General Overview of Nutrition for Field and Container Crops

Robert L. Mahler

Robert L. Mahler is Professor of Soil Science, University of Idaho, PO Box 442339, Moscow, ID 83844; telephone: 208.885.7025; e-mail: bmahler@uidaho.edu

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Introduction

Plants require 17 different essential elements for growth. These 17 essential elements include carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

These 17 essential elements (also called nutrients) are often split into 3 groups (Figure 1). The first group is the macronutrients that plants can obtain from water and/or air: carbon (C), hydrogen (H), and oxygen (O). The soil does not need to provide these nutrients; thus C, H, and O fertilizers are not marketed for agronomic, horticultural, or home and garden use.

The other 14 essential elements are split into the remaining 2 groups: soil-derived macronutrients and soil-derived micronutrients. This split is based on the actual amount of nutrient required by the plant for adequate growth. The soil-derived macronutrients are nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg). The soil-derived micronutrients are boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

Soil-Derived Macronutrients

The 6 soil-derived macronutrients are present in plants at relatively high concentrations, normally exceeding 0.1% of a plant's total dry weight. This translates into a minimum need of 20 lb of each macronutrient per acre each year (22.5 kg/ha/yr).

Nitrogen

Plants require large amounts of N for adequate growth. Plants take up N from the soil as NH_4^+ (ammonium) or NO_3^- (nitrate) (Table 1). A typical plant contains 1.5% N on a dry weight basis; this can range from 0.5% (woody plant) to up to 5.0% (legume).

Nitrogen is a component of amino acids that link together to form proteins in plants. Nitrogen is also a component of protoplasts and enzymes (Table 2). Once in the plant, N is mobile; it can move from older plant tissue to new tissue. Consequently, if N is deficient in plants, the older leaves often turn yellow-green or yellow first. As the deficiency progresses, the entire plant will be yellow.

The major source of N in soils is organic matter (Table 3). Nitrogen is the nutrient generally most limiting in agronomic, horticultural, and home and garden situations in the Pacific Northwest.

Phosphorus

A typical plant contains 0.2% P on a dry weight basis (Table 1); however, depending on the plant species this value can range from 0.1 to 0.5%. Plants take up P as an anion (negative charge): $H_2PO_4^-$, HPO_4^{2-}, or PO_4^{3-}. The actual form of the anion taken up by plants is dependent on soil pH.

Phosphorus is mobile within plants and can travel from old plant tissue to new plant tissue on demand (Table 2). Plants deficient in P are hard to visually diagnose, as deficiency symptoms are not commonly seen. A P-deficient plant is likely to be dark green but have stunted growth. Phosphorus is essential for adenosine diphosphate (ADP), adenosine monophosphate (AMP), and basal metabolism in plants.

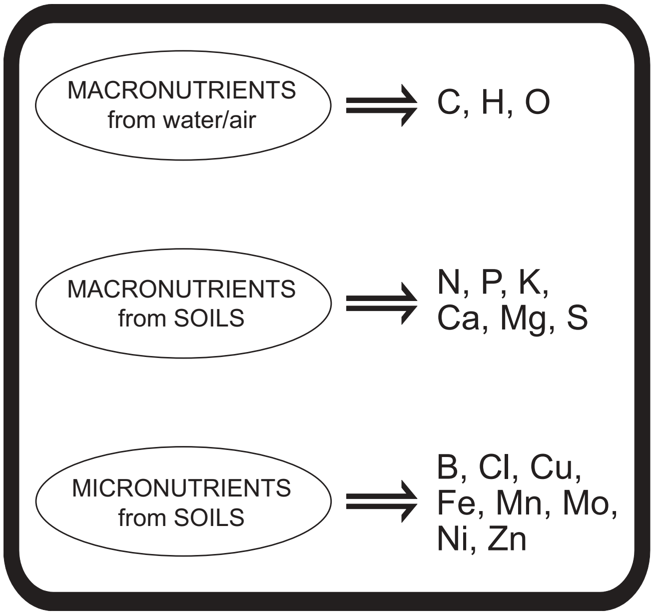

Figure 1—There are 17 essential plant nutrients required for plant growth.

