# The effects of pH and aluminium on some common New Zealand grasses and legumes: A summary of recent research

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## Abstract

Soil acidity is becoming a major factor limiting the growth of temperate pastures. This paper summarises results from solution culture of experiments designed to examine the effects of pH and aluminium (Al) on the growth of a number of species and cultivars of temperate grasses and legumes.

Increasing solution pH from 4.5 had no beneficial effect on the growth of the temperate grasses examined, except for phalaris (*Phalaris aquatica*). Similarly, increasing pH had no effect on the growth of temperate legumes when grown in the presence of adequate N, except for lucerne (*Medicago sativa*). When dependent on symbiotic N, the growth of the cultivars of *Trifolium repens*, *T. pratense* and *T. subterranean* increased with increasing pH. However, the growth of *Lotus corniculatus* and *L. pedunculatus*, when inoculated with an acid tolerant rhizobia, was unaffected by pH. These results suggest that if acid tolerant *Rhizobia trifollii* can be identified, hydrogen ion ($H^+$) toxicity may be eliminated as a factor limiting growth on acid soils.

Most of the grasses and legumes examined were sensitive to Al, with solution aluminium (Al) activities of <10µM reducing growth by 50%.

With the exception of browntop (*Agrostis tenuis*), Yorkshire fog (*Holcus lanatus*) and chewings fescue (*Festuca rubra*), which were exceptionally tolerant to Al, most of the temperate grasses examined were as sensitive to Al as the legumes. *Poa pratensis*, crested dogstail (*Cynosurus cristatus*) and prairie grass (*Bromus wildenowii*) where in fact more sensitive than the legumes. Among the legumes *Lotus pedunculatus* was the most tolerant while *L. corniculatus* and red clover (*Trifolium pratense*) were the most sensitive. White clover (*T. repens*) and subterranean clover (*T. subterranean*) were intermediate.

There was evidence that the New Zealand derived cultivars of ryegrass (*Lolium perenne*) and cocksfoot (*Dactylis glomerata*) were more sensitive to Al than cultivars with Australian or European origins.

***Additional key words:** aluminium, grasses, temperate pasture, legumes, pH, soil acidity, toxicity*

## Introduction

In legume based pastures, the process of symbiotic nitrogen (N) fixation, when coupled with leaching losses of N, and the process of net crop removal are acidifying (Helyar and Porter, 1989). There is evidence, particularly in Australia where liming is not widely practiced, that pastoral soils are becoming increasingly acid (Helyar and Porter, 1989). In New Zealand there are large areas of hill country and upland soils which are acid (pH < 5.5) and where liming is generally no longer economic (Edmeades *et al.*, 1985a).

Major factors limiting plant growth on acid soils in New Zealand are aluminium (Al) and/or hydrogen ion ($H^+$) toxicity. Toxicity due to manganese (Mn) does not appear to be a major factor in acid soils in New Zealand (Smith and Edmeades, 1983).

There is a need therefore to examine the tolerance of New Zealand grass and legume pasture cultivars to soil acidity particularly Al and $H^+$. The purpose of this paper is to summarise research conducted by MAF Technology Ruakura over the past five years.

## Materials and Methods

All of the results reported in this paper have been derived from 'flowing' solution culture or 'still' solution culture experiments in glasshouses at the University of Queensland, Brisbane, Australia, or Ruakura Agricultural Centre, Hamilton, New Zealand.

Details of the experimental methods and techniques are given elsewhere (Edmeades *et al.*, 1990 a,b,c).

Solution culture experimentation allows the examination of the effects of Al and pH without the confounding effects which occur when acid soils are limed (see Edmeades *et al.*, 1990c).

A unique feature of the solutions used in the experiments under review is that their composition and ionic strength were designed to mimic soil solutions (Edmeades *et al.*, 1985b). The importance of this has been discussed by Edmeades *et al.* (1990 a,b,c). Also, Blamey *et al.* (1990) have examined the effects of Al toxicity at low and high ionic strengths on the growth of two *Lotus* species known to be dissimilar in their tolerance to Al. They found that at high solution ionic strength, even at relatively high concentrations of solution Al, neither the sensitive (*L. corniculatus* cv. Maitland) or tolerant (*L. pedunculatus* cv. Grasslands Maku) cultivar was affected by Al. In contrast, in low ionic strength solutions, there was a clear differentiation of the sensitive and tolerant species, even at low solution Al concentrations.

## Results and Discussion

### Effects of solution pH

***Adequate N present:*** The effects of solution pH on the growth of a number of temperate grasses and legumes, when grown in the presence of adequate N, are summarised in Table 1. For most of these species increasing the pH over the range 4.5 to 6.0 had no effect on plant growth. Phalaris (*Phalaris aquatica* cv. Grasslands Maru) and lucerne (*Medicago sativa* cv. Hunter river) are exceptional, indicating the extreme sensitivity of these species to $H^+$ toxicity. This has been observed in other studies (see Edmeades *et al.*, 1990a).

