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The effect of Al and Mn on growth and mineral composition of *Casuarina equisetifolia* Forst.

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Key words: Casuarina, aluminium, manganese, toxicity

Abstract

In pot experiments (perlite) with *Casuarina equisetifolia* a strong growth depression and clear Al and Mn toxicity symptoms were found with higher treatment levels of Al and Mn. In nutrient solution dry matter yields at the highest Al treatment (2000 μM) were 37,5% for shoot and 49,5% for root biomass compared to the control. With the highest Mn treatment (3200 μM) the yield was 49% of control for both shoot and root dry matter. The lowest levels of Al and Mn treatments (250 μM Al and 400 μM Mn) resulted in a dry weight production of 78,6% for shoots and 99,3% for roots in the case of Al and 80,7% for shoots and 89,8% for roots in the case of Mn compared with the dry weight produced by control plants. The Al accumulation was relatively higher in roots than in shoots and increased with increasing Al concetrations in the nutrient solution. Also, Mn content in roots under low Mn treatments was as high as in shoots. High Al and Mn concentrations had a negative effect on the uptake of cations (Ca, Mg and Na). Aluminium had no effect on K uptake. A high decrease in the phosphorus concentrations in shoots and roots occurred in the higher treatments of Mn and especially Al. The uptake of NO_3-N from the nutrient solution was positively influenced only by the lower Al and Mn treatments. Higher concentrations of Al and Mn had no effect on the N uptake. The principal toxicity symptoms shown by the plants were the blue-green colour with brown-necrotic spots on their shoots for Al and white-chlorotic spots in the upper parts of the shoots for Mn.

Introduction

Casuarinas possess many attributes which characterize successful exotic species. They are multi-purpose plants with uses other than for fuelwood: they are adaptable to a range of environments including infertile, saline and arid sites; and can be easily established and managed. They have the ability to fix atmospheric nitrogen and some grow well under a range of enviromental stresses. Research into the physiological attributes will enable species to be manipulated to improve their productivity.

Among the known phytotoxic effects of certain elements Al toxicity is a serious problem to crop production in acid soils [22]. The toxic effects of Al on crop plants have been reviewed by Foy [7]. Aluminium toxicity is prevalent in acid soils since Al is more soluble under acid condition and eventually becomes biologically active.

Two to six billion ha of strongly acid solis, mostly in humid regions, have Al toxicity problems. Inhibition of shoot growth and root elongation, physiological and biochemical changes, and changes in nutrient and water uptake are characteristic symptoms of Al stress. Manganese toxicity has been recognised as an important factor limiting plant growth on acid and poorly drained soils [8]. Manganese toxicity produces visible symptoms that can vary between plant species.

Material and methods

Three months old seedlings of *Casuarina equisetifolia* were transplanted into pots containing perlite. One week after transplantation the different treatments commenced. There were four replicates and the experiment was arranged in a completely randomized design. The nutrient solution contained (μM:): 400 $CaCl_2$, 150 $MgSO_4 \cdot 7H_2O$, 40 $Na_2HPO_4 \cdot 12H_2O$, 94 NaH_2 $PO_4 \cdot 2H_2O$, 10 FeNaEDTA, 1010 NO_3K, 0.5 $MnSO_4 \cdot H_2O$, 0.1 $CuSO_4 \cdot 5H_2O$, 0.1 $ZnSO_4 \cdot 7H_2O$, 5 H_3BO_3, 10 NaCl, 0.05 $Na_2MoO_4 \cdot 2H_2O$. The seedlings

