

Aluminum Influence on Performance of Some Cowpea (*Vigna unguiculata*) Varieties on a Nigerian Alfisol

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Abstract: High concentrations of aluminum (Al) in tropical soils often inhibit crop performance. In this study, Al tolerance potentials of eight cowpea cultivars (Ife brown, IT87D-941-1, IT99K-1060, IT84S-224-4, IT96-610, IT93K-452-1, IT86D-719 and IT98D-810) were investigated during early growth (35 days after sowing, DAS) and at maturity (72 DAS). Using a Completely Randomized Design (CRD) and three replications, 0, 20 and 50 μM AlCl_3 were applied to 2 kg samples of an alfisol (Typic Paleustalf) contained in polythene bags, giving 8 \times 3 (cultivars X Al levels) treatment combinations. Plant height, shoot biomass, nodule count as well as soil pH, available P, extractable Al and Mn were recorded during early growth while number and weights of pods were recorded at maturity. Genotypic (G) and G \times Al effects were significant for the growth and yield parameters while Al effect was insignificant, except on extractable Al after cropping.

Key words: Aluminum toxicity % tolerance potential % vigna unguiculata % typic paleustalf

INTRODUCTION

Cowpea (*Vigna unguiculata*) is an important grain legume widely cultivated in the tropics and subtropics. It is a principal source of protein, vitamins and minerals for overwhelming majority of people in Latin America and Africa. However, agricultural and dietary surveys conducted in parts of developing countries indicate that production has not kept pace with population growth and attempts should be made to increase production by the beginning of 21st century [1]. A major constraint to production of the crop is aluminum (Al) toxicity particularly in many humid tropical regions [2]. It tends to increase soil acidity which in turns increases solubility of iron (Fe) manganese (Mn), zinc (Zn), copper (Cu) and aluminum (Al) with Al and Mn reaching levels that are phytotoxic. It also interferes with ion uptake processes especially phosphorus (P). The mechanism of Al bounded-P is thought to be an adsorption-precipitation reaction between Al and P at root surface or root free space [3] such that P could either be adsorbed by hydroxyl-Al already precipitated in root free space or be precipitated as insoluble phosphate. According to Kochian [4] restriction of plant growth by excess Al could either be due to direct inhibition of nutrient uptake or disturbance of root cell functions. Because root cell

function is disrupted cell elongation and division is impeded thereby root growth is restricted such that ability of plants to explore soil volume for nutrients and water is reduced. George and Carolyn [5] observed that Al levels reduced calcium (Ca) and Manganese (Mn) contents of leaves, thereby causing root and foliar injury in sugar maple seedlings. However, no negative effect of Al on growth was observed. Though, liming of acid soil could result in concentration soluble and exchangeable Al being lowered to negligible levels at which Al toxicity no longer limit crop growth [6], the cost involved in liming as well as its limitation to surface layer [7] necessitates the need for some level of genetic tolerance to toxic levels of aluminum. Akinrinde *et al.* [8] noted that combining sound management practices with genetic tolerance to Al could ameliorate negative impact of acid soil stress on cowpea performance. Tolerance levels have, however been reported to be influenced by genetic background [9-11]. The present study was undertaken to evaluate the potential of eight cowpea cultivars to tolerate different levels of Al on a Nigerian alfisol.

MATERIALS AND METHODS

The soil used for this study was collected from teaching and research farm, University of Ibadan, Nigeria.

The soil was air-dried, sieved (2 mm) and analyzed at soil and plant analytical laboratory of the International Institute of Tropical Agriculture (IITA). Seeds of eight cowpea cultivars were also collected from IITA. The cultivars include Ife brown, IT87D-941-1, IT99K-1060, IT84S-2246-4, IT96D-610, IT93K-452-1, IT86-719 and IT98-810.

