KSKL Teacher Guide | Soil Chemistry Overview

Soils transport and move water, provide homes for thousands of bacteria and other creatures, and have many different arrangements of weathered rock and minerals. When soils and minerals weather over time, the chemical composition of soil also changes.

Soil chemistry is the branch of soil science that deals with the chemical composition, chemical properties, and chemical reactions of soils. Soils are heterogeneous mixtures of air, water, inorganic and organic solids, and microorganisms (both plant and animal in nature). No two soils are exactly alike. Soil reactions and processes occur over a wide range of spatial and temporal scales. Soil chemistry is concerned with the chemical reactions and processes involving these phases. For example, carbon dioxide in the air combined with water acts to weather the inorganic solid phase. Chemical reactions between the soil solids and the soil solution influence both plant growth and water quality (Sparks, 2019).

Soil chemistry traditionally focused on the chemical reactions in soils that affect plant growth and plant nutrition. However, beginning in the 1970s and certainly in the 1990s concerns increased about metal(loid)s, nutrients (particularly nitrogen and phosphorus), and organic contaminants in soil and their impact on water quality and plant, animal, and human health. (Sparks, 2019)

Let's explore Soil Chemistry

Ion Exchanges

Ion exchange involves the movement of cations (pronounced cat-ions) (positively charged elements like calcium, magnesium, and sodium) and anions (negatively charged elements like chloride, and compounds like nitrate) through the soils.

Cation exchange is the interchanging between a cation in the solution of water around the soil particle, and another cation that is stuck to the clay surface. The number of cations in the soil water solution is much smaller than the number that is attached to soil particles.

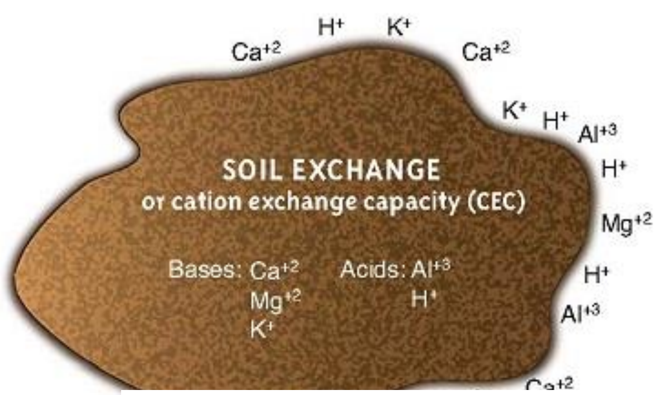


Figure 1: This diagram represents soil cations attached firmly to the soil.

The total amount of positive charges that the soil can absorb is called the **cation exchange capacity (CEC).** CEC impacts how quickly nutrients move through the profile. A soil with a low CEC is much less fertile because it cannot hold onto many nutrients, and they usually contain less clays. Most cations involved in ion exchange are plant nutrients except for hydrogen, aluminum and sodium. Ion exchange reactions in soils are very important to plant nutrient availability and retention in soil because the surface charge on soil particles allows the soil to store large quantities of nutrients and release small amounts into soil solution as they are depleted by plant uptake. If your soil has a low CEC, it is important to apply fertilizer in small doses, so it does not infiltrate into the groundwater. A soil with a low CEC is less able to hold spilt chemicals.

Soil pH

The ***soil pH*** is a measure of soil acidity or alkalinity. pH can range from 1 to 14, with values 0-7 being acidic, and 7-14 being alkaline. Soils usually range from 4 to 10. The pH is one of the most important properties involved in plant growth, as well as understanding how rapidly reactions occur in the soil.

For example, the element iron becomes less available to plants a higher the pH is. This creates iron deficiency problems. Crops usually prefer values between 5.5-8, but the value depends on the crop. The pH of soil comes from the parent material during soil formation, but humans can add amendments to soils to change them to better suit plant growth. Soil pH also affects organisms.

Sorption and Precipitation

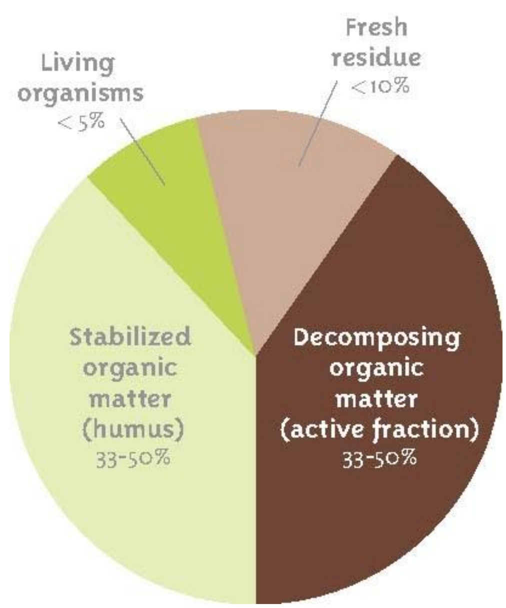
Soil particles have the ability to capture different nutrients and ions. **Sorption** is the process in which one substance takes up or holds another. In this case, soils that have high sorption can hold a lot of extra environmental contaminants, like phosphorus, onto the particles.