For a few of the species and cultivars examined, increasing the pH actually decreased growth. However, this effect was not consistent over all the cultivars of subterranean clover (*Trifolium subterranean*) and perennial ryegrass (*Lolium perenne*) examined (Table 1). The reason for these detrimental effects of increasing pH on yield is not clear although it has been suggested (Edmeades *et al.*, 1990c) that they are due to pH induced Fe deficiency. If this is so they are an artifact of the experimental system rather than a real physiological effect.

From these summarised results it can be concluded that, with the noted exceptions of lucurne and phalaris, temperate grasses and legumes which are not reliant on symbiotic N grow well at low pH (pH 4.5) and sometimes not so well at higher pH levels. It is unlikely therefore that $H^+$ toxicity per se is a major factor limiting the growth of grasses on acid grassland soils. The situation with temperate grassland legumes, dependent

**TABLE 1: Summary of the effects of increasing solution pH on the growth of a number of temperate legumes and grasses.**

| Species | Cultuvar | Effect of increased pH on plant yield | Source[2] |
|---|---|---|---|
| *Trifolium repens* | Grasslands Pitau | nil[1] | a |
| | Grasslands Huia | nil | a |
| | Grasslands G18 | nil | a |
| | Grasslands Tahora | nil | a |
| *T. pratense* | Grasslands Turoa | nil | a |
| | Grasslands Pawera | nil | a |
| *T. subterranean* | Tallarook | decrease | a |
| | Woogenellup | nil | a |
| *Medicago sativa* | Hunter river | increase | a |
| *Lotus corniculatus* | Maitland | nil | a |
| *L. pedunculatus* | Grasslands Maku | nil | a |
| *Lolium perenne* | Grasslands Nui | decrease | a |
| | Grasslands Ruanui | nil | a |
| *L. hybridium* | Grasslands Manawa | nil | b |
| | Grasslands Ariki | nil | b |
| *L. multiflorum* | Grasslands Tama | nil | b |
| | Grasslands Paroa | nil | b |
| | Grasslands Moata | nil | b |
| *Festuca arundinacea* | Grasslands Roa | nil | a,b |
| *Phalaris aquatica* | Grasslands Maru | increase | a |
| *Bromus wildenowii* | Grasslands Matua | nil | b |
| *Dactylis glomerata* | Grasslands Wana | nil | b |
| | Grasslands Kara | nil | b |
| | Grasslands Apanui | nil | b |
| *Paspalum dilatatum* | Grasslands Raki | decrease | b |
| *Holcus lanatus* | Massey Basyn | nil | b |
| *Agrostis tenuis* | not known | nil | b |
| *Festuca rubra* | not known | nil | b |
| *Cynosurus cristatus* | not known | nil | b |

[1] nil indicates effect not statistically significant
[2] a = Edmeades *et al.*, 1990a; b = Edmeades *et al.*, 1990c

on symbiotic N fixation, is confounded by the pH requirement of the rhizobia-host plant symbiosis.

***Appropriate rhizobia present:*** Table 2 summarises the effects of pH on the growth of some temperate legumes when dependent on symbiotic N fixation. In contrast to Table 1, these results demonstrate the combined effects of pH on host plant growth, nodulation and the overall effectiveness of the symbiosis. The rhizobia used were those generally recommended for each species.

For cultivars of *Trifolium repens* and *T. pratense* increasing the pH increased plant growth. In all cases maximum growth was achieved at pH 6.0 (Edmeades *et al.*, 1990b). These results, together with those in Table 1, show that the process of nodulation and nodule effectiveness are more sensitive to pH than host plant growth *per se*. This is supported by the fact that nodule numbers and nodule mass paralleled increases in plant growth (Edmeades *et al.*, 1990b).

For the two cultivars of *T. subterranean*, plant growth tended to increase with increasing pH, but these effects were not statistically significant. This suggests that these cultivars are less sensitive to pH changes, when inoculated with rhizobial strain WU95, than the cultivars of *T. repens* and *T. pratense.*

The lack of detrimental effects of low pH on the growth of both inoculated *Lotus* species is consistent with the lack of any pH effects on host plant growth and the known acid tolerance of the NZP2037 strain of *Rhizobium lotii* (Cooper *et al.*, 1985) used in this experiment. The apparent beneficial effect at pH 4.5 on the growth of *L. pedunculatus* needs confirmation.

