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EFFECT OF ALUMINIUM ON PLANT GROWTH AND MINERAL NUTRITION OF BARLEY

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Abstract

Barley seedlings were grown in nutrient solution to study the effect of aluminium (0.0, 0.2 and 0.6 mM) on plant growth and mineral nutrition. Chlorosis appeared on the young leaves of Al toxic plants and was severe on high Al level. Stems of the Al-treated plants were purple, while the roots were short thick and brown in colour. Dry matter yield of barley shoot and root decreased progressively with increase in Al-level. The concentration of K, Ca, Mg and Mn substatially decreased in shoot and root while P decreased in shoot but it increased in root with high Al compared to control.

With increased Al levels the concentrations of Al and Zn increased in shoot and root, while Fe content in shoot was not greatly affected but in root decrease in Fe uptake was observed.

Introduction

Aluminium toxicity is an important growth limiting factor for plants in many acid soils of the world (Foy, 1974 a; Kamprath & Foy, 1971; McLean, 1976; Olmos & Camargo, 1976). Aluminium in soil becomes more soluble at low pH and a high concentration of aluminium in the soil solution may be toxic to plants. In various crops aluminium toxicity is first evidenced by root injury and then by characteristic symptoms on the leaves (Fleming & Foy, 1968; Lee, 1971b; Macleod & Jackson, 1965 and Gupta et al, 1973). The mechanism of aluminium toxicity is suggested to be the inactivation of P especially in the roots (Clarkson, 1967; Wright & Donahue, 1953).

Mclean & Gilbert (1927) classified barley as a crop whose growth was depressed by 2 ppm Al while Ligon & Pierre (1932) recorded a reduction in barley at 1 ppm in solution at a pH of 4.5. Valmis (1953) reported that 0.7 ppm Al in soil solution from acid soil gave 67% yield reductions. It is known that aluminium in soluble or ionic form restricts the root development of many agronomic plants and its toxicity results in abnormal root development due to accumulation of Al in roots. Clarkson (1966b) found that 85-90% of the Al in barley roots is adsorbed on to the cell wall of the roots.

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Aluminium toxicity is associated with P deficiency (Foy, 1975). The symptoms are abnormally dark green leaves, a purpling of stems and small leaves with short internodes. This attributed in part to the precipitation of P as aluminium phosphate which occurs in or on the root (Clarkson, 1966b).

Al toxicity have been associated with reduced uptake of several nutrients by plants particularly Ca and P. Johnson & Jackson (1964) found that Al reduced both the absorption and accumulation of Ca by wheat. Lee (1971b) found that Al inhibited the transport of P to potato plant tops, decreased the absorption of Ca, Mg and Zn by roots and caused the accumulation of P, Al, Mn, Cu and Fe in plant roots.

In the present paper the effect of variable levels of Al on the growth and mineral composition of barley is reported.

Materials and Methods

Experiment was carried out in green house in nutrient solution under different Al levels using barley cv. Zephyr as test crop. Barley seeds were soaked for 24 hr in areated water and then placed in a tray and kept in darkness. When the seeds germinated the tray was put into green house. Polystyrene pots of 300 ml capacity used in this experiment, w.re first painted black on the outside wall and finally three holes were made in the covers of the pots in order to hold the seedlings during growth.

Ten day old barley seedlings were transplanted, 3 seedlings per pot, containing 300 ml nutrient solution. The culture solution contained, Nitrogen, 10.0; Potassium, 2.0; Calcium, 1.5; Phosphorus, 1.0; Magnesium, 1.0; Sulphur, 1.0; Iron, 0.1; Boron. 0.03; Manganese, 0.01; Copper. 0.001, Zine, 0.001, and Molybdenum, 0.0002 mM (Adams et al., 1973) All the pots were placed in green house and grown in natural sunlight. The plants were grown for 10 days in half-strength solution and thereafter for four days in full strength solution which were renewed every third day.

After two weeks from the date of transplanting, the plants were again transferred to solutions containing 0.0,0.2 and 0.6 mM Al levels as $Al_2\ (SO4)_3$ with four replicates in each treatment. The pots were randomized and the plants were grown for another 2 weeks. Observations on growth were recorded and shoots and roots were collected at harvest time. After thorough washing, in distilled water, these parts were dried at $80^{O}C$ for 24 hr for dry weight determination.

Plant samples were wet-digested using a mixture of nitric-perchloric-sulphuric acids. The digest was used for the determination of total P, K, Ca, Mg, Fe, Mn, Zn, Cu and Al. Total P was determined colorimetrically (Jackson, 1958) and Al using Aluminon reagent (Chenery, 1948). K, Ca and Mg were determined using an EEL flame phtometer while Fe, Mn, Zn and Cu were estimated directly from the digest by an EEL atomic absorption spectrophotometer.

