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# Breeding for Acidity Stress in Plants

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## INTRODUCTION

Acid soils are the soils that fall below 7 on pH scale These are harmful for plant growth and constraint to agricultural production and are formed when the basic elements like Ca, Mg and K washed (leached) down when the rain water percolates downwards. Acidification is further intensified by agricultural practices like inefficient use of nitrogen etc. At low soil pH, it's not only the $H^+$ ion activity that leads to adverse effects on plants, but toxicity of element like Al and Mn & deficiency of P, Ca, Mg, N, K, S, Zn and Mo limit the plant growth. Although poor fertility of acid soils due to combination of mineral toxicities and deficiencies, Al toxicity is the single most important factor, being a major constraint for crop production on 67% of the total acid soil area. Therefore, toxicity due to Aluminum known to be the most common form of acidity stress in plants

### Development of Acid Soils

Soil acidity is determined by the amount of hydrogen ($H^+$) activity in soil solution and also influenced by edaphic, climatic and biological factors. Based on various studies, it can be concluded that

a. Soils developing from granite parent materials acidify at a faster rate than soils developed from calcareous parent materials
b. Sandy soils acidify more rapidly than clay soils due to their smaller reservoir of alkaline cations and higher leaching potential
c. High rainfall affects the rate of soil acidification depending on the rate of water percolation through the soil profile
d. Soil acidification is intensified by the removal of cations through the harvesting of crops and by acid precipitation from polluted air

a. Organic matter decaying to form carbonic acid and other weak acids also contributes to acidification
b. Net $H^+$ production occurs through natural processes such as nitrification of ammonical nitrogen

**Adverse Effects of Soil Acidity on Plants**

Acid soils are phytotoxic as a result of nutritional disorders, deficiencies, or unavailability of essential nutrients. Aluminium toxicity is known to be the most important growth-limiting factor for plants in acid soils followed by toxicity due to manganese.

**1. Aluminium toxicity:** The primary response to aluminium stress occurs in the roots. Aluminium-injured roots become stubby and brittle, root tips and lateral roots thicken and turn brown. The root system as a whole is affected, with many stubby lateral roots and no fine branching making roots inefficient in absorbing nutrients and water. Therefore, main symptom of Al toxicity is rapid inhibition of root growth. A number of mechanisms may be responsible for causation of these adverse effects on roots that may include Al interaction within the cell wall, the plasma membrane, or the root symplasm.

**2. Manganese toxicity:** Mn toxicity is the second most common problem in acid soils and often occurs with Al toxicity. It may occur in any soil having pH below 5.5 and may be responsible for reduction in activity of various enzymes. It may increase the activity of various oxidases, may reduce respiration and ATP levels or may affect Ca and Fe metabolisms in plant system. Mn toxicity symptoms occur mostly in shoots that may be manifested as leaf chlorosis and necrosis, leaf crinkling, cupping or puckering based on the plant species.

Therefore, Al and Mn mineral toxicity may cause toxic effects due to:

- Membrane instability, protein denaturation (Aluminium toxicity)
- or, reduction in enzyme activities, respiration and ATP levels; increase in activity of oxidases (Manganese toxicity)

**Plant Species Tolerant to Acid Soils**

Some plant species more tolerant to acid soils (particularly Aluminum tolerance) as compared to others, for example, cassava (*Manihot esculenta),* cowpea (*Vigna unguiculata),* groundnut (*Arachis hypogea),* pigeon pea *(Cajanus cajan),* potato *(Solanum tuberosum),* rice *(Oryza sativa)* and rye (*Secale cereale*). Rye is one of the most stress tolerant species in the *Triticeae* family. Several studies comparing Al tolerance in rye with that of other cereals have shown that rye has the highest tolerance, followed by triticale, wheat and barley.

**Mechanisms of Aluminium Tolerance in Plants**

Aluminium tolerance can be divided into mechanisms that

- facilitate Al exclusion from the root apex (external tolerance mechanisms)
- confer the ability to tolerate Al in the plant symplasm (internal tolerance mechanisms)

Due to the common assumption that most Al in the root is apoplasmic and penetration of Al into the symplasm in general is very low, the amount of research addressing internal tolerance mechanisms is limited as compared to external mechanisms. But, it has also been demonstrated that 50-70% of total Al might be present in the symplasm and Al can be present in the symplasm after only 30 minutes exposure to a solution containing Al.

Several external tolerance mechanisms have been suggested, of which the most important are exudation of organic acids, immobilization at the cell wall, exudation of phosphate, active Al efflux across the plasma membrane, production of root mucilage, Al exclusion via alterations in rhizosphere pH, selective permeability of the plasma membrane.

The most important internal tolerance mechanisms are Al-binding proteins, chelation in the cytosol, compartmentation in the vacuole, evolution of Al tolerant enzymes and elevated enzyme activity.

