Indian J. Plant Physiol., Vol. 7, No. 1, (N.S.) pp. 56-61 (Jan.-March, 2002)

SOLUTION CULTURE STUDIES ON THE INFLUENCE OF ALUMINIUM ON NUTRIENTS CONCENTRATION IN WHEAT SEEDLINGS

D.U. PATEL[a], S.C. KUMAR[b], V. RAMACHANDRAN[a*] AND V.V. ATHALYE[a]

[a]Nuclear Agriculture and Biotechnology Division, [b]Analytical Chemistry Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400 085

Received on 28 June, 2001, Revised on 28 Feb., 2002.

SUMMARY

Nutrient culture experiment was conducted on wheat (*Triticum aestivum* L.) seedlings to evaluate the influence of aluminium on tissue concentration of P, K, Ca, Mg, Cu, Fe, Mn and Zn. Neither Al toxicity symptoms nor reduction in plant dry matter yield were noticed in wheat plant even up to 320 μg ml^{-1} Al in nutrient solution. Root Al concentrations enhanced with increase in solution Al concentrations, whereas, the reverse was true for shoot. At lower Al treatments (0 to 40 μg ml^{-1}), the change in pH of nutrient solution was quite faster and it increased from initial 4.8 to a maximum of 6.6 depending on the treatments. At higher Al treatments (80 to 320 μg ml^{-1}), the change in pH was, however, slower and it either remained at 4.8 or decreased up to a minimum of 4.4, resulting into higher accumulation of Al in roots. In general, plant tissue concentrations of P, Ca, Mg, Cu, Fe, Mn and Zn were reduced by the increasing solution concentrations of Al, whereas, the reverse was true for K.

Key words : **Aluminium, plant nutrients, solution culture, wheat seedlings.**

INTRODUCTION

Aluminium (Al) is an important entity of acid soils and Al-toxicity appeared to be the major cause of the acid soil infertility (Wallace 1989). Presence of high amounts of Al in acid soils affect primarily the roots system and reduce the yield of crops. Under acid soil conditions (pH<5.0) the solubility of Al minerals is higher, and Al is released into soil solution (Lindsay 1979). Wright (1989) and Foy *et al.* (1999) reported the manifestation of Al toxicity in different ways, namely, drought stress, P-deficiency, Ca-deficiency, high bulk density, water logging and associated oxygen deficiency in soil and distrubance in mineral nutrition of plants. The critical concentration of Al depends on several factors, such as organic matter content of the soil, fertility level, plant species and cultivars within species (Fageria 1992). However, Al was also found to improve significantly the growth of wheat, barley and oats in hydroponics (Shkolnik 1984). Since factors like nutrient concentrations, pH, ionic strength and other parameters are difficult to alter in soil culture, investigations through nutrient culture techniques have been practised. The present paper reports the preliminary studies aimed at evaluating the influence of applied Al on plant toxicity and uptake of plant nutrients, namely, P.K, Ca, Mg, Cu, Fe, Mn and Zn by wheat seedlings using solution culture.

MATERIALS AND METHODS

Wheat (*Triticum aestivum* L. cv. Kalyansona) seeds were germinated in quartz sand and then grown in quarter-strength nutrient solution for one-week. The plants were subsequently transferred to one litre of full-strength

*Corresponding author

nutrient solution 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 12 h 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 followed by blotting to eliminate the entrained moisture. The age of plant at harvest was 28 days and the duration of Al treatment was 14 days. The tissues were dired 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 JY 2000 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

Aluminium concentrations of 40 to 320 μg ml^{-1} in the solution culture significantly enhanced the dry matter yield (DMY) of root, whereas, no significant differences, in general, were noticed in the DMY of shoot at various Al treatments (Table 1). No visual Al toxicity symptoms were noticed either in the root or in the shoot of wheat seedlings.

