Venter, H.J., 2017. Soil acidity in the Kakanui ranges. In: *Science and policy: nutrient management challenges for the next generation*. (Eds L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 8 pages

SOIL ACIDITY IN THE KAKANUI RANGES

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Abstract

Aluminium toxicity is the primary yield limiting constraint associated with acidic soils, limiting the ability of roots to utilize soil moisture and nutrients. Elevated Al levels were observed for routine customer samples received from the Kakanui ranges. Prominent commercial laboratories in New Zealand measure only 0.02 M $CaCl_2$ extractable Al ($CaCl_2$-Al) while exchangeable Al measured in 1M KCl (KCl-Al) is also an established method but no longer offered in New Zealand. In order to compare these two different test methods for Al on Firm Brown soils, surface and subsoil samples in 15 cm increments up to 60 cm were obtained from a farm located in the Kakanui ranges. Samples were analysed for $CaCl_2$-Al, KCl-Al, basic cations in 1M ammonium acetate, pH in water and 1 M KCl.

Surface soils (0 – 15 cm) that received no lime had mean values for pH (H_2O) 4.9, pH (KCl) 3.7, $CaCl_2$-Al 23 mg/kg and KCl-Al saturation of 61 %. Where lime was applied in the past, mean values were pH (H_2O) 5.7, pH (KCl) 4.5, $CaCl_2$-Al 2 mg/kg and KCl-Al saturation of 8 %. Subsurface soil layers 15 – 30 cm, 30 – 45 cm and 45 – 60 cm had mean values ranging for pH (H_2O) 5.3 – 5.4, pH (KCl) 3.8 – 3.9, $CaCl_2$-Al 17 - 25 mg/kg and KCl-Al saturation of 49 – 76 %. Poor root penetration into the subsoil beyond 15 cm was observed during sample collection is likely a result of high soil acidity levels. Relationships between soil acidity parameters weakened progressively from the 0 – 15 cm down to the 45 – 60 cm soil layer.

Ameliorating surface soil acidity through liming is standard practice while ameliorating subsoil acidity is either done through subsoil liming, surface application of lime or gypsum. A soil – gypsum laboratory incubation showed this soil to be unresponsive to gypsum for decreasing KCl-Al concentrations in a closed system, although Aluminium saturation decreased.

Introduction

Aluminium toxicity is the primary yield limiting constraint associated with acidic soils, limiting the ability of roots to utilise moisture and nutrients (Kamprath, 2010). High aluminium levels in the root zone exceeding normal sampling depths (Whitley *et al.* 2016) can exacerbate poor growing conditions for crops. Currently the method of choice for measuring extractable aluminium in New Zealand soils is 0.02 M $CaCl_2$ ($CaCl_2$-Al), likely as a result of a preliminary toxicity threshold earlier established (Edmeades *et al.* 1983) and less obvious $CaCl_2$-Al being easier (Shuman 1990) to determine from an procedural point of view than 1 M KCl exchangeable aluminium (KCl-Al). In the past KCl-Al was used in New

Zealand (Lee 1988; Percival *et al.* 1996; Singleton et al. 1987; Willoughby 1986) and is widely used as measure of aluminium toxicity in Australia (Guo *et al.* 2012), Brazil (Abreu Jr *et al.* 2003), China (Lei *et al.* 2016), Canada (MacLeod & Jackson 1967; Shuman 1990) and the USA (Schroder *et al.* 2011).

Analytical Research Laboratories analyse numerous soil samples annually for $CaCl_2$-Al of which 20 % tested have a pH ≥ 6 where KCl-Al is negligible (Sumner & Yamada 2002). Singleton *et al.* (1987) and Whitley *et al.* (2016) reported $CaCl_2$-Al values exceeding 3 mg/kg at pH values 5.9 to 7 while De Sousa *et al.* (1985) reported KCl-Al to be non-existent at pH 5.5 highlighting the likely effect of differences in soil weathering status affecting Al quantities recorded for different soil types and also the difference in critical Al concentrations in relation to pH for these two Al measurement methods.

The acid reaction of soil as measured by pH is ascribed to the hydrolysis of Al ions in soil solution forming H^+ ions (Kamprath 2010). Presence of fertiliser salts in the soil or salt in the pH measuring medium displaces Al into solution therefore lowering the pH. Salt pH swamps the fertiliser salts present in the soil while water pH is exposed to the effects of fertiliser salts that may depress the pH value by up to 0.75 units (Sumner 1994; Kissel *et al.* 2004, MacLeod & Jackson 1967).

