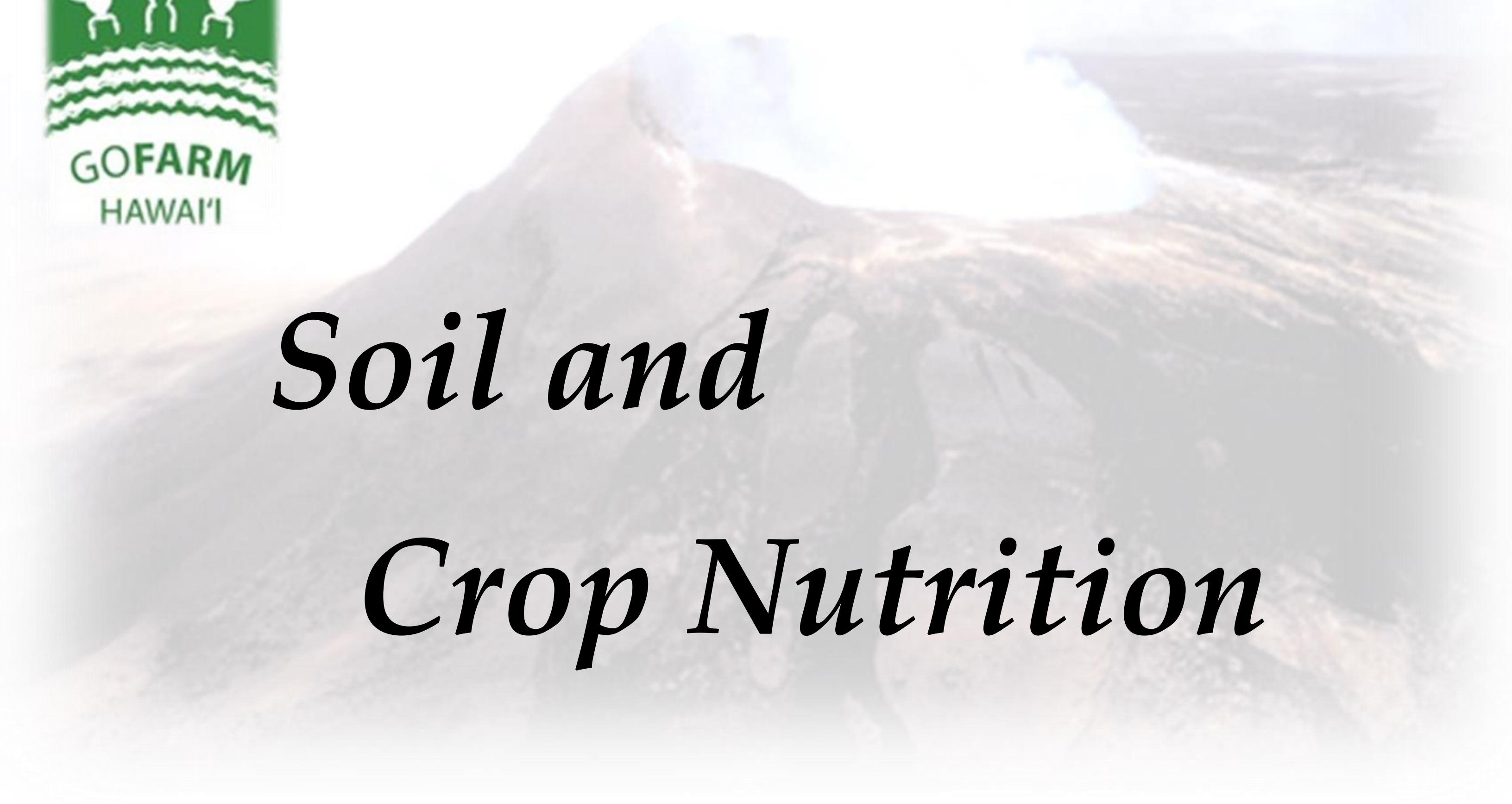

Soil and Crop Nutrition

Student Study Guide

Presented by

GoFarm Hawai'i

Learning Objectives

- Define pH and describe its effects on nutrient availability
- Explain what the macro and micro plant nutrients are and describe their movement in the soil
- Describe mineralization/immobilization
- Describe mobile and immobile nutrients
- List and classify 18 essential plant nutrients.

