Soil Fertility Basics

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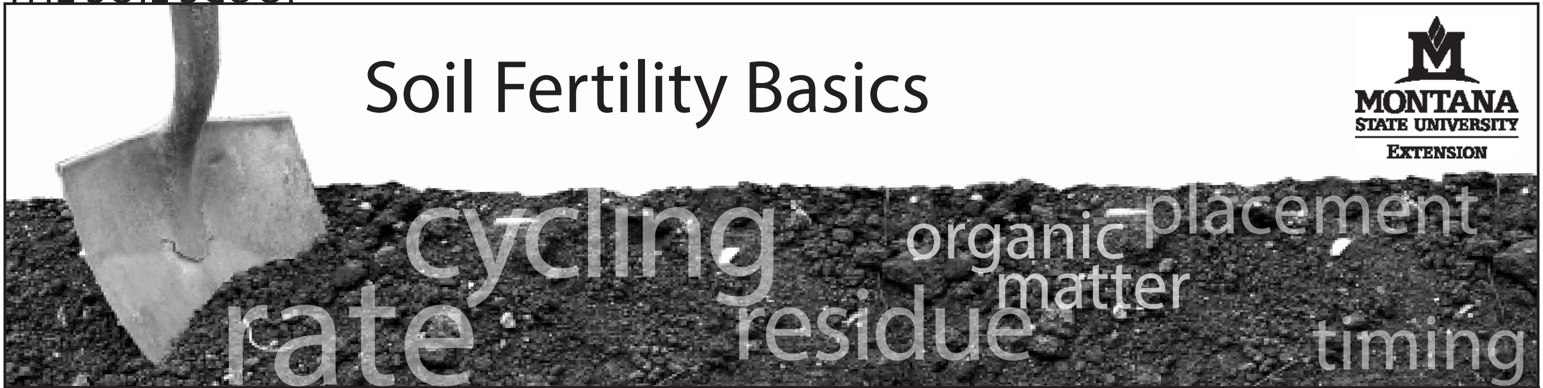

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Plants require 17 nutrients to grow and reproduce, and insufficient amounts of these nutrients can limit plant growth. Three non-mineral nutrients acquired from air and water (carbon, hydrogen, and oxygen) generally don't limit plant growth. The six macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur) are needed in larger quantities, with the "primary" macronutrients nitrogen (N), phosphorus (P) and potassium (K) most commonly limiting plant growth. Of the eight micronutrients, which are needed in smaller amounts, boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), sulfur (S) and zinc (Zn) deficiencies have been observed in Montana, while molybdenum (Mo) and nickel (Ni) have not.

Soils have large quantities of most nutrients, yet the majority of these nutrients are not in soil water and cannot be readily taken up by plants. Instead, they are in minerals, organic matter, or are "exchangeable nutrients" that are held to soil particles by weak electric charges.

CATION EXCHANGE CAPACITY

Soil has an overall negative electric charge because clay and organic matter (OM) in soil have many more negative charges on their surfaces than positive charges. Positively charged nutrient cations are attracted and held to these negatively charged surfaces like a magnet, removing nutrients from soil water. These attractions are weak, so as nutrients are taken up by a plant, more nutrients held to soil can release and become available (Figure 1). Cation exchange capacity (CEC) is a measure of how much negative charge is in a soil. A higher CEC soil can hold more nutrients, minimizing nutrient losses due to water leaching them out, and is a good indicator of soil fertility.

Clays, the smallest soil particles, have a high CEC because they have more exposed surface area to hold nutrients than silts and sands and because of chemical changes that happen as clay forms. Like clay, organic matter has a high surface area and a high CEC. In addition, OM retains water and releases nutrients as it decomposes, functioning as a slow-release fertilizer. Soils can also hold anions, which are negatively charged particles, but anion exchange capacity (AEC) is substantially smaller than CEC and less important for soil fertility.

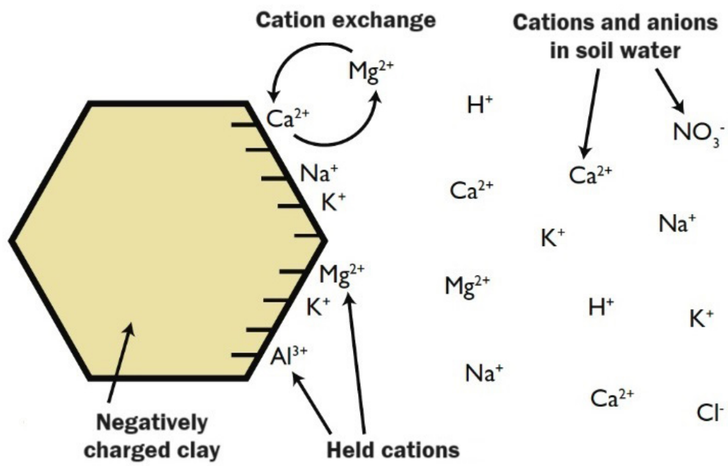

Figure 1. A simplified representation of cation exchange capacity on a clay particle (adapted from Brady and Weil, 2002; see *Soil & Water Module 1* for reference).

