

Plant Essential Nutrients and Their Role¹

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The purpose of this publication is to inform Extension agents, consultants, and farmers about plant essential nutrients, benefits, and deficiency symptoms. This publication provides a whole plant picture with deficiency symptoms for each nutrient and the location of those symptoms on the plant. The publication also includes the pH scale representing the nutrient availability across different soil pH levels. This publication explains the nitrogen cycle and the important interaction of macro- and micronutrients.

Plants need 17 essential nutrient elements to complete their life cycle (i.e., growth and reproduction) (Table 1). Carbon (C), hydrogen (H), and oxygen (O) are provided by air and water, and there is little control over the availability of these nutrients. For most plants, these three elements make up 94% or more of the dry tissue. The other 14 elements collectively represent less than 6% of the plant dry matter. A deficiency of one or more of these 14 elements often affects crop production.

Fourteen of these essential nutrients, provided by the soil or supplemented by fertilizers, are divided into two groups: macronutrients (required in large amounts) and micronutrients (required in small amounts). The macronutrients are nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg). The micronutrients include manganese (Mn), iron (Fe), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), chlorine (Cl), and nickel (Ni). Various removal, fixation, and release mechanisms

greatly influence the availability of nutrients to plants from the soil.

Nutrients of Concern to Florida Growers

Macronutrients

NITROGEN (N)

Nitrogen is the most limiting nutrient for plant growth. Figure 1 illustrates transformations in the N cycle. In most soils, the bulk of soil N is found within 2 feet of the surface. N is a principal component of all living cells and is necessary for all proteins, enzymes, and metabolic processes involved in synthesizing and transferring energy. Nitrogen is a structural part of chlorophyll that is responsible for photosynthesis. Nitrogen is also responsible for stimulating rapid, vigorous growth, and increasing seed and fruit yield.

NITROGEN CYCLE

The Major Transformations of Nitrogen

- Bacteria convert atmospheric N₂ gas into available forms such as nitrites, nitrate, and ammonia.
- Nitrification is a conversion of ammonia to nitrate.
- Denitrification is a conversion of nitrite to gaseous forms of nitrogen.

Soil N is present in three major forms.

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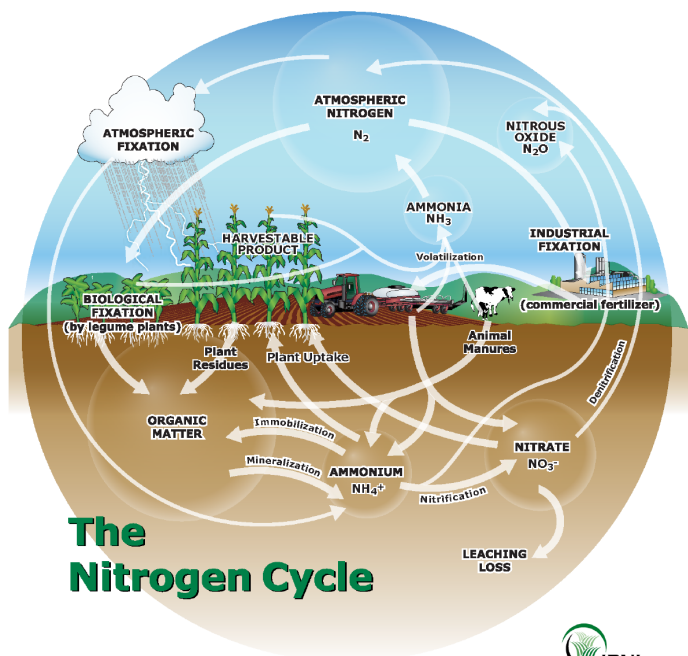


Figure 1. Nitrogen cycle.
Credits: IPNI

- **Elemental N** is found in a gaseous form in the soil atmosphere, a stable diatomic molecule. The atmosphere has 78% of elemental N. This atmospheric N has direct significance for plants. The nitrogen-fixing bacteria convert environmental N (elemental N) to plant-available N in the soil.
- **Organic N** makes up nearly 5% of the soil organic matter (humus) by weight and nearly 98% of the total soil N. Organic N is available to plants once converted to inorganic forms (ammonium and nitrate) by soil organisms.
- **Fertilizer N** for crops is inorganic N, and it is comprised of three types: ammonium (NH_4^+), nitrate (NO_3^-), and urea ($CO(NH_2)_2$). While urea is an organic N fertilizer, it is converted to ammonium form quickly after exposure to moist, aerated soil by the urease enzyme.

