CCA 1.5 NM CEU

Plant Nutrient Functions and Deficiency and Toxicity Symptoms

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Introduction

This module is the ninth in a series of extension materials designed to provide extension agents, Certified Crop Advisers (CCAs), consultants and producers with pertinent information on nutrient management issues. To make the learning 'active', and to provide credits to CCAs, a quiz accompanies this module. In addition, realizing that there are many other good information sources including previously developed extension materials, books, web sites and professionals in the field, we have provided a list of additional resources for those wanting more in-depth information about plant nutrient functions and deficiency and toxicity symptoms.

Objectives

After reading this module, the reader should be able to:

1. Identify and diagnose common plant nutrient deficiency and toxicity symptoms
2. Know potential limitations of visual diagnosis
3. Understand how to use a key for identifying deficiency symptoms
4. Distinguish between mobile and immobile nutrient deficiencies

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Background

As discussed in *Nutrient Management Module 2, Plant Nutrition and Soil Fertility (NM 2),* plants require essential nutrients for normal functioning and growth. A plant's sufficiency range is the range of nutrient amount necessary to meet the plant's nutritional needs and maximize growth (Figure 1). The width of this range depends on individual plant species and the particular nutrient. Nutrient levels outside of a plant's sufficiency range cause overall crop growth and health to decline due to either a deficiency or toxicity. Nutrient deficiency occurs when an essential nutrient is not available in sufficient quantity to meet the requirements of a growing plant. Toxicity occurs when a nutrient is in excess of plant needs and decreases plant growth or quality. Common nutrient deficiencies in Montana and Wyoming are nitrogen (N) and phosphorus (P), with some deficiencies of potassium (K), sulfur (S), boron (B), chloride (Cl), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). Micronutrient deficiencies are fairly uncommon with deficiencies of B, Cl, Fe and Zn occurring most often *(Nutrient Management Module 7, Micronutrients: Cycling, Testing, and Fertilizer Recommendations; NM 7).* Nutrient toxicity is less common than deficiency and most likely occurs as a result of over-application of fertilizer or manure.

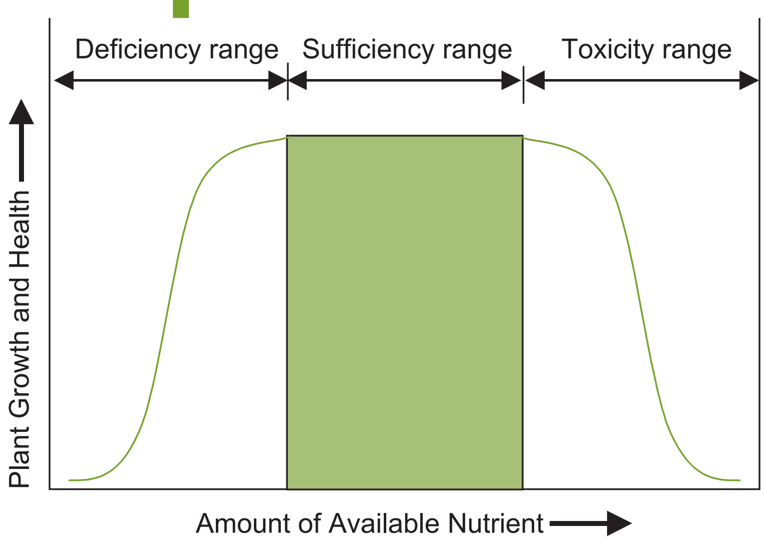


Figure 1. Relationship between plant growth and health and amount of nutrient available. (Brady and Weil, 1999)

Q&A #1

How is plant analysis used as a diagnostic tool?

Plant analysis consists of testing nutrient concentrations in specific plant parts during specific growth stages (Jacobsen and Jasper, 1991). If nutrient concentrations in a sample are below or above an established sufficiency range, then the plant is deficient or in excess for that element. Plant analyses can be performed relatively quickly in the field using semi-quantitative test kits or more extensively in a laboratory (Havlin et al., 1999). As a diagnostic tool, plant analysis improves the chances of making a correct diagnosis and can be particularly useful in identifying hidden hunger or pseudo deficiencies.

The three basic tools for diagnosing nutrient deficiencies and toxicities are 1) soil testing, 2) plant analysis and 3) visual observations in the field. Both soil testing *(Nutrient Management Module 1, Soil Sampling and Laboratory Selection)* and plant analysis (Q & A #1 and #2) are quantitative tests that compare soil or plant concentrations to the sufficiency range for a particular crop. Visual observation, on the other hand, is a qualitative assessment and is based on symptoms such as stunted growth or a yellowing of leaves occurring as a result of nutrient stress. This module focuses on visual nutrient deficiency and toxicity symptoms observed in common crops grown in Montana and Wyoming.