Reports on the effect of Al on the dry matter yields and its toxicity in different plant species are at variance. According to Tanaka and Navasero (1966), for plants receiving normal supplies of other nutrients, the critical concentration of Al in culture solution was about 25 ppm and Al toxicity symptoms often developed above 300 ppm of Al in the rice shoot. Further, 3-13 ppm of Al in culture solution accelerated the growth of various crops, 0.9-9 ppm of Al enhanced the rice yield and 120 ppm was found to be critical concentration for rice crop. However, concentration of only 6.7 ppm was also reported to be harmful to young rice plants. (Tanaka and Navasero 1966). Studies of Sarkar and Debnath (1989) on the effect of Al on two wheat cultivars revealed that Al concentrations of 10 ppm and above in solution culture significantly reduced the root dry weight, whereas, shoot dry weight

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

Al concentration in nutrient solution (μg ml^{-1})	Dry matter yield (g jar^{-1}) Root	Shoot	Aluminium (μg g^{-1} dry wt.) Root	Shoot	Transport index
0	0.065a*	0.28a	310a	95d	55.3c
5	0.065a	0.30ab	2858b	95d	13.5b
10	0.077ab	0.34ab	3706bc	97d	10.7b
20	0.070a	0.32ab	3917bc	96d	10.4b
40	0.086bc	0.37b	3843bc	73c	8.8b
80	0.098c	0.34ab	4685bc	20a	1.5a
160	0.088bc	0.28a	5489c	39ab	2.3a
320	0.086bc	0.30ab	8179d	51b	2.2a

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

was reduced only at 20 ppm of Al. In contrast, the present studies on wheat seedlings have shown no reduction in plant yield upto 320 ppm of Al concentration in solution. A reduction in biomass of maize plants by 5-30 μM Al has been reported by Pintro *et al.* (1996), 81 mg l^{-1} Al by Lidon and Barreiro (1998) and 3 mg l^{-1} Al by Lidon *et al.* (2000), indicating thereby the variation in the toxic level of Al with respect to the cultivars of particular plant species. The observed enhancement in the root DMY of wheat seedlings up to 320 ppm of solution Al concentration in the present study can be attributed to the cultivar and plant species difference.

The concentrations of Al in the root of wheat seedlings significantly increased as the Al concentration in nutrient solution increased from 0 to 320 μg ml^{-1} whereas, the reverse was true for shoot (Table 1). The significant reduction in shoot Al, however, was noticed from 40 to 320 μg ml^{-1} of Al treatments. Aluminium concentration in shoot (945 μg g^{-1}) of control treatment is on par with the supply concentration of 5 to 20 μg ml^{-1} Al treatments. Similar observations were reported by Fageria and Carvalho (1982), Sarkar and Debnath (1989) and Pintro *et al.* (1996) for rice, wheat and corn plants, respectively. Root Al was found to be higher than that of corresponding shoot Al concentration. It varied from about 3 times in control to about 160 times at the highest Al-treatments. These findings are in agreement with earlier work of Tanaka and Navasero (1966), Fageria and Carvalho (1982), Pavan and Bingham (1982), Sarkar and Debnath (1989), Pintro *et al.* (1996), Lidon and Barreiro (1998) and Lidon *et al.* (1999, 2000). The higher concentration of Al in root and very much lower concentration in shoot of wheat seedlings, as obtained in the present study, indicate the higher absorption and retention of Al in root and less translocation to shoot (Fageria and Carvalho 1982, Sarkar and Debanath 1989, Lidon *et al.* 1999, 2000). It is noted that the reduction in shoot concentration of Al is in spite of increasing root concentration of Al. Data on transport index (Table 1) further confirm that higher Al concentration in nutrient solution has a profound in hibitiory effect on Al transport from root to shoot.

Aluminium treatments of 0 (control), 5, 10 and 20 μg ml^{-1} changed the pH of nutrient solution from initial 4.8 to about 5.0-5.7 within 24 h and the pH of the solution gradually and continuously increased up to a maximum of 6.2 at the end of 14 days of plant growth (Fig. 1).

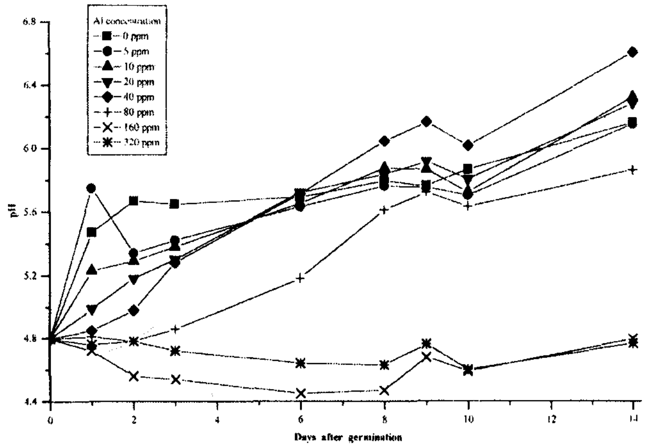

Fig. 1. Changes in pH of Al - treated nutrient solution in relation to days after germination of wheat seedlings

