Impact of Aluminium on Nutrient Profile of Soil under Various Genotypes of Garden Pea

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Authors' contributions

This work was carried out in collaboration among all authors. Author MTA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PS and ASM managed the analyses of the study. Authors CD, AKS, LW and BNH managed the literature searches. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

The aim of this study was to examine the influence of Al on nutrient profile of soil grown with various pea genotypes. The study involved growing two tolerant pea (Kashi Samrath and Kashi Samridhi) and two susceptible (Matar Ageta-7 and AP-3) genotypes with increasing added rate of Al (0, 12 ppm and 24 ppm) in soil. Al application in soil resulted in significant decrease in nutrient availability of soil mainly nitrogen, phosphorus and potassium. The addition of Al caused decrease in soil pH causing a negative effect on the yield of susceptible pea genotypes. However, in tolerant genotypes, there was no significant effect on yield, despite a decrease in soil pH and an imbalance of nutrients.

1. INTRODUCTION

Garden pea (*Pisum sativum* var *hortense*) is grown worldwide for its quality protein in the human diet. Among biotic and abiotic stresses affecting pea yield, aluminium (Al) toxicity is a major problem, particularly in acidic soil condition. Worldwide, soil acidity problem

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accounts for 40% of the world arable land [1] in which Al toxicity is a major problem and resulted in low productivity in plants [2]. In India 24.34 million ha, comprising of 7.4% of the total geographical area of soil is highly acidic (pH=5.5) where the productivity of pea is very low under these soil conditions. Generally, leguminous species are highly sensitive crops to Al toxicity as compared to other cereals crops [3]. Pea plants exposed to Al toxicity showed negatively affected in growth and physiology [3]. Toxic Al concentrations showed inhibition in pea root growth and injured root tissues of pea [4] causing disturbance in its activity. Al^{3+} caused displacement of cations such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) from the apoplast of root cells and inhibit their uptake. Higher concentrations and contents of hydrogen ion (H^+), aluminium (Al^{3+}) and manganese (Mn^{2+}) in acidic soils are known for the major causes of poor plant growth due to their toxic effects on plants as well as micro-organisms association such as N-fixing bacteria [5].

Al present in soil form complex compound with phosphorous (P) like aluminium phosphate thereby making P unavailable causing nutrient imbalance resulting toxicity and deficiency of nutrients. The interaction of Al with other nutrients is merely understood therefore, to identify impact of Al on nutrient profile of soil under various genotypes of garden pea, the study was carried out against Al tolerance and susceptible pea genotypes.

2. MATERIALS AND METHODS

The experiment was layout in a factorial completely randomized design with the first factor comprised of 4 pea genotypes and the second factor comprised of 3 levels of Al treatment, control, and two proportions i.e., 12 ppm and 24 ppm.

2.1 Seed Collection

For the present study four pea genotypes were taken. Two tolerant genotypes (Kashi Samrath and Kashi Samridhi) were collected from ICAR-India Institute of Vegetable Research Varanasi and two susceptible genotypes Azad Pea-3 (CSAUA&T, Kanpur) and Matar Ageta-7 (Punjab Agricultural University, Ludhiana). Al tolerance and susceptibility of pea genotypes during the seedling stage were ascertained based on morphological parameters using sand culture experiments (data not reported here).

2.2 Growing Condition

The genotypes were grown in soil culture in pot under naturally ventilated polyhouse condition at College of Horticulture and Forestry in the year 2018-2019. Plastic pots (30 × 25 cm) were filled with 7 kg well mixed sandy loam soil and treatment was given using $AlCl_3.7H_2O$. The soil has pre-cropping value of organic carbon (1.5%), available nitrogen (100.8 mg/kg), available P (19 mg/kg), available K (120 mg/kg), Exchangeable Ca and Mg (8 mg/kg and 2.4 mg/kg, respectively), available B (0.3 mg/kg) and Exchangeable Al (KCl) (0.2 mg/kg) levels prior to sowing. No fertilizers were applied for avoiding interaction between Al and other nutrients. The pea crop was grown for three months and after harvesting the representative soil samples were collected, air dried, crushed gently with wooden pestle and mortar and sieved through a 2 mm stainless steel sieve. The materials passed through the sieve were kept in a plastic container with proper labeling and analyzed for various properties at laboratory of Soil Science and Agricultural Chemistry, College of Horticulture and Forestry, Pasighat.