The Soil - A Living Organism

Soils are very diverse and complex systems of life. The soil itself can be viewed as a living organism, because it is a habitat for plants, animals and micro-organisms that are all interlinked. The availability or lack of nutrients shapes agricultural systems in fundamental ways:

- **Production yield**
- **Crop quality**
- **Profitability**

PLANT NUTRIENT UPTAKE

- Plants absorb nutrients through two structures: roots and leaves. The leaves absorb carbon dioxide and the roots absorb all the other nutrients.
- Carbon dioxide is the basic building block for all organic compounds produced by plants. This is absorbed from the air through the stomatal openings in the leaves and is essential for the manufacture of sugars and carbohydrates (starch).
- Plants absorb mineral nutrients through their roots by two processes. The first, as noted above, is through the absorption of water containing soluble nutrients. The second is by direct absorption of ions from the soil. This is an energy demanding process.
- Roots must have photosynthate (ATP and sugar) present in the root and oxygen available around the root for ion absorption.
- Plants can also absorb large, complex molecules such as hormones and vitamins directly from the soil. This is done through open spaces in the covering of the root structures that are filled with proteins. These openings let in specific molecules at specific sites.

- **CEC**, an abbreviation for **Cation Exchange Capacity**, refers to the amount of negative charges available on the surface of soil particles.
- It gives an indication of the potential of the soil to hold plant nutrients, by estimating the capacity of the soil to retain cations, which are positively-charged substances.
- Therefore, the CEC of the soil directly affects the amount and frequency of fertilizer application.
- Clay soil particles and organic matter carry a negative charge on their surfaces. Cations are attracted to the negatively-charged particles by electrostatic forces. The net charge of the soil is, therefore, zero.
- The predominant cations in agricultural soils are: K^+, Ca^{2+}, Mg^{2+}, Na^+, Al^{3+} and H^+. These are also being referred to as "Exchangeable Cations", because they can be replaced by other cations present in the soil solution.
- Only a small portion of the plant nutrient cations are in the soil solution. The exchangeable cations, which are bound to the soil surfaces, are in equilibrium with soil solution. The CEC, therefore, provides a reservoir of nutrients to replenish those removed by the plant.

Material	**CEC (meq/100g)**
Clays	
Kaolinite	3-15
Illite	15-40
Montmorillonite	80-100
Organic Matter	200-400
Soil Texture	
Sand	1-5
Loamy Sand to Sandy Loam	5-10
Loam	5-15
Clay Loam	15-30
Clay	>30

- The minerals considered to be major plant nutrients are divided into three groups.
    - **Cations** (+charged ions) are calcium, magnesium, and potassium.
    - **Anions** (- charged ions) are nitrogen, phosphorus, and sulfur.
    - Trace minerals are essential but are needed only in small amounts.
- Soil fertility refers to the quality of a soil that enables it to provide essential chemical elements in quantities and proportions necessary for the growth of plants.
- The major nutrients that plants use are nitrogen (N), phosphorus (P), potassium (K) and sulfur (S). These are referred to as **macronutrients**.
- Organic matter releases many plant nutrients as it is broken down in the soil, including nitrogen (N), phosphorus (P) and sulfur (S). It is also one of two sources of cation exchange capacity (CEC) in the soil. (Clay is the other major source.)
- CEC represents the sites in the soil that can hold positively charged nutrients like calcium (Ca^{++}), magnesium (Mg^{+}) and potassium (K^{+}).
- If CEC is increased, the soil can hold more nutrients and release them for plant growth.
- **Soil water** is particularly important in nutrient management. In addition to sustaining all life on Earth, soil water provides a pool of dissolved nutrients that are readily available for plant uptake.
- In nutrient management, soil aeration influences the availability of many nutrients. Particularly, **soil air** is needed by many of the microorganisms that release plant nutrients to the soil. An appropriate balance between soil air and soil water must be maintained since soil air is displaced by soil water.

Achieving Balanced Nutrition

- Several nutrients compete with each other over uptake by the plant, so keeping adequate ratios is important for avoiding deficiency.
- For example an excess of potassium competes with calcium and magnesium absorption.
- A high iron/manganese ratio can result in manganese deficiency, and high sulfur concentration might decrease the uptake of nitrate.