Aluminium treatment of 40 μg ml^{-1} changed the pH of nutrient solution from 4.8 to about 5.0 after two days and the pH increased continuously up to 6.6 at the end of 14 days. The changes in pH due to concentration of 80 μg Al ml^{-1} nutrient solution indicated a different pattern- about 5 days to reach pH 5.0, increased continuously and remained less than the pH of other lower Al-treatments throughout the period of 14 days and perhaps reflected in the minimum Al concentration in shoot of this treatment. On the other hand, nutrient solutions containing higher concentrations of 160 and 320 μg Al ml^{-1} either remained at pH 4.8 or decreased up to a minimum of about 4.4 throughout the plant growth period of 14 days.

The observed change in pH of nutrient solution with respect to the different Al treatments is well reflected in the plant concentrations of Al (Table 1). At solution concentrations of 10-40 μg Al ml^{-1}, the root Al concentration was only 12 times more than the control (0 Al), whereas, higher Al concentrations of 80, 160 and 320 μg ml^{-1} enhanced the root Al concentrations by about 15, 18 and 26 times, respectively. These results are fairly in agreement with Broomfield (1987), who reported rapid increase in the available Al from soil when the soil pH was below 5.0. Dong *et al.* (1999) also reported similar findings, where uptake of Al by tea leaves increased when soil pH decreased below 5.0. According to Lindsay (1979), under acid soil conditions (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 its plant availability is more. Data in Table 1 and Fig. 1 on Al concentration and changes in pH of nutrient solution, respectively, together indicate that translocation of Al to shoot is governed by pH and supply concentration of Al in the nutrient solution.

Effect on phosphorus concentration

Significant reduction in P concentrations were noticed at solution Al concentrations of 80-320 $\mu g\ ml^{-1}$ and 40-320 $\mu g\ ml^{-1}$ for root and shoot, respectively (Table 2). The observed reduction in P concentrations of wheat plant tissues could be due to the inactivation of P, especially in the roots, which is attributed in part to the precipitation of P as Al-phosphate in and on the roots (Tanaka and Navasero 1966). Pavan and Bingham (1982) reported similar findings and suggested precipitation of P by Al on root surface or in the root cells and thereby reducing P transport to plant tops. Further, this immobilization of P in or upon the root may subsequently induce deficiency of P (Jackson 1967, Helyar 1978, Foy *et al.* 1978).

The results in Table 2 are in agreement with Fageria and Carvalho (1982), who found drastic reduction of P concentration and content in tops as well as in roots of rice crop at higher concentrations of 40 and 60 ppm of Al in nutrient solution. According to them, presence of positively charged hydrated Al oxides on the cell surfaces were responsible for absorption, precipitation and further fixation of P, which was not available for plant uptake. Decreased plant uptake of P in different plant species due to excess Al in nutrient solution is also reported by many researchers (Foy and Brown 1963, Pavan and Bingham 1982, Shkolnik 1984, Lidon *et al.* 1999, 2000).

Potassium concentration

Results on the plant concentrations of K indicate varying effects of different Al treatments (Table 2). In the case of root, Al concentrations of 20, 40 and 80 $\mu g\ ml^{-1}$ significantly enhanced K concentration, whereas, only 320 $\mu g\ ml^{-1}$ Al significantly enhanced the shoot K concentration as compared to control. Lidon *et al.* (2000) reported similar findings, where K concentrations of maize root continuously increased with solution Al concentrations of 9 to 81 $mg\ l^{-1}$. In contrast, Fageria and Carvalho (1982) reported that incresed Al concentrations of nutrient solution exerted an inhibitory effect on K concentration and content of rice cultivars.