Visual Symptoms as a Diagnostic Tool

Interpreting visual nutrient deficiency and toxicity symptoms in plants can be difficult and plant analysis or soil testing is necessary to confirm nutrient stress. Precautions in identifying nutrient stress symptoms include the following:

1. **Many symptoms appear similar.** For instance, N and S deficiency symptoms can be very alike, depending upon plant growth stage and severity of deficiencies.
2. **Multiple deficiencies and/or toxicities can occur at the same time.** More than one deficiency or toxicity can produce symptoms, or possibly an abundance of one nutrient can induce the deficiency of another (e.g. excessive P causing Zn deficiency).
3. **Crop species, and even some cultivars of the same species, differ in their ability to adapt to nutrient deficiencies and toxicities.** For example, corn is typically more sensitive to a Zn deficiency than barley and will show Zn deficiency more clearly *(NM 7)*.
4. **Pseudo (false) deficiency symptoms (visual symptoms appearing similar to nutrient deficiency symptoms).** Potential factors causing pseudo deficiency include, but are not limited to, disease, drought, excess water, genetic abnormalities, herbicide and pesticide residues, insects, and soil compaction.
5. **Hidden hunger.** Plants may be nutrient deficient without showing visual clues.
6. **Field symptoms appear different than 'ideal' symptoms.** Many of the plants shown in this module as photographs were grown under controlled nutrient conditions, and deficiency/toxicity symptoms observed in the field may or may not appear as they do here. Experience and knowledge of field history are excellent aids in determining causes for nutrient stress.

In addition to the above precautions, visual observation is also limited by time. Between the time a plant is nutrient deficient (hidden hunger) and visual symptoms appear, crop health and productivity may be substantially reduced and corrective actions may or may not be effective. Therefore, regular soil or plant testing is recommended for the prevention and early diagnosis of nutrient stress.

If visual symptoms are observed, record which crop(s) are affected, their location with respect to topography, aspect, and soil conditions, a detailed description of symptoms and time of season that the symptoms first appeared. Affected field locations can be marked and monitored over time using either flagging or GPS readings. This information will be useful in preventing nutrient stress in subsequent years.

Q&A #2

I suspect a nutrient deficiency. How do I collect a plant sample for submission to an analytical laboratory?

If you suspect nutrient stress, sample when symptoms first appear. To ensure quality results, multiple samples should be collected from comparable locations (similar topography, aspect and soil type) and at the same time of day. Is important to collect the part of the plant that will give the best indication of the nutrient status of the whole plant. The youngest mature leaf is typically used, however, appropriate plant parts to test will vary with crop type and growth stage (see Appendix for additional resources). Collect numerous (20-30) subsamples of parts from plants that appear both abnormal and healthy, if possible. Subsamples may be combined for one sample. To gather plant samples, use a clean plastic or paper container (metal containers can contaminate samples). If the samples have soil, fertilizer, or spray residues on them, clean gently with a dry brush or with deionized or distilled water. Do not prolong washing because it can leach nutrients out of the tissue. Air-dry samples in the shade in either a paper bag or envelope. To avoid decomposition, do not use plastic bags or send fresh samples. When mailing samples to the laboratory, include type and variety of crop, current and past crop management practices, irrigation frequency (if applicable), soil type (if known),visual appearance of crop, and any insect or disease problems.

Diagnosing Nutrient Deficiencies

Common Deficiency Symptoms

A first step in diagnosing nutrient deficiencies is to describe the symptoms. Each deficiency symptom is related to some function of the nutrient in the plant (Havlin et al., 1999). The role of each essential nutrient in the plant is listed in Table 1 of NM 2. Symptoms caused by nutrient deficiencies are generally grouped into five categories: 1) stunted growth, 2) chlorosis, 3) interveinal chlorosis, 4) purplish-red coloring and 5) necrosis. Stunting is a common symptom for many deficient nutrients due to their varied roles in the plant. For example, when nutrients involved in plant functions such as stem elongation, photosynthesis, and protein production are deficient, plant growth is typically slow and plants are small in stature. Chlorosis and interveinal chlorosis are found in plants deficient of nutrients necessary for photosynthesis and/or chlorophyll (green leaf pigment involved in photosynthesis) production. Chlorosis can result in either the entire plant or leaf turning light green to yellow, or appear more localized as white or yellow spotting. Interveinal chlorosis is illustrated in Figure 2 and occurs when certain nutrients [B, Fe, magnesium (Mg), Mn, nickel (Ni) and Zn] are deficient. Purplish-red discolorations in plant stems and leaves are due to above normal levels of anthocyanin (a purple colored pigment) that can accumulate when plant functions are disrupted or stressed. This symptom can be particularly difficult to diagnose because cool temperatures, disease, drought and even maturation of some plants can also cause anthocyanin to accumulate (Bennett, 1993). Certain plant cultivars may also exhibit this purple coloring. Necrosis generally happens in later stages of a deficiency and causes the parts of the plant first affected by the deficiency to brown and die. Since a number of nutrient deficiencies can produce similar symptoms, further evaluation of symptoms related to particular leaf patterns or locations on the plant are needed to diagnose nutrient specific deficiencies. These specifics will be discussed in detail later in the module.

Figure 2. Interveinal chlorosis. (Fe deficiency; Bennett, 1993)

Plant Nutrient Deficiency Terminology

Burning: severe localized yellowing; scorched appearance.

Chlorosis: general yellowing of the plant tissue; lack of chlorophyll.

Generalized: symptoms not limited to one area of a plant, but rather spread over the entire plant.

Immobile nutrient: not able to be moved from one part of the plant to another.

Interveinal Chlorosis: yellowing in between leaf veins, yet veins remain green.

Localized: symptoms limited to one leaf or one section of the leaf or plant.