2.3 Experimental Methods

Available N of the soil sample was estimated by modified Kjeldalh's method [6] and expressed as mg/kg. The available phosphorus in soil sample was extracted by [7] Bray and Kurtz (1945). The phosphorus was determined by colorimetrically and expressed as available phosphorus in mg/kg soil. Available K content of the soil sample was extracted with neutral normal ammonium acetate [8]. Soil pH was determined using the pH meter. 20 g of soil sample was taken in a beaker and 50 ml of distilled water was added (1:2.5 soil water suspension). The contents were stirred intermittently for 30 minutes with a glass rod then the pH was recorded.

The Ca and Mg were determined by using complexometric titration method. The NH_4OAc leachate was titrated with 0.01M EDTA, a sequestering agent which forms unionized complexes with Ca and Mg ions [9]. First, the total concentration of Ca and Mg was obtained using eriochrome black-T dye as an indicator and a buffer to get a pH of 10.0. The NH_4Cl and NH_4OH buffer of pH 10 was used. In a separate aliquot, Ca was determined with EDTA using murexide as an indicator after precipitating Mg as $Mg(OH)_2$ by adding 10% NaOH solution to increase the pH to 12. The titration was

performed immediately after alkali addition. Magnesium was calculated from the difference between the above two titrations. Boron in the soil was estimated by using spectrophotometric [10]. Aluminium was extracted by 1 M KCl and the level was determined colorimetrically using aluminon-acetate buffer [11].

2.4 Statistical Analysis

The experiment was laid out in a factorial completely randomized design with three replications. Two way ANOVA analysis was done using SPSS (version 21). Mean for the main effect was compared using DMRT and for interaction least significant difference (LSD) was used at 5% probability level.

3. RESULT AND DISCUSSION

3.1 Influence of Al Addition on Exchangeable Al (KCl) (mg/kg)

Externally added Al had a significant increase in exchangeable Al content of pea grown soil. Exchangeable Al content of soil grown with tolerant genotype was significantly lower than susceptible genotype (Table 1). Al treated soil grown with Kashi Samrath and Kashi Samridhi had exchangeable Al 11.54 mg/kg and 12.26 mg/kg, respectively. Whereas, exchangeable Al content of soil grown with genotypes Matar Ageta-7 and AP-3 was 12.66 mg/kg and 16.19 mg/kg, respectively (Table 1). There was a significant increase (p=0.05) in exchangeable Al with the addition of 12 ppm and 24 ppm Al. Despite enhanced level of Al content of soil in tolerant genotypes over pre-experimental values, it coped to perform well. This may be due to genotypic tolerance of the plant to Al toxicity [1].

Interaction between genotypes and Al was also found significant (Table 2). Highest Al was observed in soil grown with susceptible genotypes AP-3 (27.81 mg/kg) and Matar Ageta-7 (23.93 mg/kg) at 24 ppm Al level. Al treated soil grown with tolerant genotypes had less exchangeable Al as compared to susceptible genotypes. It may be due to the exudation of organic acid by plant roots which neutralizes the toxic Al. Exudation of organic acid is external defence mechanism of legumes to neutralize toxic Al [12].