Calcium and magnesium

The effect of increasing Al concentrations in nutrient solution on Ca and Mg concentrations of wheat seedlings indicate a gradual, continuous and significant reduction of both nutrient elements in root as well as in shoot (Table 3). Concentrations of both Ca and Mg in shoot were found to be higher than that of root indicating thereby the higher translocation to shoot and less retention in roots of these

Table 2. Effect of Al concentrations in nutrient solution on phosphorus and potassium concentrations ($\mu g\ g^{-1}$ dry wt.) in wheat seedlings

Al concentration in nutrient solution ($\mu g\ ml^{-1}$)	Phosphorus		Potassium	
	Root	Shoot	Root	Shoot
0	137c*	113c	32552ab	55844a
5	138c	110c	37964abcd	57882ab
10	150c	105bc	42130bcd	52011a
20	155c	109c	42893cd	48948a
40	143c	93b	45457d	51209a
80	94b	56a	44893d	50096a
160	69ab	51a	30140a	62381ab
320	67a	54a	33088abc	72166b

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

Table 3. Effect of Al concentrations in nutrient solution on calcium and magnesium concentrations ($\mu g\ g^{-1}$ dry wt.) of wheat seedlings.

Al concentration in nutrient solution ($\mu g\ ml^{-1}$)	Calcium		Magnesium	
	Root	Shoot	Root	Shoot
0	7573d*	18436b	1358e	6882d
5	5356cd	19375b	1272de	5321c
10	4771bc	17530b	1127cd	4646bc
20	4026abc	17237b	1086cd	5434c
40	3451abc	10409a	1041cd	4119ab
80	2218a	10439a	892bc	5422c
160	1884a	9001a	598ab	3814ab
320	1964a	7013a	582a	3263a

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

Table 4. Effect of Al concentrations in nutrient solution on micronutrient concentrations (μg g^{-1} dry wt.) of wheat seedlings

Al concentration in nutrient solution (μg ml^{-1})	Copper		Iron		Manganese		Zinc	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
0	353f	26bc	10467c	221c	1352c	347cd	389d	103c
5	300e	24bc	5939b	183abc	1366c	325c	306d	85bc
10	231d	25bc	4243a	200bc	1779d	389cd	202c	91bc
20	190c	27c	4149a	202bc	1781d	397d	200c	99c
40	125b	20b	3588a	168abc	1431c	363cd	170bc	73ab
80	118b	14a	3715a	140a	502b	209b	155abc	55a
160	68a	14a	3158a	166abc	163a	123a	109ab	58a
320	56a	13a	3132a	153ab	175a	118a	94a	58a

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

elements as compared to either Al (Table 1), P (Table 2) or micronutrients (Table 4) in wheat seedlings. These findings are in agreement with Pavan and Bingham (1982), Fageria and Carvalho (1982) and Pintro *et al.* (1996). The observed reduction in Ca and Mg concentrations of both root and shoot with respect to increased Al concentration of nutrient solution is ascribed to the competition of Al with these elements for common binding sites at or near the root surface and subsequent reduction in uptake of these elements (Fageria and Carvalho 1982).

Micronutrients

Data on the concentration of micronutrients, namely, Cu, Fe, Mn and Zn in wheat seedlings indicate a gradual and significant reduction in the root concentration of all micronutrients except Mn at increasing Al treatments of nutrient solution (Table 4). Aluminium concentrations of 10 and 20 μg ml^{-1} significantly enhanced, and higher concentrations of 80-320 μg ml^{-1} significantly reduced the root Mn concentrations. In the case of shoot, in general, Al concentrations of 40 to 320 μg ml^{-1} nutrient solution significantly reduced the Cu, Fe, Mn and Zn concentrations. Similar inhibiting effects of Al on plant micronutrients have been reported by Foy and Brown (1963) for cotton plants, Fageria and Carvalho (1982) for rice cultivars, Pavan and Bingham (1982) for coffee leaves and Pintro *et al.* (1996) for corn plants. The reduced concentration of micronutrients in wheat plants as noticed in the current study could be due to the reduction of cellular respiration in plants by Al causing an inhibition in the uptake of micronutrients as reported by Fageria and Carvalho (1982).

REFERENCES

Bliss, C.I. (1967). Statistics in Biology Vol.1. Statistical Methods for Research in the Natural Sciences. McGraw-Hill Book Company.

Broomfield, S.M. (1987). Simple test for the assessment of aluminium and manganese levels in Acid soils. *Aust. J. Exp. Agril.* **27**: 399-404.

Dong, D., Du, Y., Liu,, C. and Wang, S. (1999). Influence of soil pH on aluminium availability in the soil and aluminium in tea leaves. *Commun. Soil Sci. Plant Anal.* **30**: 873-883.