In the first experiment, 2 kg samples of experimental soils were weighed into each of 72 polythene bags, moistened to 60% Field Capacity (FC) and treated with three A1 levels (0, 20, 50 μM AlCl_3). Seeds were pre-germinated by moistening in filter papers and placing in germination boxes under laboratory conditions to enhance uniformity. After four days, four seedlings were planted in each polythene bag. The treatment combinations (cultivar \times A1 levels; 8 \times 3) were replicated three times in a Completely Randomized Design (CRD). Plant height (at weekly intervals from 2-5 weeks of growth) number of root nodules and shoot biomass yield were measured. The pH, available P, extractable A1 and Mn of soil samples (per pot) after cropping were also measured. Soil pH was read with pH meter, available P with spectrophotometer and extractable Mn with atomic absorption spectrophotometer.

In the second experiment, the eight-cowpea cultivars were grown in another set of 2 kg samples of the soil and treated to 0 and 50 μM A1 levels. Using CRD, the treatments were again replicated three times giving 8 \times 2 \times 3 experimental units. After six weeks of growth, plants were sprayed with Karate at the rate of 1 ml per 160 ml of water to control insect pests. The yield parameters measured were number of pods and pod weight. Experimental data were subjected to analysis of variance (ANOVA) using Sigmastat software (version 2.03, SPSS inc) and F-test was employed to evaluate significance of treatments. The student-Newman-Keul's test was used to compare means at 5% level of significance.

RESULTS AND DISCUSSION

The pre-cropping soil analytical data is presented in Table 1. It shows that the alfisol is sandy loam with moderate acidity (pH 6.6 in H_2O). Available P was low (7.0 mg kgG^{-1}) while exchangeable K (1.15 cmol kgG^{-1}) exceeded the critical value of 0.15 cmol kgG^{-1} [12]. Total N value 4.10 g kgG^{-1} was considered sufficient for plant growth as it exceeded the 1.5 g kgG^{-1} critical value [12].

Experiment 1: The effects of cultivar and A1 treatment on cowpea plant height are presented in Table 2. It is

Table 1: Physico-chemical properties of soil before cropping

Properties	
Clay (g kgG^{-1})	114.00
Silt (g kgG^{-1})	134.00
Sand (g kgG^{-1})	752.00
Textural Class	Sandy loam
pH (H_2O)	6.60
pH (KCl)	5.40
Total N (g kgG^{-1})	4.10
Organic carbon (g kgG^{-1})	0.19
Exchangeable acidity (g kgG^{-1})	0.40
Available P (mg kgG^{-1})	7.01
Exchangeable bases (C mol kgG^{-1})	
Ca	1.45
Mg	0.11
Na	0.96
K	1.15
CEC	4.07
Base Saturation	90.17

Table 2: Effects of genotype (a) and aluminum (A1) addition on cowpea height at successive growth periods

	Plant height			
	2WAP	3 WAP	4 WAP	5 WAP
Genotypic effect				
IT98K	18.67	33.67	43.67	59.89
IT87D	25.00	50.00	60.50	66.11
Ife Brown	25.67	43.33	53.33	60.11
IT96D	24.28	40.17	50.29	50.00
IT86D	24.11	37.44	46.78	49.11
IT99K	23.11	37.78	47.78	39.00
IT84S	20.00	33.72	43.44	59.11
IT93K	26.89	41.11	51.11	71.56
$\pm\text{SE}$	0.84	1.84	1.79	1.76
Effect of A1 level				
0 μM AlCl_3	24.67	41.00	51.04	55.75
20 μM AlCl_3	23.08	40.29	49.96	57.38
50 μM AlCl_3	22.65	37.85	47.83	57.46
$\pm\text{S.E}$	0.53	1.13	1.10	1.08

S.E = Standard Error, WAP = weeks after planting

obvious that cowpea height is cultivar dependent as certain cultivars were significantly taller than others. At the fifth week of growth, IT93K plants were the tallest (71.60 cm), followed by IT87D plants with heights (66.10 cm) that was significantly higher than those of Ife brown plants (60.10 cm). Height of other varieties followed the decreasing order of IT98K (59.89 cm)/IT84S (59.11 cm) >IT96D (50.00 cm)/IT86D (49.11 cm) >IT99k (39.00 cm).