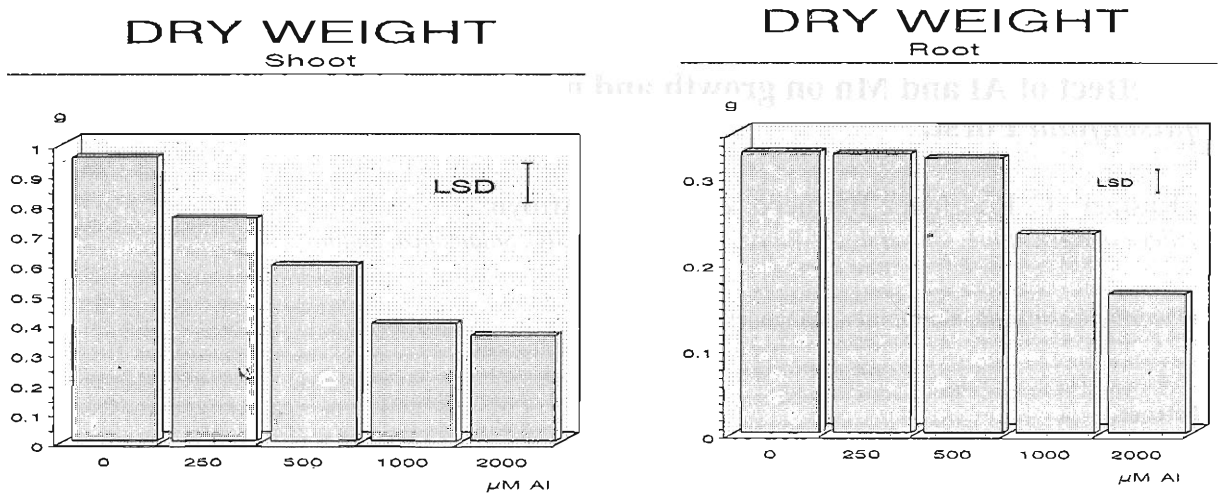

Fig. 1. Dry weight of shoots (left) and roots (right) at different levels of aluminium in the nutrient solution. Media of four plants. (LSD at $p \frac{3}{4} 0.05$).

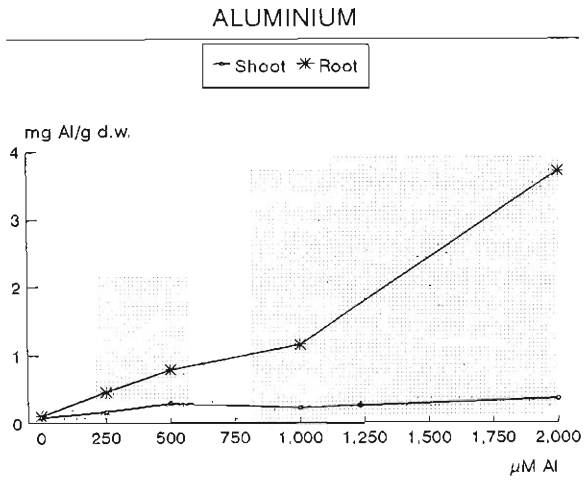

Fig. 2. Aluminium content of shoots and roots at different levels of aluminium in the nutrient solution. Values are media of four plants.

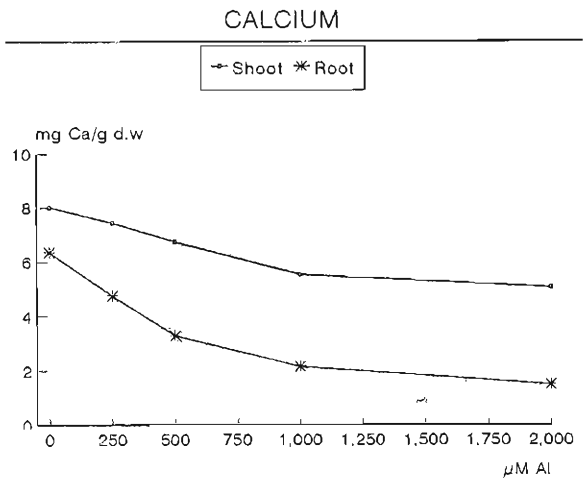

Fig. 3. Calcium content of shoots and roots at different levels of aluminium in the nutrient solution. Values are media of four plants.

were exposed to five levels of Al (0, 250, 500. 1000 and 2000 μM) supplied as $AlCl_3$ or to five levels of Mn (5, 400, 800, 1600 and 3200 μM) supplied as $MnSO_4$. The pH in all treatments was adjusted to 4.0 with HCl or NaOH. The appropriate solutions were applied to field capacity twice weekly.

Twelve weeks after transplantation the pots were harvested. Dry weights were determined for shoots and roots. Samples were analyzed for N by micro Kjeldahl procedure; for K, Ca, Mg, and Mn by atomic absorption spectrophotometry; for P by colorimetry using the vanado-molybdophosphoric yellow method and for Al by inductively coupled plasma emission spectrometry.

