JARQ 26, 26–33 (1992)

Promotive Effects of Aluminium on Tea Plant Growth

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Abstract

Stimulatory effects of aluminium (Al) on the growth of tea plants (*Camellia sinensis L.*) and nutrio-physiological roles of Al in tea plants were examined. The findings obtained were as follows: (1) Tea plants preferred primarily acidic conditions; (2) When Al was supplied to tea plants in the presence of P, growth was greatly stimulated, probably by improvement of the absorption and the utilization of P. The optimum level of Al for tea plants increased with increasing P supply; (3) Application of Al improved the absorption and the utilization of K. In addition, Al remarkably alleviated excessive toxicity of Mg; (4) Application of Al was similar to but more favorable than the effect of B on the growth of tea roots; and (5) The growth of excised tea roots in shaking liquid culture in vitro was stimulated by supplying Al and P together, but was not affected by Al and P supplied separately.

Discipline: Tea industry
Additional key words: boron, calcium, hydroponic culture, potassium, magnesium

Introduction

Aluminium (Al), a major soil component, is ionized in acid soils, the pH of which is below 5.0, and has inhibitory effects on the growth of many plant species. Aluminium has been shown to impair root elongation and to interfere with the uptake and utilization of phosphorus (P), calcium (Ca), magnesium (Mg) and other essential elements[8]. In plant tissues, Al is recognized to bind directly and toxically to DNA, calmodulin and other cell constituents[2]. However, tea plants grow very well in strong acid soils and they accumulate Al in their mature leaves. Chenery[1] was the first to demonstrate in a field experiment the stimulatory effect of Al on the growth of tea plants.

A series of experiments were carried out with the purpose of confirming stimulatory effects of Al in solution culture of tea plants[3,4], and in shaking liquid culture of excised tea roots differentiated from stem segments[7]. Further analyses were made to identify nutrio-physiological roles of Al in tea plant growth. This report accounts for the results of those studies pertaining to effects of Al in relation to some essential elements.

Materials and methods

In each experiment, 3 plants of one-year-old rooted cuttings of tea plants (*Camellia sinensis* L.) were established in a plastic pot (1/2,000 a) containing 10 *l* of tap or distilled water, and grown for a period of 3 or 4 months from March to July or August. Each treatment was in duplicate.

The culture solution was the same as used previously[3,4], with the pH adjusted to 4.5 every 2 days, except during the experiment dealing with a pH problem.

When the plants were sampled, the roots were washed in dilute HC1 (pH 3.0) for 3 min and rinsed with distilled water. At sampling time, the shoot tips, leaves, stems and roots were separated, dried, and dry weight determined. The contents of Al and other nutrients were then determined by colorimetric or atomic absorption spectro-photometric methods.

In *in vitro* experiments[7], the stems of young tea shoots at plucking time were cut into pieces of 5 mm length each, which was cultured in half strength MS medium containing 10^{-6}M NAA and 0.75% agar for 4 to 8 weeks. Root tips which differentiated from the tea stem segments were then excised and cultured in half strength MS medium containing 1×10^{-7}M NAA on a shaker at 25°C in darkness, for 4 weeks. Root length was measured with a caliper.

Results and discussion

1) Effects of Al and co-supply of Al and P on tea plant growth

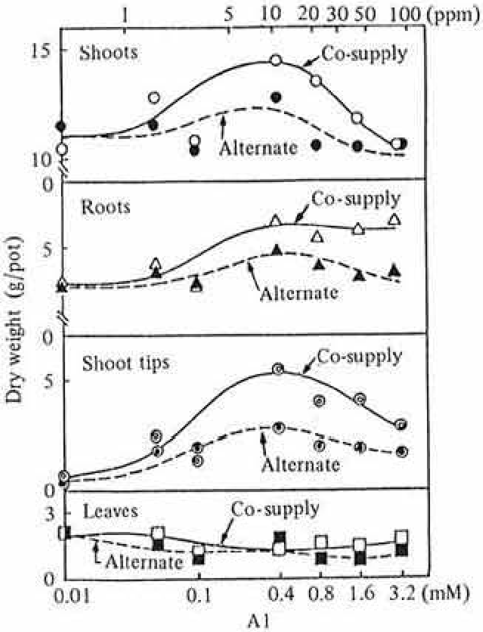

Fig. 1. Effects of co-supply and alternate supply of P and Al on the growth of tea plants
Tea plants were grown in pH 4.0 culture solution.

