INFLUENCE OF ALUMINIUM ON MINERAL NUTRIENTS OF RICE SEEDLINGS GROWN IN SOLUTION CULTURE

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SUMMARY

Solution culture studies were carried out on rice (*Oryza sativa* L.) seedlings to evaluate the influence of aluminium on P, K, Ca, Mg, Cu, Zn, Fe and Mn concentrations. No toxicity symptoms and reduction in plant dry matter yield was observed even up to 320 µg ml^{-1} Al in nutrient solution. Al concentrations of 10 µg ml^{-1} and above significantly reduced shoot Al concentrations, whereas, the reverse trend was noticed with respect to root Al. Higher Al treatments of 80-320 µg ml^{-1} stabilized the pH of nutrient solution to about 4.8 – 5.0 during the period of 14 days of plant growth resulting into significantly higher accumulation of Al in rice roots. In general, concentrations of all the nutrients except K in roots were reduced with increasing solution concentrations of Al; whereas, effect of Al on concentration of different nutrients in rice shoot was varied, while Al concentrations of 40-320 µg ml^{-1} significantly reduced the shoot concentrations of P, Ca, Zn and Mn, the reduction in Cu concentration was noticed only at 160 and 320 µg ml^{-1} and no variations were obtained with respect to Fe and Mg concentrations. However, enhancement in the shoot concentration of K was noticed at 40-320 µg ml^{-1} Al as compared to control.

***Key words*: Aluminium, plant nutrients, rice seedlings, solution culture**

INTRODUCTION

About 30% of cultivable land in our country has acidic soils and rice is one of the major crops grown in these soils. Aluminium (Al) toxicity is one of the main factors for acid soil infertility. According to Broomfield (1987), at pH <5, the availability of soil Al increases rapidly, which affects the root system and thereby reduce the yield of crops. Aluminium toxicity is manifested in many ways, namely, drought stress, P-deficiency, Ca-deficiency, high bulk density, waterlogging and associated oxygen deficiency in soil and disturbance in mineral nutrition of plants (Foy *et al.* 1999). Factors like organic matter content of the soil, fertility level, plant species and cultivars determine the critical concentration of Al (Fageria 1992). Use of nutrient culture techniques facilitate the control of parameters like pH of culture, concentration of nutrient elements, ionic strength etc. (Pintro *et al.* 1999), which are otherwise difficult to control in soil culture studies. The present investigation is aimed at evaluating the influence of Al on plant toxicity and uptake of plant nutrients, namely, P, K, Ca, Mg, Cu, Fe, Mn and Zn by rice seedlings using solution culture techniques.

MATERIALS AND METHODS

Rice (*Oryza sativa* L. cv. Hari) seeds were germinated in quartz sand and then grown in quarter-strength nutrient solution for a week. The seedlings were subsequently transferred to one litre of full-strength nutrient solution

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containing Al as aluminium sulphate [$Al_2(SO_4)_3.16\ H_2O$] at doses of 0 (control), 5, 10, 20, 40, 80, 160 and 320 µg ml^{-1}. The nutrient solution corresponded to Long Ashton nutrient solution (Hewitt 1966) modified to replace Na^+ by K^+ (D'Souza and Mistry 1970). Two seedlings were kept in each jar and 4 replicates constituted each treatment. The initial pH of the nutrient solution was adjusted to 4.8 using 0.1N KOH or 0.1N HCl. The evapotranspiration losses from the solution were made up daily by distilled water. The experiment was conducted in a growth room where temperature was maintained at 23±1°C, the relative humidity 65±2% and the plants were illuminated for 12h photoperiods at 1300 µW cm^{-2} measured at 10 cm above the top of the jars. The pH of the Al-treated nutrient solutions was measured periodically. After 14 days of growth, the root and shoot were harvested separately and the root given 10 sec rinse in distilled water to remove surface contamination and dried by blotting. Twenty eight days old plants were used and the duration of Al treatment was 14 days. The tissues were dried to constant weight at 70°C, weighed and wet-ashed using 5:1 HNO_3:$HClO_4$ mixture (Perkin-Elmer 1976). Concentration of metals, namely, Al, Ca, Mg, Cu, Fe, Mn and Zn in the acid extracts was determined using Jobin Yvon JY2000 ICP emission spectrometer. Phosphorus was determined by Ammonium vanadate method (Koenig and Johnson 1942) and K was determined using ELICO Model CL360 flame photometer. Further, computation of transport index of Al was done using the formula,

Transport index = (Shoot content / Total plant content) x 100.