Results and discussion

In this experiment we examined the effect of different Al and Mn concentrations in nutrient solutions on dry weight production, cation uptake and mineral composition of roots and shoots and the occurrence of toxicity symptoms in *Casuarina equisetifolia*.

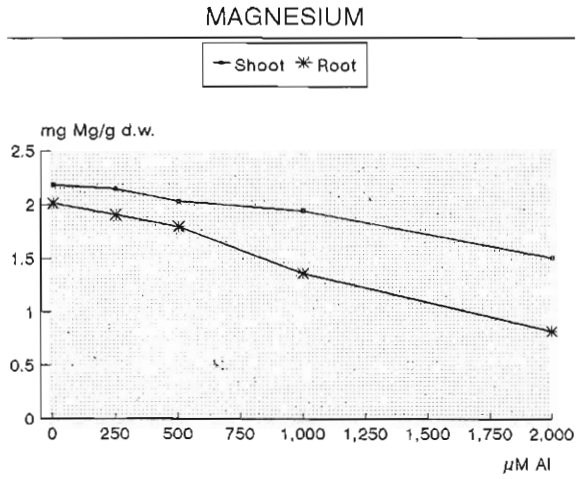

Fig. 4. Magnesium content of shoots and roots at different levels of aluminium in the nutrient solution. Values are media of four plants.

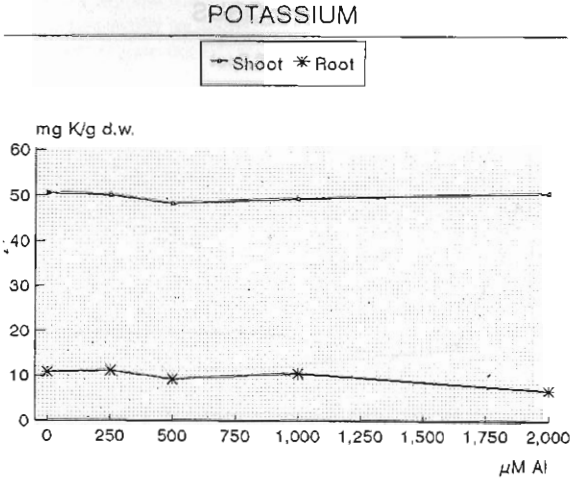

Fig. 6. Potassium content of shoots and roots at different levels of aluminium in the nutrient solution. Values are media of four plants.

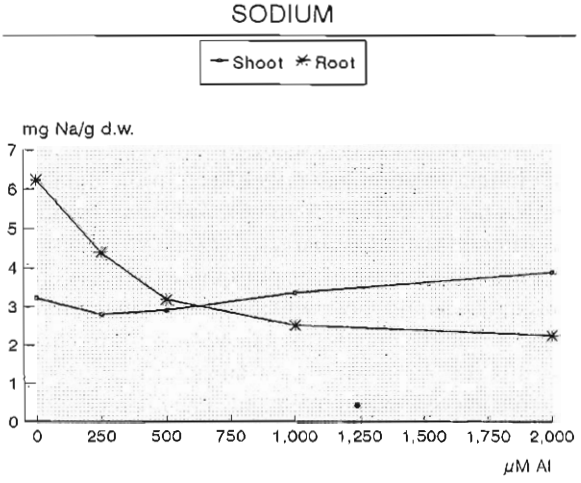

Fig. 5. Sodium content of shoots and roots at different levels of aluminium in the nutrient solution. Values are media of four plants.

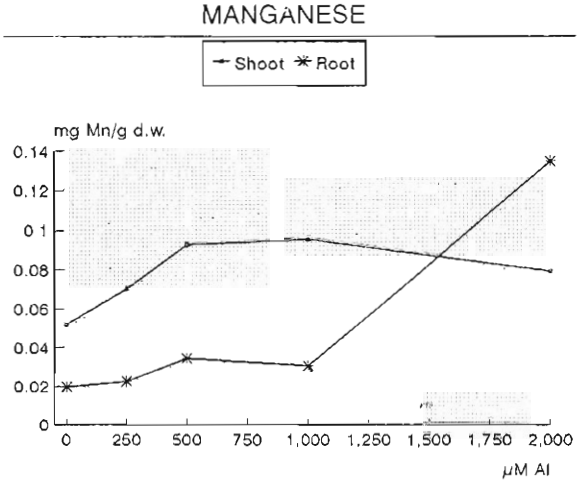

Fig. 7. Manganese content of shoots and roots at different levels of aluminium in the nutrient solution. Values are media of four plants.