Table 3: Effects of Genotype (G) and aluminum (Al) addition on cowpea nodulation, yield and post crop soil parameters

	Biomass (g potG ¹)	No. of Nodules	pH (H ₂ O)	Available P	Extr. Al mg kgG ¹	Extr. Mn	No. of pods	Pod weight (g)
Genotype effects								
IT98K	14.00	14.11	6.0	26.53	27.60	41.80	3.33	5.25
IT87D	15.98	17.22	6.0	38.72	31.70	87.90	3.17	7.83
Ife Brown	12.96	18.11	6.2	50.99	31.80	41.30	3.33	7.37
IT96D	13.78	15.33	6.5	59.27	31.30	43.20	3.67	4.23
IT86D	11.56	15.56	6.6	66.74	30.80	47.30	3.67	4.13
IT99K	13.32	18.22	6.6	47.00	31.50	36.70	3.00	2.95
IT84S	12.3	12.22	6.4	30.40	30.50	40.00	3.17	4.02
IT93K	13.42	13.56	6.4	38.97	31.00	10.70	3.67	4.67
± S.E	1.04	0.64	0.1	3.56	1.37	30.30	0.21	0.50
Effect of Al-level								
0 μM AlCl ₃	12.45	16.04	6.3	46.58	20.50	52.40	3.29	4.79
20 μM AlCl ₃	13.59	15.38	6.3	45.05	N.D	N.D	N.D	N.D
50 μM AlCl ₃	14.20	15.17	6.5	42.86	41.10	58.90	3.46	5.33
± S.E	0.64	0.39	0.10	2.18	0.69	15.20	0.11	0.25

N.D = Not determined, S.E = Standard Error

Table 4: Effects of genotype and aluminum (GX Al) interaction on cowpea plant height at successive growth periods

μM AlCl ₃ applied	IT98K	IT87D	Ife Brown	IT96D	IT86D	IT99K	IT84S	IT93K
2 WAP								
O	21.67	27.67	20.33	25.67	24.33	21.67	27.00	29.00
20	16.00	23.67	28.33	23.33	26.00	23.67	17.00	26.67
50	18.33	23.67	28.33	23.83	22.00	24.00	16.00	25.00
± S.E	1.49	1.49	1.49	1.49	1.49	1.49	1.49	1.49
3 WAP								
O	41.83	56.17	35.33	37.83	36.67	36.67	41.17	42.33
20	31.00	47.83	47.33	44.00	39.83	40.67	28.83	42.83
50	28.17	47.5	47.33	38.67	35.83	36.00	31.17	38.17
± S.E	3.19	3.19	3.19	3.19	3.19	3.19	3.19	3.19
4 WAP								
O	51.83	66.17	45.33	48.17	46.67	46.67	51.17	52.33
20	41.00	57.83	57.33	54.03	47.83	50.83	38.00	52.83
50	38.17	57.50	57.33	48.67	45.83	45.83	41.17	48.17
± S.E	3.11	3.11	3.11	3.11	3.11	3.11	3.11	3.11
5 WAP								
O	60.00	69.00	59.00	52.00	46.67	43.00	46.33	70.00
20	56.67	69.00	51.33	52.33	52.00	36.67	68.00	74.00
50	64.00	60.33	70.00	45.67	48.67	37.33	63.00	70.00
± S.E	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05

S.E = Standard Error

Aluminum treatments also influenced growth of cowpea plants in that untreated plants were insignificantly taller than those treated with Al in the first four weeks of growth. At fifth week of growth, treated plants became significantly taller than untreated ones thereby indicating a stimulatory effect at this stage of growth. The effect of interaction between genotype and aluminum (G*Al) is

presented in Table 4. Stimulatory and inhibitory roles were obvious at successive growth periods. Plants treated to 20 μM Al level were generally taller than those treated to 50 μM Al level and untreated plants. The 20 μM Al level could be considered stimulatory to growth of IT87D, IT96D, IT86D, IT84S and IT93K plants. George and Carolyn [5] reported similar stimulatory effects of Al on

the growth of sugar maple seedlings. Akinrinde *et al.* [8] also observed no genotypic difference in cowpea response to 20 μM Al treatment though there was strong Al induced inhibition of growth in two genotypes Epace 10 and Santo Inacio tested. Thornton *et al.* [13] also reported that growth of sugar maple seedling was enhanced by low levels of aluminum (2.7 and 13.5 mg IG^{-1}) and inhibited at higher level greater than 27 mg IG^{-1} . Stimulation of growth by Al has also been observed in plants such as eucalyptus and radiata pine [14] red spruce [15] and northern red oak [13]. However, stimulatory effects of Al has been attributed to alleviation of hydrogen ion toxicity [16, 17] and stimulation of iron and phosphorus uptakes [18].

