acidity has to be mitigated by the initial application of up to 10 - 15 t/ha of surface-applied lime which is rotary hoed in to a depth of 200 mm and then disc-ploughed to 400 mm (During, undated). This programme should increase soil pH to 4.8 – 5.0 in the top 100 mm and 4.2 to 4.5 in the 100 – 150 mm layer. Lime was then recommended to be applied annually at 0.9 t/ha per required 0.1 pH unit to increase soil pH to 5.3 to 5.5 in the top 75 mm. At the next pasture renewal, if soil pH is less than 5.0 to 5.5 in the top 75 mm and 4.5 to 5.0 in the 75 – 150 mm layer, it was recommended that up to a further 10 t/ha of lime should be broadcast and disc-ploughed to 400 mm depth (During undated). More recently, lime has been incorporated into the soil by cultivation down to 200 mm soil depth and spading has been used to mix lime down to lower depths (Snell pers comm.)

This traditional method of liming Organic soils is expensive because of the deep cultivation needed to incorporate lime into the lower soil profile and the extra cost of renewing pastures that have declined in production due to dry summers and autumns because of limited root growth in the still-acid sub-soil at depths where the lime is not able to penetrate (Shannon, unpublished results). The deep insertion of lime, if successful in reducing the need for cultivation will also reduce the emission of greenhouse gases from farm machinery and the from decomposition of the organic matter. Wallace Partnership imported a tractor-drawn lime insertor from Brazil in 2020 that is capable of inserting up to 5 t/ha of lime down to 400 mm soil depth assuming ideal soil moisture conditions. Up to now lime has been inserted at rates of 3-4 t/ha down to this depth in November to March over about 150 ha per year from 2021 to 2023.

This paper describes the interim effect of the deep insertion of lime by presenting short-term trends in soil pH and Al levels and summer rooting depth in 2021

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and 2023 from the insertion of lime into a developing Waikato Organic soil.

Methodology

Sites

In February 2021, soil profile samplings were undertaken on 46 paddocks of Moanatuatua deep peat on the Monavale Farms of Wallace Partnership near Cambridge. These paddocks had been first sown in the 1960's with cultivation and re-grassing carried out about every ten years. Initially 10 – 15 t/ha of lime was ground-spread with 1-5 t/ha re-applied with each renewal event. The pasture in each paddock was mainly composed of ryegrass (*Lolium perenne*), other grasses such as cocksfoot (*Dactylis glomerata*) and Yorkshire fog (*Holcus lanatus*) and white clover (*Trifolium repens*). In February 2023, re-sampling was carried out on 12 of the 46 paddocks that represented a range of locations.

The average paddock anion storage capacity (ASC) levels in the top 75 mm on most of the farms were in the low range of less than 60% (O'Connor et al. 2001). These lower ASC's indicated that the farms were still in the developing stage where soil carbon is being lost as carbon dioxide as the soils oxidise from cultivation causing shrinkage.

Deep insertion of lime

Wallace Partnership used their soil inserter to place lime at 3 - 4 tonnes/ha down the soil profile to between 200-400 mm depths using either a 33/66 or 66/33% ratio of lime in each 200-300 and 300-400 mm layer during summer 2021. The calcium carbonate content of the Ag Lime used was 94.1% and it had 97.3% of the particles passing a 2 mm sieve and 53.8% passing a 0.5 mm sieve.

Measurements

The same sampling method was used for the 2021 (46 paddocks) and 2023 (12 paddocks) measurements using a small mechanical excavator to take a single set of samples from each paddock. At a randomly selected site, a pit was dug down to 500 mm depth, then a tape used to identify the profile depths for sample collection.

A spade was inserted into the soil at the bottom of each layer, then a trowel used to scrape down the respective layer to collect a sample of 200–300 g. Using this technique also allowed plant rooting depth and depth of soil moisture to be recorded in both years. The soil samples from three depths (0-200mm, 200-300mm, 300-400mm) were analysed for soil pH (water extractant) and exchangeable Al concentration ($CaCl_2$ extraction) by Hill Laboratories in Hamilton.

Statistical analysis

Initial results were collated to calculate a mean and standard deviation, with subsequent confidence intervals calculated to represent the situation before amelioration. The relationship between pH and Al concentration was defined by applying a simple logarithmic function. The soil sample results from each paddock in 2021 and 2023 were compared using a pair-sampled T - test (The jamovi Project 2022).

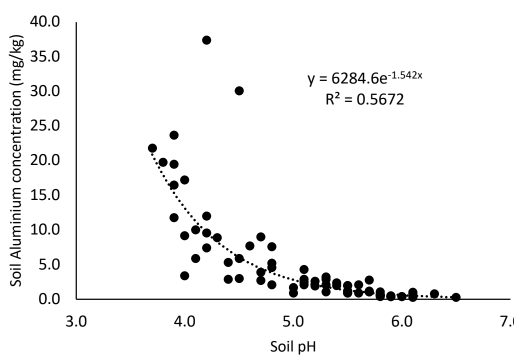
Results

Soil results from 2021

From the 46 paddocks sampled, the mean soil pH declined with depth while soil Al concentration increased (Table 1). The confidence intervals around each value were low and similar for soil pH but greater for soil Al concentration.

From these results, the relationship between soil pH and aluminium concentration for the deep peat on Monavale Farms is shown in Figure 1.