$CaCl_2$-Al method involves 10 g of soil extracted with 20 cm^3 0.02 M $CaCl_2$ solution followed by gravitational filtration and Al measured on ICP-OES. For low density soils where sufficient filtrate cannot be collected the test cannot be done. KCl-Al contrasts the $CaCl_2$-Al method by exhaustive extraction of Al and is not affected by soil density. A preliminary threshold value of 3 mg/kg Al was established (Edmeades *et al.* 1983) while the uncertainty of measurement for this test is ± 0.4 mg/kg.

Subsoil acidity is a major yield-limiting factor in vast areas of the world (Shainberg *et al.* 1989) and occurs over a diverse spectrum of environmental conditions (Sumner 1995). Agriculturally realistic liming rates are of little benefit in ameliorating subsoil acidity while excess alkalinity from substantial lime applications, which would be un-economic on hill country pastures, does not move readily down the soil profile. Gypsum has been used in the Brazil, South Africa and the USA to ameliorate subsoil acidity resulting in substantial yield responses (7 – 200 %) in a number of important crops (Sumner 1993) which includes lucerne, wheat and barley. It is suggested that gypsum ameliorates subsoil acidity by increasing the Ca concentration and decreasing KCl-Al through a mechanism of self-liming (Reeve & Sumner 1972) and precipitation of solid phases (Hue et al. 1985)

The objectives of this study is to correlate and evaluate soil acidity parameters measured on soil samples collected from different depths on the Kakanui ranges and to explore the response of the subsoil to gypsum in a closed system incubation.

Materials and methods

Soil

Soils samples were collected from a farm in the Kakanui ranges receiving 600 - 900 mm rain per annum varying with altitude. Sampling depths on these Firm Brown soils were 0 – 15, 15 – 30, 30 – 45 and 45 – 60 cm with 30, 30 , 25 and 13 samples collected for each depth increment respectively. These soils developed over Schist and un-weathered parent material was encountered in soil layers below 15 cm. A random selection of surface soil layer customer samples from over New Zealand was also included for comparison.

Incubation with gypsum

Representative subsoil from the 15 – 45 cm soil layer was incubated at field water capacity at 38 °C for 21 days. Seven gypsum rates between 0 and 18.3 ton/ha per 15 cm soil layer were replicated twice.

Analytical methods

Soils were dried at 38 °C, ground to pass a 2 mm screen and analysed for $CaCl_2$-Al, KCl-Al, pH water, pH in 1 M KCl, 1 M ammonium acetate exchangeable Ca, Mg, K and Na. Percent Aluminium saturation was calculated as (KCl-Al/ECEC)*100 where ECEC is the effective cation exchange capacity, which is the sum of KCl-Al and Ca, Mg, K and Na.

Results

Inter-correlations between soil acidity parameters

Analytical results revealed that conventional liming had a significant effect on soil acidity parameters in the 0 – 15 cm soil layer enabling the separation of samples from previously limed areas from those that have received little or no lime (Table 1).

Table 1. Mean soil analytical parameters

Sampling depth in cm	pH(H_2O)	pH(KCl)	$CaCl_2$-Al mg/kg	KCl-Al mg/kg	Bases me/100g	Al saturation %
0 - 15 (unlimed)	4.9	3.7	23	573	3.8	61
0 - 15 (limed)	5.7	4.5	2	86	11.9	8
15 - 30	5.2	3.9	19	399	3.8	53
30 - 45	5.3	3.9	19	360	1.7	69
45 - 60	5.4	3.8	25	396	1.4	76

Concentration of base cations decreased with soil depth, corresponding with an increase in Al saturation. Base saturation properties of this soil is similar to a highly weathered Ultisol described by Liu & Hue (2001) which was used in a gypsum leaching study and reporting decreased KCl-Al levels upon treatment with gypsum. Brown soils have some of the highest Al concentrations for New Zealand soils (Whitley *et al.* 2016). Limited or no root development was observed below 15 cm indicating that nutrient and moisture utilisation below 15 cm are restricted by high levels of Al toxicity.

