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EFFECT OF AL AND FE ON THE GROWTH AND MINERAL CONTENT OF BARLEY

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Abstract

The dry matter yield of barley tops and roots decreased at high Al-treated plants, while the roots were short, thick and spotted brown in colour. Chlorosis observed on the Al treated plants when the sources of Fe were ferric. Plants applied with ferrous iron did not show any such chlorotic symptom.

Al addition in the nutrient solution decreased the concentration of P in 1st leaf but it increased in the roots when the sources of iron were ferric. With ferrous iron, an increase of P in the youngest leaf and its decrease in root was observed. Mn concentration decreased in all plant parts except the stems where more Mn content was recorded. Increased concentration of Al was observed in all plant parts at high Al level.

Introduction

Aluminium is not an essential plant nutrient but generally has toxic effects on plant growth. The growth, uptake and accumulation of mineral elements are depressed and altered extensively in plants grown with Al (Guerrier & Morard, 1978; Matsumoto & Hirasawa, 1979).

Aluminium toxicity is known to effect the plant growth in several ways. It probably has adverse effects on the protoplasm of the cells (Clarkson, 1966). It has been observed to cause precipitation of phosphate inside cell-walls thus reducing the transport of P from the root to the shoot and causing P deficiency. Al toxicity as a whole is strongly related to P deficiency, because of its high chemical affinity for P (Hsu, 1968). Its toxic effects generally result in an abnormal root development with short and thick roots.

Reduced P and Ca uptake are most commonly reported with Al toxicity but reduced uptake of other mineral element have also been reported. Many of the specific effects of Al on mineral element uptake and utilization been reviewed (Foy, 1974).

Growth of plants is usually reduced when grown with Al, however, beneficial effects of low Al on growth have been reported (Hackett, 1962). Interactions of Al with other mineral elements have been suggested as factors effecting both beneficial (Grime & Hodgson, 1969), and inhibitory effect of Al (Foy, 1974). Plant growth is reduced when essential mineral elements become limited or are in excess, and deficiencies of certain elements inhibit top growth more than root growth (Clark, 1970). The present study reports the effect of a high Al level on dry matter yield and mineral content of barley grown in nutrient solution.

Material and Methods

Expt. 1. Ten day old barley seedlings raised in a tray in glass house were transferred in pots, 3 seedlings in each containing 300 ml half strength Hoagland nutrient solution. The composition of the nutrient solution was (m M/l) : 10.0 N, 1.0 P, 2.0 K, 1.0 Mg, 0.02 B, 0.02 Mn, 0.001 Zn, 0.001 Cu, 0.002 Mo and 0.1 Fe (as Fe-EDTA). The plants were grown for 2 weeks and then four pots were supplied with 0.6 mM Al solution and another four were kept as control. There were four replicates of each treatment. The plants were grown for further two weeks. Chlorotic symptom appeared on the young leaves. The youngest and the 4th leaf were collected from each plant. After washing in water, plant parts were dried at 80°C. The samples were wet-ashed with tri-acid mixture. P was determined colorimetrically (Jackson, 1958), and Al by aluminon reagent (Chenery, 1948). Fe and Mn were estimated directly from the digest by an EEL atomic absorption spectrophotometer.

Expt. 2. In another set barley seedlings were grown in pots for 10 days in half strength Hoagland solution (source of Fe was Fe-EDTA) followed by one week in solution without P. Then the following treatments were given (i) P without Al; (ii) P with Al (0.6 mM); (iii) P with higher Mn (0.02 mM) and without Al (iv) higher Mn (0.02 mM) with higher Al (0.6 mM); (v) and without P and Al. There were 4 replicates of each treatment. Plants were grown for 2 weeks with occasional renewal of solutions. Plants were harvested and the tops and the roots were washed and dried. P, Fe, Mn and Al were determined on various plant parts.