Phosphorus deficiencies in soils can be diagnosed with a soil test. Phosphorus availability is related to soil pH. In general, soils with pH values between 5.5 and 6.8 have adequate levels of plant available P. However, P availability is much lower in soils with pH values below 5.5 or above 6.8 (Table 3).

Potassium

Plants typically contain 1.0% K on a dry weight basis (Table 1). This value can range from 0.5 to 5.0% depending on the plant species. Potassium is held by the clays in soils and is taken up as K^+ by plants.

Potassium is mobile in plants (Table 2). Potassium deficiencies can be diagnosed by looking at the older plant tissue. Deficiencies appear along the outer margins of older leaves as streaks or spots of yellow (mild deficiencies) or brown (severe deficiencies). Potassium plays several roles in plants. It is important for water and energy relationships and has been linked to improved cold hardiness.

Soils in the Pacific Northwest generally contain adequate amounts of potassium for plant growth (Table 3). Potassium problems are isolated to soils where alfalfa and potatoes have been grown for several decades.

Sulfur

Plants take up S from the soil as SO_4^{2-} (sulfate) (Table 1). Because the plant available form of S is negatively charged, it can be leached out of plant root zones with excess precipitation or excess watering. A typical plant contains 0.1% S on a dry weight basis, but this can range from 0.05 to 0.5%.

Sulfur, like N, is a component of some amino acids that link together to form proteins in plants. Sulfur is also a component of protoplasts and enzymes (Table 2). Once in the plant, S has only fair mobility; the new plant tissue will first show a sulfur deficiency. Consequently, if S is deficient in plants the new tissue will often turn yellow-green or yellow.

Sulfur is widely deficient in soils in the Pacific Northwest (Table 3). Low levels of soil organic matter or excess watering can result in S deficiencies.

Calcium

A typical plant contains 0.5% Ca on a dry weight basis (Table 1). However, woody plants may contain up to 5.0% Ca. Calcium, taken up by plants as Ca^{2+}, is required for cell division, cell elongation, and cell structure (Table 2). Since Ca is not mobile in plants, Ca-deficiency symptoms appear at the growing tip of the plant.

Soils in the Pacific Northwest contain plenty of Ca (Table 3). Consequently, Ca deficiencies in plants under agronomic,

Table 1—Uptake form and typical plant content of the 14 soil-derived essential nutrients required for plant growth.

Essential nutrient	Uptake form	Plant content: Average	Plant content: Range
		percent	
Nitrogen	NO_3^-, NH_4^+	1.5	0.5 to 5.0
Phosphorus	$H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}	0.2	0.1 to 0.5
Potassium	K^+	1.0	0.5 to 5.0
Sulfur	SO_4^{2-}	0.1	0.05 to 0.5
Calcium	Ca^{2+}	0.5	0.5 to 5.0
Magnesium	Mg^{2+}	0.2	0.1 to 1.0
		ppm	
Boron	H_3BO_3, $H_2BO_3^-$, HBO_3^{2-}	20	2 to 100
Chlorine	Cl^-	100	80 to 10,000
Copper	Cu^{2+}	6	2 to 20
Iron	Fe^{2+}	100	50 to 1,000
Manganese	Mn^{2+}	50	20 to 200
Molybdenum	MoO_4^{2-}	0.1	0.05 to 10
Nickel	Ni^+	<<< 0.001	?
Zinc	Zn^{2+}	20	10 to 100

Table 2—Function and mobility within plant tissue of the 14 soil-derived essential nutrients required for plant growth.