PHOSPHORUS (P)

Phosphorus is an essential part of photosynthesis. In young plants, P is most abundant in tissue at the growing point. The immediate source of P for plants is dissolved in the soil solution. Concentrations of phosphate ions in the soil solution may be as low as 0.001 parts per million (ppm), and in-plant dry weight could be in the range of 0.1–0.5%. Soil P is most available for plant growth in the soil pH range of 6.0–7.0 (Figure 2).

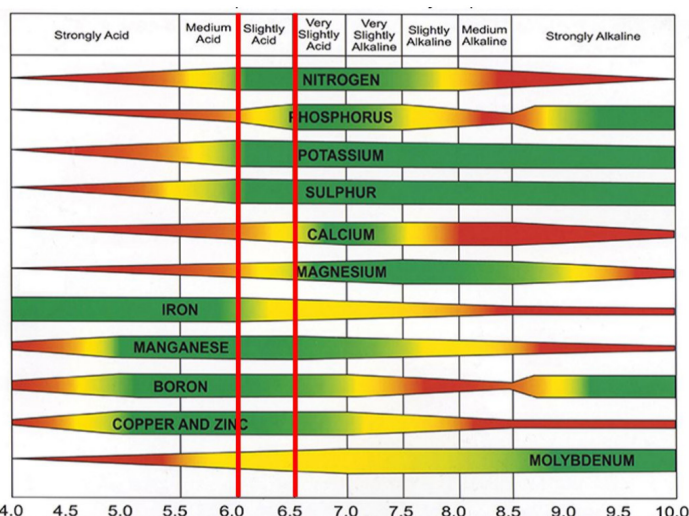


Figure 2. Soil pH affecting nutrient availability in the soil.

Credits: No-Till Farmer (<https://www.no-tillfarmer.com/articles/8691-what-is-my-soil-test-report-telling-me>)

POTASSIUM (K)

Unlike N and P, potassium is not found in organic combination with plant tissues. Potassium plays an essential role in the metabolic processes of plants. Adequate amounts are required for several enzymatic reactions, such as those involving the adenosine phosphates (ATP and ADP), which are energy carriers in the metabolic processes of both plants and animals. Most Florida soils have low nutrient holding capacity, so K concentration tends to be low.

CALCIUM (CA)

Calcium, an essential part of plant cell wall structure, is required for the normal plant transport system, retention of other elements in the plant, and structural support to plant cells. It also counteracts the effect of alkali salts and organic acids within a plant. Calcium helps in balancing Mg and K ions in the plant cells. Too much of any of these elements may cause insufficiencies of the other two.

MAGNESIUM (MG)

Magnesium is part of chlorophyll in all green plants and is essential for photosynthesis. It also helps to activate many plant enzymes needed for growth.

SULFUR (S)

Sulfur is a constituent of three amino acids, cystine, cysteine, and methionine. S is also present in glycosides, which give the characteristic odors and flavors in mustard, onion, and garlic plants. It is required for nodulation and N fixation of legumes.

Micronutrients

Micronutrient deficiencies most commonly limit crop growth under the following conditions:

- Highly leached, acidic sandy soils: These soils are common in Florida, with a pH range of 4.5–6.5. The organic matter content in such soils ranges from 0.5–2%. These soils are not suited for crop production without fertilizers, amendments, and proper drainage.
- Muck soils: These soils are distinctly black in color, with 20–80% organic matter content. They are typically found south of Lake Okeechobee.
- Soils with high pH: These soils are common in southwest Florida near the Immokalee area. The pH range in these soils is 7–8.5 because of excess application of lime and naturally occurring CaCO_3 below the soil surface.
- Soils that have been intensively cropped and heavily fertilized with macronutrients.

Tabulated Nutrient Functions and Deficiency Symptoms

Table 1 represents all the essential nutrient functions in plant development and metabolism. The mobility of each nutrient within the plant determines the location on the plant where the first symptoms of that specific nutrient deficiency will appear. For example, nitrogen deficiency appears on older leaves first because it is mobile, and the plant defense system protects young leaves. Similarly, soil mobility influences whether the nutrient tends to leach or runoff. However, because many Florida soils have very low capacity to retain nutrients, some elements such as phosphorus and potassium that would be considered immobile in soils with higher clay content can actually move through Florida sands with low clay and organic matter percentages. This is an environmental concern in the case of phosphorus when P applications exceed the soil's capacity to retain P, and excess P can then move into the drainage water. Additionally, potassium can be leached in Florida sands. As with nitrogen, the timing of fertilizer applications is important to meet crop demand. It is important to consider how nutrients are retained and how they can move in Florida soils.