Relationships between the two pH measurements deteriorated with increasing soil depth (Figure 1). The good relationship for the 0 – 15 cm soil layer may be ascribed to the effect of applied fertiliser displacing soil acidity components into solution. It can be reasoned based on observations by MacLeod & Jackson (1967) that decreasing cation concentrations with depth resulted in decreased Al solubility and therefore comparatively higher water pH values compared to pH(KCl) values.

A good correlation between pH water and Al saturation % is observed for the surface soil layer, while correlations for the deeper soil layers decrease with depth (Figure 2). The same trend was also observed for correlations between pH(KCl) and Al saturation % which negate the notion that 1 M KCl swamped the fertiliser salt effect, which most likely happened, but it appears that other factors are responsible for this anomaly of which weathering differences between surface and subsoil layers may be a one.

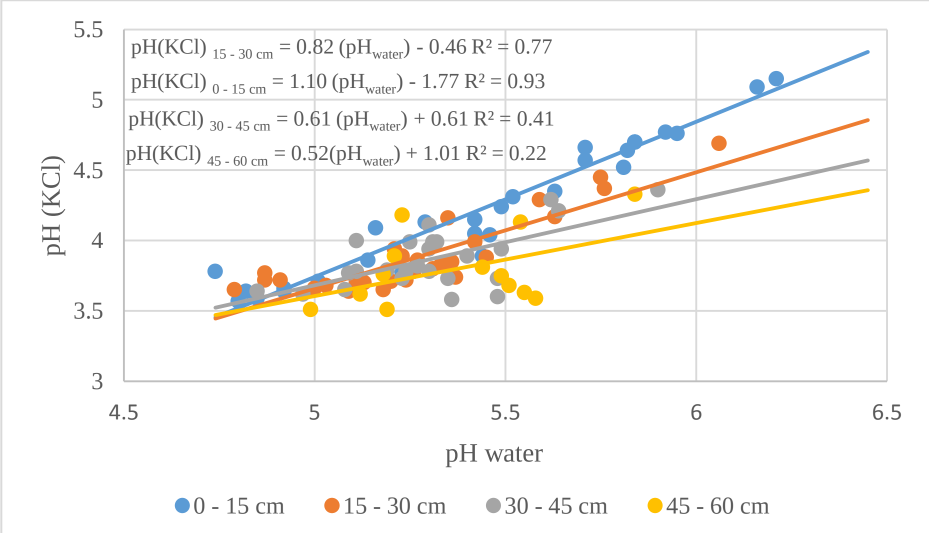

Figure 1. Relationships between pH water and pH(KCl) for the four different soil depth increments.

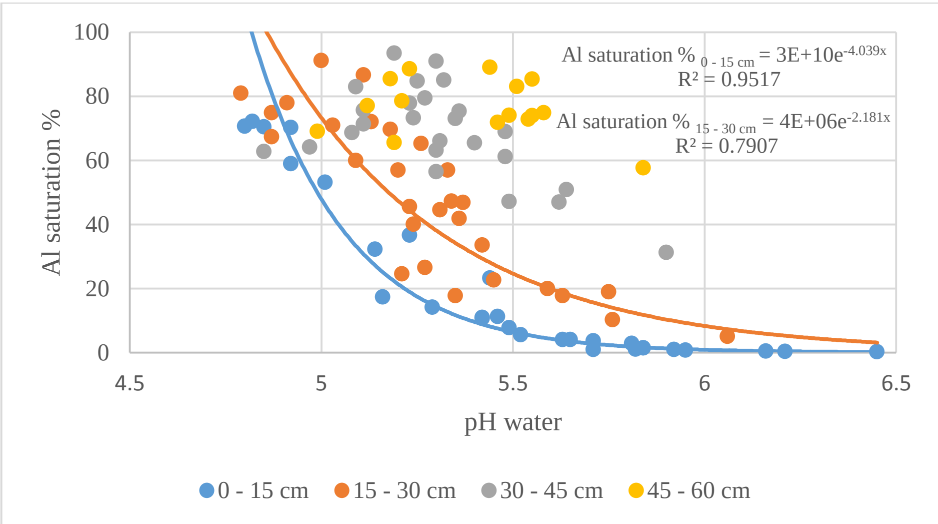

Figure 2. Relationship between pH water and Al saturation % for the four different soil depth increments.