Mobile nutrient: able to be moved from one plant part to another.

Mottling: spotted, irregular, inconsistent pattern.

Necrosis: death of plant tissue; tissue browns and dies.

Stunting: decreased growth; shorter height of the affected plants.

Mobile and Immobile Nutrients

Another step in identifying deficiency symptoms is to determine whether the deficiency is the result of a mobile or immobile nutrient based on where the symptom appears in the plant. Mobile nutrients are nutrients that are able to move out of older leaves to younger plant parts when supplies are inadequate. Mobile nutrients include N, P, K, Cl, Mg and molybdenum (Mo). Because these nutrients are mobile, visual deficiencies will first occur in the older or lower leaves and effects can be either localized or generalized. In contrast, immobile nutrients [B, calcium (Ca), Cu, Fe, Mn, Ni, S and Zn] cannot move from one plant part to another and deficiency symptoms will initially occur in the younger or upper leaves and be localized. Zn is a partial exception to this as it is only somewhat immobile in the plant, causing Zn deficiency symptoms to initially appear on middle leaves and then affect both older and younger leaves as the deficiency develops.

Identification key

The 'key' on pages 6 and 7 can be used for identifying nutrient deficiencies based on common symptoms. It consists of alternative statements about the appearance of different plant structures. If possible, it may be helpful to have a healthy plant on hand for comparison purposes. Beginning at the top of the key, read the first statement and determine whether the statement applies to the plant(s) being evaluated. If the statement describes the plant's symptoms, proceed along the 'YES' arrow to the next statement. If not, follow the 'NO' arrow to an alternative statement. Continue this process until the probable nutrient responsible for the deficiency is identified. Although most descriptions in this key are generalized to accommodate common symptoms seen in various crops, bear in mind that deficiency symptoms differ among crop types and plant specific symptoms may not be listed (see text for detailed descriptions of deficiencies and Appendix for resources on specific crop symptoms).

Figure 3. N deficiency in barley. Top leaves are N deficient, bottom leaf is normal.

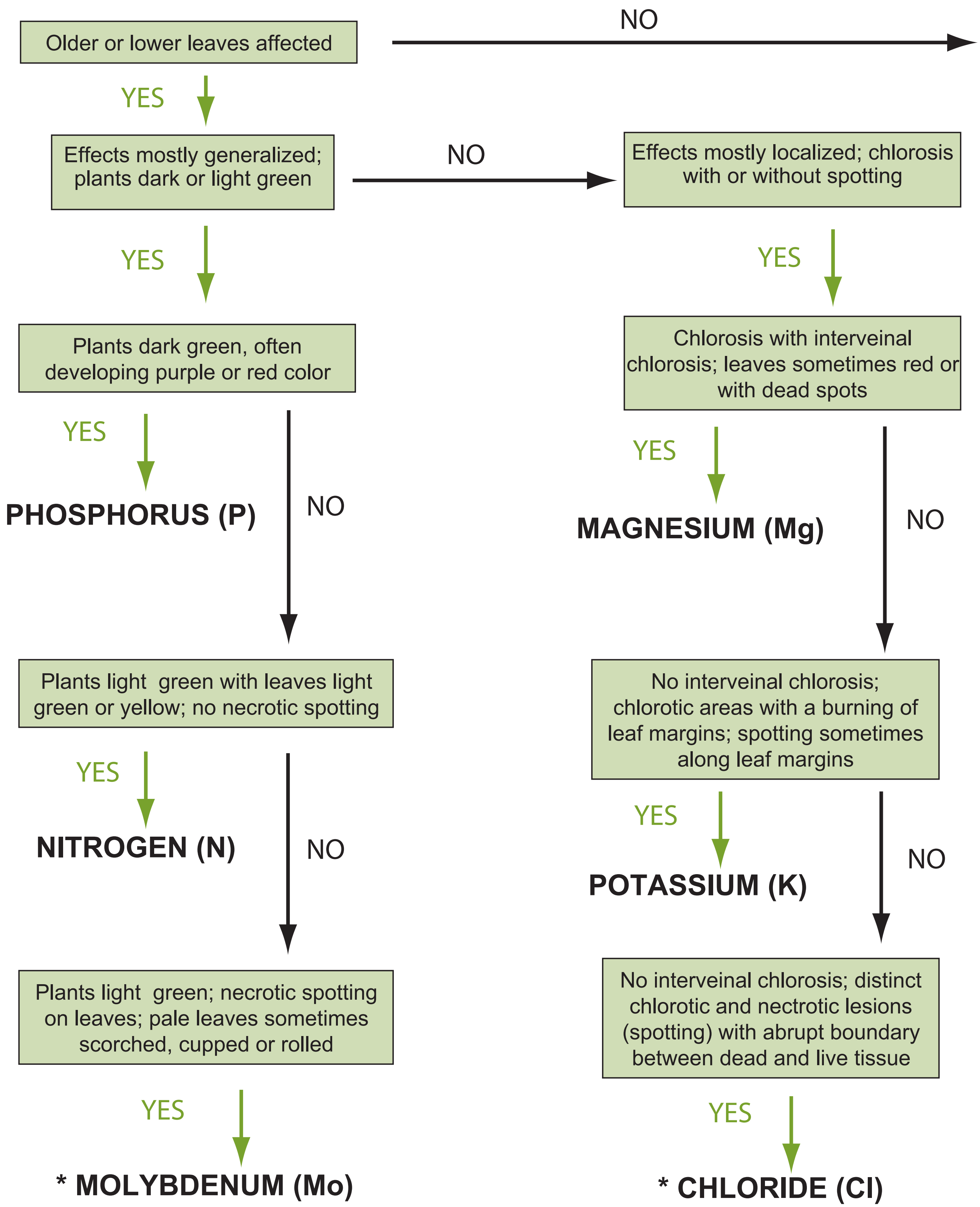
Mobile Nutrients

Nitrogen (N)