It is relevant to compare the differential effect of pH on the *Trifolium* species when grown with adequate N and when dependent on symbiotic N (Table 1 and 2) with the lack of a differential effect for the *Lotus* species. These results suggest that if genuinely acid tolerant strains of *Rhizobia trifollii* could be selected, then $H^+$ toxicity as a factor limiting the growth of these pastoral legumes in acid soils could be eliminated.

**TABLE 2: Summary of effects of solution pH on the growth of some temperate legumes when dependent on symbiotic N fixation (from Edmeades *et al.*, 1990b).**

| Species | Cultivar | Effect of increased pH on plant yield | Rhizobia |
|---|---|---|---|
| *Trifolium repens* | Grasslands Pitau | increase | CB875 and NA40 |
| | Grasslands Huia | increase | |
| | Grasslands G18 | increase | |
| | Grasslands Tahora | increase | |
| *T. pratense* | Grasslands Turoa | increase | TAI |
| | Grassland Pawera | increase | |
| *T. subterranean* | Tallarook | nil[1] | WU95 |
| | Woogenellup | nil | |
| *Lotus corniculatus* | Maitland | nil | NZP2037 |
| *L. pedunculatus* | Grasslands Maku | decrease | NZP2037 |

[1] nil indicates effect not statistically significant

## Effects of Al

The results summarised in Table 3 show the activity of monomeric Al $\{Al^{3+}\}$ in solution required to reduce the growth of a number of temperate grasses

**TABLE 3: Generalised ranking of temperate grasses and legumes to aluminium toxicity (from Edmeades *et al.*, 1990 a,b,c).**

| Species | Aluminium activity ($Al^{3+}$) required to reduce yield by 50% |
|---|---|
| *Poa pratensis*<br>*Cynosurus cristatus*<br>*Bromus wildenowii* | 1-2 |
| *Lolium perenne* (NZ cultivars)<br>*Trifolium pratense*<br>*Lotus corniculatus* | 2-3 |
| *Lolium perenne* (Australian and European cultivars)<br>*L. hybridium*<br>*L. multiflorum*<br>*Phalaris aquatica*<br>*Dactylis glomerata*<br>*Festuca arundinacea*<br>*Trifolium repens* | 3-5 |
| *T. subterranean* | 5-6 |
| *Paspalum dilatatum*<br>*Lotus pedunculatus* | 7-8 |
| *Festuca rubra*<br>*Holcus lanatus* | ~12 |
| *Agrostis tenuis* | >30 |

and legumes by 50%. The results for the legumes are from experiments in which adequate N was supplied. However, there is little difference, taking into account experimental errors, in the effects of Al on inoculated and uninoculated plants (Edmeades *et al.*, 1990b).

These results do not support the generalization that grasses are more tolerant of Al than legumes. While some grasses such as browntop, Yorkshire fog and chewings fescue are more tolerant to Al relative to the legumes, there are other grasses e.g. *Poa pratensis*, crested dogstail and prairie grass which are more sensitive. Generally the ryegrasses appear to be at least as sensitive to Al as the legumes normally grown in association with them in New Zealand pastures.

Of the legumes, *L. pedunculatus* cv. Grasslands Maku was exceptional in its tolerance to Al. This is consistent with field trial evidence (Lowther, 1980). *L. corniculatus* cv. Maitland was quite different, being relatively sensitive to Al.

There is evidence, (Edmeades *et al.*, 1990c) that the New Zealand derived perennial ryegrass cultivars are more sensitive to Al than cultivars derived from Australia and Europe. Furthermore these New Zealand cultivars are more Al sensitive than the hybrid (*Lolium hybridium*) and Italian (*L. multiflorum*) ryegrass cultivars. It is possible that these differences could reflect the fact that most New Zealand ryegrass material has been selected from and breed on fertile and therefore high pH soils.

The three cocksfoot cultivars examined exhibit a range in tolerance to Al with Grasslands Wana being more tolerant than Grasslands Apanui. Grasslands Kara was intermediate. Once again the European origin of Grasslands Wana may explain its greater tolerance.

The exceptional tolerance of the 'weed' grasses chewings fescue, Yorkshire fog and particularly browntop, may explain their ability to aggressively colonise low fertility soils.

## Conclusions

Within NZ agriculture, many agronomic factors must be considered when selecting pasture species for acid soils. Thus it is generally not possible to sow species according to their relative Al-tolerance. However, the results explain why some species grow poorly in acid soils. The rankings produced in this work also allow the exclusion of the Al toxicity as a limiting factor in some soils by the presence of Al sensitive species.

This work identified NZ bred perennial ryegrass to be more sensitive to Al than white clover. Therefore work is being conducted at Ruakura Agricultural Centre to select Al tolerant lines of ryegrass suitable for NZ pastures.

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