Soil pH is an important chemical characteristic that determines the availability of soil nutrients for plant roots to absorb. The ideal soil pH for availability of most nutrients is 6.5. However, with different pH ranges in Florida, one strategy to manage nutrients may not be useful for the entire state. Therefore, when possible, producers need to maintain their soil pH in the ideal range to get the maximum benefit

of their applied fertilizers. Figure 2 explains the availability of different fertilizers across different pH ranges.

It is very important to diagnose nutrient deficiency in crop plants. Each nutrient has specific deficiency symptoms, and visual analysis could help growers learn a lot about plant health. It is recommended that once the plant shows any deficiency symptoms, a representative tissue sample should be collected for lab analysis to confirm a deficiency. Figures 3 and 4 represent the nutrient deficiency of major and minor essential nutrients, respectively.

Visual tissue assessment

In Nutrient Management Module 9
<http://landresources.montana.edu/nm>

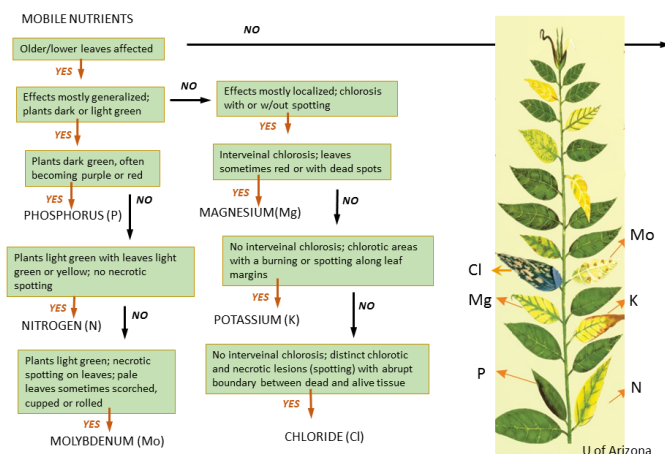


Figure 3. Deficiency symptoms of mobile plant nutrients.
Credits: McCauley et al. (2011)

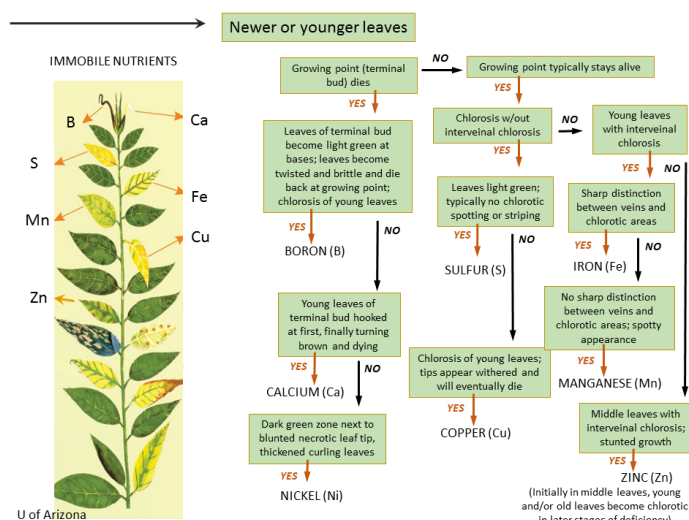


Figure 4. Deficiency symptoms of immobile plant nutrients.
Credits: McCauley et al. (2011). Courtesy of Montana State University

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Table 1. Essential elements required by plants. Source: Hochmuth et al. (2018).