Essential Plant Nutrients

- Plants need eighteen chemical elements for their growth—**carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulfur (S),calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), boron (B), zinc (Zn), molybdenum (Mo), nickel (Ni), copper(Cu), cobalt (Co), and chlorine (Cl).**
- Plants obtain carbon as carbon dioxide (CO_2) and oxygen partially as oxygen gas (O_2) from the air.
- The remaining essential elements are obtained mainly from the soil.
- Plant growth will take place normally until it is restricted by the supply of an essential nutrient. A deficiency of any essential nutrient cannot be corrected by the addition of other crop inputs. This forms the basis of Liebig's "Law of the Minimum", which says that the level of crop production is limited by the nutrient in shortest supply.
- The availability of these nutrients is influenced either directly or indirectly by the presence of organic matter and **pH**.
- The elements needed in large amounts - carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium magnesium, sulfur - are called **macronutrients**.
- The other elements, called **micronutrients**, are essential elements needed in small amounts.

Primary Nutrients:

- Nitrogen (N), Phosphorus (P), and Potassium (K) vary in ratios and are represented by the 3 numbers present on fertilizer packaging.
- NPK is not in abundance in certain soil systems so tend to be the most frequently applied nutrients. They are usually applied in larger quantities than other crop nutrients.

Nitrogen

- ✓ Vital for vegetative plant growth and development
- ✓ N is a major part of the chlorophyll molecule and is therefore necessary for photosynthesis.
- ✓ N is biologically combined with C, H, O, and S to create amino acids, which are the building blocks of proteins.
- ✓ Essential for plant cell division
- ✓ Aids in production and use of carbohydrates

- ✓ Since all plant enzymes are made of proteins, N is needed for all of the enzymatic reactions in a plant.
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- Nitrogen is the most limiting nutrient for plant growth and yield in most agricultural situations.
- Almost all of the nitrogen stored in crop residues, soil organic matter, manures and composts, is in the form of complex organic molecules (e.g., proteins) that are not available to plants (i.e., cannot be taken up by plant roots). We rely on a handful of microbial species to convert this organic nitrogen into the ammonium (NH_4) and nitrate (NO_3)forms that plant roots can utilize
- Nitrogen is one of the most important essential elements for plants and is required in comparatively large amounts.
- Successful nitrogen management can optimize crop yields and increase profitability while minimizing nitrogen losses to the environment.
- The atmospheric nitrogen (N_2), is a major reservoir of nitrogen but it is unavailable to most plants. About 78% of the Earth's atmosphere is N_2).
- The nitrogen cycle reveals the harmonious coordination between different biotic and abiotic elements. Processing, or fixation, is necessary to convert gaseous nitrogen into forms usable by living organisms. Some fixation occurs in lightning strikes, but most fixation is done by free-living or symbiotic bacteria. These bacteria have the nitrogenase enzyme that combines gaseous nitrogen with hydrogen to produce ammonia, which is then further converted by the bacteria to make its own organic compounds. Some nitrogen-fixing bacteria, such as Rhizobium, live in the root nodules of legumes (such as peas or beans).
- Here they form a mutualistic relationship with the plant, producing ammonia in exchange for carbohydrates. Nutrient-poor soils can be planted with legumes to enrich them with nitrogen.
- Only legume plants (beans and peas) can use atmospheric nitrogen in biological processes that involve bacteria.

- Small amounts of usable nitrogen are deposited by rain.
- Most of the nitrogen in soil is contained in organic matter. The organic matter is relatively stable and it is not directly available to plants.
- Plants can absorb nitrogen only in its inorganic forms, NO_3 (**nitrate**) and NH_4 (**ammonium**). Only about 2-3% of the nitrogen in the organic matter becomes available to plants per year, in a process called "**mineralization**".
- This process involves bacteria that convert organic nitrogen to mineral nitrogen, which is available to plants. The mineralization process is influenced by environmental factors, such as temperature, moisture, aeration, and soil pH.
- For example, excess moisture limits the availability of nitrogen and slows down the mineralization. Mineralization is optimal at 30C and at neutral to slightly acidic pH.
- The Earth's atmosphere is about 78 percent nitrogen, making it the largest pool of nitrogen.
- Nitrogen is essential for many biological processes; it is in all amino acids, is incorporated into proteins, and is present in the bases that make up nucleic acids, such as DNA and RNA.
- In plants, much of the nitrogen is used in chlorophyll molecules, which are essential for photosynthesis and further growth.
- Nitrogen is a key component of soil organic matter and is required by plants in large quantities. It is often the first limiting nutrient in cropping systems.

