Aluminium toxicity expression on nutrient uptake, growth and root morphology of *Trifolium repens* L. cv. 'Grasslands Huia'

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**Summary** Hydroponic experiments were undertaken to examine the effect of increasing aluminium levels on the mineral nutrition and root morphology of *T. repens* growing in nutrient solution. Toxicity symptoms appear between 27.8 and 47.5 μM Al³⁺ activity (148 to 297 μM total aluminium). The threshold level corresponding to a 10% reduction in leaf fresh weight is estimated to be approximately 20 μM Al³⁺ activity.

The concentration of aluminium in the leaves of white clover increases exponentially with aluminium activity in the nutrient solution. The uptake of divalent cations was inhibited but aluminium enhanced potassium and nitrogen concentrations in both leaves and roots.

At high pH (pH 6.0) the speciation of aluminium is controlled by the formation of solid aluminium phosphate and aluminium hydroxide except at the lowest aluminium level (37 μM) where 99.9 per cent is present as the DTPA complex. As the concentration of total aluminium increases, the percentage of Al-DTPA and soluble aluminium hydroxide decreases whilst solid Al(OH)₃ increases rapidly to reach a maximum of 91.6 percent (of the total aluminium) in the 1180 μM aluminium treatment. At pH 4.5 the dominant forms of aluminium are free aluminium ion Al-DTPA, AISO₄ and AIOH₂⁺.

The roots of aluminium stressed plants showed symptoms typical of aluminium toxicity.

**Introduction**

Aluminium toxicity suppresses legume growth on acid soils where the soil solution aluminium ionic activity may be high. These effects have been widely studied in many species including non-legumes. When two legumes were compared higher levels of aluminium in shoots of *T. repens* were found compared with *Lotus* species and it was concluded that growth of white clover is more susceptible to aluminium toxicity.

It has recently been shown that liming acid soils increased the 'Al-bound' phosphorus fraction in white clover roots relative to the roots of plants in unlimed soils. Significant negative correlations between available aluminium and yield were found. Furthermore the authors showed that the inhibition on root growth by aluminium was greater in *Trifolium repens* than in *Lotus pendunculatus*. In nutrient culture solution, aluminium depressed levels of calcium in the tops of white clover.
In many studies on aluminium toxicity, aluminium-phosphate interactions are often cited\textsuperscript{2,21,28}. Such interactions are partly due to strong complexation and precipitate formation between aluminium and phosphate ions in the pH range 4.5–7.0. Consequent immobilization of phosphorus within plant roots has been suggested as the reason for aluminium toxicity often being expressed in leaves as an apparent phosphorus deficiency. Other modes of aluminium toxicity are evident in the interference with: calcium and potassium utilization, cell division, water uptake, root respiration and with the deposition of polysaccharides in cell walls\textsuperscript{5,6,17}. Recent evidence suggests that nitrogen metabolism is involved in the differential aluminium tolerances of plant genotypes\textsuperscript{7}.

Other work using white clover grown in hydroponic solutions has shown that low concentrations of aluminium both enhanced and reduced the uptake of several nutrients including phosphorus and ammonia\textsuperscript{25}. This work has been extended to a study of growth and root morphology in \textit{T. repens} growing in nutrient solution subjected to ionic aluminium concentrations ranging up to a level sufficient to cause severe phytotoxic symptoms. This paper reports these results. Both the level and chemical form of aluminium can effect direct or plant induced changes to the chemical environment around the root zone. These changes can in turn affect the speciation of other nutrients influencing their availability to the plant. Several chemical mechanisms can be proposed to account for these changes. In this work frequent analysis of nutrient levels and pH throughout the treatment period enabled any changes in the level and presence of various chemical species to be calculated. This information is used to aid in the interpretation of aluminium effects on nutrient uptake in white clover as measured by the concentration changes of several elements in leaf and root tissue.

\textbf{Methods}

Seedlings of \textit{Trifolium repens}, cv ‘Grasslands Huia’ were prepared and grown under conditions described by Pritchard \textit{et al.}\textsuperscript{25}. The plants were grown for 3 weeks in a growth cabinet before starting the aluminium treatments. Conditions were such that the control plants were growing vigorously throughout the duration of the experiment.

At the start of the experiment, 14 pots (28 plants) were selected containing young plants of similar size and habit. Two replicates of 7 aluminium treatments (0, 0.037, 0.074, 0.148, 0.297, 0.593 and 1.18 mM aluminium as the sulphate) were prepared. The concentrations of the constituent elements in the nutrient solution were: calcium 0.7 mM, potassium 0.7 mM, magnesium 0.125 mM, nitrate 3.0 mM, ammonium 1.0 mM, phosphorus 0.105 mM, sulphur 0.37 mM, ferric ion (as diethylenetriaminepentaaetic acid or DTPA complex) 50 \( \mu \)M, manganese 1.32 \( \mu \)M, zinc 0.85 \( \mu \)M, copper 0.12 \( \mu \)M, molybdenum 0.05 \( \mu \)M and boron 6.0 \( \mu \)M. Each individual treatment solution was adjusted to pH 6.0 using Analar 0.1 M NaOH solution.