De Sousa *et al.* (1985) reported KCl-Al to only increase below water pH 5.5 on weathered soils from the Cerrado while high levels of Al are already present at the same pH for the Kakanui soils where pH 6 corresponds with the levels recorded for Brazilian soils (Relationship not shown). For the relationship between pH(KCl) and KCl-Al, pH(KCl) 4.5 was observed the threshold for Al levels to increase.

Yield response relationships for Al saturation have been established for maize (Farina & Channon 1991; Fox, 1979; Wade *et al.* 1988) in South Africa, North America and Indonesia. The maize threshold value for Al saturation in South Africa is 20 % which is similar to extension guidelines used in NSW for rye-grass (Upjohn *et al.* 2005). In the absence of New

Zealand yield response data for KCl-Al the value of 20 % Al saturation is compared to 3 mg/kg $CaCl_2$-Al in the relationship between last mentioned parameters (Figure 3).

Predictions for Al toxicity in the surface soil samples were in agreement but discrepancies were observed for the subsoil samples where $CaCl_2$-Al were below 3 mg/kg although Al saturation values were above 20 % and ameliorative actions would be deemed necessary that is not supported by the $CaCl_2$-Al method.

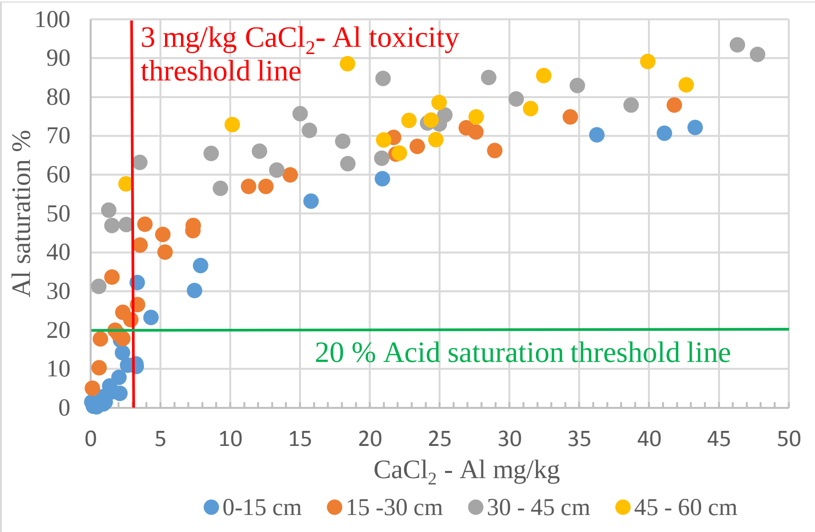

Figure 3. The relationship between $CaCl_2$-Al and Al saturation for four different soil depth increments for soil from the Kakanui ranges.

The relationship between $CaCl_2$-Al or Al saturation for random customer surface soil samples show less agreement between these parameters in predicting Al toxicity (Figure 4). 33 % of the samples fell into the south-eastern quadrant where the $CaCl_2$-Al threshold indicate ameliorative action to be taken although Al saturation is below 20 % where no action would be recommended. It is understandable that this approach would probably not be applicable to intensive farming systems but make economic sense for hill country sheep and beef enterprises.

Soil – gypsum incubation

Al saturation decreased with increasing gypsum rates (Figure 5) on the back of increasing Ca concentrations in the soil as is also illustrated by the increase in Ca saturation that took place which is in agreement with Reeve& Sumner (1972). $CaCl_2$-Al initially decreased followed by a slight increase that can be ascribed to Al being displaced into solution, however the changes in $CaCl_2$-Al are not mirrored by pH water (Figure 6) where a significant decrease in pH is observed as result of the gypsum salt effect. Understandably the same effect was not observed for pH(KCl). Inconsistent responses of KCl-Al were observed that need further investigation considering that leaching of Al was not facilitated while it was observed in field trials that Al leached deeper into the soil profile (Farina & Channon 1988; Sumner 1993).