It is generally recognized that the presence of Al ions induces precipitation of aluminium phosphate. With the purpose of identifying interactions of Al and P in tea plants, their growth in the presence of both Al and P was compared with that under the alternate supply of Al or P every other week[3].

Growth of tea plants was clearly stimulated with the co-supply compared with that under the alternate supply of Al and P (Fig. 1). Such differences were clearly observed in shoot tips and roots. Under the co-supply of Al and P, the growth stimulation was maximized at 0.4 mM Al. The largest content of P in the tea shoots was observed in the presence of 0.4 mM Al. An increased uptake of P took place in a culture solution of pH 4.5, when measured by ^{32}P, in the presence of Al (Table 1). This result means that tea plants utilize P very well for their growth in the presence of Al.

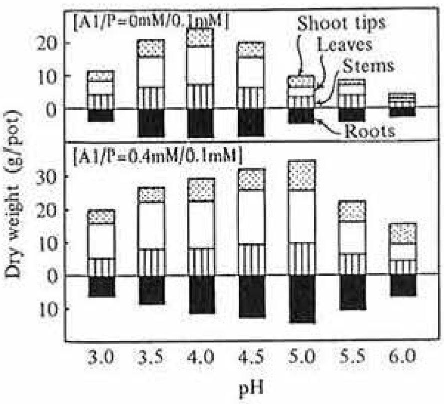

Fig. 2. Effects of pH on the growth of tea plants grown under two Al concentrations

Table 1. Effects of Al on the ^{32}P uptake of tea plants grown in pH 4.5 culture solution

	+Al				−Al*			
	Dry weight /plant (g)	P mg /plant	^{32}P /plant ($\times 10^3$ cpm)	^{32}P /P mg ($\times 10^3$ cpm)	Dry weight /plant (g)	P mg /plant	^{32}P /plant ($\times 10^3$ cpm)	^{32}P /P mg ($\times 10^3$ cpm)
Shoot tips	1.1	5.9	221	37	0.8	4.1	142	35
Leaves	5.6	22.7	431	19	4.2	23.4	362	16
Stems	3.9	11.4	851	75	3.0	10.8	610	57
Roots	2.7	18.8	6508	346	1.9	20.3	6598	325
Total	13.3		8016		9.9		7712	

One-year-old rooted cuttings of tea plant were transplanted in nutrient solution with 0.4 mM Al. The culture solution containing ^{32}P, which was prepared and aged for 1 week before the ^{32}P was added, was supplied to 2 plants for 2 days.
* Al was withheld for 54 days before ^{32}P supply.

2) Optimum pH on tea plant growth

It is well known that tea plants grow well in acidic fields. The optimum pH for tea plant growth was examined in both the presence and the absence of 0.4 mM of Al[6]. As shown in Fig. 2, their growth was most active in a wider range of pH 3.0 and 5.5 under the presence of Al, compared with a range of 3.5 and 4.5 without Al. This result suggests that tea plants prefer acidic conditions, and Al effects are not caused by the protection of H^+ toxicity.

Growth of microorganisms on tea root surface was observed at the two levels of pH, 5.0 and 5.5 in the presence of Al. They were also subjected to special conditions of P starvation. In the absence of Al under a low pH range, microorganisms were scarce. Under this condition, no VA mycorrhyza was observed. Two photographs of the root surface were taken by a SEM ultra microscope, which presented white nets (Plate 1) and fungus penetrating into root cells. It is inferred from this observation that there