Nitrogen is needed by plants for the production of proteins, nucleic acids (DNA and RNA) and chlorophyll. Symptoms of N deficiency are general chlorosis of lower leaves, stunted and slow growth and necrosis of older leaves in severe cases (Figure 3). N deficient plants will mature early and crop quality and yield are often reduced (Jones, 1998). In cereals, yellow discoloration from the leaf tip backward in the form of a 'V' is common (Figure 3; Jacobsen and Jasper, 1991). Insufficient

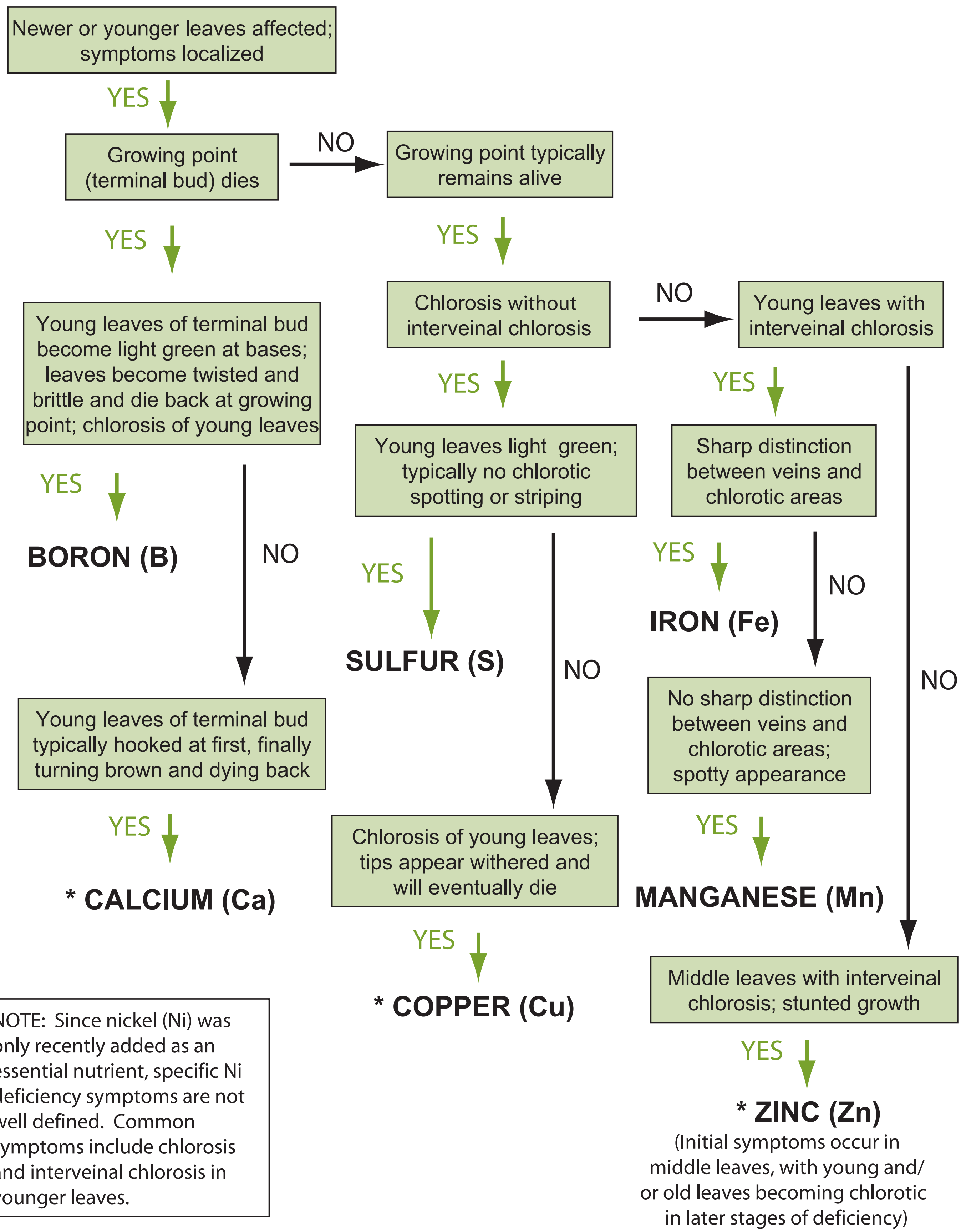
Figure 4. Uniform distribution of N deficiency symptoms as a result of fertilizer application 'misses'. Photo by Ryan Stoffregen/Courtesy of International Plant Nutrition Institute.