Figure 1 The relationship between soil pH and Al concentration at 0 - 400 depth on a Moanatuatua soil



There was a moderate relationship between soil pH and exchangeable Al concentration (Figure 1). The inverse shape of this curve was similar to that for mineral soils (Moir and Moot 2014).

Soil results from 2021 and 2023

Soil pH

The soil pH for each soil layer from the same paddocks sampled in 2021 and 2023 is shown in Table 2.

There were significant increases ($P < 0.05$) in soil pH from 2021 to 2023 in the 300 – 400 mm layer and in the 200 – 300 mm layer when 66% of the lime was inserted there (Table 2). For all the other soil layers and ratios of lime rates, there were no significant changes ($P > 0.05$) in soil pH between the two years.

Table 1 Mean and 95% confidence interval (CI) for soil pH and Al concentrations measured at different soil depths in February 2021.

Soil depth (mm)	Soil pH		Al concentration (mg/kg)	
	Mean	95% CI	Mean	95% CI
0 – 200	5.6	0.1	1.8	0.6
200 – 300	4.8	0.2	7.2	2.1
300 - 400	4.2	0.1	18.1	3.4

Table 2 Mean soil pH levels for different soil layers with different ratios of lime rates

	Ratio of Lime applied at either 200-300 or 300-400 mm below the soil surface					
	33% to 66%			66% to 33%		
Soil depth (mm)	2021	2023	P value	2021	2023	P value
0 - 200	5.9	5.6	0.07	5.7	5.6	1.00
200 - 300	5.6	5.3	0.427	4.5	5.3	0.014
300 - 400	4.2	4.9	0.044	4.2	4.6	0.352

Table 3 Mean soil Al concentrations (ppm) for different soil layers with different ratios of lime

	Ratio of Lime applied at either 200-300 or 300-400 mm below the soil surface					
	33% to 66%			66% to 33%		
Soil depth (mm)	2021	2023	P value	2021	2023	P value
0 - 200	1	1	0.798	1.3	1.5	0.62
200 - 300	1.9	2.5	0.577	9.8	2.3	0.071
300 - 400	10.5	5	0.021	17.9	6.3	0.026

Table 4 Mean rooting depth (mm) for different soil layers (mm) with different ratios of lime (%)

	Ratio of Lime applied at either 200-300 or 300-400 mm below the soil surface					
	33% to 66%			66% to 33%		
	2021	2023	P value	2021	2023	P value
Rooting depth	285	305	0.554	257	282	0.66

Soil Aluminium

Insertion of the lime to the 200-300 and 300-400 mm layers at the ratio of 33/66% resulted in a significant decrease ($P < 0.05$) in soil Al concentration in the 300 – 400 mm layer where the largest proportion of the lime was inserted but no significant change ($P > 0.05$) in the other two layers (Table 3). When the lime was injected at a ratio of 66/33% in the two layers, there was a significant decrease in Al concentration in the 300 – 400 mm layer but no significant change in the other two layers.

Rooting depth

The rooting depth measured in 2021 and 2023 where lime was applied in different ratios to the lower two soil layers (Table 4) shows that there was no significant change ($P > 0.05$) in rooting depth between years for each ratio of lime rate.

Soil moisture

Soil moisture level as observed below the surface was similar for both years with 371 mm soil depth in 2021 and 394 mm in 2023.

Discussion

It is fully realised that a trend with only two points spanning two years is only short-term and not fully indicative of the longer-term effect of deep insertion of lime. But the increase in soil pH in the 200-300 mm and 300-400 mm measured layers where most of the lime was applied plus the decrease in soil Al concentrations at these depths shows that the lime deposited in these layers is already reducing acidity. Predictably this effect is generally greater in the layer where more of the lime is deposited. This result shows that theoretically there should be no impediment to root growth down to 300 - 400 mm soil depth where the inserted lime has had the effect of reducing soil acidity. This depth of root penetration would then allow access during summer to the soil moisture present at an average depth of 371 mm in 2021 and 394 mm in 2023. The proviso to this is that the roots of the grass plants present in the pasture are capable of extending below their average current depths of 278 mm in 2021 and 293 mm in 2023. If they cannot exploit the opportunity to access this moisture then consideration could be given to introducing new grass species with the ability to achieve lower rooting depth. It will take several years into the future before the success of the aim of longer-persisting improved pastures from the deep insertion of lime can be definitely proven but the results so far are very encouraging.

The non-significant change in soil pH and soil Al in the 0 – 200 mm was expected since none of the lime inserted in 2021 was applied to the surface or placed in that layer. The average soil pH of 5.6 in the 0 – 200 mm layer in 2003 was greater than the soil pH of 5.0 – 5.5 in the 0 – 75 mm layer and 4.5 – 5.0 in the 75 – 150 mm layer recommended by Roberts and Morton (2017).

Conclusions

Insertion of 3-4 t/ha of lime to 200-400 mm soil depth on a deep peat increased soil pH and also decreased soil Al concentrations. These beneficial effects at both of the 200 – 300 and 300 - 400 mm layer was greatest when the highest proportion of lime was inserted into that layer. This decrease in soil acidity provided the opportunity for the grass roots to grow down to 400 mm soil depth where they could potentially access soil moisture during summer.

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