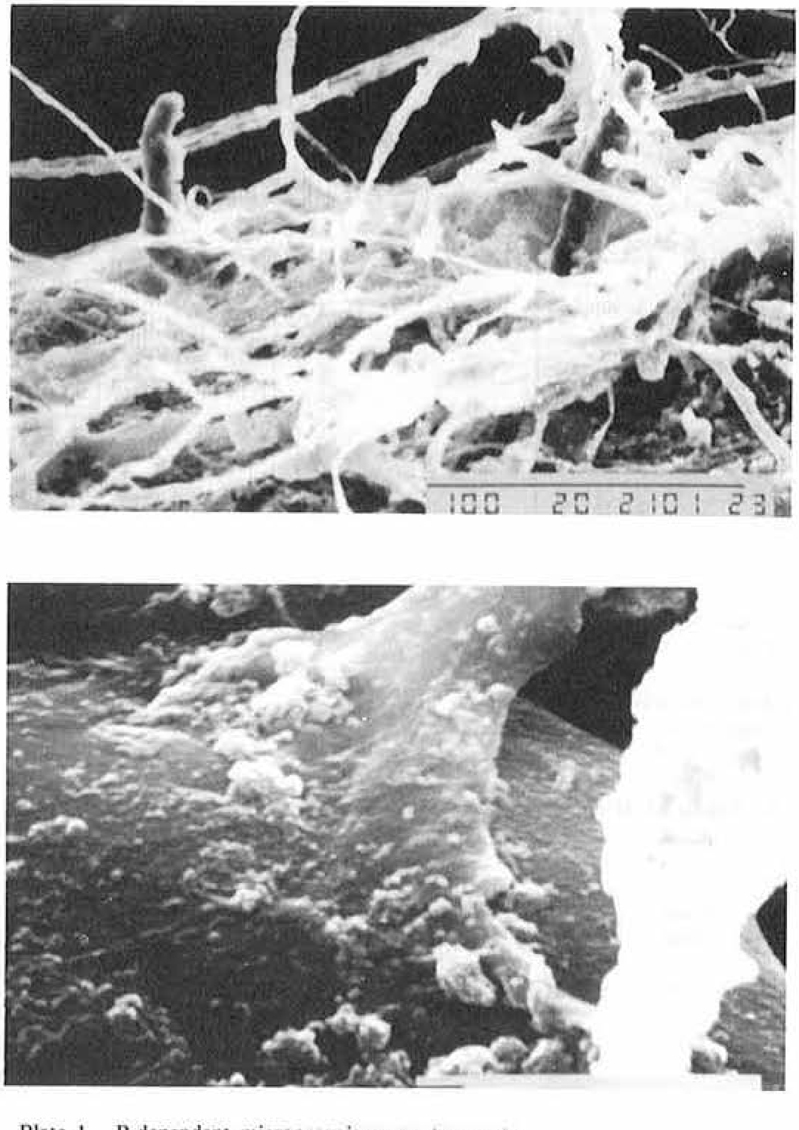

Plate 1. P-dependent microorganisms on tea roots
The photographs were taken with a scanning electron microscope.
(Above: ×500, Bellow: ×7,500)

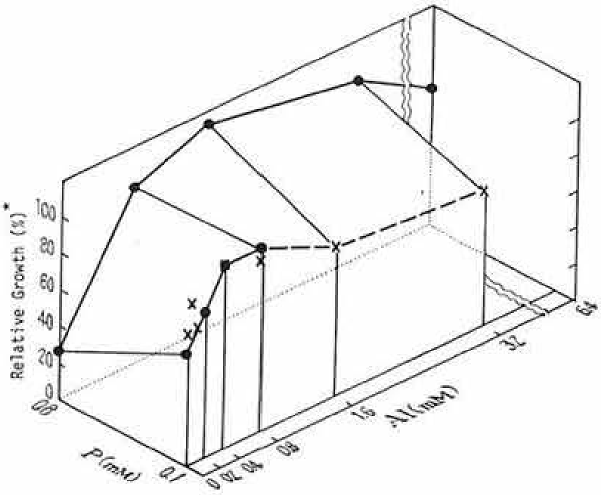

Fig. 3. Growth responses of tea shoots to supply of Al and P in the culture solution
* Relative growth: Relative value to Al 0.4 – P 0.1 mM.
●: Data of experiment in 1985[4].
×: Data of experiments in 1984[3].

is a contribution of phosphate solublizing bacteria or fungi to the absorption of P in tea plants. They may be called "P-dependent microorganisms".