Nitrogen Losses

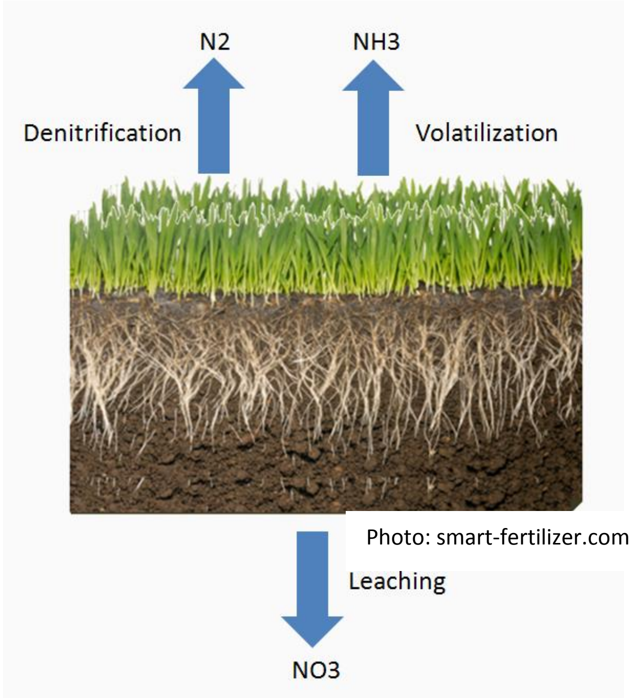
- Nitrogen might be lost from the soil and, therefore, become unavailable for plants, in several ways:

    1. Leaching – nitrate (NO3) easily moves downward along with water, as it is not held by soil. As a result it might be washed out below the root zone, with the flow of water.

    2. Volatilization – nitrogen is lost as an ammonia (NH3) gas. This might happen when fertilizers containing urea are surface-applied.

    3. Denitrification – nitrate-nitrogen (N-NO3) is converted back, by bacteria, into nitrogen gas, that is lost into the air. This process occurs when the soil is saturated or very wet.

Ammonium/Nitrate Ratio



Nitrogen is the building block of amino acids, proteins and chlorophyll. Plants can absorb nitrogen either as **Nitrate (NO_3^-)** or **Ammonium (NH_4^+),** and therefore, the total uptake of nitrogen usually consists of a combination of these two forms.

- The **ratio between** Ammonium and Nitrate is of a great significance, and affects both plants and soil/medium.
- For optimal uptake and growth, each plant species requires a different **ammonium/nitrate ratio**.
- The correct ratio to be applied also varies with
  - temperature
  - growth stage
  - pH in the root zone
  - soil properties
- Ammonium metabolism consumes much more oxygen than metabolism of nitrate.
- Ammonium is metabolized in the roots**,** where it reacts with sugars.
  - These sugars have to be delivered from their production site in the leaves, down to the roots.
- On the other hand Nitrate is transported up to the leaves, where it is reduced to Ammonium and then reacts with sugars.
- At higher temperatures the plant's respiration is increased, consuming sugars faster, making them less available for Ammonium metabolism in the roots. At the same time, at high temperatures, Oxygen solubility in water is decreased, making it less available as well.
- Therefore, the practical conclusion is that **at higher temperatures applying a lower Ammonium/Nitrate ratio is advisable**.

- Ammonium is a **cation** (positively charged ion), so it competes with other cations (Potassium, Calcium, Magnesium) for uptake by the roots.
- An unbalanced fertilization, with too high Ammonium content, might result in Calcium and Magnesium deficiencies. (Potassium uptake is less affected by the competition.)
- As already mentioned, Ammonium/Nitrate ratio may change the pH near the roots. These pH changes may affect solubility and availability of other nutrients.