Figures 1–17 show the data for the total dry matter production and the mineral composition of shoots and roots.

The relative difference of dry weight production between treatments and control were 78,6% in shoot and 99,3% in root for the 250 μM Al treatment. With the highest Al treatment level (2000 μM) dry weight production for shoots reached only 37,5% and for roots 49,5% of dry matter produced in the control (Fig. 1). The first symptoms of Al toxicity and a clear reduction of shoot growth occurred about 5 weeks after the Al treatment in the higher Al levels. Blue-green colour and brown-necrotic spots in the shoots and dark brownish roots may be interpreted as special Al toxicity symptoms for *Casuarina equisetifolia*.

The Al concentrations of the roots increased parallely with Al treatment levels but Al concentrations of the shoots maintained more or less stable throughout all treatment levels and were considerably lower than those found in roots (Fig. 2). Frederique *et al.* [10] found also higher accumulations of Al and Fe both in roots and in shoots in the pea mutant E.107. Furthermore Al toxicity symptoms were more pronunced in roots than in shoots. In our experiment damages occurred principally in shoots (Fig. 1). The observed Al toxicity symptoms were not comparable to those

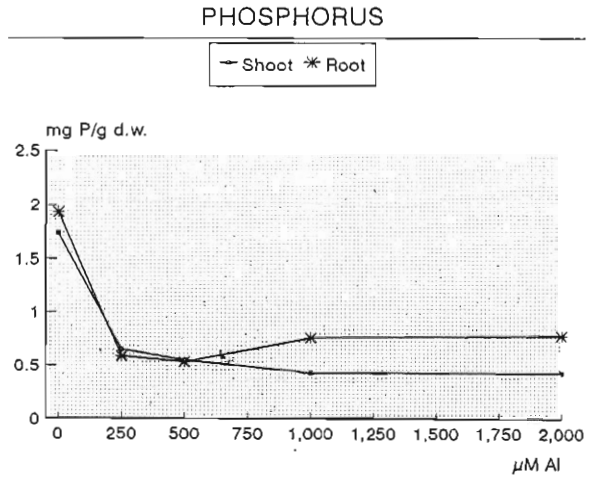

Fig. 8. Phosphorus content of shoots and roots at different levels of aluminium in the nutrient solution. Values are media of four plants.

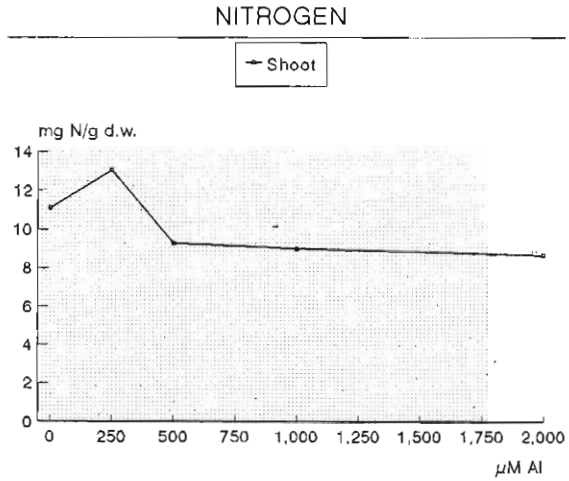

Fig. 9. Nitrogen content of shoots at different levels of aluminium in the nutrient solution. Values are media of four plants.

reported by other authors with different plant species [7, 24].

The negative effects of high Al concentrations on the uptake of the cations Ca (Fig. 3), Mg (Fig. 4) and Na (Fig. 5) were also reported by other authors for different crop plants. Aluminium reduces Ca and Mg uptake rate per unit root surface [23]. The growth limitation by H^+ and Al may be caused by replacement of base cations in exchange sites which disturbs both cell wall structure [2], plasma membranes [20] and cation uptake [23].

The order Ca> Mg> K has been demonstrated in respect to the ameliorative effect on Al toxicity [17]. Brunet and Neymark [3] has reported, that acid soil toxicity does not only depend on the absolute H^+ and Al concentrations but also on the ratios between H^+, Al and base cations in the soil solution.