3.2 Influence of Al Addition on pH

Averaged across Al concentration pH of the soil grown with pea genotypes was lower than pre-experimental value. Soil grown with Kashi Samrath genotype has the highest pH (5.71) which was at par with Matar Ageta-7 (5.67) followed AP-3 (5.59) and lowest was in Kashi Samridhi (5.52) (Table 1). The addition of Al reduced he pH of the soil significantly (p=0.05). The pH value of the soil decreased by 0.22 (p=0.05) with addition of 12 ppm Al and a decrease in pH value of 0.71 (p=0.05) was observed with the addition of 24 mg/kg Al with respect to control (Table 1).

Pea genotype grown in the presence of Al had a significant impact of post experimental pH of soil. In control and 12 ppm Al level, the pH was found to be highest in soil grown with Matar Ageta-7. However, at 24 ppm Al level pH of soil grown with Kashi Samridhi was found to be highest (5.73). Cardus et al. (1987) [13] observed a decrease in soil pH with Al application in white clover. The decrease of pH in soil may be due to an increase in Al^{3+} ions in the soil which contributes to the exchangeable acidity. In soil grown with tolerant genotype Kashi Samridhi, there was no effect of Al addition on pH. This may be due the excretion of organic acid in rhizosphere which binds with Al^{3+} to form a complex. Free Al contributes to the soil pH, when Al^{3+} binds with the organic acids there is no effect on soil pH.

3.3 Influence of Al Addition on Available Nitrogen (mg/kg)

The effect of Al addition was found significant for the main effect of genotypes. Available N content was found highest in soil grown with Kashi Samrath genotype (105.50 mg/kg) which was at par with Kashi Samridhi and AP-3 (Table 1). Soil grown with Matar Ageta-7 has the lowest content of available N (91.90 mg/kg). Averaged across genotype available N significantly decreased with the addition of Al compared to control. A decrease of 13.41% and 13.32% in available N content was observed with the addition of 12 and 24 ppm Al in soil (Table 1). Interaction between Al treatment and genotypes was found to be non-significant.

At pH below 5.4, Al converts in soluble form resulting in inhibition of microbial growth [14]. Inhibition of microbial growth affects the nitrification, de-nitrification and ammonification process resulting in decreased available N in soil of Al treated plant than control. Low pH also slows the process of microbial growth. In tolerant genotype Kashi Samrath and Kashi Samridhi,

there was no effect of Al on pH of soil indirectly not inhibiting the microbial growth resulting in no significant decrease in available nitrogen.

3.4 Influence of Al Addition on Available Phosphorus (mg/kg)

Post-experiment available phosphorus was found highest in soil grown with Matar Ageta-7 (18.75 mg/kg) which was at par with AP-3 (17.35 mg/kg) followed by Kashi Samridhi (15.98 mg/kg) and the least available P in soil was observed in Kashi Samridhi (12.66 mg/kg) pea genotype (Table 1). Due to Al treatment, the post experimental value of available P significantly decreased from 19.20 mg/kg in control to 16.36 mg/kg at 12 ppm Al treatment and further reduced to 14.60 mg/kg at 24 ppm Al level.

Interaction between Al and genotype was found significant for the available P content of soil. At control and 12 ppm Al level available P was found highest in soil grown with Matar Ageta-7. However, at 24 ppm Al level, the available P was found to be highest in soil grown with AP-3.

Findings are in conformity with the report of Kushwaha et al. [15] in cowpea. High levels of soluble Al in acid soil cause a decrease in P which mainly occurs due to precipitation and formation of Al-phosphate complexes in acid soil solution [16].

3.5 Influence of Al Addition on Available Potassium (mg/kg)

There was no significant difference observed in available K of soil among the four pea genotypes. Averaged across genotype Al treatment significantly reduced the available K content of soil. In control 120 mg/kg available K was recorded with significant reduction at 12 ppm Al treatment (102 mg/kg) and a further decrease to 68 mg/kg at 24 ppm Al treatment (Table 1).

The interaction effect was found significant. In the presence of Al, soil grown with tolerant variety *viz*. Kashi Samrath and Kashi Samridhi showed a lesser reduction in available K as compared to susceptible varieties *viz*. Matar Ageta-7 and AP-3 (Table 2). Rodriguez & Rowell [17] observed a reduced release of K from the exchangeable fraction after treatment with Al due to the blocking of the exchange sites.