Phosphorus (P)

- ✓ Promotes early root formation and growth
- ✓ Involved in photosynthesis, respiration, energy storage and transfer, cell division, and enlargement
- ✓ Improves quality of fruits, vegetables, and grains
- ✓ Vital to flower and seed formation
- ✓ Helps plants survive harsh winter conditions
- ✓ Increases water-use efficiency
- ✓ Hastens maturity

- In photosynthesis and respiration, P plays a major role in energy storage and transfer (as ADP and ATP)
- P is part of the RNA and DNA structures, which are the major components of genetic information.
- Seeds have the highest concentration of P in a mature plant, and P is required in large quantities in young cells, such as shoots and root tips, where metabolism is high and cell division is rapid.
- P aids in root development, flower initiation, and seed and fruit development.
- P has been shown to reduce disease incidence in some plants and has been found to improve the quality of certain crops.
- Phosphorus is an essential **macro-element**, required for plant nutrition.
- It participates in metabolic processes such as photosynthesis, energy transfer and synthesis and breakdown of carbohydrates.
- Phosphorus is found in the soil in organic compounds and in minerals.

- Nevertheless, the amount of readily available phosphorus is very low compared with the total amount of phosphorus in the soil. Therefore, in many cases phosphorus fertilizers should be applied in order to meet crop requirements.

The reactions of phosphorus in soil

- Phosphorus is found in soils both in an organic form and an un-organic (mineral) form and its solubility in soil is low. There is equilibrium between solid phase phosphorus in soil and the phosphorus in the soil solution.
  Plants can only take up phosphorus dissolved in the soil solution, and since most of the soil phosphorus exists in stable chemical compounds, only a small amount of phosphorus is available to the plant at any given time.
- When plant roots remove phosphorus from the soil solution, some of the phosphorus adsorbed to the solid phase is released into the soil solution in order to maintain equilibrium.
- The types of phosphorus compounds that exist in the soil are mostly determined by soil pH and by the type and amount of minerals in the soil. Mineral compounds of phosphorus usually contain aluminum, iron, manganese and calcium.
- **In acidic soils** phosphorus tends to react with **aluminum, iron and manganese**, while in alkaline soils the dominant fixation is with calcium.
- The optimal pH range for maximum phosphorus availability is 6.0-7.0.
- In many soils decomposition of organic material and crop residue contributes to available phosphorus in the soil.

Phosphorus deficiency

- Symptoms of phosphorus deficiency include stunted growth and dark purple color of older leaves, inhibition of flowering and root system development. In most plants these symptoms will appear when phosphorus concentration in the leaves is below 0.2%.

Phosphorus in excess

- Excess of phosphorus mostly interferes with uptake of other elements, such as iron, manganese and zinc. Over-fertilization with phosphorus is common and many growers apply unnecessarily high amounts of phosphorus fertilizers, especially when compound NPK fertilizers are used or when irrigation water is acidified using phosphoric acid.

Potassium

- ✓ Improves quality of seeds and fruit
- ✓ Increases disease resistance
- ✓ Carbohydrate metabolism and the break down and translocation of starches
- ✓ Tuber and fruit development
- ✓ Essential to carbohydrate and protein synthesis
- ✓ Increases photosynthesis
- ✓ Increases water-use efficiency
- ✓ Important in fruit formation
- ✓ Activates enzymes and controls their reaction rates

- Potassium is an essential plant nutrient and is required in large amounts for proper growth and reproduction of plants. Potassium is considered second only to nitrogen, when it comes to nutrients needed by plants, and is commonly considered as the "quality nutrient."
- It affects the plant shape, size, color, taste and other measurements attributed to healthy produce.
- Plants absorb potassium in its ionic form, K^+.
- In Photosynthesis, potassium regulates the opening and closing of stomata, and therefore regulates CO_2 uptake.
- Potassium triggers activation of enzymes and is essential for production of Adenosine Triphosphate (ATP).
  - ATP is an important energy source for many chemical processes taking place in plant issues.
- Both uptake of water through plant roots and its loss through the **stomata** are affected by potassium.
- Known to improve drought resistance.
- Potassium is essential at almost every step of the protein synthesis.
- In starch synthesis, the enzyme responsible for the process is activated by potassium.

- Activation of enzymes – potassium has an important role in the activation of many growth related enzymes in plants.