Biomass yield: The effects of cultivars and Al treatment on shoot biomass yield of cowpea are presented in Table 3. IT96D, IT93K and Ife brown plants were similar in yield with respective values of 13.78, 13.42 and 12.96 g potG^{-1} . These three cultivars had higher biomass yield than IT99K (13.30 g potG^{-1}) and IT84s (12.30 g potG^{-1}) plants. IT87D plants had higher biomass yield than other varieties. Aluminum treatments also significantly enhance biomass production.

The effect of interaction between genotype and Al was also evident (Table 6) yield of IT93K plants was

enhanced at 20 μM Al level; whereas it was reduced in IT93K plants at both 20 and 50 μM Al levels.

Number of root nodules: Table 3 presents the effect of cultivar and aluminum treatments on root nodule formation. Nodulation varied significantly among the genotypes. Though, similar number of nodules was observed in IT99K (18.2) and Ife brown plants (18.1), these values were significantly higher than those of IT87D plants. IT86D and IT96D plants produced fewer nodules, about 16 and 15, respectively than IT87D plants (18.0). IT84S had the least number of nodules (11.6), which was significantly lower than those of other varieties. Aluminum treatment also influenced nodulation. The untreated plants generally produced higher number of nodules than treated plants. However, the number of nodules among plants treated to different Al levels was insignificantly different from one another. Interaction between cultivars and Al treatment had pronounced effect on nodulation as the cultivars responded to each of the Al treatment levels differently (Table 6).

Soil parameters: Varietal effect on soil pH was not significant among IT96D, IT86D and IT99K plants (Table 5). The soils on which they were grown had similar post-crop pH values (6.5, 6.6, 6.6), which were

Table 5: Effects of Genotype and aluminum (G x A1) interaction on post crop soil parameters Cowpea Genotypes

$\mu\text{M AlCl}_3$ applied	IT98K	IT87D	Ife Brown	IT96D	IT86D	IT99K	IT84S	IT93K
pH (H_2O)								
0	6.10	5.90	6.30	6.30	6.60	6.50	6.40	6.40
20	5.90	6.00	6.10	6.30	6.50	6.50	6.50	6.20
50	6.10	6.00	6.20	6.80	6.80	6.60	6.40	6.50
\pm S.E	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Available P (mg kgG^{-1})								
0	25.28	44.01	39.69	71.80	58.57	64.30	28.20	40.80
20	28.02	35.62	50.58	54.82	70.83	53.53	32.20	34.70
50	26.30	36.54	62.69	51.20	70.83	23.17	30.80	41.32
\pm S.E	6.17	6.17	6.17	6.17	6.17	6.17	6.17	6.17
Extractable Al (mg kgG^{-1})								
0	20.00	20.30	20.00	23.70	22.30	20.30	19.70	19.00
50	40.00	43.00	43.70	39.00	39.30	42.70	41.30	43.00
\pm S.E	19.40	19.40	19.40	19.40	19.40	19.40	19.40	19.40
Extractable Mn (mg kgG^{-1})								
0	40.00	39.00	41.30	40.80	42.00	35.50	40.50	37.10
50	40.00	36.50	41.30	45.50	52.50	42.90	35.90	177.00
\pm S.E	22.90	22.90	22.90	22.90	22.90	22.90	22.90	22.90

S.E; standard Error

Table 6: Effects of genotype and aluminum (G x A1) interaction on nodulation and yield of cowpea