Element and Chemical Symbol	Source and Uptake Form	Mobility in Plants	Mobility in Soils	Plant Content (dry weight)	Function of Plant	Primary Deficiency Symptoms in Plants	Interactions
NUTRIENTS FROM WATER AND AIR							
Hydrogen (H)	Air	Mobile	Mobile		Plant osmotic balance, part of carbohydrate.		
Oxygen (O)	Air	Mobile	Mobile		Part of carbohydrate, respiration.	Leaves wilting (anaerobic conditions).	
Carbon (C)	Air	Mobile	Mobile		Part of carbohydrate, needed for photosynthesis.		
MACRONUTRIENTS				%			
Nitrogen (N)	Air/Soil and NO_3^- , NH_4^+	Mobile	Mobile	0.5–5	Proteins, chlorophyll, nucleic acids, enzymes.	Light green/ yellow color on older leaves.	High interaction with S.
Phosphorus (P)	Soil and H_2PO_4^- , HPO_4^{2-} , PO_4^{3-}	Mobile	Can be mobile in Florida sands	0.1–0.5	ATP, ADP, a constituent of protein and enzymes.	Stunted plant growth, dead areas on the leaf; older leaves turn purple.	
Potassium (K)	Soil and K^+	Mobile	Mobile in Florida sands	0.5–5	Photosynthesis, protein synthesis, carbohydrate translocation across plant parts, water relations, energy relations, cold hardness.	Yellowing of leaf margin, slow growth, lodging.	
Sulfur (S)	Soil and SO_4^{2-}	Mobile	Mobile	0.05–0.5	Proteins, enzymes.	Young leaves turn yellow; opposite of N deficiency.	
Magnesium (Mg)	Soil and Mg^{2+}	Mobile	Immobile	0.1–1	Chlorophyll, enzymes activator.	Older leaves turn yellow, reddish, or bronze with veins remaining green.	
Calcium (Ca)	Soil and Ca^{2+}	Immobile	Immobile	0.5–5.0	Cell structure, cell elongation, cell division.	Poor root growth, root rot, early death of growing points.	

Element and Chemical Symbol	Source and Uptake Form	Mobility in Plants	Mobility in Soils	Plant Content (dry weight)	Function of Plant	Primary Deficiency Symptoms in Plants	Interactions
MICRONUTRIENTS				ppm			
Iron (Fe)	Soil and Fe^{2+}	Immobile	Immobile	50–1,000	Chlorophyll synthesis, metabolism, enzyme electron transfer. Its deficiency is often induced by alkaline soil pH, and can be generated by high concentrations of Mn. High Fe can also cause Mn deficiency, such as in northeast Florida soils.	Interveinal chlorosis.	
Manganese (Mn)	Soil and Mn^{2+}	Immobile	Mobile	20–200	Hill reaction-photosystem II, enzyme activation.	Induced in high pH soils, similar to Fe deficiency, manganese availability is closely related to the degree of soil acidity. Deficient plants are usually found on slightly acid or alkaline soils.	High Mn concentration may induce Fe deficiency in plants.
Boron (B)	Soil and H_3BO_3 , H_2BO_3^- , HBO_3^{2-}	Immobile	Mobile	2–100	Sugar translocation, cell development, growth regulators.	Deformed fruits/flowers, thick petiole; B deficiency may occur on alkaline and acid soils but is more prevalent on calcareous, alkaline soils.	
Chlorine (Cl)	Soil and Cl-	Mobile		80–10,000	Photosynthesis.	Cl toxicity is more common than deficiency due to high applications.	

Element and Chemical Symbol	Source and Uptake Form	Mobility in Plants	Mobility in Soils	Plant Content (dry weight)	Function of Plant	Primary Deficiency Symptoms in Plants	Interactions
Zinc (Zn)	Soil and Zn^{2+}	Immobile	Immobile	10–100	It controls the synthesis of indoleacetic acid, a hormone that regulates plant growth. Zinc deficiency can result in stunted plant growth. Zn is also active in many enzymatic reactions.	Common in fruit trees and corn in the early spring; green/yellow strips on new leaves; “white bud of corn” is a common name for zinc deficiency.	
Copper (Cu)	Soil and Cu^{2+}	Immobile	Immobile	2–20	Enzyme activation.	Light green to yellow color most common in small grains; stunted growth, blotching.	Excess Cu may also induce Fe deficiency.
Molybdenum (Mo)	Soil and MoO_4^{2-}	Immobile		0.05–10	N fixation, N use; molybdenum is required in very small amounts.	Deficiencies similar to those for N are also common among legumes in very acidic soils (pH below 5.5).	Molybdenum deficiency triggers N deficiency.
Nickel (Ni)	Soil and Ni^{+}	Unknown	Immobile		Fe metabolism.	Nickel deficiency can lead to urea accumulation in the plant and development of necrotic spots on the leaves.	