Essential nutrient	Mobility in plant	Function in plant
Nitrogen	Good	Proteins, protoplasts, enzymes
Phosphorus	Good	ATP, ADP, basal metabolism
Potassium	Good	Water relations, energy relations, cold hardiness
Sulfur	Fair/poor	Proteins, protoplasts, enzymes
Calcium	Very poor	Cell structure, cell division, cell elongation
Magnesium	Good	Chlorophyll, enzymes
Boron	Very poor	Sugar translocation, cell development, growth regulators
Chlorine	Good	Photosynthesis
Copper	Poor	Enzyme activation
Iron	Poor	Chlorophyll synthesis, metabolism, enzyme activation
Manganese	Poor	Hill reaction-photosystem II, enzyme activation
Molybdenum	Poor	Nitrogen fixation, nitrogen use
Nickel	Unknown	Iron metabolism

Table 3—Typical soil content and most likely associated problems in the Pacific Northwest for the 14 soil-derived essential nutrients required for plant growth.

Essential nutrient	Typical soil content	Likely problems
Nitrogen	1 to 2% organic matter	Widespread
Phosphorus	1 to 4 ppm (Morgan); 4 to 20 ppm (Olson)	Widespread; low pH (<5.5); high pH (>6.5)
Potassium	>100 ppm	Isolated to potatoes, alfalfa
Sulfur	<10 ppm	Widespread
Calcium	Plenty	No problems
Magnesium	Plenty	No problems
Boron	0.1 to 0.7 ppm	Low organic matter soils, high ppt
Chlorine	Plenty	No problems
Copper	1.0 to 3.0 ppm	Soils with over 8% organic matter
Iron	Plenty in low pH soils	High soil pH values (>7.5)
Manganese	Plenty	Very isolated
Molybdenum	No soil test	When growing legumes in soils with pH values <5.4
Nickel	No soil test	No problems
Zinc	0.3 to 2.0 ppm	Where topsoil has been removed

horticultural, or lawn and garden situations have never been observed in the region.

Magnesium

Plants typically contain 0.2% Mg on a dry weight basis (Table 1). This value can range from 0.1 to 1.0% depending on the plant species. Magnesium is held by the clays and organic matter in soils and is taken up as Mg^{2+} by plants.

Magnesium is mobile in plants (Table 2). Magnesium deficiencies can be diagnosed by looking at the older plant tissue. Deficiencies appear as interveinal chlorosis in the older plant leaves; the veins of the leaves stay dark green but the areas between the veins appear yellow-green, yellow, or white in color. Magnesium is a component of chlorophyll in plants.

Most soils in the Pacific Northwest contain adequate amounts of Mg for plant growth (Table 3). Magnesium problems are isolated to soils with pH values below 5.2.

Soil-Derived Micronutrients

The 8 soil-derived micronutrients are present in plants at relatively low concentrations, often just a few parts per million (ppm) of a plant's total dry weight. These values translate into a need of 0.5 to 2 lb of most micronutrients/ac/yr (0.6 to 2.3 kg/ha/yr).

Boron

Plants require about 20 ppm of B (Table 1). Boron is taken up by plants as an uncharged molecule (H_3BO_3) or as an anion ($H_2BO_3^-$, HBO_3^{2-}). Since the plant-available form of B is not positively charged, it is leachable in soils and is often lost from the plant root zone by over-irrigation or excess precipitation.

In plants, B promotes the translocation of sugars, cell development, and is believed to be important for growth regulators (Table 2). Boron is not mobile in plants. Consequently, B-deficiency symptoms most likely appear on the growing tip of the plant. In B-deficient plants the growing tip is often deformed.

Soils that contain less than 1.5% organic matter or are over-irrigated tend to be deficient in B (Table 3). Boron deficiencies are common on agronomic crops, fruit trees, and in urban gardens. For additional information on B, see University of Idaho CIS 1085, *Boron in Idaho*, available at URL: http://info.ag.uidaho.edu/catalog/catalog.html.

