ALUMINUM TOXICITY IN ACIDIC SOILS

Acidic soils (particularly when the pH drops below 5.5), can severely limit crop production. While acidic conditions are problematic on their own, the dissolution of toxic metals, particularly aluminum (Al), is what restricts plant growth. Even a small amount of aluminum compounds dissolving into the soil can lead to serious aluminum toxicity in susceptible crops.

HARSCO ENVIRONMENTAL

ALUMINUM REACTIONS — ACIDIC SOILS

Under acidic soil conditions, aluminum and hydrogen will preferentially occupy exchange sites on the soil colloids, which include mineral particles and organic matter. This will prevent base cations from attaching to the surfaces, reducing the CEC of the soil profile. As this process continues, the concentration of H+ on the surface increases to a point where the mineral structures themselves are attacked, releasing Si^{4+}, Fe^{3+}, Al^{3+}, and other ions that happen to be contained in the minerals.

$$\mathbf{Al_2Si_2O_2\,(OH)_4\ (kaolinite) + 6H^+ \rightarrow 2Al^{3+} + 2Si(OH)_4 + 2H_2O}$$

As acidification continues, more aluminum is released from the clay minerals, allowing Al^{3+} to become the dominant exchangeable cation. As aluminum and H^+ saturation on these exchange sites rise, the concentrations of both ions in the soil solution also increase due to the ionic equilibrium processes. In solution, aluminum undergoes a well-known pH-dependent hydrolysis series. Al^{3+} and the mononuclear hydroxides $Al(OH)^{2+}$ and $Al(OH)^{2+}$ have been suggested to be the most toxic chemical species of aluminum.

$$\mathbf{Al^{3+} + H_2O \rightarrow Al(OH)^{2+} + H^+}$$
$$\mathbf{Al^{2+} + H_2O \rightarrow Al(OH)^{2+} + H^+}$$
$$\mathbf{Al(OH)^{2+} + H_2O \rightarrow Al(OH)^3 + H^+}$$

ALUMINUM TOXICITY

When the soil pH falls below 5.0, aluminum is solubilized and becomes bioavailable in the soil water where it can be absorbed by plant roots. Many soil scientists believe there is a strong correlation between the effects of low pH and aluminum toxicity. It appears that a low pH-induced increase in membrane permeability may play a role in the establishment of aluminum toxicity.

The most prominent symptom of aluminum toxicity is the inhibition of root growth. Plant roots become stubby, take on a brownish color, and either deteriorate or stop growing altogether. As a result, plants are unable to absorb water and nutrients, often appearing stunted and exhibiting nutrient deficiency symptoms — a condition that predisposes crop plants to drought, nutrient deficiencies, and other stresses.

Aluminum uptake is limited mainly to the root system, where it accumulates in the epidermis and the outer cortex. The root apex (root cap, meristem, and elongation zone) accumulates more aluminum and attracts greater physical damage than the mature root tissues. Aluminum has easy and rapid access to the root via the apoplasm.

Inhibition of root growth is considered to be the result of restricted cell elongation (early stages) and cell division (later stages). This is likely because aluminum binds to the cell wall and reduces the wall's ability to expand. Significant evidence exists to show that the primary site of aluminum toxicity resides in the cell wall-plasma membrane-cytoskeleton continuum.

Traditional Solution: Lime materials are often recommended to treat acidic soils in order to prevent the development of aluminum toxicity. Initially, lime materials (calcium carbonate) react with the acidic soil solution creating OH- ions that attract (neutralize) H^+ ions, forming water and CO_2. This decreases the number of H^+ ions in the soil solution, reduces soil active acidity, and increases soil pH.

$$\mathbf{CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3 \rightarrow Ca^{2+} + H_2O + CO_2}$$

Next, calcium (Ca) that is released during the initial reaction replaces hydrogen and aluminum on exchange sites of soil and organic matter. This reduces soil reserve acidity and increases base (Ca^{2+}) saturation of soil particles and soil organic matter.

Finally, hydroxide ions (OH-) produced from the reaction of limestone and the acidic soil solution react with aluminum displaced by calcium on the soil particles to form non-toxic aluminum hydroxide precipitates.

However, reactions with lime in acidic soils result in the production of CO_2 that can either escape the soil as greenhouse gasses or contribute to future acidity as the produced CO_2 comes into contact with water.

Many soil scientists are now recommending consideration of the use of products that contain calcium silicate as a more suitable material for preventing aluminum toxicity in acidic soil.