### Aluminium Resistance

Aluminum resistance may be in the form of avoidance which may be achieved by one or more of the following strategies:

1. Some Al-resistant plants raise the pH of their rhizosphere which reduces Al solubility and uptake, e.g. Al resistant genotypes of wheat, barley rice, peas, maize
2. In some cases, Al is excluded from entering the root as in wheat variety Atlas-66
3. Al may be compartmentalized in roots and thereby, excluded from the shoot, e.g. In Al resistant genotypes of alfalfa, rye and triticale
4. High levels of Al may be accumulated in older leaves while younger leaves contain relatively low levels of aluminum, e.g. In tea
5. In some cases, Al tolerance may involve nutritional aspects, e.g. Tolerance to high $NH_4^+$ concentration in strongly acid soils, resistance to Ca deficiency, resistance to P deficiency etc.

### Manganese Resistance

Manganese resistance may be either due to avoidance or tolerance. The various strategies used by the plants are as follows:

1. In some cases, there is a reduced transport of Mn from root to shoot, e.g. In Maize
2. In case of apple, Mn distribution is such that the different concentrations accumulate in different parts of the shoot
3. It has been suggested that Mn is oxidized in the root to $Mn^{2+}$ and that the rate of oxidation is quite higher in Mn resistant genotypes
4. Tolerance to Mn toxicity has been suggested in many cases but clear-cut evidence is lacking and many of the cases may be due to compartmentation (in cell wall)

### Genetics of Resistance to Acidity stress

Soil acidity due to mineral toxicity is determined by many genes and there are only two instances of clearly established monogenic control. Al resistance in barley is specified by a single dominant gene *Alp*. Similarly, Al resistance in maize inbreeds is reported to be controlled by a single gene with multiple alleles. Al resistance in maize seems to be pleiotropic effect of the heat resistance gene *Lte2*. Al resistance genes are located on wheat chromosomes $5A^L$, $6A^S$, $2D^L$, $4D^L$, $4B^L$, 5D and 7D. In case of rye chromosomes 3R, 4R and 6R are involved. However, in sorghum and alfalfa, Al resistance is shown to be polygenic and the heritability these genes is relatively high.

### Sources of Soil Acidity Resistance

Acidity stress resistance may be found in old varieties adapted to acid soils with mineral toxicities, cultivated varieties bred and cultivated in acid soil regions (Brazilian Wheats are reputedly resistant to Al toxicity)

### Selection Criteria for Acidity Stress Resistance

**Al Toxicity**

1. Al mainly retards root growth and, as a result, reduces shoot growth. Therefore, shoot dry matter is often used as a criterion in pot and nutrient cultures
2. Root length is often evaluated in hydroponic cultures and used as the basis of selection

3. Root weight is assayed in hydroponic systems and sometimes used for selection
4. In addition, root deformation and discoloration may be evaluated in hydroponic cultures and used for selection
5. In such cases where Al resistance is based on Al exclusion from root, e.g., in wheat, roots of Al-stressed seedlings are stained with hematoxylin
6. In field experiments, yield is used as an integrated measure of resistance. Yield of each genotype should be evaluated both under Al toxicity stress and non-stress conditions, and selection should be based on high mean performance and low decline due to stress.

### Mn Toxicity

The various selection- criteria for Mn toxicity resistance:

1. Since shoot growth is inhibited before root growth due to Mn toxicity, shoot growth estimated as dry matter accumulation or as some other parameter is a very good selection criterion
2. Parents of and lines isolated from crosses should be evaluated for shoot growth under both Mn toxicity stress and non-stress conditions
3. Selection should be based on mean performance as well as reduction caused by Mn toxicity stress

### Strategies for Screening for Al Tolerance

Different screening methods have been used to evaluate Al tolerance which include cell and tissue culture, nutrient solution culture, soil bioassays and field evaluations. Laboratory- and greenhouse-based techniques for screening for Al tolerance are widely used because they are quick, highly accurate, non-destructive, and can be applied at early developmental plant stages. But field-based techniques are more laborious.

### Problems in Breeding for Mineral Toxicity Resistance

Mineral toxicity/deficiency profile varies with the location of problem soil. Therefore, varieties developed for one site may not be suitable for other locations. Al and Mn toxicities occur together in most acid soils. Therefore, breeding for specific resistance to Al or Mn may not serve the purpose. Al and Mn toxicities interact with other mineral nutrients, e.g. Ca, P and Mg. Proper care should be taken during selection and evaluation stages of the breeding programmes. Root observations have to be done in hydroponic systems, which are expensive and require considerable expertise. Final evaluations have to be done under deficiency/toxicity stress as well as non-stress conditions; this doubles the workload and, as a consequence, the expenditure, etc. Mineral deficiency symptoms develop only when mineral concentration goes down below a threshold level. Chemical and biochemical assays may be used when deficiency symptoms do not develop, but these require expertise and financial resources

## CONCLUSION

Aluminium and Manganese toxicity are the major limiting factors to good crop growth in acid soils. The toxicity can be ameliorated by surface application of lime, this is often not economically or physically feasible. Combining the use of Al/Mn tolerant cultivars with liming is often the most effective strategy for improving crop production on acid soils. To breed genotypes with improved Al tolerance, reliable, efficient screening methods must be available to the researcher. Selection and development of genotypes with enhanced tolerance to acid soils and toxic levels of Al is the only reasonable solution to this problem. Several screening methods have been employed for this purpose, from genotype screening in the laboratory to soil bioassays and field evaluations.