Potassium deficiency in plants

- Potassium deficiency might cause abnormalities in plants, usually they are growth related.
    - **Chlorosis** – scorching of plant leaves, with yellowing of the margins of the leaf. This is one of the first symptoms of Potassium deficiency. Symptoms appear on middle and lower leaves.
    - **Slow or Stunted growth** – as potassium is an important growth catalyst in plants, potassium deficient plants will have slower or stunted growth.
    - **Poor resistance to temperature changes and to drought** – Poor potassium uptake will result in less water circulation in the plant. This will make the plant more susceptible to drought and temperature changes.
    - **Defoliation** - left unattended, potassium deficiency in plants results in plants losing their leaves sooner than they should. This process might become even faster if the plant is exposed to drought or high temperatures. Leaves turn yellow, then brown and eventually fall off one by one.
- Other symptoms of Potassium deficiency:

    - ✓ Poor resistance to pests
    - ✓ Weak and unhealthy roots
    - ✓ Uneven ripening of fruits

Factors that affect potassium uptake by plants

- **Oxygen level** – oxygen is necessary for proper root function, including uptake of potassium
- **Moisture** - the more moisture found in the soil, the easier it is for plants to absorb potassium.
- **Soil tilling** – research has shown that regularly tilled soil allows for better potassium uptake.

- **Soil temperature** – 60-80 degrees Fahrenheit is the ideal soil temperature range for root activity and most of the physiological processes in plants. The lower the temperature, the slower absorption becomes.

Fixed potassium – potassium that becomes slowly available to plants over the growing season. Clay minerals have the ability to fix potassium. During wetting and drying of the soil, potassium becomes trapped in-between the mineral layers (clay minerals have a layer structure). Once the soil gets wet, some of the trapped potassium ions are released to the soil solution. The slowly available potassium is not usually measured in regular soil testing.

Exchangeable potassium – is readily available potassium, which plants can easily absorb. This fraction of Potassium is held on the surface of clay particles and organic matter in soil. It is found in equilibrium with the soil solution and is easily released when plants absorb potassium from the soil solution. Exchangeable potassium is measured in most soil testing.

Secondary Nutrients:

- Calcium, Magnesium, and Sulfur are often times adequate in certain soil systems and applied in lower quantities than other primary nutrients

Micro Nutrients

- Boron, chlorine, cooper, iron, manganese, molybdenum, zinc, nickel, cobalt, etc.
- Used in very small amounts
- Important to plant development
- Work "behind the scene" as activators

Limiting Factors That Affect Crop Yield

- It's not only the total fertilizer application rate that affects crop yield, but also the specific application rate of each nutrient individually.
- According to Leibig's Law of Minimum, crop yield is determined by the most limiting factor in the field.

Photo: smart-fertilizer.com

- This implies that if only one nutrient is deficient, yield will be limited, even if all other nutrients are available in adequate quantities.
- According to the law of "limiting factor", if one nutrient is deficient, other nutrients cannot compensate for the deficiency, and the crop may suffer, resulting in decreased quality and/or yield.

How do you know what your crop needs?

- Visual Assessments
- Soil and Tissue Testing

Mobile Nutrients

- Nutrients that move to areas where they are lacking.
- Move from older leaves to younger tissue
- Results in discoloring in older leaves
  - ✓ Nitrogen
  - ✓ Phosphorus
  - ✓ Potassium
  - ✓ Magnesium
  - ✓ Chloride
  - ✓ Molybdenum

Immobile Nutrients

- These nutrients cannot move
- Deficiencies will appear in younger leaves
  - ✓ Boron
  - ✓ Calcium
  - ✓ Copper
  - ✓ Iron
  - ✓ Manganese
  - ✓ Nickel
  - ✓ Sulfur
  - ✓ Zinc

pH affects absorption

- Many growers have a problem of low pH of their soil. Some soils are acidic by nature and, in other cases, low pH is the result of prolonged and intensive fertilization and irrigation.
- Soil pH below 5.5 might result in reduced yields and damages to the crop.
- Under these pH conditions, the availability of micronutrients such as manganese, aluminium and iron increases and toxicity problem of micronutrients might occur.
- On the other hand, at low pH, availability of other essential nutrients, such as K, Ca and Mg is decreased and might result in deficiencies.
- The most commonly used technique to elevate the soil pH is applying agricultural lime.
- Solubility of lime is relatively low, so if it is applied only to the soil surface, it usually affects only the top layer of the soil, not more than a few centimeters deep.
- In soils, intensive fertilization with ammonium-based fertilizers or ammonium-forming fertilizers (urea) may lower soil pH.