3) Stimulatory effects of Al under low or high P supply

The growth of tea plants was affected significantly by the amount of P and Al as shown in Fig. 3[4]. The maximum growth of roots and shoots took place at 0.4 mM Al in the presence of 0.1 mM P and at 1.6 mM Al in the presence of 0.8 mM P. With the presence of 0.1 mM P, Al promoted the absorption of P, accelerating the plant growth. When a large amount of 0.8 mM P was supplied, Al alleviated the toxicity of excess P, enhancing the absorption of P, and promoted the tea plant growth (Fig. 4). These results suggest that Al play a regulatory role for absorption and utilization of P.

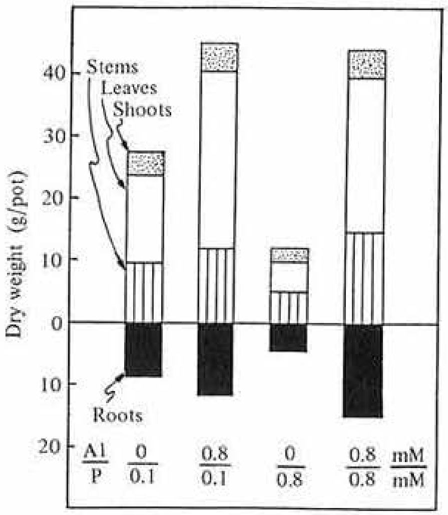

Fig. 4. Roles of Al on the growth of tea plants under low and high P supplies

4) Stimulatory effects of Al under K supplies

To examine interactions of Al with K in tea plants, they were grown under seven concentrations ranging from 0 to 3 mM (120 ppm) K with and without the provision of 0.4 mM Al[6].

Shoot and root growth of tea plants was greatly stimulated by Al supply, especially under low levels of K (Fig. 5). The uptake of K by the plants was also stimulated by Al supply; a large amount of K accumulation was observed in the roots.

5) Stimulatory effects of Al under Ca provisions

Tea plants were grown under seven concentrations ranging from 0 to 3 mM (120 ppm) Ca with and without the supply of 0.4 mM Al[6].

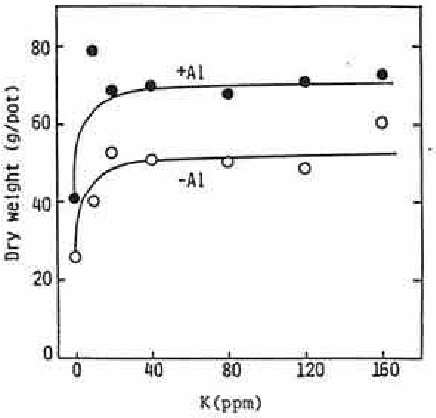

Fig. 5. Effects of Al and K supply on the growth of tea plants

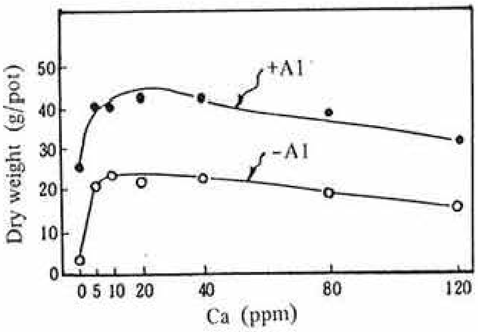

Fig. 6. Effects of Al and Ca supply on the growth of tea plants

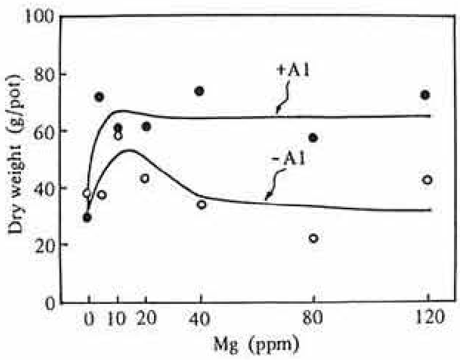

Fig. 7. Effects of Al and Mg supply on the growth of tea plants

Shoot and root growth of tea plants was noticeably stimulated by Al supply, especially under Ca starvation (Fig. 6). The concentration of Ca in the plants decreased with Al presence, while the amount of Ca itself in the plants increased. And the decrease in Ca concentration in the solution, which was caused by the plant uptake of Ca, was accelerated by an additional supply of Al (data not shown).