Soil **precipitation** occurs during chemical reactions when a nutrient or chemical in the soil solution (water around soil particles) transforms into a solid. This is important if soils are really salty. Soil chemists study the speed of these reactions under many different conditions.

Soil Organic Matter Interactions

Soil chemists also study soil **organic matter** (OM), which are materials derived from the decay of plants and animals. They contain many hydrogen and carbon compounds. The arrangement and formation of these compounds influence a soils ability to handle spilt chemicals and other pollutants.

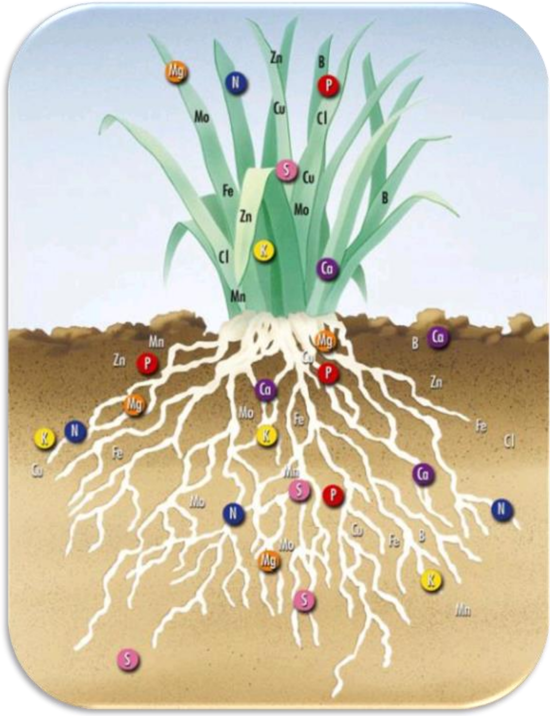
The organic matter in soil has four major categories, based on where the organic matter is in its life cycle.



Oxidation and Reduction Reactions

Soils that alternate between wet and dry go from having a lot of oxygen (dry) to not a lot of oxygen (wet). The presence or absence of oxygen determines how soils chemically react. **Oxidation** is the loss of electrons, and **reduction** is the gaining of electrons at the soil surface. These type of reactions occur every day, and are responsible for creating things like rust. Soils, because they contain a lot of iron, can also rust, or if they contain a lot of water, can turn a light gray color. This is partially responsible for all of the different colors that are found, and creates the speckles usually found deeper in the soil.

Essential Plant Nutrients



An essential nutrient is a nutrient element that a plant (or living organism) needs to function, grow or complete its life cycle. If that element or nutrient is lacking or deficient, there is a negative impact on the plant (or organism). As much as this is true for plants, so it is for humans, animals, microorganisms.

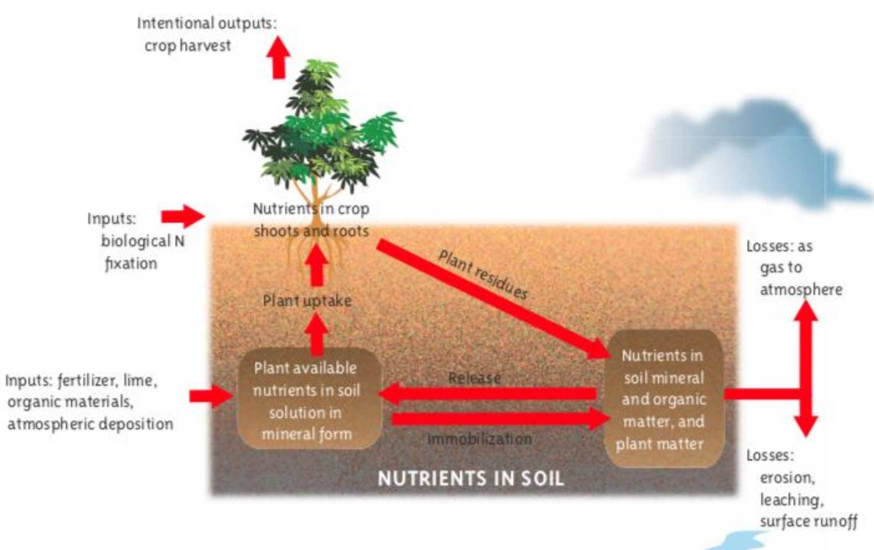
Some essential plant nutrients are referred to as macronutrients because they are needed (and are found) in large amounts in the plant tissue. Examples are nitrogen, phosphorus, calcium, magnesium, sodium, potassium, and sulfur.