In our study the increasing of Al concentration in the nutrient solution had only effect on the uptake of Na, but not of K (Figs. 5 and 6). This may be due to the different chemical character of the two ions.

The high decrease of the phosphorus (P) concentrations in shoots and root swith the Al and Mn treatments (Figs. 8 and 16) may be explained by an immobilisation of P by Al or Mn in the nutrient solution or an inactivation of P within the plant. The higher decrease

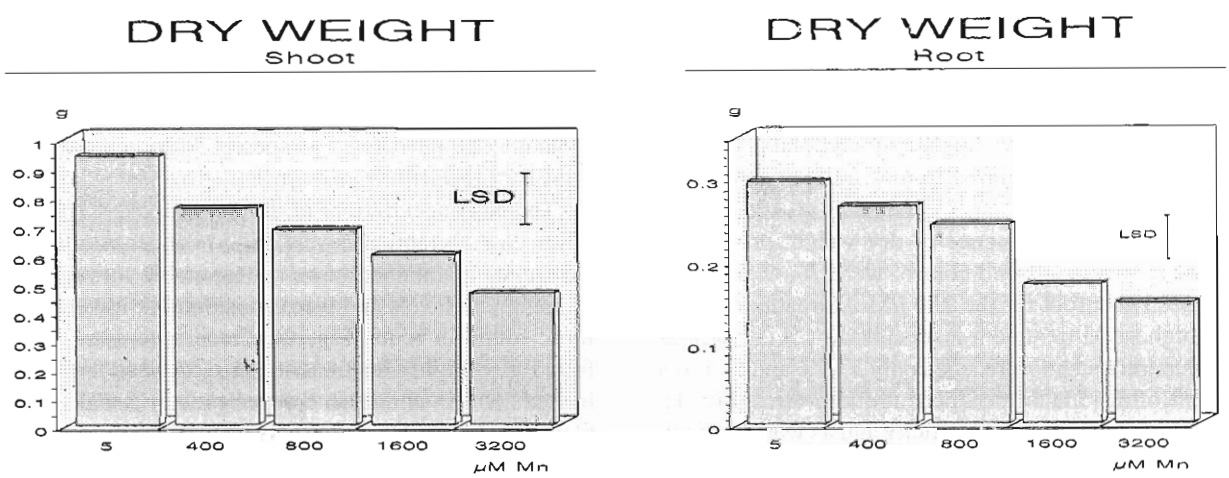

Fig. 10. Dry weight of shoots (left) and roots (right) at different levels of manganese in the nutrient solution. Media of four plants. (LSD at $p \leq 0.05$).

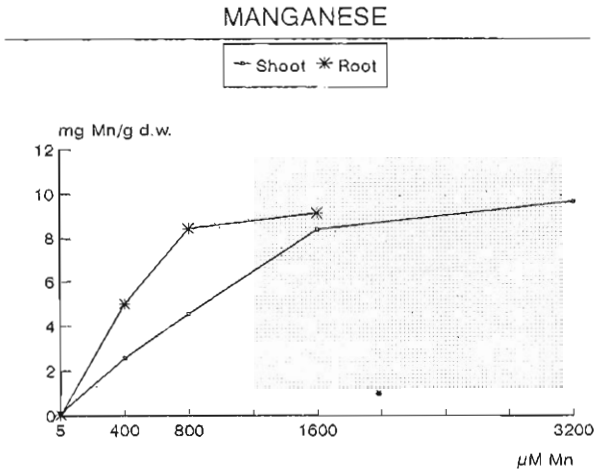

Fig. 11. Manganese content of shoots and roots at different levels of manganese in the nutrient solution. Values are media of four plants.