Results and Discussion

The first visual symptom of disorder on the gorwth of barley plant, was apparent after 5 days of Al treatments. The youngest leaves developed chlorosis which continued until it became interveinal stripes down the entire leaf (Table 1). This symptom was more pronounced at 0.6 mM of Al, and was suspected to be due to iron deficiency. The possible reason for the chlorotic symtpom on young Al-treated barley leaves may be due to Al^{3+} which probably competes with Fe^{3+} for exchange sites at the root surface. Tanaka & Navasero (1966) have shown that aluminium interacts with iron at root surface and thus blocks the passage of iron entry into plant roots. Another possiblity is that aluminium prevents the reduction of Fe^{3+} to Fd^{2+} in the growth medium It is known that plants generally take up iron in bivalent form for its chlorophyll synthesis. Aluminium induced an iron deficiency chlorsis in acid-soil sensitive barely and wheat varieties (Otsuka, 1969).

Concentration of Fe in plant tops was not very much affected by aluminium although it was slightly less in plant receiving Al compared to the control (Table 2). In roots, an increase of aluminium content was associated with a decrease of iron. It would suggest that possibly there is an interaction between Al and Fe for the exchange sites.

Change of color of stems to purple, a characteristic of P deficiency, appeared in Al-treated plants (Table 1). This symptom remained until harvest and would indicate an effect of Al on P nutrition. The present finding was largely in accord with the results of Wright & Donahue (1953), who claimed that P deficiency was the most prominent symptom of Al injury.

Concentration of P was low in plant tops where additon of Al to the growth medium was made. P content in plant roots increased with increase in Al level (Table 2). The result indicate that P accumulates in the roots of plant grown in Al solutions with reduced translocation of P to the tops. This supports other evidences that Al interact with P in the plant root system. Aluminium is believed to precipitate P inside plant roots and thereby cause P deficiency in plant tops (Macleod & Jackson 1965). The bio-chemical evidence indicates that Al binds P on root surface and/in cell walls and in the free space of plant roots (Clarkson, 1966b) making P less available to metabolic sites within the cells.

Roots of Al-treated Plants were short, thick and brown in colour while the roots in control were normally healthy and fibrous (Table 1). Similar findings have been reported by Hewitt (1952).

The dry matter yield of barley shoots and roots decreased progressively with increase in Al level (Table 1). This indicates that barley was sensitive to the concentration of Al in the growth medium. Al content of roots was far higher than the tops (Table 2). A large proportion of the aluminium going into the plant was possibly precipitated on the roots. The high Al content of the roots of barley suggests that the precipitation of aluminium involved, at least partly, in the formation of aluminium phosphate. In this context

Table 1. Effect of different levels of Al on the morphological characters of plant leaves, stems and roots.

Al level (mM)	Leaves			Stems			Roots
	5 days+	10 days	At harvest	5 days	10 days	At harvest	At harvest
0.0	Normal green	Normal green	Normal & healthy	Normal	Normal	Normal & thick	White, healthy long well-branched.
0.2	Slight spotty chloro-sis.	Slight spotty chloro-sis.	Spotty chloro-sis.	Purple	Purple	Slight pruple	Yellowish-White.
0.6	Slight spotty chloro-sis.	Spotty chloro-sis.	Interve-nal chloro-sis.	Slight purple	Deep purple	Deep purple	Brown spotted, thick and less branched.

+ The number of days after the initiation of the Al treatment.

Table 2. Effect of Al on the dry matter yields and nutrients content of barley grown in nutrient solutions.

Al levels (mM)	Dry Wt. of plant parts (g/pot)	Major nutrients content % in dry Wt.				Minor nutrients contents $\mu g/g$ dry Wt.				
		P	K	Ca	Mg	Fe	Mn	Zn	Cu	Al
					Tops					
0.0	0.802	0.809	5.25	0.201	0.245	180.0	93.75	48.75	31.00	123.47
0.2	0.723	0.659	4.51	0.070	0.156	195.0	61.75	55.25	25.63	167.50
0.6	0.634	0.472	3.14	0.061	0.105	170.0	44.25	61.25	27.50	228.13
LSD 5%	0.061	0.104	0.31	0.018	0.012	NS	3.46	5.00	NS	26.32
					Roots					
0.0	0.320	0.975	4.79	0.061	0.108	714.30	208.25	81.22	74.14	535.21
0.2	0.265	1.070	2.98	0.032	0.072	695.56	96.21	102.04	55.39	1065.28
0.6	0.224	1.286	1.85	0.047	0.047	464.40	160.39	129.12	30.19	1163.08
LSD 5%	0.029	0.109	0.41	0.005	0.007	NS	23.25	26.75	14.60	67.98

Clarkson (1966b) has revealed that most of the aluminium in injured barley roots was associated with the cell-wall material.

Increased Al levels caused a decrease in the concentration of K, Mg and Ca in tops and roots compared with control. Al apparently competes with these elements for root absorption sites. The concentration of Mn in plant tops and roots decreased progressively with increased Al level (TAble 2). The decrease was highly significant at 5% level. The data suggest that Al has a depressing effect on the uptake and utilization of Mn by barley plants. The concentration of Zn in plant tope and roots increased with increased Al level. This possibly indicates that Al stimulates plant roots to take up more Zn by barley palnts. Aluminium addition did not influence the concentration of Cu in barley tops while the copper content in roots decreased regularly with increased Al level and the treatments differed significantly. The evidence presented here supports the conclusion that aluminium was exerting a major effects on the growth and nutrient contents of barley plant.

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