Those that are required in trace quantities are referred to as micronutrients. Examples are iron, manganese, boron, copper, zinc, etc. Although small amounts of these are needed, they are essential for different reasons such as metabolism or enzyme activity.

Nutrient Supply to Plants and Nutrient Cycling in Soil

The Law of Conservation of Mass states that matter is neither created nor destroyed. It’s easy to see that in the cycling of nutrients in soil. Plants are consumed by animals and humans, and the nutrients are released back into the soil through decay of plant and animal matter. Chemical reactions occur in the soil to maintain a balance or buffer nutrients in the soil solution through *adsorption* and *desorption* on clay particles and organic matter.

When too many nutrients are released into the soil solution through decomposition or microbial metabolism of organic matter, and addition of fertilizer, either precipitation as soil minerals or adsorption to soil solids can occur. When nutrients are removed from solution by plants, more nutrients are released to the solution to maintain a balance between the amount on the soil solids and soil solution however, when crops are harvested away from the farm, nutrients in those crops are removed from the soil and the soil needs to be replenished.



Both human activity and environmental factors can influence nutrient balance and affect the mineral and biological processes in soils.

Nutrient Management

Not all nutrients removed from soil is returned or cycled back to the soil. When crops are harvested, nutrients are removed and often do not cycle back to soil immediately, or to where it might be useful to the soil. Eventually, the soil is not able to supply enough nutrients to growing plants and a deficiency of specific elements is created.

Fertilizers are commonly applied to soils to supply the deficient nutrients in a soil but they can be lost through soil erosion, surface water runoff, and leaching to groundwater, all of which create environmental impact or damage. It is important to manage fertilizer additions. Cycling of nutrients in the soil is completed when plant and organic residues are recycled or returned to the soil. As these plant residues *decompose*, they release the elements and nutrients contained in them back to the soil. These enter into the nutrient balance and are made available to growing plants and microorganisms.

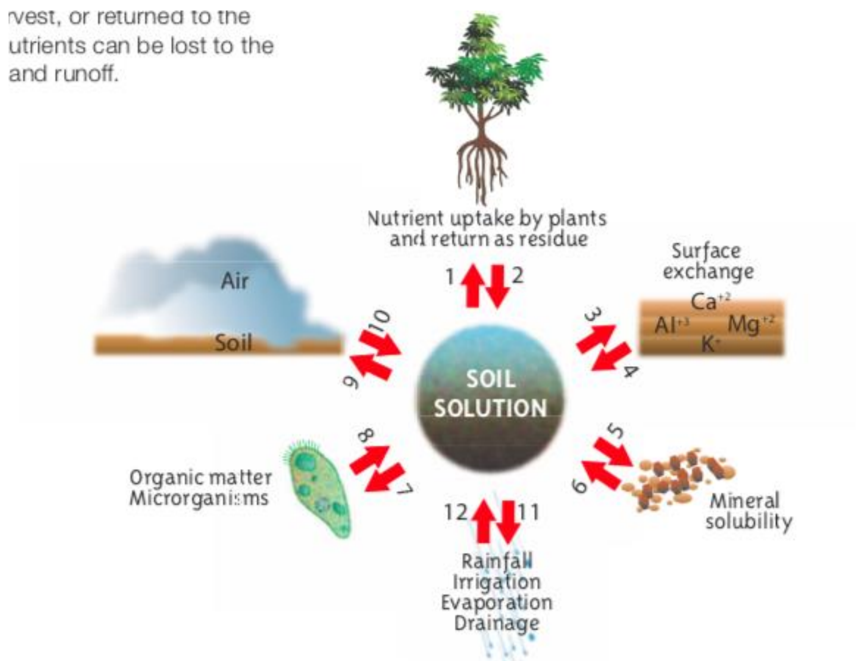


Figure 4–2. Various soil components and processes that influence plant nutrient concentration in the soil solution. Can any of these be influenced by management? Here's a hint: in figure 4–1 we saw that erosion can result in loss of nutrients.

Source:

Sparks, D.L. (2019). Fundamentals of Soil Chemistry. In Encyclopedia of Water, P. Maurice (Ed.). https://doi.org/10.1002/9781119300762.wsts0025

Lindbo, D.L., Kozlowski, D.A., Robinson, C. (2012). Know Soil Know Life. Soil Science Society of America, Madison, WI.

Soil Science Society of America. (2022). Soil Chemistry. Available at: https://www.soils4teachers.org/chemistry