Data of the experiment were subjected to statistical analysis using Duncan's multiple range test (Bliss 1967).

RESULTS AND DISCUSSION

Dry matter yield (DMY)

In general, solution Al concentrations of 20 µg ml^{-1} and above enhanced the DMY of root (Table 1); however, no significant variations were noticed in the DMY of shoot at different Al treatments. No visual toxicity symptoms were noticed in both root and shoot of rice seedlings even up to 320 µg Al ml^{-1} of nutrient solution.

Conflicting reports exist on the effect of Al on DMY of various plant species. Tanaka and Navasero (1966) reported that 25 ppm of Al in culture solution was the critical concentration and above 300 ppm toxicity symptoms often developed in rice crop. Enhancement in rice yield with 0.9-9 ppm of Al and accelerated growth of various crops by 3-13 ppm of Al in culture solution has also been reported (Tanaka and Navasero, 1966). Investigations of Patel *et al.* (2002) on wheat seedlings revealed that up to 320 ppm of solution Al concentration no visual toxicity symptoms have been noticed as observed in the present studies. They reasoned the cultivars and plant species differences for their observation. According to Tang Van Hai *et al.* (1989), solution Al concentrations of up to 4 ppm stimulated the growth of rice plants. On the other hand, studies of Sarkar and Debnath (1989), Pintro *et al.* (1996), Lidon and Barreiro (1998) and Lidon *et al.* (2000) on wheat and maize crops revealed a reduction in DMY of these crops at various Al concentrations depending on the cultivars and plant species. Experimental results on the effect of Al on 30 upland rice cultivars by Fageria and Carvalho (1982) also indicated varying critical toxic levels of Al from 100 to 417 ppm depending on the cultivars. Hence, the result on the DMY of rice seedlings as obtained in the present study can be ascribed to the cultivars and plant species differences.

Aluminium

Solution Al concentrations of 5 ppm and above significantly enhanced the uptake of Al by roots (Table 1); at lower concentration of 5 ppm, the uptake was about 4 times the control (0 ppm Al) which varied significantly up to about 14 times the control at the highest solution Al concentration of 320 ppm. The reverse trend was noticed for rice shoot, where solution Al concentration of 10 ppm and above (Table 1) significantly reduced the shoot uptake of Al; however, no significant differences were noticed among the concentrations of 20 to 320 ppm of Al. The present findings with respect to rice root are in agreement with that of Tanaka and Navasero (1966) and Fageria and Carvalho (1982); however, shoot uptake of Al in the present investigation was different. The observed increase in the uptake of Al in root with respect to increased Al concentration in the growth medium has been reported by many researchers for various plant

Table 1. Effect of Al concentration in nutrient solution on dry matter yield and aluminium uptake of rice seedlings

Al concentration in nutrient solution (µg ml^{-1})	Dry matter yield (g) Root	Dry matter yield (g) Shoot	Aluminium (µg g^{-1}) Root	Aluminium (µg g^{-1}) Shoot	Aluminium (µg g^{-1}) Transport index
0	0.017abc*	0.095a	970a	408cd	69d
5	0.015a	0.081a	3794b	454d	40c
10	0.016ab	0.094a	4699b	325bc	29b
20	0.023bcd	0.098a	4671b	288ab	21b
40	0.025d	0.110a	8578c	199a	9a
80	0.023cd	0.092a	11953d	219a	7a
160	0.022bcd	0.110a	12786d	275ab	9a
320	0.024d	0.099a	13709d	267ab	7a

*Values followed by the same letter within each column are not significantly different at 5% level by Duncan's multiple range test.

species. Recent work of Patel *et al.* (2002) on wheat plants have shown that the uptake by roots varied from about 9 to 26 times the control at the lower and higher solution Al concentrations, respectively. The present results indicate the higher absorption and retention of Al by rice root and less translocation to shoot which is in agreement with earlier studies of Fageria and Carvalho (1982), Sarkar and Debnath (1989), Lidon *et al.* (1999, 2000) and Patel *et al.* (2002) for various plant species.

The transport index data (Table 1) indicate significantly higher translocation of Al from root to shoot at lower solution Al concentrations of 0 to 20 ppm as compared to higher concentrations of 40 to 320 ppm. In other words, higher solution Al concentrations significantly inhibited the transport of Al from root to shoot of rice seedlings. The present findings agree with that of Patel *et al.* (2002), who reported similar inhibitory effects of higher solution Al concentrations on the translocation of Al from root to shoot of wheat seedlings.