$\mu\text{M AlCl}_3$ applied	IT98K	IT87D	Ife Brown	IT96D	IT86D	IT99K	IT84S	IT93K
Biomass yield (g potG ⁺)								
0	14.33	15.43	12.93	14.33	12.00	8.33	10.00	12.27
20	14.50	15.40	11.50	12.33	11.17	16.83	13.67	13.33
50	13.17	17.10	14.43	14.67	11.50	14.80	13.23	14.67
± S.E	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
No. of nodules								
0	3.33	18.33	18.33	13.00	18.67	18.00	12.00	16.67
20	15.33	15.33	18.00	17.33	14.00	18.67	11.67	12.67
50	13.67	18.00	18.00	15.64	14.00	18.00	12.67	11.33
± S.E	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
No. of pods								
0	2.67	3.33	3.33	3.33	3.67	3.00	3.33	3.67
50	4.00	3.00	3.33	4.00	3.67	3.00	3.00	3.67
± S.E	0.30	0.30	0.30	0.30	0.30	0.30	0.3	0.30
Pod weight (g potG ¹)								
0	1.67	9.13	7.40	3.20	4.63	3.17	4.33	4.77
50	8.83	6.53	7.33	5.27	3.63	2.73	3.70	4.57
± S.E	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70

S.E = Standard Error

significantly higher than those soils in which IT84 (6.40) IT93K (6.40) plants were grown. IT98K and IT87D plants were similar in pH with values of 6.0 treatment of soil with A1 reduced pH values, suggesting increase in acidity. The effect of interaction between cultivar and A1 treatment was significant Table 5.

Available P values ranged from 26.53 to 66.74 mg kgG¹ with IT98K and IT86D plants having the least and highest values, respectively. Aluminum treatments reduced available P from 46.58 mg kgG¹ (at 0 μM A1) to 42.86 mg kgG¹ at 50 μM A1) Table 3. However, interaction between genotype and A1 treatment was obvious (Table 5). Although pre-cropping soil analytical data revealed that the soil is P hungry (7.01 mg kgG¹), the result after harvest showed higher available P values, which indicate the possibility of precipitation, immobilization and adsorption of P by soil colloidal particles after A1 addition. Extractable A1 and Mn were generally not affected by cultivars whereas A1 treatments influenced these parameters A1 addition significantly increased extractable A1 but insignificantly increased Mn (Table 3). Though Al tolerance have always been associated with Mn tolerance either negatively [19] or positively [20], co-occurrences of tolerance to both elements was reported by Macfie *et al.* [20]. Interaction effects between genotype and A1 treatment on extractable A1 and Mn

were not significant (Table 5). Despite increase in levels of A1 and Mn over pre-cropping values, some cultivars such as IT98K, IT87D and IT93K still managed to perform. Kochian [4] and Xianguang *et al.* [21] reported genotypic tolerance of plants to A1 and Mn toxicity.

Experiment 2: The effects of cultivar and aluminum treatments on pod formation and pod weight are presented in Table 3. Cultivar and aluminum treatment significantly influenced pod formation IT960 and IT86D plants (3.67) significantly produced more pods than IT98K and Ife brown plants (3.33). IT99K and IT84S plants were similar with respective values 3.00 and 3.17. Untreated plants had lower number of pods than those treated to 50 μM at level. The effects of interaction between cultivar and A1 addition were generally significant (Table 6) as different varieties produced different number of pods at different A1 levels of 0 and 50 μM . However, A1 treatment did not reduced pod weight. Cultivars were observed to influence pod weight. IT87D (7.83 g potG¹) and Ife brown (7.37 g potG¹) significantly outweighed other cultivars. Effects of interaction between genotype and A1 treatment were generally significant (Table 6).

Lower values of pod weight were observed at μOM A1 level except in IT98K and IT86D.

CONCLUSIONS

This study evaluated tolerance potentials of eight cowpea cultivars to Al. In terms of number of pods and pod weight, IT98K plants outclassed other varieties. However, there is need to further evaluate the effects of the Al rates via a continuous application through irrigation water as soil colloidal particles might have adsorbed Al ions thereby rendering them ineffectively inhibitory to growth even at 50 μ M Al level bearing in mind the inclusion of higher rate beyond 50 μ M.

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