MOBILE NUTRIENTS



*If symptoms don't meet any of the key descriptions, either go back through the key another time or refer to text for more specific symptom descriptions.

IMMOBILE NUTRIENTS



NOTE: Since nickel (Ni) was only recently added as an essential nutrient, specific Ni deficiency symptoms are not well defined. Common symptoms include chlorosis and interveinal chlorosis in younger leaves.

amounts of N in cereals will result in few tillers, slender stalks, short heads, and grain with low protein content. Leaf curling and small tubers are common in potatoes deficient of N. Fields deficient in N can be either uniform or patchy in appearance, depending on the cause of the deficiency. For example, fertilizer application 'misses' will result in uniform strips of deficiency, whereas N deficiency as a result of soil characteristics such as organic matter content will be patchy (Figure 4).

Phosphorus (P)

Plants require P for the development of ATP (energy), sugars and nucleic acids. Cool soils during the early growing season may be a factor causing P deficiency. P deficiency symptoms are usually more noticeable in young plants, which have a greater relative demand for P than more mature plants (Grundon, 1987). P deficient plants generally turn dark green (both leaves and stems) and appear stunted (Figure 5). Older leaves are affected first and may acquire a purplish discoloration due to the accumulation of sugars which favors anthocyanin synthesis; in some cases, leaf tips will brown and die (Figure 6). Plants suffering from P deficiency appear weak and maturity is delayed. Leaf expansion and leaf surface area may also be inhibited, causing leaves to curl and be small. Small grains with P deficiency tend to be stressed and predisposed to root rot diseases, and some cultivars will turn red or purple. In alfalfa, an upward tilting of leaflets may occur. Potato P deficiency symptoms include leaves curling upward and tubers having brown internal specks, often radiating out from the core. P deficiency in corn is usually visible in young plants with leaves turning purple. From a field perspective, P deficiency is likely to occur on tops of ridges or other exposed areas that have highly eroded or weathered soils, or in areas that have been leveled, exposing subsoils high in calcium carbonate ($CaCO_3$). Crops grown in soils high in $CaCO_3$ are prone to P deficiency due to the precipitation of insoluble Ca-P minerals.

Figure 5. P deficiency in alfalfa (left) and normal alfalfa (right). P deficient leaf is dark green and stunted. (Jacobsen and Jasper, 1991)

Figure 6. P deficiency in corn. Leaves are purplish and tips are brown and necrotic.

Potassium (K)

Potassium is utilized by plants in the activation of enzymes, photosynthesis, protein formation and sugar transport. K deficiency does not immediately result in visible symptoms (hidden hunger). Initially, there is only a reduction in growth rate, with chlorosis and necrosis occurring in later stages (Mengel and Kirkby, 2001). Affected older leaves will show localized mottled or chlorotic areas with leaf burn at margins (Figure 7). Chlorotic symptoms typically begin on the leaf tip, but unlike the 'V' effect caused by N deficiency, K deficient chlorosis will advance along the leaf margins towards the base, usually leaving the midrib alive and green. As the deficiency progresses, the entire leaf will yellow. Small white or yellow necrotic spots may also develop, beginning along leaf margins (Figure 8). Another indication of K deficiency is reduced straw or stalk strength in small grains and corn, resulting in lodging problems, reduced disease resistance and reduced winter-hardiness of perennial or winter annual crops (Jacobsen and Jasper, 1991). Some small grains, especially barley, develop excessive numbers of tillers when K is deficient. Grain will be low in protein and appear shriveled. In alfalfa, white spots will appear on leaf edges. Due to K's role in sugar accumulation, root crops (i.e. potatoes, sugar beets) will have small tubers.

Figure 8. K deficient (left) and normal (right) trifoliates. White spotting occurring along leaf margins in deficient leaf.

Chloride (Cl)

Chloride is required by the plant for leaf turgor and photosynthesis. Until recently, little information was documented on Cl deficiencies, as symptoms were often misdiagnosed as physiological leaf spot. However, more recent studies have shown Cl deficiencies to exist in Montana, with visual symptoms observed in winter wheat and durum wheat cultivars (Engel et al., 1998; Engel et al., 2001). Plants with insufficient Cl show chlorotic and necrotic spotting along leaves with abrupt boundaries between dead and live tissue (Figure 9). Wilting of leaves at margins and highly branched root systems are also typical Cl deficient symptoms, found mainly in cereal crops (Mengel and Kirkby, 2001). Cl deficiencies are highly cultivar specific and can be easily mistaken for leaf diseases.

Figure 7. K deficiency in corn. Older leaves are chlorotic and leaf edges are burned, but the midrib remains green. (Bennett, 1993)

Magnesium (Mg)

Magnesium is the central molecule in chlorophyll and is an important co-factor for the production of ATP. Mg deficiencies are not common, as Mg concentrations are sufficient in most Montana and Wyoming soils. Symptoms of Mg deficiency include interveinal chlorosis and leaf margins becoming yellow or reddish-purple while the midrib remains green. In wheat, distinct mottling as yellowish-green patches will occur, and alfalfa leaves may curl and have reddish undersides. Reduced Mg concentrations in wheat forage can lead to grass tetany (low blood serum Mg) in animals grazing on winter wheat (Jacobsen and Jasper, 1991). Leaves of Mg deficient sugar beets and potatoes are stiff and brittle and veins are often twisted.

