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Soil pH Affects Nutrient Availability

Fertilizers, whether commercial or from manure sources, will not be effective if soil pH isn't managed. Besides nutrient availability, soil biology and pesticide efficacy can also be pH dependent.

Unfortunately, due to varying soil types and crop needs, there isn't a single pH that is ideal. While most crops are assigned a suitable pH range (6.0 to 6.5), producers can maximize yields by better understanding soil properties and crop response.

Acidic Soils have a pH Less than 7

The pH scale (0-14) measures hydrogen (H) concentration, which causes acidity. A pH of 7 is considered neutral while anything lower is acidic. Any pH greater than 7 (alkaline) will have more base (OH) than H. Pure water is a combination of H and OH (H_2O).

It may seem best to maintain a neutral pH 7, but H doesn't reach plant toxicity levels until below pH 4.5. It is elements like aluminum (Al), iron (Fe) and manganese (Mn) that can cause plant toxicity in acid soils.

While Acidity is Caused by H, There can be Many Different Sources

Minerals in the soil (Al and Fe) cause acidity by splitting water and releasing H (Figure 1). These minerals are called *acidic cations*. Calcium (Ca), magnesium (Mg) and potassium (K) are *base cations* because they do not split water, and therefore don't create acidity.

$$Al^{+3} + 3H_2O \Leftrightarrow Al(OH)_3 + 3H^{+}$$

Figure 1. Dissolved aluminum can react with water to create acidity

Ammonium (NH_4^{+}) fertilizers (e.g. urea), manure or compost also add acids to soil. Some products, such as elemental sulfur (S), are applied to purposefully lower the soil pH.

Soils can Become More Acidic as Base Cations are Leached out by Rainfall

Although pure water has a pH 7, natural rainfall is slightly acidic due to carbon dioxide (CO_2) in the atmosphere. When CO_2 dissolves in rainwater, the pH is approximately 5.6. This should not be confused with "acid rain," where sulfur from fossil fuels creates sulfuric acid, depressing rainfall pH below 5.

Soil pH in Maryland will range from 5 to 7, similar to the slightly acidic rainfall the state receives (Figure 2). The opposite can be seen in dry, arid environments, where less rainfall can lead to alkaline soils (pH > 7).

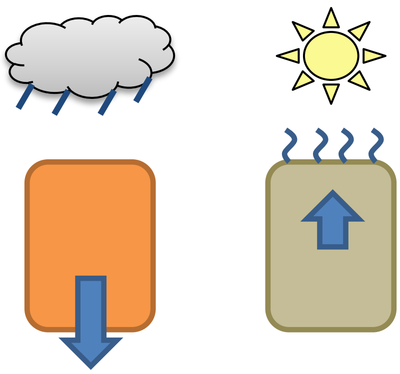

Figure 2. Rainfall in Maryland (orange soil) can leach out basic cations and leave behind acids (Al and H). Desert soils (brown) may actually have more evaporation leading to salt accumulation and an alkaline pH at the surface

Soil Type and Weathering can Predict the Amount of Base Cations (Ca, Mg, K, and Na)

Younger soils typically have less acids and more bases. As these soils are leached and weathered over time, they will become more acidic (Figure 2). Most soils in Maryland can be considered highly weathered, particularly those with greater clay content. It is a good rule of thumb that soils high in clay are also high in Al.

Parent materials that contribute bases back to the soil will maintain a moderate pH, such as those on the Piedmont (central Maryland). In the Ridge and Valley province of the Appalachians, soils may form from carbonate limestone bedrock and maintain a neutral to alkaline pH. Soils lacking a ready source of dissolvable nutrients (e.g. Eastern Shore sands) are likely to be more acidic. In addition, quartz sands have low *cation exchange capacity* (*CEC*). The CEC is a measure of the capacity of a soil to hold nutrients, so that quartz sands with a low CEC will not retain as many bases.

Soil CEC Holds Acids and Bases, but not all Soils have the Same CEC

Clay soils with higher CEC hold more bases (Ca, Mg, K, and Na) as well as acids (Al, H). Producers must manage their soil type properly, understanding that soil with greater CEC will require more lime to raise the pH. Soil with greater CEC will also acidify slower.

The Al and H held on the CEC is referred to as **reserve** acidity. The amount of acids held on the soil must also be measured by a testing lab to calculate the correct lime requirement to reach the target pH.

Crop Being Grown Determines the Target Soil pH

Most field crops prefer a pH range of 6 to 7, while some plants thrive in more acidic conditions (azaleas or blueberries). Crops like potatoes may be more susceptible to diseases at alkaline soil pH.

With different varieties or hybrids, it is increasingly difficult to predict variability within a crop. Studies of soybeans and corn indicate that some varieties may be more susceptible to Mn and Al toxicity. The susceptibility of your variety of choice may not be well known, which requires field observations to discern any differences.

While crop ranges are good guidelines, they do not take other important soil characteristics into account. This includes the toxicity of elements such Al and Fe, as well as the availability of macro and micronutrients.

Soil pH Affects the Availability of N and P

Nitrogen (N), from urea fertilizers or mineralized from organic matter, is in the form of ammonium (NH_4^+). In alkaline soils, NH_4^+ becomes ammonia (NH_3), and can be volatilized (lost as a gas). In acid soils, the additional H helps maintain NH_4^+ concentrations, which can adsorb to the CEC.