The pH of control (0 ppm Al) treatment enhanced from initial 4.8 to 5.4 after 24 h, which increased gradually up to around 5.7 at the end of 14 days of plant growth (Fig. 1). Aluminium concentrations of 5 to 80 ppm enhanced the pH from initial 4.8 to about 4.9–5.2 after 24h growth period; like control, a gradual increase in pH up to 5.2–5.6 at the end of 14 days was also noticed. On the other hand, higher Al concentrations of 160 and 320 ppm reduced the pH from initial 4.8 to about 4.5–4.6 after 2 days of plant growth; further, the pH of the nutrient solution increased slightly to about 4.7–4.8 after 5 days and remained more or less same throughout the period of 14 days of plant growth.

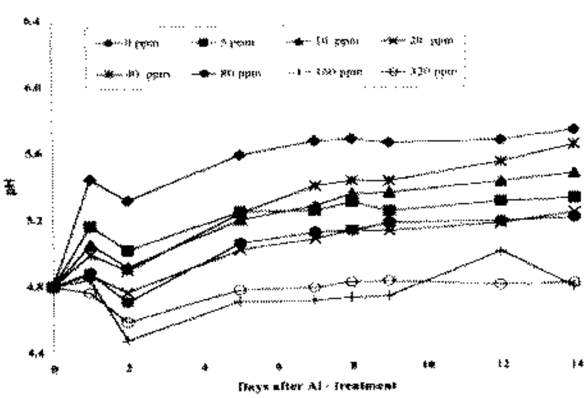

Fig. 1. Changes in pH of Al-treated nutrient solution in relation to days after growth of rice seedlings

Lower pH must have played an important role in the enhancement and accumulation of Al in the root of these treatments (Table 1). The availability of Al in the culture (soil) solution increases rapidly at this pH (Broomfield 1987), thereby resulting in higher accumulation of Al in rice root. At pH < 5.0, the stability of Al minerals is reduced, the solubility of Al minerals is higher and Al is released into the soil solution and hence making it available. (Lindsay 1979).

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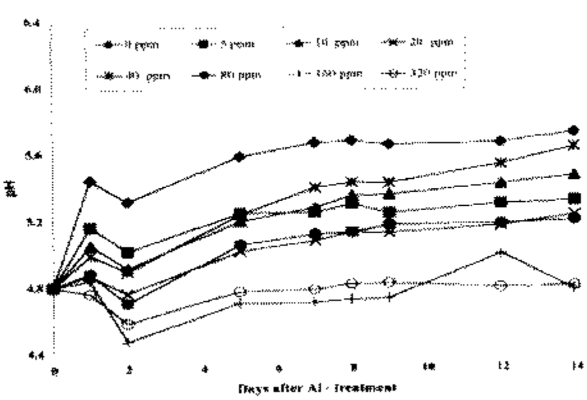

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Phosphorus

The concentration of P in both shoot and root of rice seedlings was significantly reduced at the higher Al concentrations of 160 and 320 ppm as compared to other treatments (Table 2). In the case of shoot, no specific trend was followed up to 80 ppm, whereas, P concentration of root at 5 to 80 ppm was on par with control (0 ppm Al). The inactivation of P in roots by precipitation of aluminium phosphate in and on the roots (Tanaka and Navasero, 1966) probably reduced the P concentration in both shoot and root at the higher Al treatments. Fageria and Carvalho (1982) reported similar findings where 40 and 60 ppm of Al in nutrient solution resulted in drastic reduction of P concentration and content of both tops and roots of rice crop. They attributed their findings to the presence of positively charged hydrated Al oxides on the cell surfaces that were responsible for absorption, precipitation and further fixation of P, which was not available for plant uptake. Earlier studies of Lidon *et al.* (1999, 2000) and Patel *et al.* (2002) also reported similar findings, where excess Al in nutrient solution significantly decreased the uptake of P in various plant species.

Potassium

In root, the highest Al concentration of 320 ppm significantly enhanced the K concentration as compared to other Al treatments of 0 – 80 ppm, whereas, in shoot, Al treatments of various concentrations, in general, enhanced K concentration as compared to control (Table 2). The present results are in contrast to the findings of Fageria and Carvalho (1982) and Tan and Keltjens (1990), who reported an inhibitory effect of Al on K concentration of rice cultivars and sorghum plants, respectively. However, Lidon *et al.* (1999, 2000) have reported an enhancement in the K concentration of maize plant with 9 to 81 mg L^{-1} of solution Al concentration. The present experimental data further reveal that the concentration of K in rice shoot was more than that of root, indicating thereby greater translocation of K from root to shoot as against Al and P. Similar findings have been reported by Patel *et al.* (2002) for wheat seedlings grown in Al-treated nutrient solution.