Molybdenum (Mo)

Molybdenum is needed for enzyme activity in the plant and for nitrogen fixation in legumes. Due to this interrelationship, Mo deficiency symptoms often resemble N deficiency symptoms with stunted growth and chlorosis occurring in legumes. Other symptoms of Mo deficiency include pale leaves that may be scorched, cupped, or rolled. Leaves may also appear thick or brittle, and will eventually wither, leaving only the midrib.

Figure 9. Cl deficiency in hydroponically grown WB881 durum wheat. (Engel et al., 2001)

Immobile Nutrients

Sulfur (S)

As S is an essential constituent of certain amino acids and proteins, S deficiency results in the inhibition of protein and chlorophyll synthesis. S deficiency symptoms can be difficult to diagnose as effects can resemble symptoms of N and Mo deficiencies. In contrast to N or Mo deficiency, however, S deficiency symptoms initially occur in younger leaves, causing them to turn light green to yellow (Figure 10). In later growth, the entire plant may be pale green. There are no characteristic spots or stripes. Additionally, plants deficient in S tend to be spindly and small, and stems are often thin.

Figure 10. S deficient wheat plant (left) has light green leaves and stunted growth as compared to normal wheat plant (right).

Boron (B)

Primary functions of B in plants are related to cell wall formation and reproductive tissue. Plants suffering from B deficiency exhibit chlorotic young leaves and death of the main growing point (terminal bud). In addition to chlorosis, leaves may develop dark brown, irregular lesions that will progress to leaf necrosis in severe cases. Whitish-yellow spots may also form at the base of leaves. Due to disturbances in cell wall growth, leaves and stems of B deficient plants become brittle and distorted and leaf tips tend to thicken and curl. Affected plants grow slowly and appear stunted as a result of shortened internodes (stem segment between points where leaves are attached). Because B tends to accumulate in reproductive tissues, flower buds may fail to form or are misshapen, and pollination and seed viability is usually poor in B deficient plants (Jacobsen and Jasper, 1991; Wiese, 1993). In alfalfa and canola, B deficiency symptoms include rosetting (the clustering of leaves in crowded circles), yellowing of upper leaves and poor flowering (Figure 11). B deficient sugar beets have stunted growth and young leaves curl and turn brown or black. In later stages of the deficiency, the crown and root of the beet begins to rot and disease sets in, affecting the whole plant (Mengel and Kirkby, 2001). The healthy part of the beet root will be low in sugar.

Figure 11. Alfalfa with B deficiency; chlorosis of upper leaves and rosetting of leaves near base. (Jacobsen and Jasper, 1991)

Iron (Fe)

Iron plays an important role in plant respiratory and photosynthetic reactions. Fe deficiency reduces chlorophyll production and is characterized by interveinal chlorosis with a sharp distinction between veins and chlorotic areas in young leaves (Figure 12). As the deficiency develops, the entire leaf becomes whitish-yellow and progresses to necrosis. Plant growth is slow. When viewed from a distance, Fe deficient fields exhibit irregularly shaped yellow areas, especially where the subsoil is exposed at the surface (Follett and Westfall, 1992).

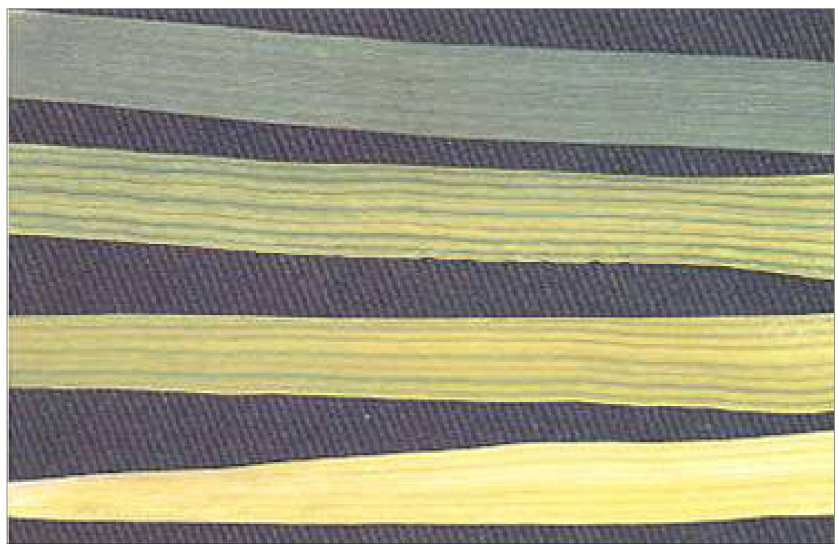


Figure 12. Progression of Fe deficiency in wheat leaves. Top leaf normal; middle leaves showing interveinal chlorosis with prominent green veins; and bottom leaf entirely chlorotic. (Grundon, 1987)

Zinc (Zn)

Zinc is needed by plants for growth hormone production and is particularly important for internode elongation. As previously noted, Zn has intermediate mobility in the plant and symptoms will initially show up in middle leaves. Zn deficient leaves display interveinal chlorosis, especially midway between the margin and midrib, producing a striping effect; some mottling may also occur (Figure 13). Chlorotic areas can be pale green, yellow, or even white. Severe Zn deficiency causes leaves to turn gray-white and fall prematurely or die. Because Zn plays a prominent role in internode elongation, Zn deficient plants generally exhibit severe stunting. Flowering and seed set is also poor in affected plants.