6) Stimulatory effects of Al under Mg provisions

Tea plants were grown under seven concentrations ranging from 0 to 5 mM (120 ppm) Mg with and without the presence of 0.4 mM Al[6].

Shoot and root growth of tea plants was stimulated by Al supply, except under the condition of Mg starvation (Fig. 7). The plant growth was hampered by the provisions of 1.6 mM (40 ppm) and higher amounts of Mg. However, the toxicity caused by the Mg excess was alleviated by Al supply. This result suggests that Al repress Mg uptake of tea plants.

7) Stimulatory effects of Al under boron starvation

Stimulatory effects of boron (B) on pollen tube growth are well known. It was observed that the growth of tea pollen tubes was promoted by 1 mM B in Al-free medium, but not in the presence of 3 μM Al. Although the tea pollen tube growth was moderately stimulated by 3 μM Al in a B-free medium, no effect was recognized under the supply of 1 mM B[8].

In regard to the effect of Al on root growth of tea plants under the varying conditions of B, larger effects were observed under B starvation, (Table 2)[6]. However, the Al effect on shoot tip growth was small. These results suggest that Al substitute part of the functional role of B in plant roots.

8) Effects of Al and P on tea roots in in vitro liquid culture

Effects of Al on the growth of excised tea roots in the presence of 0.6 mM P in the shaking liquid culture are shown in Fig. 8[7]. Stimulatory effects on root length were observed 3 weeks after the Al supply. An increase in fresh weight was also observed.

In the absence of P, Al repressed a little the growth of roots (Fig. 9). Effects of P on the growth of excised tea roots without the supply of Al are shown in Fig. 10. No significant effect of P supply was observed. However, in the presence of 0.5 mM Al, root growth was extremely stimulated by P supply (Fig. 11). The increased growth was also observed in fresh weight (data not shown).

From these results, it could be assumed that Al contributes to the growth of tea roots through its regulatory effect on the utilization of P by depositing P on the root surface. In this *in vitro* experiment, the roots grew without any microorganism in the rhizosphere.

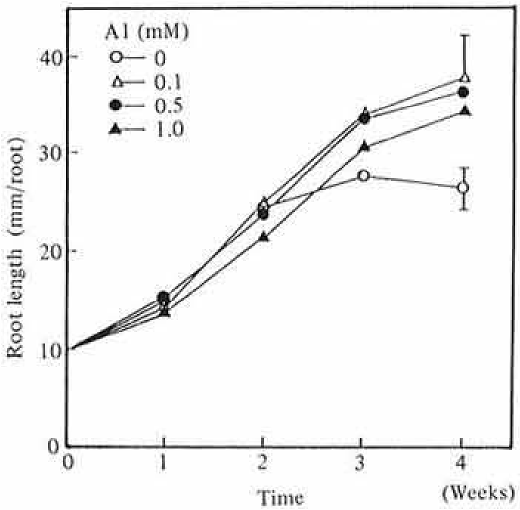

Fig. 8. Effects of Al on the growth of tea roots in the presence of P (0.6 mM) in shaking liquid culture
Bars indicate SD.

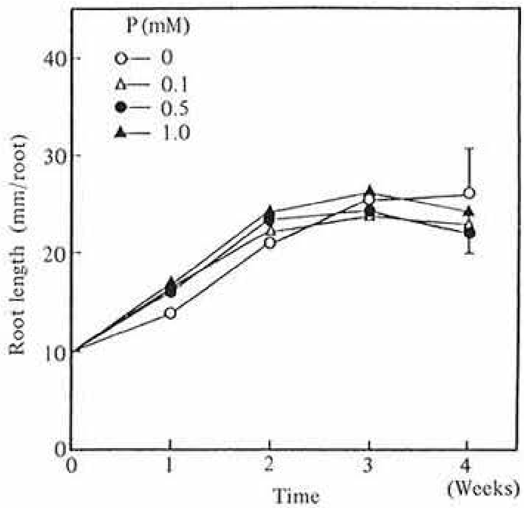

Fig. 10. Effects of P on the growth of tea roots in the absence of Al in shaking liquid culture
Bars indicate SD.