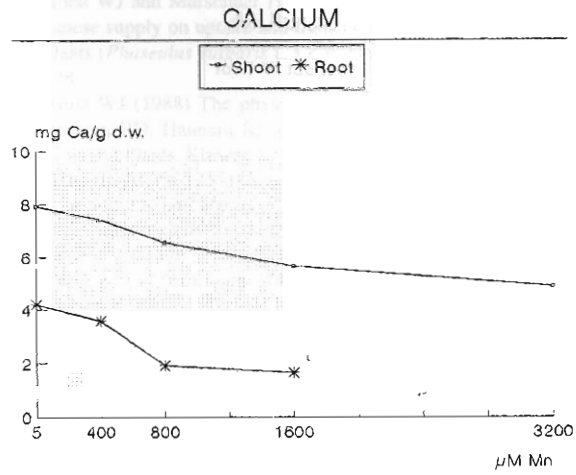

Fig. 12. Calcium content of shoots and roots at different levels of manganese in the nutrient solution. Values are media of four plants.

of the plant P concentration in the Al treatments compared to those of the Mn treatments may be due to a stronger precipitation of P by Al than by Mn in the nutrient solution.

The N uptake by the plants is characterized by an increase of the N content under low treatment levels of Al and Mn, while the plant N content is maintained constant at higher levels of Al and Mn in the nutrient solution (Figs. 9 and 17).

A highly significant depression of dry weight production of shoots and roots (51% compared to control) was also found with the highest Mn treatment (3200 μM) (Fig. 10). In the range of 400–800 μM Mn the Mn concentrations were higher in the roots than in the shoots (Fig. 11). The observed Mn toxicity symptoms were not comparable with those found by many other authors on different crop plants [8, 14, 15, 21]. About 6 weeks after the Mn treatment toxicity symptoms occurred simultaneous with a growth depression in the higher Mn treatments. The principal symptoms were white-chlorotic spots in the upper part of the shoots and dark brownblack roots. Mn toxicity can be influenced by genotypic differences between plants [14], temperature [25] and light intensity [26].

The negative effect of elevated concentrations of Mn on the concentration of cations mainly Ca and Mg in shoots and roots (Figs. 12 and 13), Na only in roots (Fig. 14) and K only in shoots (Fig. 15) were also found by other authors for different crop species. Heenan and Campbell [13] reported that Mn depresses the uptake of other cations. High Mn supply depressed the uptake of Ca and Mg in tomato but had relatively little influence on the K uptake [18]. Mn toxicity induces Ca deficiency particulary in younger tissues both in cotton [9] and in bean [15]. In our experiment the negative effect of manganese on the plant uptake of K and Na could be detected since the lower levels (400–800 μM of Mn). Higher levels of Mn (800–3200 μM) in the nutrient solutions showed no additional effect on the uptake of K and Na (Figs. 15 and 14).

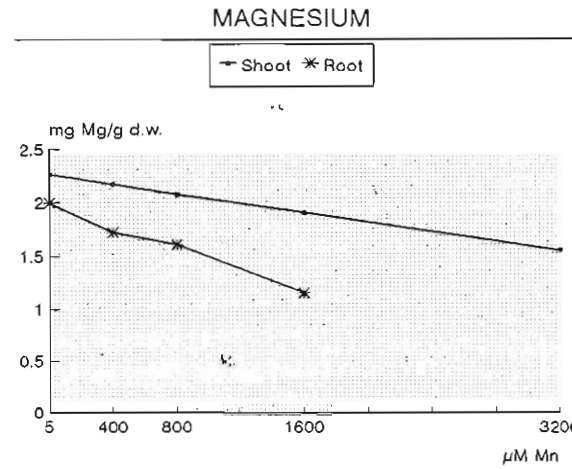

Fig. 13. Magnesium content of shoots and roots at different levels of manganese in the nutrient solution. Values are media of four plants.

Chinnery and Harding [4] reported that the presence of Fe, Ca and Mg can modify the uptake of manganese from solution. Maas *et al.* [19] showed that cations stimulate the uptake of manganese ions into excised roots. Uptake of Mn has been shown to retard

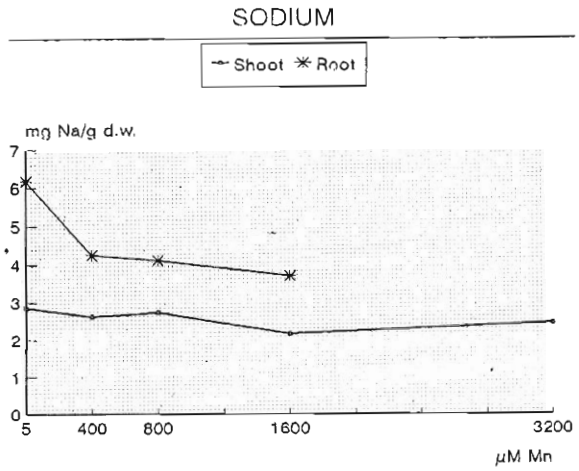

Fig. 14. Sodium content of shoots and roots at different levels of manganese in the nutrient solution. Values are media of four plants.