3.6 Influence of Al Addition on Exchangeable Calcium and Mg (mg/kg)

The main effect for genotype was found significant. The highest exchangeable Ca was observed in soil grown with Matar Ageta-7 (7.83 mg/kg) which was at par with Kashi Samrath (7.17 mg/kg) followed by Kashi Samridhi (6.17 mg/kg) and least in AP-3 (5.67 mg/kg) (Table 1). Averaged across genotype Al treatment had no significant effect on soil exchangeable calcium.

The interaction effect was found significant. At control and 12 ppm Al level soil of Matar Ageta-7 had highest Ca content (9.0 mg/kg and 8.5 mg/kg, respectively). Al treatment decrease soil pH resulting in Ca deficiency in soil [18].

The main effect of Al and genotype and their interaction was found non-significant on exchangeable Mg content of soil.

3.7 Influence of Al Addition on Available Boron

Pea genotypes grown in the presence of Al had non-significant effect on post experimental available boron content of soil.

3.8 Influence of Al on Yield of Garden Pea Genotypes

Pea genotypes grown in the presence Al had significant difference in pod yield. Averaged across Al concentration the pod yield was found highest in Kashi Samrath (112.20 g/pot) followed by Kashi Samridhi (74.33 g/pot), AP-3 (53.73 g/pot) and least in Matar Ageta-7 (40.03 g/pot). Averaged across genotypes a decline of 13.44% (p=0.05) and 28.62% (p=0.05) in yield was observed with the addition of 12 and 24 ppm Al, respectively.

Interaction between Al treatment and genotypes was found significant. At 12 ppm Al level significant decline in yield was observed in AP-3 (Fig. 1). At 24 ppm Al level significant (p=0.05) reduction in yield was observed in Matar Ageta-7 and AP-3 (Fig. 1). However, there was no significant effect of added Al on yield of Kashi Samrath and Kashi Samridhi. The exposure of seedling to Al causes damage to the roots which lead to deficiency, mainly of N, P, and K, ultimately resulting in reduction of yield [19]. Legesse et al. [20] observed a significant reduction in yield of common bean. In tolerant

Table 1. Effect of genotypes and Al concentration on the characteristics of post-experimental soil and yield

Main Effect Genotypes	pH	Exchangeable Al	Available N	Available P	Available K	Exchangeable Ca	Pod yield (g/pot)
				mg/kg			
Matar Ageta-7	5.67ab	12.66a	91.90b	18.75a	95.30a	7.83a	40.03d
AP-3	5.59bc	16.19b	101.30a	17.35ab	106.20a	5.67b	53.73c
Kashi Samrath	5.52c	12.26a	105.50a	12.66c	91.20a	7.17a	112.20a
Kashi Samridhi	5.71a	11.54a	103.60a	15.98bc	97.40a	6.17b	74.33b
Aluminium concentration							
Control	5.90a	4.56a	110.30a	19.20a	120.80a	6.88a	81.50a
12 PPM Al	5.68b	13.81b	95.90b	16.36b	102.90b	6.88a	70.55b
24 PPM Al	5.29c	21.12c	95.60b	14.67c	68.80c	6.38a	58.17c

Table 2 Interaction effect of added Al on the characteristics of post experimental soil under varied tolerance of garden pea genotypes