Expt. 3. To study the effect of Al on plants receiving different sources of Fe, three sets of six pots each of which was supplied with one of the following sources of Fe: ferric-EDTA, ferric citrate and ferrous sulphate. Barley seedlings were grown for 10 days in half strength Hoagland solution. Afterwards Al (0.6 mM) was added to three pots of each Fe source, while the three pots were kept without Al treatment. The plants were grown for 2 weeks in a glass house. The youngest leaf of each plant of each treatment was collected and the bulked sample was divided into two. The third leaf was harvested similarly. The stems plus remaining leaves and roots were harvested. Samples were digested and the different plant parts analyzed.

Results and Discussion

Barley plants showed chlorotic symptom on the young leaves of Al-treated plants and at the later stage of growth the symptom changed into interveinal stripe. Deficiency of Fe and Mn generally develops such type of symptom on the young leaves of many cereal crops (Otsuka, 1969; Gerretsen, 1949; Brown 1956). Chlorotic leaves and roots were analyzed for Mn and Fe. Table 1 shows that there was a decrease in Mn content in

Table 1. Effects of Al on P, Fe, Mn and Al content of leaves and roots of barley plant.

Treatments	0 Al (control)			0.6 mM Al		
Element	Leaf		Roots	Leaf		Roots
content	Youngest	4th		Youngest	4th	
	Element content (μg/g dry wt.)					
P	7730	8100	7830	5800	6500	8200
Fe	170	240	600	168	351	610
Mn	50	80	100	41	73	77
Al	98	136	218	132	198	1313

chlorotic leaves and the roots of barley in high Al level. This effect was not shown with Fe and so Mn deficiency being the cause of the chlorotic symptom was examined first. For further evidence a second experiemnt was set up including a higher Mn supply level (0.02 mM). Similar chlorotic disorder appeared in the Al toxic plants even though the Mn content in the leaves was much higher than in the first experiment. It was therefore concluded that the chlorotic symptom was not due to Mn. In a further test three different Fe sources were used, alongwith a high Al level. Plants receiving Al and having Fe as ferric-EDTA and ferric-citrate as sources developed chlorotic symptom as noted before but the plants receiving Fe as ferrous sulphate did not. This would indicate that the source of Fe was important factor influencing the development of chlorotic symptom. It was thus concluded that the chlorosis of young leaves was due to physiological deficiency of Fe.

When Fe^{3+}-EDTA was used as iron source there was very little difference between the concentration of Fe in leaves and tops of Al treated plants and the controls. Where three Fe sources were examined the Fe content in chlorotic Al toxic leaves was similar to, or greater than, the concentration in non-chlorotic leaves. Also the Al toxic but non-chlorotic leaves receiving Fe as $FeSO_4$ did not contain substantially higher concentration of Fe than equivalentchloroticleaves of plants receiving Fe as Fe^{3+}-EDTA and Fe^{3+}-citrate.

Table 3. The effect of Al on the P, Fe, Mn and Al content of leaves, stems and roots of barley plant (expt. 3).

Al levels in nutrient solution (mM)	Dry wt. tops g/pot	Dry wt. root g/pot	Youngest leaf				3rd leaf				Stems+remaining leaves				Roots			
			P% in dry wt.	μg/g dry wt.			P% in dry wt.	μg/g dry wt.			P% in dry wt.	μg/g dry wt.			P% in dry wt.	μg/g dry wt.		
				Fe	Mn	Al		Fe	Mn	Al		Fe	Mn	Al		Fe	Mn	Al
O Al	1.56	0.58	0.81	509	65.5	37.5	1.23	891	68.6	45.4	0.52	310	34.8	47.0	1.19	6312	28.2	56.3
+ Al	1.01	0.48	0.83	589	25.1	60.9	0.82	576	25.9	31.4	0.40	148	71.5	103.0	0.96	3587	23.7	516
O Al	1.64	0.70	[illegible]	270	36.7	16.8	0.76	495	81.3	23.6	0.56	100	20.4	25.9	0.67	860	80.5	13.9
+ Al	1.50	0.56	0.75	322	23.6	29.4	0.72	326	27.0	6.03	0.54	82.5	63.5	53.4	0.74	827	30.5	513
O Al	1.42	0.63	0.71	414	34.7	19.3	0.67	448	80.1	8.87	0.53	158	11.3	51.1	0.62	5803	71.6	46.9
+ Al	1.31	0.49	0.89	693	20.3	79.5	0.87	383	35.8	83.6	0.56	145	54.0	114	0.80	1833	17.2	460

O Al= No Al; + Al= 0.6 mM;

1 = Ferrous sulphate
2 = Ferric - EDTA
3 = Ferric citrate

Table 2. Effect of Al on the dry yield of tops and roots and nutrient content of barely plant (Expt 2).