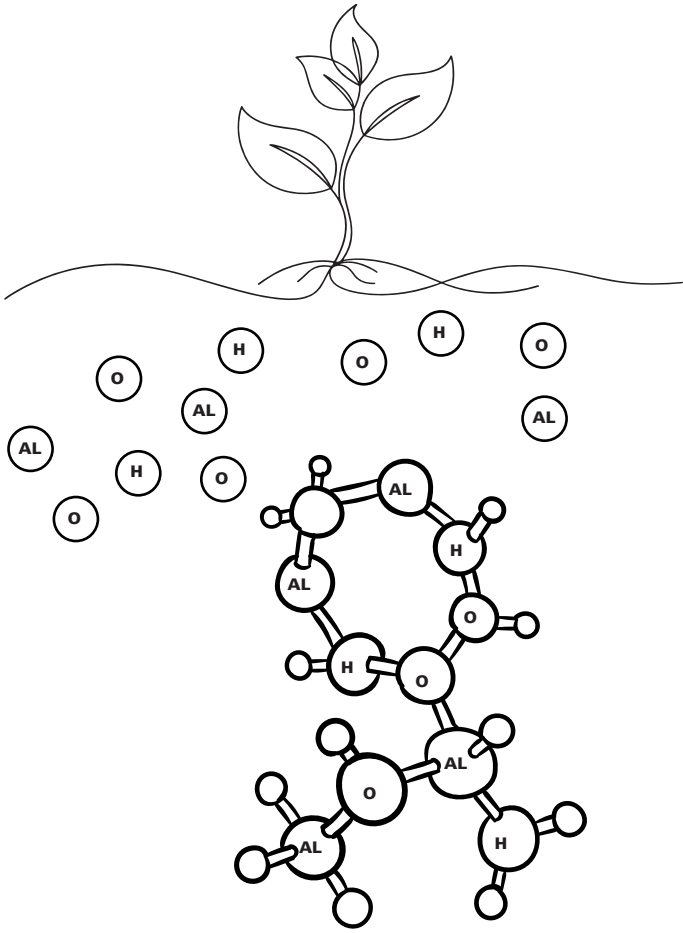


Photo Caption: Graphic representation of aluminum and toxic mononuclear hydroxides species in soil profile. As aluminum undergoes hydrolysis in soil solution, it gives off H^+ ions that further contribute to acidic conditions.

AGROWSIL: THE SILICON SOLUTION

AgrowSil is a calcium silicate-based soil conditioner that provides the most effective and efficient means to correct chemical imbalances, nutrient deficiencies, and soil toxicity issues associated with acidic soil. AgrowSil is particularly effective in establishing silicate anion processes that reduce aluminum toxicity in the soil as well as in the plant.

In the soil profile, silicon (Si) released by AgrowSil is present as monosilicic and polysilicic acids and is capable of complexing with inorganic and organic compounds. Polysilicic acids and organic silicon complexes are important sources and sinks of silicon, helping to replenish the soil solution following crop use. Further, these compounds can have a significant effect on soil properties such as soil aggregation, water holding capacity, cation exchange, and buffering capacities of soils.

The silicate anion in AgrowSil participates in several processes that contribute to aluminum detoxification. Unlike the carbonate anion (CO_3^{2-}) found in most liming materials, the silicate anion in AgrowSil carries out aluminum detoxification in both the soil and the plants.

Raising pH: When calcium silicate is applied to acidic soils, it quickly forms monosilicic acid. Monosilicic acid is a natural inorganic buffer. It attracts H^+ anions, resulting in a decrease in active acidity (increasing pH) without forming CO_2. Raising pH reduces aluminum solubility (mobility), which significantly lowers the threat of aluminum toxicity. During the reaction, Ca^{2+} is released, helping to address calcium deficiencies in the soil profile.

$CaSiO3 + 2H^+ + H_2O \rightarrow Ca^{2+} + H_4SiO_4$
(monosilicic acid)

Complexing with Aluminum in Soil Solution: Monosilicic acids complex with aluminum and aluminum hydroxide species to form fewer toxic aluminosilicates and hydroxyaluminosilicates than liming.

$H_4SiO_4 + 2Al^{3+} \rightarrow Al_2Si_2O_5 + 2H^+ + 3H_2O$
$2Al^{3+} + 2H_4SiO_4 + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 6H^+$

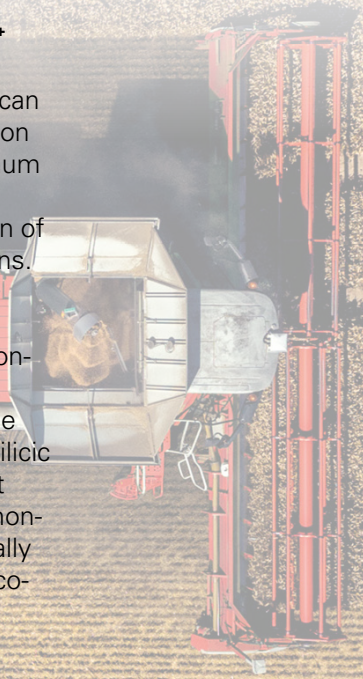
Sorption on Exchange Sites: Monosilicic acid can also adsorb onto aluminum and other metal oxides on soil surfaces. This resilification process fixes aluminum in place, reducing reserve acidity, and creates new negatively charged exchange sites via deprotonation of the silanol groups (Si-OH) that attract nutrient cations.

Aluminum Detoxification in Plants: Treating acidic soils with calcium silicate also produces silicon-mediated plant detoxification of aluminum. There is consensus that silicon (monosilicic acid) reduces the biologically active aluminum in the cell wall. Monosilicic acid accumulates in the cell wall fraction of the root apex where it complexes with aluminum, forming non-toxic hydroxyaluminosilicates. This process essentially sequesters toxic aluminum in an aluminum/silicon co-deposit, thus detoxifying the aluminum.

AgrowSil®

Consideration for the Use of AgrowSil

AgrowSil supplies the soil with monosilicic acids, polysilicic acids, and organosilicon compounds that are interchangeable with each other and provide the soil with a comprehensive, multifunctional menu of beneficial geochemical reactions. These reactions enhance the management and correction of nutrient deficiencies, metal toxicity (aluminum and other metals), phosphorus fixation, and soil deflocculation caused by acidic soils. Due to its multi-function anion, AgrowSil is unequalled in its mode-of-action, spectrum, efficacy, and longevity when compared to liming materials.



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