Crop specific symptoms include smaller leaf size in alfalfa, gray or bronze banding and reduced tiller production in small grains and abnormal grain formation (Wiese, 1993). Zn deficiency generally does not affect fields uniformly and deficient areas usually occur where topsoil has been removed (Follett and Westfall, 1992). Zn deficiencies in forage have been shown to reduce reproductive efficiency in cattle (Paterson, 2002).

Calcium (Ca)

Calcium is a component of plant cell walls and regulates cell wall construction. Ca deficiency is uncommon in many Montana and Wyoming areas due to the presence of calcium carbonates and gypsum in most agriculture soils. Insufficient Ca can cause young leaves to become distorted and turn abnormally dark green. Leaf tips often become dry or brittle and will eventually wither and die. Stems are weak and germination is poor.

Copper (Cu)

Copper is needed for chlorophyll production, respiration and protein synthesis. Cu deficient plants display chlorosis in younger leaves, stunted growth, delayed maturity (excessively late tillering in grain crops), lodging and, in some cases, melanosis (brown discoloration). In cereals, grain production and fill is often poor, and under severe deficiency, grain heads may not even form (Figure 14). Cu deficient plants are prone to increased disease, specifically ergot (a fungus causing reduced yield and grain quality; Solberg et al., 1999). The onset of disease-caused symptoms may confound the identification of Cu deficient symptoms. Winter and spring wheat are the most sensitive crops to Cu deficiency (Solberg et al., 1999). In the field, Cu deficiency symptoms occur in irregular patches with melanosis being the most obvious symptom, particularly in wheat stands. Similar to Zn deficiency, forage that is deficient in Cu can cause reduced reproductive efficiency in cattle (Paterson, 2002).

Figure 13. Zn deficiency displaying striped interveinal chlorosis.

Figure 14. Cu deficiency in wheat: severely affected (left), moderately affected (center), unaffected (right). Deficient wheat shows melanosis with poor grain production and fill.

Manganese (Mn)

Chloroplasts (plant organelles where photosynthesis occurs) are the most sensitive of cell organelles to Mn deficiency (Mengel and Kirkby, 2001). As a result, a common symptom of Mn deficiency is interveinal chlorosis in young leaves (Figure 15). However, unlike with Fe deficiency, there is no sharp distinction between veins and interveinal areas, but rather a more diffuse chlorotic effect. Two well-known Mn deficiencies in arable crops are grey speck in oats and marsh spot in peas. White streak in wheat and interveinal brown spot in barley are also symptoms of Mn deficiency (Jacobsen and Jasper, 1991).

Nickel (Ni)

Nickel is required by plants for proper seed germination and is beneficial for N metabolism in legumes and other plants in which ureides (compounds derived from urea) are important in metabolism (Gerendas et al., 1999). Ni is the metal component in urease, an enzyme that catalyzes the conversion of urea to ammonium (Havlin et al., 1999). Though Ni deficiency symptoms are not well documented and believed to be non-existent in Montana and Wyoming, symptoms include chlorosis and interveinal chlorosis in young leaves that progress to plant tissue necrosis. Other symptoms include poor seed germination and decreased crop yield.

Diagnosing Nutrient Toxicities

As insufficient nutrient content can cause visual symptoms to occur in plants, so too can an excess. In Montana and Wyoming, macronutrient (N, P and K) toxicities most often occur as a result of the over-application of fertilizers or manure. Secondary macronutrient (Ca, Mg and S) toxicities are rare in this region and toxic effects on crop health have not been documented. Micronutrient toxicities can occur and are likely caused by over-application of fertilizer or manure, using irrigation water high in micronutrients or salts, or in areas where soil micronutrient concentrations are abnormally high (i.e. areas exposed to mining activity or high metal minerals in subsoil). In addition, high amounts of non-essential elements such as arsenic (As), cadmium (Cd) and lead (Pb) can be directly toxic to plants and livestock or cause a nutrient imbalance in the plant, in which essential nutrient deficiencies or toxicities may possibly occur.

N, P and K

Plants with excess N turn a deep green color and have delayed maturity. Due to N's positive effect on vegetative growth, excess N results in tall plants with weak stems, possibly causing lodging. New growth will be succulent and plant transpiration high (low water use efficiency; Jacobsen and Jasper, 1991). N toxicity is most evident under dry conditions and may cause a burning effect. Plants fertilized with ammonium (NH_4^+)-based fertilizers may exhibit NH_4^+ toxicity, indicated by reduced plant growth, lesions occurring on stems and roots and leaf margins rolling downward, especially under dry conditions.

Figure 15. Mn deficient wheat displaying interveinal chlorosis.

Excess P indirectly affects plant growth by reducing Fe, Mn and Zn uptake; thus, potentially causing deficiency symptoms of these nutrients to occur (see specific deficiency descriptions). Zn deficiency is most common under excess P conditions. Due to a cation imbalance, K toxicity can cause reduced uptake and subsequent deficiencies of Mg, and in some cases, Ca (see Mg and Ca deficiency descriptions).