Calcium and magnesium

The increasing solution Al concentrations significantly reduced both root and shoot concentrations of Ca (Table 3). Concentration of Ca in shoot was more than that of root indicating greater translocation of Ca from root to shoot. In the case of Mg, continuous, gradual and significant reduction in root concentration was obtained with respect to increasing solution Al concentration, whereas, no significant difference was noticed among the various treatments of Al in rice shoot. Further, the data indicate less translocation of Mg from root to shoot. As reported by Fageria and Carvalho (1982), the observed reduction in root concentrations of Ca and Mg with increasing solution Al concentrations could be attributed to the competition of Al with Ca and Mg for common

Table 2. Phosphorus and potassium concentrations (mg g^{-1}) of rice seedlings grown in nutrient solution

Al concentration in nutrient solution (µg ml^{-1})	Phosphorus Root	Phosphorus Shoot	Potassium Root	Potassium Shoot
0	16.4b*	9.2c	24.253a	37.268a
5	17.1b	15.3e	19.797a	54.825abc
10	15.6b	7.8bc	20.468a	49.079abc
20	17.3b	12.1d	22.788a	51.252abc
40	15.9b	6.1b	23.007a	63.338c
80	16.9b	7.3bc	23.792a	65.270c
160	5.5a	3.6a	25.079ab	43.837ab
320	6.4a	3.9a	31.742b	57.916bc

*Values followed by the same letter within each column are not significantly different at 5% level by Duncan's multiple range test.

Table 3. Calcium and magnesium concentrations (mg g^{-1}) of rice seedling grown in nutrient solution

Al concentration in nutrient solution (µg ml^{-1})	Calcium		Magnesium	
	Root	Shoot	Root	Shoot
0	9.713e*	26.969d	4.117d	0.699a
5	8.701de	28.223d	3.218cd	0.682a
10	7.304cd	29.801d	3.211cd	0.607a
20	5.673bc	18.632c	2.689bc	0.633a
40	5.246b	14.744bc	2.248ab	0.530a
80	4.412ab	14.759bc	1.601a	0.539a
160	4.081ab	9.799a	1.491a	0.561a
320	3.325a	10.205ab	1.535a	0.565a

*Values followed by the same letter within each column are not significantly different at 5% level by Duncan's multiple range test.

binding sites at or near the root surface and subsequent reduction in uptake of these elements. According to Shkolnik (1984), Al absorbed by cell walls may strongly inhibit the active sites of enzymes situated in the cell walls, thereby significantly impairing the uptake of nutrients and active transport.

Micronutrients

The concentration of Cu, Fe, Mn and Zn in rice root (Table 4) was significantly reduced with increasing Al concentration of nutrient solution. In general, concentration of all the micronutrients except Fe was also decreased with increased Al treatments in shoot (Table 4). The observed inhibitory effect of Al on plant micronutrients has been reported by Patel *et al.* (2002) in wheat seedlings. The reason for the reduction in the concentration of micronutrients in rice plants as noticed in the current study could be attributed to the reduction of cellular respiration in plants by Al causing an inhibition in the uptake of micronutrients (Fageria and Carvalho, 1982). The present study further revealed that the concentration of all the micronutrients except Mn in shoot was less than that of root indicating less translocation of these elements from root to shoot due to inhibitory effect of Al on the micronutrients.

Table 4. Micronutrient concentrations (µg g^{-1}) of rice seedlings grown in nutrient solution.

Al concentration in nutrient solution (µg ml^{-1})	Copper		Iron		Manganese		Zinc	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
0	1365e*	73c	25763c	415abc	1455c	3879c	922d	188b
5	1281de	72bc	22249c	492c	414ab	3396bc	706c	185b
10	1042c	68bc	20685c	416bc	293ab	2885b	611bc	175b
20	811b	75c	13496b	292ab	202a	4216c	411ab	170b
40	611a	60b	13371b	282a	512b	2895b	376a	139a
80	694ab	63bc	10953ab	295ab	405ab	2668b	393a	135a
160	750ab	45a	10309ab	477c	242a	987a	317a	124a
320	713ab	37a	6952a	415abc	193a	1286a	339a	121a

*Values followed by the same letter within each column are not significantly different at 5% level by Duncan's multiple range test.

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