SOIL TEXTURE AND NUTRIENT MOBILITY

There are 12 major soil textures determined by the percentage of sand, silt, and clay in a soil (Figure 2). Sands are larger soil particles (0.5 to 2.0 mm), clays are the smallest (invisible to the eye, <0.002 mm), and silts are in between. Texture strongly influences plant nutrition by affecting its CEC and the movement of water and nutrients. Sandy soils have a low ability to hold nutrients; sand has less surface area to hold nutrients, isn't negatively charged, and compacts loosely in soil, creating large, empty pore spaces that allow water to drain out and remove nutrients. On the other hand, soils high in clays have larger surface areas, high CECs, and are tightly packed with smaller pore spaces that hold water and nutrients in place like a sponge.

Nutrients vary greatly in their relative mobility within a soil. There are two ways nutrients can move to plant roots: mass flow and diffusion. Mass flow is when nutrients are transported by the movement of water. Diffusion is a much slower process, where nutrients move from areas of high nutrient concentration to low concentration (similar to food coloring spreading in still water until it is evenly mixed). Nitrogen and sulfur are very mobile and move through mass flow, which makes them prone to leaching out of sandy soils, but they can also reach plant roots more easily and can be applied mid-season. Phosphorus is immobile and must slowly diffuse to roots for plants to access it, so phosphorus fertilizer needs to be placed near seeds during planting to be available in the current growing season.

SOIL pH

The pH of a soil is a measure of the soil's acidity based on its hydrogen (H^+) concentration. Soils can be alkaline/basic (pH > 7), neutral (pH near 7), or acidic (pH < 7). Soil pH affects the availability of all nutrients.

Base cation nutrients (Na^+, K^+, Ca^{2+}, Mg^{2+}) hold more weakly to soil at low (acid) pH, so they can leach out of acid surface soils and become less available. The high concentration of H^+ displaces nutrients and neutralizes the negative charges on clays and organic matter. The optimum pH appears to be near 7, but every plant has different nutrient needs and optimum pH levels.

Metal toxicity can also become an issue for plants at lower pH levels. Metals like Cu, Fe, Mn, and Zn are less available at high pH because metals are held very tightly to the soil or form solid minerals. Fertilizing with ammonia-based fertilizers is one way that pH decreases and soils become acidic over time. An unpublished study by Agvise Laboratories, Inc. found the number of Montana soil samples with pH less than 6 doubled between 2002 and 2022 (Northwood, North Dakota).

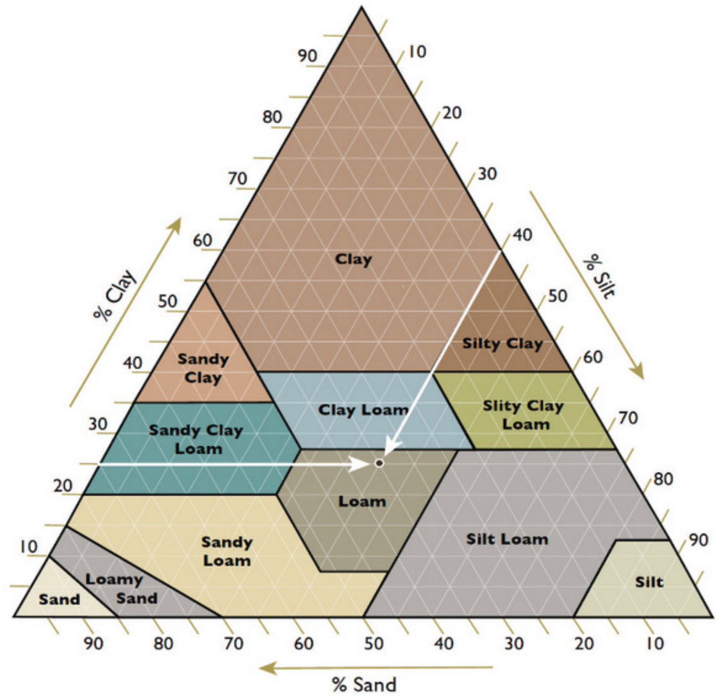

Figure 2. Texture triangle showing soil textural classes according to the percentages of sand, silt and clay. A soil with 35% sand, 25% clay and 40% silt is loam.

ROOTS & MYCORRHIZAE

Both plant roots and mycorrhizae, which are beneficial fungi that colonize plant root systems, exude acids that release nutrients from clays into soil. Mycorrhizae grow their own roots ("hyphae") which increase the surface area of soil accessed and help with nutrient and water uptake, in exchange for energy supplied by the host plant.

Some crops, such as corn, are highly dependent on this association, while others (e.g., canola) cannot support mycorrhizal fungi.

For more information:

Soil and Water Management Modules

- *Module 1: Basic Soil Properties*

Nutrient Management Modules

- *Module 2: Plant Nutrition and Soil Fertility*
- *Module 8: Soil pH and Organic Matter*

These modules and other information on soil fertility are available at http://landresources.montana.edu/soilfertility/

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