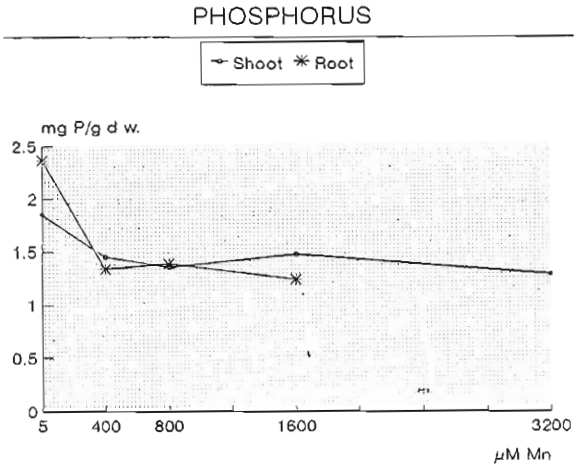

Fig. 16. Phosphorus content of shoots and roots at different levels of manganese in the nutrient solution. Values are media of four plants.

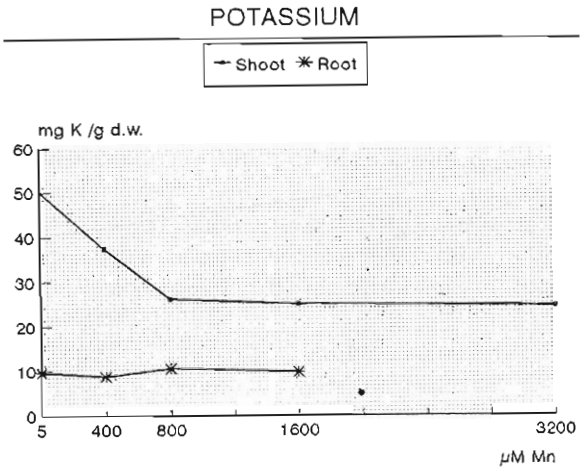

Fig. 15. Potassium content of shoots and roots at different levels of manganese in the nutrient solution. Values are media of four plants.

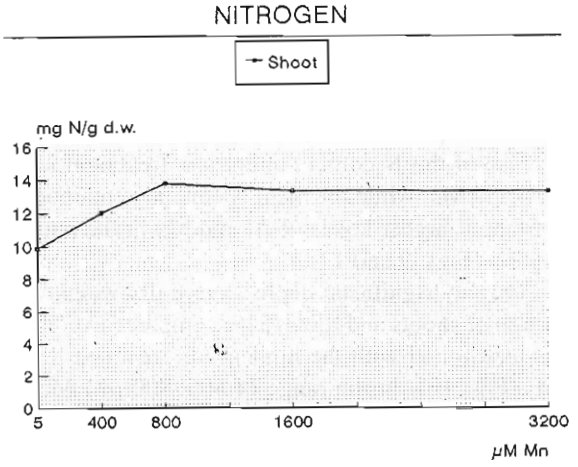

Fig. 17. Nitrogen content of shoots at different levels of manganese in the nutrient solution. Values are media of four plants.

the uptake of Ca and Mg [12]. Allen and Robinson [1] reports that the Mn toxicity is the inhibition of cations uptake such as Mg and ferrous iron (Fe^{+2}) and ferric iron (Fe^{+3}) by Mn adsorption. That was the case of our experiment, since white chlorosis spots is shoots in not only a symptom of Mn toxicity but also a symptom of Mg deficiency.

Lime treatment is a recommended method for alleviating Al toxicity in acid soils [6], although many investigators have shown that Al toxicity is not always economically correctable with conventional methods of soil liming [5].

Ganesan and Sankaranaraanan [11] have reported that Ca is more likely to bring out the beneficial effect of ameliorating Al toxicity through some other mechanisms other than Al uptake. Therefore the alternative approach to alleviate Al toxicity would be to select breed plant genotypes that have greater tolerance to Al.

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