# Soil chemistry.

## The link between soil physical properties and soil nutrients.

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There's just no way around soil chemistry. It's important to understand it so you can connect the dots from:

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soil physical properties…… to soil structure….. to nutrient availability…. to nutrient uptake …… plant growth.

Maybe it shouldn't be called "chemistry" because that is a word sometimes scares people. Rather, let's think of these topics as "the transformation of matter - the structure, composition, properties and reactive characteristics of substances, especially at the atomic and molecular levels". That's the dictionary definition. Maybe that definition makes matters worse. A more relatable definition, also in the dictionary, gives a picture of the "chemistry" of love. In that sense, chemistry is "a spontaneous reaction between two people, especially a mutual sense of attraction or understanding."

If we think of chemistry in these human terms, we see that we're really just talking about relationships and reactions between two things. In soil chemistry we will be examining a few relationships too. We'll look at changes, transformations, shape-shifting of nutrients in soil depending on the conditions in the soil.

We'll stick to three basic terms, 1) the pH of soil, 2) cation exchange capacity, and 3) base saturation. Once you understand these terms, you'll begin to understand how soil works to either hold nutrients or release nutrients to the plants. Once you know that, you'll know how to add nutrients as fertilizers or other soil amendments.

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1. **pH** - This “word” is pronounced simply like the two letters p and h. The lower case “p” is actually a mathematical symbol for “inverse logarithm”. The capital H is the symbol for the molar concentration of **Hydrogen** ions in a liter of a liquid, like water. There is an analogy made by Henry Foth that “the pH of a soil is like the temperature of an animal. Both tests are easily made and provide basic information useful in diagnosing what is likely to be the disease or the problem”. I go further and suggest that knowing a soil’s pH, C.E.C, and % base saturation are all tools used by the organic and sustainable agriculturalist to manage soils well, apply nutrients conscientiously, and increase the health of soils and the bottom line of the farm or garden. It is important to know about soil pH because it affects all the nutrients in the soil and how well the plant can use them.

If you remember high school chemistry, water made up of two **H**ydrogen atoms and one **O**xygen atom. Because of this, water is commonly known as $H_2O$. It is also depicted as H--O--H where the “--“dashes are weak bonds that hold the whole water molecule together.

In almost all solutions, some water molecules break apart and result in ions of hydrogen. These are atoms that have a slight electrical charge because one of the hydrogen ions has generously lent an electron (it has a little negative or minus sign charge) to the other hydrogen ion so that it could stay bonded with the Oxygen atom. Now the arrangement looks like this: OH- is now separate from an H+

The H+ is called a hydrogen ion. (occasionally it is referred to as a proton)

The OH- is called a hydroxyl ion. The name tells you exactly what it is, **hydro**gen and an **oxy**gen ion.

When the pH of a soil solution is 7 it means that there are equal numbers of OH- (hydroxyl) and H+ (hydrogen) ions present. Specifically, there is one hydrogen ion (H+) in every 10,000,000 (ten million) moles per liter of water. (Note the seven zeroes). There is also one hydroxyl ion (OH-) in every 10,000,000 moles per liter of water. This is considered pure or neutral water.

A pH of 6 means there are 10 times more hydrogen (H+) ions than a pH of 7. (one in every 1,000,000) (note the six zeros). There are also, then 10 times fewer OH- (hydroxyl) ions in this solution. This is called an “acidic” solution. Whenever there are more H+s than OH-s then the solution is acidic.

A pH of 8 is just the opposite; it means there are 10x more OH- ions than a neutral state and 10x less H+ ions. (There is only one in every 100,000,000 moles/liter) (note 8 zeros). This is considered a “base” solution. Whenever there are more OH-s than H+s in a solution it is considered “basic”.

OK, so what does it matter if there are a lot of H+ ions in a soil solution compared to OH- ions? The range of soil pH is usually 4 to 10 (the entire scale goes from 0 to 14). In the U.S. farm regions soils are typically in the 5.5 to 8.5 range. A pH between 6.0 and 6.8 is considered ideal for most crops. At this slightly acidic pH, there is enough free nutrient cations in solution on which the plant can feed. Cations are ions that carry a positive charge, just like the hydrogen ion (H+). The typical nutrient cations need by the plant are calcium (Ca ++), magnesium (Mg ++) and potassium (K+).

In acidic soils, those with lots of H+ ions, the hydrogen ion may replace the other positively charged nutrient ions on the soil particle surfaces. This means the positively charged nutrient ions (cations) are bumped off the soil particle and are floating around, free, in the soil solution, ready to be absorbed by the plant cells.

## 2. C.E.C. This stands for Cation Exchange Capacity. This measurement tells us whether or not a particular soil has few or many sites or spaces that can catch and hold and release nutrients. C.E.C. tells us if the cations can readily exchange places with hydrogen ions and become available for absorption by the plant. A soil with high C.E.C .is potentially quite a good soil for growing crops compared to a soil with low C.E.C. This value cannot be readily changed; it is a function of the soil's parent material.

CEC can be compared to a bank. A large bank has a lot of money available for exchange. Some is in the vault, locked away, and some is in circulation. Similarly, soils with C.E.C's measuring 20 (milliequivalents/100grams) have a larger reserve of cation sites (or vault space) than soils with a CEC of 10 meq/100g. The units of measure are a bit too complex to go into in this paper, but it can be said that high C.E.C. soils can hold perhaps thousands of pounds of cation nutrients per acre at any given time.