Micronutrients

For many crops, the range between deficiency and toxicity is narrower for micronutrients than macronutrients (Brady and Weil, 1999). This is particularly true for B in which the average sufficiency and toxicity ranges for various crops overlap one another: 10-200 ppm (sufficiency range) and 50-200 ppm (toxicity range; Jones, 1998). B toxicity results in chlorosis followed by necrosis. Symptoms begin at the leaf tip and margins and spread toward the midrib. As the toxicity progresses, older leaves will appear scorched and fall prematurely. In sugar beet, a yellow-tinted band will occur around leaf margins (Ulrich et al., 1993).

Other micronutrients causing potential toxicity symptoms include Cu, Mn, Mo, Ni and Zn. Studies suggest excess Cu will displace Fe and other metals from important areas in the plant, causing chlorosis and other Fe deficiency symptoms, such as stunted growth, to appear (Mengel and Kirkby, 2001). High Ni concentrations can also cause Fe to be displaced. Interveinal chlorosis may appear in new leaves of Ni toxic plants and growth may be stunted. Mn toxicity symptoms are generally characterized by blackish-brown or red spots on older leaves and an uneven distribution of chlorophyll, causing chlorosis and necrotic lesions on leaves. While Mo toxicity does not pose serious crop problems (crops may appear stunted with yellow-brown leaf discolorations), excess amounts of Mo in forage have been found to be toxic to livestock (Havlin et al., 1999). Zn toxicity is not common, but can occur on very saline soils. Symptoms include leaves turning dark green, chlorosis, interveinal chlorosis and a reduction in root growth and leaf expansion. Excess Zn may induce Fe deficiency.

Summary

Nutrient deficiencies and toxicities cause crop health and productivity to decrease and may result in the appearance of unusual visual symptoms. Understanding each essential nutrient's role and mobility in the plant can help determine which nutrient is responsible for a deficiency or toxicity symptom. General deficiency symptoms include stunted growth, chlorosis, interveinal chlorosis, purple or red discoloration and necrosis. Deficiencies of mobile nutrients first appear in older, lower leaves, whereas deficiencies of immobile nutrients will occur in younger, upper leaves. Nutrient toxicity is most often the result of over-application, with symptoms including abnormal growth (excessive or stunted), chlorosis, leaf discoloration and necrotic spotting. When in excess, many nutrients will inhibit the uptake of other nutrients, thus potentially causing deficiency symptoms to occur as well.

As a diagnostic tool, visual observation can be limited by various factors, including hidden hunger and pseudo deficiencies, and soil or plant testing will be required to verify nutrient stress. Nonetheless, the evaluation of visual symptoms in the field is an inexpensive and quick method for detecting potential nutrient deficiencies or toxicities in crops, and learning to identify symptoms and their causes is an important skill for managing and correcting soil fertility and crop production problems.

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Appendix

Books/CDs

Nutrient Deficiencies and Toxicities in Crop Plants. W.F. Bennett, ed. 1993. St. Paul, Minn. American Phytopathological Society (APS) Press. 202 p.

Nutrient Deficiency Symptoms. CD. Potash & Phosphate Institute. www.ipni.net.

Plant Nutrition Manual. J. Benton Jones, Jr. 1998. Boca Raton, Fla. CRC Press. 149 p.

Soil Fertility and Fertilizers, 6th Edition. J.L. Havlin et al. 1999. Upper Saddle River, N.J. Prentice Hall. 499 p.

Extension Materials

Diagnosis of Nutrient Deficiencies in Alfalfa and Wheat, EB 43, February 1991. J.S. Jacobsen and C.D. Jasper. Bozeman, Mont. Montana State University Extension.

Excellent publication that includes a key to plant-nutrient deficiency symptoms, photographs of deficient plants, and additional information on individual nutrients, such as excess nutrient symptoms, conditions favoring deficiency and factors causing pseudo deficiency.

Nutrient Management Modules 1-15. A series of bulletins explaining many soil nutrient management topics. Can be obtained online at http://landresources.montana.edu/nm

For printed copies of these materials contact:

MSU Extension Publications
P.O. Box 172040
Bozeman, MT 59717-2040
http://www.msuextension.org/store/
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(add $1 for shipping)

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Web Resources

http://aces.nmsu.edu/pubs/_a/a-123.html

Plant analysis sampling guidelines and table of specific plant parts to be tested for various crops. Source: New Mexico State University Extension Service.

http://www.back-to-basics.net/nds/index.htm

A good website featuring photographs of all nutrient deficiencies in various crops.

http://www.hbci.com/~wenonah/min-def/list.htm

Website featuring photographs of nutrient deficiencies in numerous crops.

http://extension.missouri.edu/explorepdf/agguides/pests/ipm1016.pdf

Complete publication covering nutrient deficiency and toxicity symptoms; includes photographs of nutrient deficiencies in various crops. Source: University of Missouri Extension Service.

http://www.msuextension.org/store/

Montana State University Publications ordering information for Extension Publications.

http://landresources.montana.edu/FertilizerFacts/

Fertilizer Facts summarizing fertilizer findings and recommendations based on field research conducted in Montana by Montana State University personnel.

http://extension.agron.iastate.edu/soybean/documents/nutrientdeficiency.pdf

Nutrient deficiencies and application injuries in corn, soybean, and winter wheat with images.

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