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How to Identify Aluminium (Al) Toxicity in Acid Soils

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INTRODUCTION

Aluminium (Al) toxicity is a serious constraint to crop production in many regions around the world. Approximately 84 per cent of the soils in the North Eastern Hill (NEH) region of India are acidic in reaction, having toxicity of aluminium. The first step is, therefore to identify the problem. Should we use exchangeable (KCl-extractable) Al, Al-saturation percentage, or soil-solution Al concentration (or activity of the various Al species)?

Aluminium is not an essential element for either plants or animals. Most of the farmers have heard that too much aluminium (Al) can be harmful to plants. However, many may not be aware that there are multiple forms of Al in the soil and most of them are not directly harmful to plants. There are also multiple methods of testing the soil for these various forms of Al and several different ways to use these soil test results. Therefore, farmer should understand how Al can affect crop plants.

Available Aluminium

This test determines the amount of the "available" or easily soluble Al (Al^{+3}). Farmers can use this result to evaluate the potential of Al toxicity to their crop. This is not a routine test and must be specifically requested.

Mehlich 3-Al

It is extracted with the same chemical solution that is used in determining many plant nutrients. Mehlich (M)-3 is a stronger extracting solution than used for available Al, so the results are much larger values. The M 3-Al result has no relationship to "available Al".

Aluminium toxicity

Excess soluble/available aluminium (Al^{+3}) is toxic to plants and causes multiple other problems. Some of the more important problems include:

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1. Direct toxicity, primarily seen as stunted roots
2. Reduces the availability of phosphorus (P), through the formation of Al-P compounds
3. Reduces the availability of sulphur (S), through the formation of Al-S compounds
4. Reduces the availability of other nutrient cations through competitive interaction

The primary damage caused by excess Al^{+3} is damage to plant roots. Diagnosing this type of damage requires that farmer inspect the root systems of their crops or other plants. Of course, when plants have damaged root systems, many other above-ground symptoms are likely to appear. One of the most common will be P-deficiency. However, since Al-toxicity occurs in strongly acid soils, plants may also exhibit deficiency symptoms of calcium (Ca), magnesium (Mg), or other nutrients. There might be symptoms of manganese (Mn) toxicity, which is common when the soil pH is too low. Finally, poor root development reduces the plants ability to absorb water. Plant problems that damage the roots are difficult to diagnose with leaf analysis. This is because the uptake of these toxins is somewhat self-limiting, due to the root damage that they cause. This is most common with Al and copper (Cu) toxicities. Very little Al^{+3} in the soil solution is required to cause damage to most plants. Since Al is the most abundant element in the soil, but the soluble Al^{+3} is the toxic form, we need to know how much Al^{+3} is present in the soil and what controls its availability to plants. The availability of Al^{+3} is not completely understood, but certain soil factors are known to have a significant effect.

1. The total amount of Al present in a particular soil type
2. The soil pH
3. The types and amounts of clay in the soil
4. Soil organic matter

The soil pH is probably the single most important management factor controlling the amount of Al^{+3} in the soil solution. Soluble Al is present in the soil when the pH begins to drop below pH 6.0. However, it is inconsequential in the vast majority of soils until the pH drops below pH 5.5. Even then, it is rarely a problem until the soil pH drops below pH 5.0. However, the amount of soluble Al increases dramatically in nearly all soils as the soil pH drops below pH 5.0. In these extremely acid soils, only those species adapted to acid soils (such as pineapples, tea, coffee, and acid-loving ornamentals) or the few crop species bred to tolerate high soil Al levels can be expected to do well.

Acid sub-soil

Some soils have extremely acid sub-soils. These soils present special problems. While normal lime applications and tillage will easily correct the topsoil, lime is not mobile enough to have a significant or quick effect on subsoil acidity. When tillage is not an option, acid sub-soils become more of a problem to deal with. Lime that is surface applied or applied with only shallow incorporation affects only the top couple of inches of soil, or however deep the shallow incorporation was. If lime cannot be incorporated throughout the rooting zone of the upcoming crop, then another approach must be taken. Gypsum ($CaSO_4$) is the best solution to reduce the toxic effects of sub-soil Al^{+3} in these situations. Gypsum is not a liming agent, because it cannot neutralize acid. However, the excess Ca applied with the gypsum is a competitive cation to the toxic Al^{+3} and causes the Al^{+3} to be leached into greater soil depths (assuming enough water passes through the subsoil). Neither the lime nor the gypsum is an instant solution to excess Al^{+3}. Depending on the nature and particle size of lime, it could require up to 18 months for the lime to completely react and neutralize the acid soil. Gypsum could work faster, depending on how fast it can be leached through the subsoil.

In brief, soils differ in the amount of potentially soluble Al. Some soils can contain different amounts and types of clay, and different amounts of organic matter (OM). Different clay types can affect both the potential amounts of Al available to go into solution, as well as the amount of Al^{+3} that can be "fixed" or tied-up, after it is formed. Certain compounds in soil OM have the ability to form Al-chelates which are unavailable to plants, thus removing some of the Al^{+3} from the soil solution. All of this simply means that some farmers will have more or less difficult time in reducing the amount of Al^{+3} in their soils.

Soil aluminium saturation

Since Al^{+3} is a soluble cation, it can be evaluated by percent saturation of the soil CEC, in the same way as the major nutrient cations. Like these other cations, Al^{+3} is held on the negative sites of clay and OM (adsorbed). This adsorbed Al^{+3} is called exchangeable Al. Some of the exchangeable Al^{+3} is released into the soil solution. This "free" Al^{+3} in solution is the form that damages plants. However, the adsorbed Al^{+3} provide a ready source of additional Al^{+3} to recharge the soil solution. Like the nutrient cations, the percent of the soil CEC that is occupied by exchangeable Al^{+3} is called the percent Al saturation and it is an indicator of the reserve Al^{+3} that must be counteracted if toxicity is to be reduced or eliminated. When the exchangeable Al (per cent saturation) is greater than 60 per cent, there is a large increase in the soil solution Al^{+3}. This and previous information illustrate how both methods of evaluating soil Al have a value, and may be needed. However, these give us somewhat different information, and finally:

- Do not use Mehlich 3-Al to evaluate potential Al toxicity. It is only used to convert Mehlich 3-P into Morgan-P.
- When the soil is more acidic (pH is below 5.0), soluble Al is almost certainly a problem.
- When the soil pH is increased to be (between 5.0 and 5.5), soluble Al likely a small problem.
- When the soil pH is (5.5 and 6.0), soluble Al is not likely to be a significant problem.
- When the soil pH is above 6.0, soluble Al is almost certainly not a problem.
- Lime is the solution to excess soluble Al in the topsoil.
- Gypsum may be needed to correct excess soluble Al in the sub-soil.