The C.E.C. depends on the soil's physical properties and on the amount of organic matter present. As discussed previously, soils with fine textures like clay have a lot of surface area compared to sandy soils. They have a large "vault". Clays hold nutrients better than sandy soils. Sandy soils need to be fertilized more often because any free cations not taken up by the plant are readily leached, or washed, out of the soil by rainfall. Nitrates are positively charged nitrogen molecules that cause problems on sandy soils, leaching through them and into rural well water, for example.

Sometimes clay soils hold the nutrient ions too tightly, they do not let enough cations out of the vault and out into circulation. When this happens there may be plenty of calcium, for example, in the soil bank, but not enough in circulation to feed the plant. This is where pH comes in to the picture and, as we'll read in the next section, % Base Saturation.

All things being equal, sandy soils typically have C.E.C s of less than 5 meq/100g, and heavy clays have C.E.C. s over 20. Silt loams have more desirable C.E.C.s in between.

## 3. Percent Base Saturation. This is a measure of how much of the C.E.C. is filled up, or saturated. [The term "base" saturation is somewhat confusing because bases are technically molecules that have a negative charge so that they can accept a proton with a + positive charge. It turns out that the cations mentioned above Ca++, Mg++ , K+ as well as sodium (Na++) all are associated with compound molecules in the soil, for example $CaCO_3$ (calcium carbonate), Mg $CO_3$, K $CO_3$ and Na $CO_3$ . Each of these compounds acts slightly more negative (-) "basic" than positive (+) "acid". So, they act as "bases" in this saturation measurement.]

There are ideal levels of each nutrient saturating the soil particle (C.E.C.) sites to produce the best plant growth. Returning to the bank analogy, let's say we can have $100,000 bills total in the bank (the C.E.C.) (ok. that's a small bank but to understand the concept we need manageable numbers). In order to have the highest levels of productive economic activity, experts have determined that we should really have the money in the following denominations: $1.00 bills = 70-80%, $10 bills = 12-15% and $100 bills = 3-5% and this fictitious economy doesn't want any pennies, 0%.

Similarly, experts have determined that the plant nutrient requirements for an ideal soil will have the following saturation levels in its nutrient bank (C.E.C.) in the following ratios; Calcium base compounds occupy 70-80% of the bank, magnesium compounds occupy 12-15% of the soil bank, and potassium (K) compounds occupy 3-5% of the bank and sodium (Na) compounds occupy zero.

Unfortunately, these are not the % base saturation or fill levels found in most soils in the temperate climate of the U.S. More typically, levels of base saturation are a bit too high in potassium, moderately too high in magnesium, and moderately too low in calcium. This means that the plant may be getting adequate nutrients, but it could, if the base saturation numbers were improved, get great levels of just the right nutrients to produce a bumper crop.

**Relationships = chemistry**

There is a strong relationship between pH and % base saturation. If the % base saturation is less than 100% (it is often 70-80%) then increasing the pH can increase the amount of calcium and magnesium in the soil solution. This is good news because according to Foth (1) "many studies have been conducted that relate increases in plant growth with increases in the percentage of calcium in plants and with increasing pH or % base saturation".

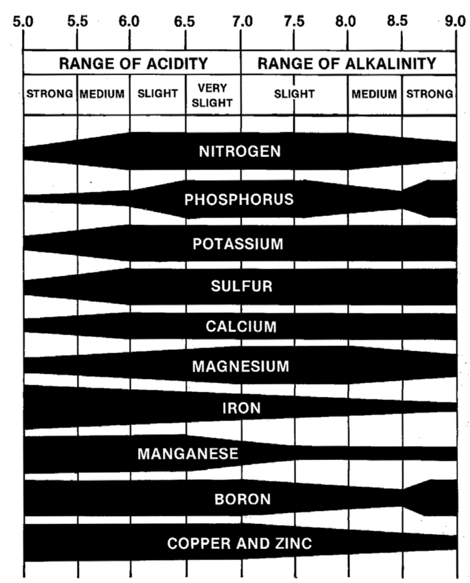
There is a strong, continuing debate between University researchers and the organic and sustainable farm community on calcium and whether it is a nutrient that limits plant growth because of its availability. It has yet to be resolved; the university says that calcium is not a limiting factor while farmers claim they have good results when balancing their soil calcium levels with pH and magnesium levels. This debate will likely go on for a few more years until soils, C.E.C., and % base saturation are better understood.

There are many charts that show the relationship of nutrient availability to the pH of soils. Nitrogen and sulfur are widely available at any pH down to about 5.3. Phosphorus and boron are most available between 5.5 and 7; they are less available at pHs above 7.5. Again, this has to do with chemistry and attractions of H+ and OH- ions to particular atoms and nutrient compounds. Look at how iron and manganese are unavailable at high (alkaline pH).

The pH of a soil also has biological effects, that is, soil some organisms thrive at lower pH than others. Fungi, for example "prefer" more acid soils than bacteria. More about that when we talk about the soil biology.

The soil tests, liming and nutrient levels and fertilizers for good crops will be explored in another paper. This paper reviewed some of the "chemistry" background needed as a foundation for exploring nutrients and fertilizers.

**AVAILABILITY OF ELEMENTS TO PLANTS AT DIFFERENT pH LEVELS FOR MINERAL SOILS**




These soil chemistry concepts apply to conventional, sustainable, and organic fields and soils. But because organic farmers need to use their brains and their knowledge to replace synthetic fertilizers, it is especially important to learn these concepts in an organic management system.