D'Souza, T.J. and Mistry, K.B. (1970). Comparative uptake of Thorium 230, Radium-226, Lead-210 and Polonium-210 by plants. *Radiation Bot.* **10**: 293-295.

Fageria, N.K. (1992). Yield and environmental stress. In: G. Stotzky (ed.), Maximising Crop Yields, pp. 164-215. Marcel Dekker Inc., New York.

Fageria, N.K. and Carvalho, J.R.P. (1982). Influence of aluminium in nutrient solutions on chemical composition in upland rice cultivars. *Plant and Soil* **69**: 31-44.

Foy, C.D. and Brown, J.C. (1963). Toxic factors in acid soils. 1. Characterization of aluminium toxicity in cotton. *Soil Sci. Am. Proc.* **27**: 403-407.

Foy, C.D., Chaney, R.L. and White, M.C. (1978). The physiology of metal toxicity in plants. *Ann. Rev. Plant Physiol.* **29**: 511-566.

Foy, C.D., Sadeghi, A.M., Ritchie, J.C., Krizek, D.T., Davis, J.R. and Kemper, W.D. (1999). Aluminium toxicity and high bulk density: Role in limiting shoot and root growth of selected aluminium indicator plants and eastern gamagrass in an acid soil. *J. Plant Nutr.* **22**: 1551-1566.

Helyar, K.R. (1978). Effects of aluminium and manganese toxicity on legume growth. In: C.S. Andrew and E.J. Kamprath (eds.) Mineral Nutrition of Legumes in Tropical and Subtropical Soils, pp. 207-231. CSIRO, Melbourne, Australia.

Hewitt, E.J. (1966). Sand and Water Culture Methods Used in the Study of Plant Nutrition. Commonwealth Agric. Bureaux, U.K.

Jackson, W.A. (1967). Physiological effects of soil acidity. In: R.W. Pearson and F. Adams (eds.). Soil Acidity and Liming, pp. 95-124. American Soc. Agron., Madison, Wisconsin, U.S.A.

Koenig, R.A. and Johnson, C.R. (1942). Colorimetric determination of phosphorus in biological materials. *Ind. Eng. Chem.* A.E. **14**: 155.

Lidon, F.C. and Barreiro. M.G. (1998). Threshold aluminium toxicity in maize. *J. Plant Nutr.* **21**: 413-419.

Lidon, F.C., Barreiro, M.G., Ramalho, J.C. and Lauriano, J.A. (1999). Effects of aluminium toxicity on nutrient accumulation in maize shoots: Implications on photosynthesis. *J. Plant Nutr.* **22**: 397-416.

Lidon, F.C., Azinheira, H.G. and Barreiro, M.G. (2000). Aluminium toxicity in maize: Biomass production and nutrient uptake and translocation. *J. Plant Nutr.* **23**: 151-160.

Lindsay, W.L. (1979). Chemical Equilibria in Soils. John Wiley & Sons, New York, U.S.A.

Pavan, M.A. and Bingham. F.T. (1982). Toxicity of aluminium to coffee seedlings grown in nutrient solution. *Sol Sci. Soc. Am. J.* **46**: 993-997.

Perkin-Elmer. (1976). Analytical Methods for Atomic Absorption Spectrometry.

Pintro, J., Barloy, J. and Fallavier, P. (1996). Aluminium effects on the growth and mineral composition of corn plants cultivated in nutrient solution at low aluminium activity. *J. Pant Nutr.* **19**: 729-741.

Sarkar, P.K. and Debnath, N.C. (1989). Effect of aluminium concentration in the rooting medium on the growth and nutrition of two cultivars of wheat. *J. Indian Soc. Soil Sci.* **37**: 506-512.

Shkolnik, M.Y. (1984). Part II. The physiological role of trace elements. In: M. Cowan (ed.), Trace Elements in Plants pp. 68-284. Elsevier Science Publ., B.V., Amsterdam, The Netherlands.

Tanaka, A. and Navasero, S.A. (1966). Aluminium toxicity of the rice plant under water culture conditions. *Soil Sci. Plant Nutr.* **12**: 55-60.

Wallace, A. (1989). Evaluation of the cause for acid-soil infertility for a dicot plant species, *Phaseolus vulgaris*. *Soil Sci.* **147**: 454-456.

Wright, R. J. 1989. Soil aluminium toxicity and plant growth. *Commun. Soil Sci. Plant Anal.* **20**: 1479-1497.