Chlorine

Plants generally contain about 100 ppm of chlorine (Table 1). Chlorine is taken up as Cl^{-} by plants and is required for photosynthesis (Table 2). Chlorine is plentiful in soils in the Pacific Northwest. Consequently, Cl deficiencies in plants will not be encountered.

Copper

Copper is taken up as Cu^{2+} by plants (Table 1). Concentrations of Cu in plants average 6 ppm, but can range from 2 to 20 ppm. Copper is a component of cytochromes in plants and needed for enzyme activation. Copper is not mobile in plants, causing deficiencies to first appear in the youngest plant tissue (Table 2).

Most soils contain adequate levels of Cu for plant growth (Table 3). Copper problems are most likely in soils that contain more than 8% organic matter, which constitutes only about 1% of the soils in the Pacific Northwest. For additional information on Cu, see University of Idaho CIS 682, *Copper in Idaho*, available at URL: http://info.ag.uidaho.edu/catalog/catalog.html.

Iron

Plants take up iron (Fe) as Fe^{2+} (Table 1). A typical plant contains 100 ppm of Fe; this can range from 50 to 1000 ppm depending on plant species. Iron is needed by plants for chlorophyll synthesis, metabolic processes, and enzyme activation (Table 2). Iron is not mobile in plants, resulting in Fe deficiencies first appearing on younger leaves. The characteristic deficiency symptom is interveinal chlorosis in the younger leaves.

In general, there is plenty of plant-available Fe in acid and neutral pH soils (Table 3). In the Pacific Northwest, Fe deficiencies are often observed in fruit trees, on golf course greens, and in ornamental plantings in urban areas. Iron deficiencies should be corrected with foliar sprays.

Manganese

Manganese is taken up as Mn^{2+} by plants (Table 1). Concentrations of Mn in plants average 50 ppm, but can range from 20 to 200 ppm. Manganese is required in the Hill reaction of photosystem II and is important for enzyme activation. Manganese is not mobile in plants, causing deficiencies to first appear in the youngest plant tissue (Table 2).

Most soils contain adequate levels of Mn for plant growth (Table 3). Manganese deficiencies are not found in acid or neutral pH soils. The few observed Mn deficiencies in Idaho occur on alkaline soils that have high levels of organic matter (greater than 6%).

Molybdenum

Plants take up molybdenum (Mo) as MoO_4^{2-} (Table 1). A typical plant contains only 0.1 ppm of Mo. However, this small amount of Mo allows plants to utilize nitrogen. In addition, legumes require Mo for nitrogen fixation (Table 2).

Molybdenum is not mobile in plants, so deficiency symptoms appear in younger plant tissue first. Molybdenum-deficient plants turn yellow-green to yellow in color. Most Mo deficiencies occur when legumes are grown in soils with pH values less than 5.4. For additional information on Mo, see University of Idaho CIS 1087, *Molybdenum in Idaho*, available at URL: http://info.ag.uidaho.edu/catalog/catalog.html.

Nickel

Nickel (Ni) was added to the essential element list in 1991. Plants require less than one part per billion Ni. Nickel is believed to be important in iron metabolism in plants. Because such a small amount of Ni is required by plants, deficiencies have never been observed in the Pacific Northwest.

Zinc

A typical plant contains 20 ppm Zn on a dry weight basis (Table 1). Plants take up zinc as Zn^{2+}. Zinc is required for protein breakdown and in enzyme activation in plants (Table 2). Zinc is not very mobile in plants; consequently deficiency symptoms first appear on the youngest plant tissue. Most soils in the Pacific Northwest contain adequate amounts of Zn (Table 3). However, Zn deficiencies do occur in soils where the topsoil or organic matter has been removed. For additional information about Zn, see University of Idaho CIS 1088, *Zinc in Idaho*, available at URL: http://info.ag.uidaho.edu/catalog/catalog.html.

Summary

Nitrogen, phosphorus, and sulfur are the macronutrients that will most likely limit the growth of field and container crops. Under certain conditions, boron and iron micronutrient nutritional problems may also be encountered.