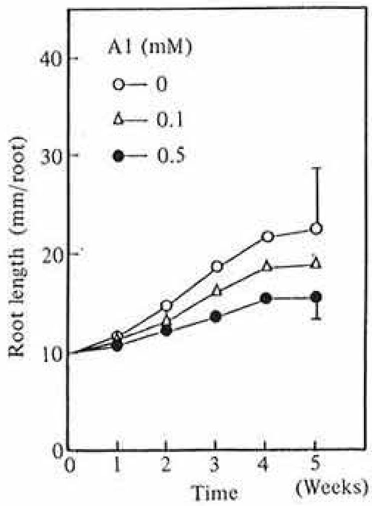

Fig. 9. Effects of Al on the growth of tea roots in the absence of P in shaking liquid culture
Bars indicate SD.

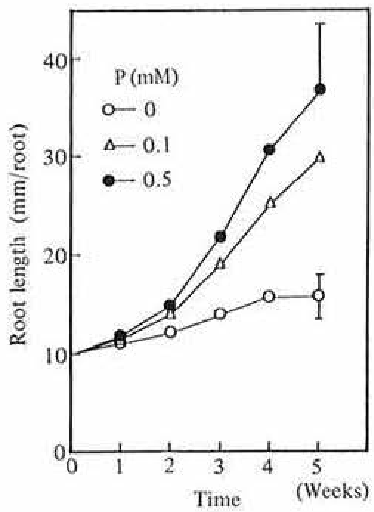

Fig. 11. Effects of P on the growth of tea roots in the presence of Al (0.5 mM) in shaking liquid culture
Bars indicate SD.

9) Growth of tea plants in culture solutions containing Al

Taking into account the results obtained as above, improved nutrients for culture solution containing Al and low levels of P were designed. The tea plants with this solution grew more vigorously than any other tea plants grown in open fields. Plate 2 shows the world's first system of hydroponically growing

Table 2. Stimulatory effects of Al and/or B supply on the tea plant growth under B and/or Al starvation culture

		Percentage of dry weight to control			
		+Al+B	−Al+B	+Al−B	−Al−B
Shoot tips	Al effect under +B	122	100	—	—
	Al effect under −B	—	—	127	100
	B effect under +Al	218	—	100	—
	B effect under −Al	—	227	—	100
	Al, B effects	277	—	—	100
Leaves	Al effect under +B	201	100	—	—
	Al effect under −B	—	—	176	100
	B effect under +Al	234	—	100	—
	B effect under −Al	—	205	—	100
	Al, B effects	412	—	—	100
Stems	Al effect under +B	180	100	—	—
	Al effect under −B	—	—	143	100
	B effect under +Al	160	—	100	—
	B effect under −Al	—	127	—	100
	Al, B effects	230	—	—	100
Roots	Al effect under +B	184	100	—	—
	Al effect under −B	—	—	267	100
	B effect under +Al	110	—	100	—
	B effect under −Al	—	159	—	100
	Al, B effects	299	—	—	100

Plate 2. Hydroponic production of tea

tea plants, which was established in December 1984. The growth rate of tea plants in the proposed hydroponic culture was approximately 6 times greater than that in the open field[5].

The proposed system for tea production has the following advantages: (1) New green tea can be produced all year round; (2) High quality tea can be produced by controlling cultural environments; and (3) Early development of tea plants can be expected through hydroponic culture.

In conclusion, the above results suggest that Al be placed in the category of beneficial elements for tea plants. Tolerance of plant resources to acidic soils has an important implication for agriculture and global environments as well. Since tea plants have great tolerance to Al, it is also an interesting species from the viewpoint of researches on physiological, biochemical and molecular responses of plants to acid conditions.

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(Received for publication, Nov. 5, 1991)