Treatments*	Dry wt. tops g/pot.	Dry wt. roots g/pot.	Element content in tops				Element content in roots			
			P% in dry wt.	μg/g dry wt. Fe	Mn	Al	P% in dry wt.	μg/g dry wt. Fe	Mn	Al
P+O Al	0.64	0.24	1.24	90.0	61.0	26.6	0.77	361	86.7	393
P+ Al	0.54	0.20	1.03	92.5	40.0	70.0	1.00	257	35.4	990
P+Mn+O Al	0.67	0.25	1.27	107.5	99.0	11.7	0.50	328	138.8	302
P+Mn+Al	0.54	0.20	0.87	77.5	41.0	61.5	1.05	391	96.7	784
OP+OAl	0.43	0.18	0.19	85.0	55.0	13.3	0.36	135	78.8	277

* O Al= NO Al; + Al= 0.6 mM and + Mn= 0.02 mM.

In all the experiments the two ferric iron sources used indicate that Al did not prevent the Fe movement to the tops but its effect is possibly concerned with the utilization of ferric iron (Fe^{3+}). The use of ferrous iron revealed that toxic Al has no clear interference with Fe^{2+} utilization and the reason for chlorotic symptom on young leaves of plants receiving Al was due to trivalent Al hindering the conversion of Fe^{3+} to Fe^{2+} within the plant. Reduction of Fe^{3+} to Fe^{2+} is essential for the uptake of iron by plant roots (Brown & Jones, 1962; Christ, 1974). Chlorophyll synthesis is affected at a very early stage of deficiency and most of the iron is found in chloroplast (Brown & Possingham, 1957). Iron is an essential element for the chlorophyll synthesis and chlorosis generally develops on the young leaves when there is interference in the utilization of ferrous iron (Price, 1968). Ferrous iron (Fe^{2+}) is an ionic activator of aconitase. Barley grew well in nutrient solution, but Al greatly inhibited its growth and especially that of its roots. The dry matter yield decreased at all sources of Fe with high Al level. The root growth was also depressed with Al level.

Where plants were transferred to a nutrient solution without P, purple coloured stems and deeper green colour of older leaves appeared after 10 days. With the application of P in the culture solution, the plants recovered within 5 days. When Al and P was added to solution, the symptoms remained unchanged, indicating an effect of Al on P nutrition. Barley roots in Al treated plants were short, thick and brown in colour. While in control and Al treated ferrous sulphate plants were healthy and fibrous.

Table 1-3 show that the concentration of P was greater in roots of the Al toxic plants than the control but a converse effect was found in leaves and tops. The translocation of P in tops was affected in Al-treated plants. The finding of Humphery & Truman (1964) Munn & McCollum, (1976) and Wright (1948) have revealed that Al interacts with P in the plant root system.

The concentration of Mn in plant leaves and tops decreased progressively in all experiments at high Al level. It was also found that there was a higher concentration of Mn in the stem of Al-treated plants than in the control. The reason for high accumulation of Mn in barley stems is not clear, but it could be due to an interference with Mn translocation possibly by affecting the $Mn^{4+} \rightleftharpoons Mn^{2+}$ redox system. Manganese is more available in acidic growth medium due to reduction of Mn^{4+} to soluble Mn^{2+}

Aluminium concentration in plant tops and roots increased with a high Al level. Available evidence indicates that Al brings about toxicity mainly via its effect on roots and that its effect includes the precipitation of P within cells and/or on their walls, interference with phosphate utilization and inhibition of mitotic cell division (Clarkson, 1967).

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