|	Matar Ageta–7	AP–3	Kashi Samrath	Kashi Samridhi	LSD (G×Al) (5%)
Al concentration	**Exchangeable Al (mg/kg)**				
Control	4.93	5.18	3.48	4.65	**3.128**
12 PPM Al	9.12	15.59	14.67	15.86	
24 PPM Al	23.93	27.81	18.64	14.11	
	pH (H$_2$O)				
Control	6.02	5.97	5.87	5.75	**0.172**
12 PPM Al	5.90	5.59	5.58	5.65	
24 PPM Al	5.10	5.20	5.12	5.73	
	Available Phosphorus (mg/kg)				
Control	21.00	19.60	17.50	17.50	**2.62**
12 PPM Al	20.21	15.73	9.80	16.50	
24 PPM Al	15.05	16.69	10.71	13.94	
	Available potassium (mg/kg)				
Control	122.8	141.2	113.7	105.5	**31.2**
12 PPM Al	106.5	123.9	89.2	92.2	
24 PPM Al	56.5	53.5	70.8	94.3	
	Exchangeable Ca (mg/kg)				
Control	9.0	4.5	6.5	7.5	**1.65**
12 PPM Al	8.5	6.0	7.0	6.0	
24 PPM Al	6.0	6.5	8.0	5.0	
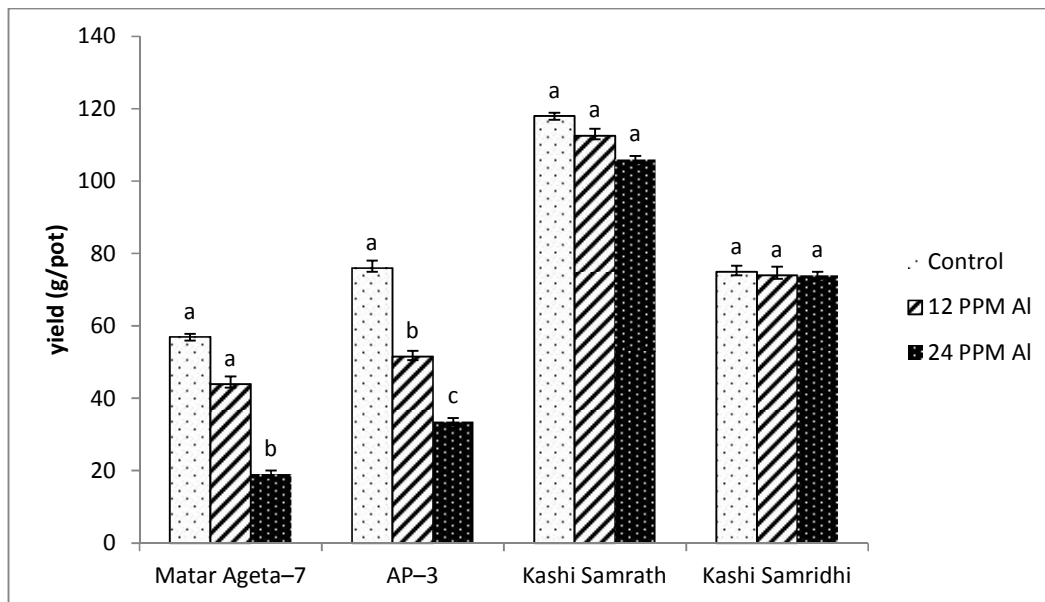
Fig. 1. Al treatment on yield of pea genotypes (DMRT with same letter shows no significant different with control (p=0.05), Error bar-S

genotypes, there was no effect of Al on yield and it may be due to better adaptability of genotype by manipulating the rhizosphere for enhanced nutrient availability. In our previous experiment [21], we observed a decrease in the yield of the susceptible genotype of Dolichos bean.

4. CONCLUSION

The addition of Al in soil resulted in a significant decrease in nutrient availability of soil and increasing soil acidity causing a negative effect on the yield of pea genotypes. Available NPK decreased significantly in soil grown with pea externally added Al. addition of al in soil caused decrease in post experimental soil pH. However, in tolerant genotypes, there was no significant effect on yield despite a decrease in pH and macronutrients.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kochian LV. Cellular mechanisms of aluminium toxicity and resistance in plants. Annual Review in Plant Physiology and Plant Molecular Biology. 1995;46:237–260.

2. Uexküll von HR, Mutert E. Global extent, development and economic impact of acid soils. Plant and Soil. 1995;171:1-15.