Uptake of nitrate (NO_3^-) by plants is best at a lower pH, while NH_4^+ is absorbed more efficiently at a neutral pH. For legumes, a pH < 6 restricts nodulation on alfalfa, but not as much on red clover. The dissolved Al observed in acid soils also can be toxic to rhizobia and plant roots, limiting legume production of N.

Denitrification, which transforms NO_3^- into gaseous N_2 in waterlogged soils, occurs at lower rates in acid soils (pH < 5).

Optimum P availability is at pH 6.5. Below 6.5, P becomes insoluble Al/Fe minerals or absorbs to oxides and clay. Above 6.5, P bonds with Ca to form solid minerals similar to Ca-phosphate fertilizers. Relatedly, Ca-phosphate fertilizers added to acid soils will readily dissolve and release P, but will have limited solubility in alkaline soils.

Potassium (K), Calcium (Ca) and Magnesium (Mg) are Indirectly Affected by pH

Potassium, Ca and Mg are less available in acid soils because they have been leached out, not necessarily due to solubility issues. Al can also dominate the CEC, limiting the soils ability to absorb and hold K. Compared to K, Ca and Mg are more competitive with Al for CEC sites. In addition, toxic levels of Mn and Al may damage plants roots, preventing uptake of Ca, Mg and K.

While alkaline soils are associated with greater concentrations of Ca, this can be in the form of precipitated $CaCO_3$ (lime).

Sulfur is Available in Soils as the ion SO_4^- over a Wide Range of pH

The ion SO_4^- form of sulfur is negatively charged and is retained better by acidic soils. It is important to remember that when elemental sulfur (S) is added to soil, it creates sulfuric acid (lowering pH). However, compounds containing SO_4^- (gypsum) do not have the same ability to lower pH.

Table 1. Micronutrients and their availability related to soil pH

Micronutrient	pH Available
Boron (B)	Acidic
Zinc (Zn)	Acidic
Manganese (Mn)	Acidic
Iron (Fe)	Acidic
Copper (Cu)	Acidic
Molybdenum (Mo)	Alkaline
Chlorine (Cl)	N/A

As pH Rises, Micronutrients Bond to the Soil or Become Insoluble Minerals and Cannot be Taken up by Plants

All the known micronutrients (Table 1) decrease in availability as pH rises, except for molybdenum (Mo). Zinc (Zn), Cu and Mn decrease 100 fold in concentration with every one unit increase in pH. These nutrients are not lost, but rather preferentially sorb to soil surfaces, where they are not plant available. When concentrations are high (e.g Fe), they will precipitate as solid minerals. When severe, deficiencies will cause obvious symptoms in the field (Figure 3). If a micronutrient deficiency is observed in an acidic soil, it is probably related to lower concentrations and the leached nature of the soil.

Figure 3. A soybean field with a manganese deficiency due to higher pH

Concentration Controls Whether a Micronutrient is Deficient or Toxic

Sandy soils are typically lower in micronutrient concentrations, so the pH has to be carefully managed. For soybean growth, sandy soils with a pH 5.5 required 4 lbs Mn/acre, but at least 17 lbs/acre was needed when the pH was 7 (Table 2). This indicates that a greater amount of micronutrient is necessary in a sandy soil to ensure availability.

Table 2. Extractable manganese concentration (lb/acre) necessary to grow soybeans in sandy soil (Camberato, 2000)

Soil pH	Mn (lb/acre)
5.5	4
6.0	9
6.5	13
7.0	>17

Finer textured clay soils often have greater micronutrient concentrations and can tolerate higher pH than sandier soils. As a result, pH recommendations from the University of Delaware for sandy soils may be 6.0, while those with finer textures can be up to 6.5.

Deficiency will be more common for the weathered soils in Maryland, but toxicity should still be considered in some cases. Elements like Fe and Mn are more available in acid soils, and if their concentration is too high, they can be toxic to crops. If a producer has over-applied a micronutrient to acid soil, the excessive concentration could reduce yields.

Al Toxicity Should be a Concern

When soil pH drops below 5.5, Al becomes soluble and is toxic to plant roots. All soils have some free Al, although it is more likely to be higher in weathered, clay soils (Figure 4).

Therefore, sandy soils low in Al could *possibly* tolerate pH lower than 5.5. In addition, soils very high in organic matter can remove Al from the soil solution, and can also tolerate lower soil pH for crop growth. In Maryland, weathered soils with high clay content are the most likely to experience Al toxicity when the pH is below 5.5.

Figure 4. The red color of this soil indicates oxide coatings and greater weathering. Soils like this will have more Al, but can also show greater tolerance to higher pH and micronutrient availability.

Understanding Soil Type and Crop Needs is Essential

There are some important things to keep in mind regarding the pH of a soil:

- A neutral pH of 7.0 is not needed to maximize production.
- Reduce Al toxicity by maintaining a pH greater than 5.5.
- Micronutrients may have a narrow range of availability versus toxicity. Watch for deficiencies when the pH is raised.
- Sandy, low CEC soils will leach nutrients faster than fields with clay soils. Due to lower concentrations, a high pH will also cause micronutrients to bond tightly to soil surfaces. A pH 6.0 or less is best.

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