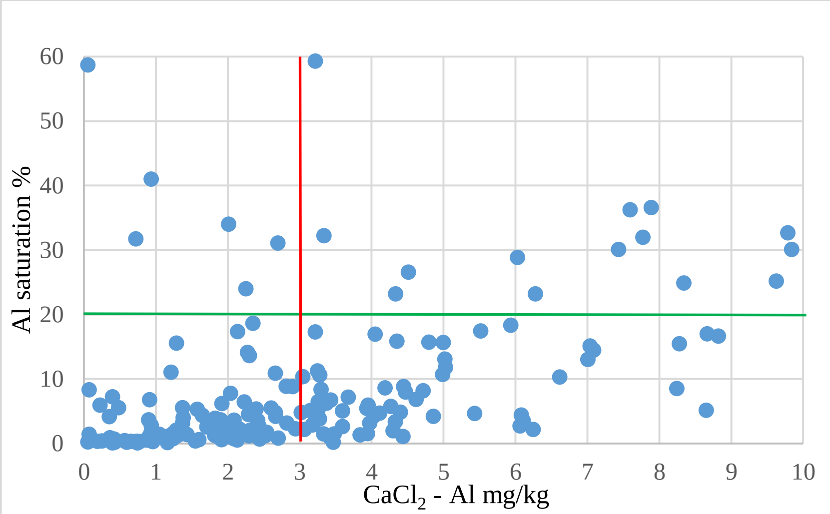

Figure 4. The relationship between $CaCl_2$-Al and Al saturation for random customer surface soil samples from over New Zealand.

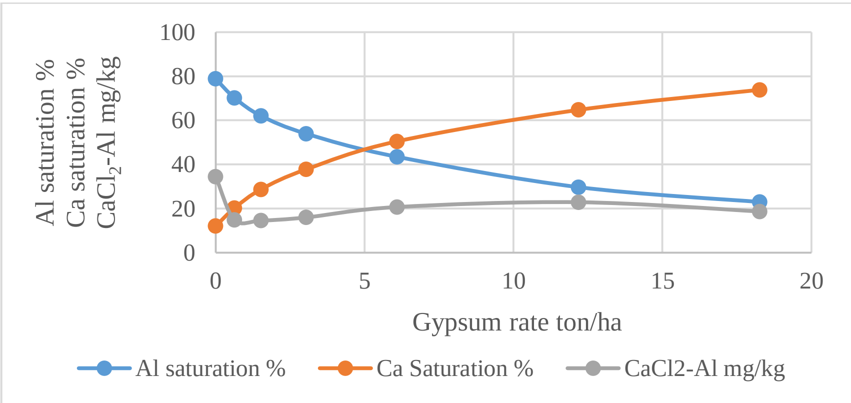

Figure 5. Changes in $CaCl_2$-Al, Al and Ca saturation of subsoil from the Kakanui ranges as a result of treatment with gypsum.

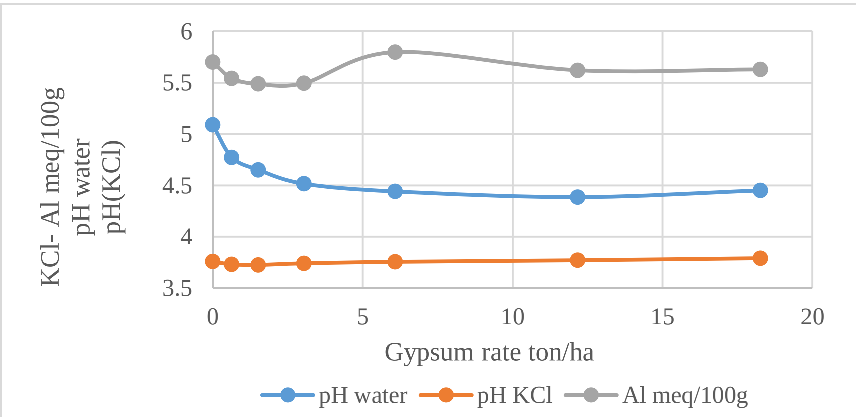

Figure 6. Changes in KCl-Al and pH of subsoil from the Kakanui ranges as a result of treatment with gypsum.

Conclusion and suggestions for further work.

Al concentrations for surface soils where lime was not applied are likely to impact on plant production, while high Al saturation levels in the subsoil restricts root development and utilization of moisture. Soil acidity parameters followed same trends observed for soils outside New Zealand, however the pH values differ at which Al parameters are minimal.

Gypsum would be able to reduce the activity of toxic Al^{3+} based on changes in Al saturation but may be uneconomic considering the quantities of gypsum required. While this closed system incubation showed little promise for amelioration of KCl-Al it may be able to proof the efficacy of gypsum in a leaching experiment since ample evidence is available from field trials showing that gypsum has a positive effect on KCl-Al in subsoils and crop yields on such soils.

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