3. Akhter A, Wagatsuma T, Khan MSH, Tawaraya K. Comparative studies on aluminum tolerance screening techniques for sorghum, soybean and maize in simple solution culture. American Journal of Plant Physiology. 2009;4(1):1-8.

4. Motoda H, Kano Y, Hiragami F, Kawamura K, Matsumoto H. Morphological changes in the apex of pea roots during and after recovery from aluminium treatment. Plant and Soil. 2010;333:49–58.
   DOI: 10.1007/s11104-010-0318-1

5. Bambara S, Ndakidemi PA. The potential roles of lime and molybdenum on the growth, nitrogen fixation and assimilation of metabolites in nodulated legume: A special reference to Phaseolus vulgaris L. African Journal of Biotechnology. 2010;9(17):2482-2489.

6. Subbiah BV, Asija GI. A rapid procedure for the estimation of available nitrogen in soils. Current Science. 1956;25:259-260.

7. Bray RH, Kurtz LT. Determination of total organic and available form of phosphorus in soil. Soil Science. 1945;59:39-45.

8. Hanway JJ, Heidel H. Soil analyses methods as used in Iowa state college soil testing laboratory, Iowa Agriculture. 1952;1–31.

9. Tucker BB, Kurtz LT. Calcium and Magnesium Determinations by EDTA Titrations. Soil Science Society of America Journal. 1961;25(1):27-29.

10. Gupta UC. A simplified procedure for determining hot-water-soluble boron in Podzol soils. Soil Science.1967;103:424-428.

11. Barnhisel R, Bertsch PM. Aluminium. In: Methods of soil analysis part 2. Agronomy, no. 9 (2). American Society of Agronomy and Soil Science Society of America. Madison, Wisconsin United States. 1982;275- 300

12. Matsumoto H, Motoda H. Aluminum toxicity recovery processes in root apices; possible association with oxidative stress. Plant Sci. 2012;186:1–8.

13. Caradus JR, Mackay AD, Pritchard, MW.Towards improving the aluminium tolerance of white clover. In Proceeding of New Zealand Grassland Association. 1987;48:163-169.

14. Zhao XQ, Shen RF. Aluminum–Nitrogen Interactions in the Soil–Plant System. Front. Plant Science. 2018;9:807.
    DOI: 10.3389/fpls.2018.00807

15. Kushwaha JK, Pandey AK, Dubey RK, Singh V, Mailappa AS, Singh, S. Screening of cowpea (*Vigna unguiculata* (L.) Walp.) for aluminium tolerance in relation to growth, yield and related traits. Legume Research, 2017; 40(3):434-438.

16. Iqbal MT. Acid tolerance mechanisms in soil grown plants. *Malays. J. Soil Sci.*, 2014; 6:1-21.

17. Rodriguez O, Rowell D. Influence of aluminum hydroxide on potassium release from two Colombian soils. Communications in soil science and plant analysis. 2005;36(19-20):2783-2792.

18. Tandzi LN, Mutengwa CS, Ngonkeu ELM, Gracen V. Breeding maize for tolerance to acidic soils: A review. Agronomy. 2018;8:84.
    Available:https://doi:10.3390/agronomy8060084

19. Vitorello VA, Capaldi FR, Stefanuto VA. Recent advances in aluminium toxicity and resistance in higher plants. Brazilian Journal of Plant Physiology. 2005;17(1):129-143.

20. Legesse H, Nigussie-Dechassa R, Setegn G, Bultosa G. Chemical quality of common beans as influenced by genotype and aluminium rates under two soil liming regimes. Afr. J. Food Agric. Nutr. Dev. 2015;15(2):9872-9891.

21. Ansari MT, Pandey AK, Mailappa AS, Singh S. Screening of dolichos bean [*Lablab purpureus* (L.) Sweet] genotypes for aluminium tolerance. Legume Research-An International Journal. 2019;42(4):495-499.

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