Other factors affecting soil pH include:

- **Parent material** - type of rocks from which the soil developed.
- **Rainfall** - soils under high rainfall conditions are more acid than soils formed under dry conditions.
- **Soil organic matter** - soil organisms are continuously decomposing organic matter. The net effect of their activity is that hydrogen ions are released and the soil becomes more acidic.
- **Native vegetation** - the type of the native vegetation under which the soil was formed affects the pH of the soil. Soils formed under forest vegetation tend to be more acidic.

Soil Testing

To achieve good yield and quality, nutrient balance has to be maintained. Nutrient imbalance may result in deficiencies, toxicities or interference of one nutrient with the absorption of others. This may result in stress to the crop, causing a decrease in quality and/or yield.

- Growers can roughly estimate how much fertilizers should be applied to their crop according to general fertilizer recommendations. But a more accurate, cost-effective fertilizer application requires soil testing.

- Soil test allows you to know the starting point, and this is a very valuable piece of information.
- The soil sample should represent the entire field as closely as possible. If the field is not uniform, and consists of different areas with different properties, each area should be sampled.
- The soil test report, together with the grower's close familiarity with his crop and field conditions, give the grower the starting-point for deciding on a fertilizer program.
- Soil testing gives makes a good starting point for making better fertilizer management decisions. The soil test results should be put in context and their interpretation should be adjusted to the individual crop behavior and specific field conditions.

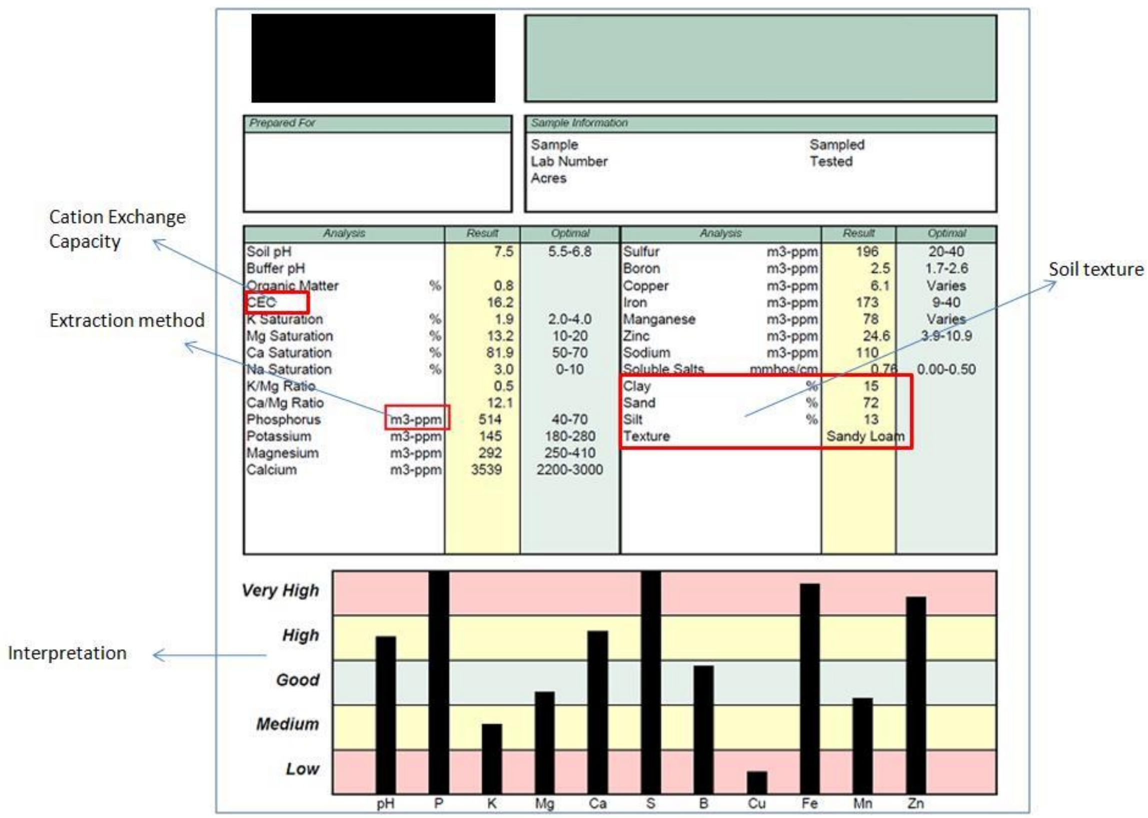


Photo: smart-fertilizer.com

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