
# Integrated Pest Management

# CROP NUTRIENT DEFICIENCIES & TOXICITIES

*Plant Protection Programs*
*College of Agriculture, Food and Natural Resources*

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**Credits**

Unless otherwise credited in the captions, the photographs were provided by the authors. Many of the symptom descriptions were taken from MU publication G9132, *Signs of Crop Hunger*, by Marshall Christy.

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College of Agriculture Food and Natural Resources



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# CROP NUTRIENT DEFICIENCIES AND TOXICITIES

Soil fertility is one of several factors, including light, moisture, weeds, insects, and diseases, that affect crop yield (Figure 1). An important part of crop farming is being able to identify and prevent plant nutrient deficiencies and toxicities. This publication provides background information on the nature and development of crop nutrient disorders under the growing conditions commonly encountered in Missouri. It is a guide to identifying crop nutrient problems through observable symptoms on crop plants. Information is provided on effects of climatic conditions on plant nutrient availability, and the results of soil and plant tissue testing.

Plants require 14 mineral elements for normal growth and reproduction. Each of these nutrients has a function in plants and is required in varying amounts in plant tissue (see Table 1). *Macronutrients* (nitrogen, phosphorus, potassium, calcium, magnesium and sulfur) are required in the largest amounts. *Micronutrients* (iron, copper, manganese, zinc, boron, molybdenum, chlorine and nickel) are required in relatively smaller amounts in plants. Other mineral elements that are beneficial to some plants but are not considered essential include sodium, cobalt, vanadium, selenium, aluminum and silicon.

A deficiency occurs when an essential element is not available in sufficient quantity to meet the needs of the growing plant. Nutrient toxicity occurs when an element is in excess of plant needs and decreases plant growth or quality. Nutrient deficiency or toxicity symptoms often differ among species and varieties of plants.

**Table 1. Essential plant nutrients.**

| Name | Chemical symbol | Relative % in plant* | Function in plant | Nutrient category |
|---|---|---|---|---|
| Nitrogen | N | 100 | Proteins, amino acids | Primary macronutrients |
| Phosphorus | P | 6 | Nucleic acids, ATP | |
| Potassium | K | 25 | Catalyst, ion transport | |
| Calcium | Ca | 12.5 | Cell wall component | Secondary macronutrients |
| Magnesium | Mg | 8 | Part of chlorophyll | |
| Sulfur | S | 3 | Amino acids | |
| Boron | B | 0.2 | Cell wall component | Micronutrients |
| Chlorine | Cl | 0.3 | Photosynthesis reactions | |
| Copper | Cu | 0.01 | Component of enzymes | |
| Iron | Fe | 0.2 | Chlorophyll synthesis | |
| Manganese | Mn | 0.1 | Activates enzymes | |
| Molybdenum | Mo | 0.0001 | Involved in N fixation | |
| Nickel | Ni | 0.001 | Component of enzymes | |
| Zinc | Zn | 0.03 | Activates enzymes | |

*Relative amounts of mineral elements compared to nitrogen in dry shoot tissue. May vary depending on plant species.

## HOW NUTRIENT DISORDERS DEVELOP

The occurrence of nutrient deficiencies or toxicities is a result of soil, crop, climatic, and cultural factors. These factors interact to influence the availability of nutrients to crop plants over the course of a growing season.

Soil properties influence the form, amount, retention and movement of soil nutrients. The effects of soil properties on water availability also influence nutrient availability, because water is essential for chemical reactions, biological activity, and the transport and absorption of nutrients by roots. Among the critical soil chemical properties affecting soil nutrient availability are soil pH (a measure of the acidity or alkalinity of a soil) and soil cation exchange capacity (a measure of the capacity of the soil to retain positively charged nutrient ions). Some important physical properties affecting nutrient availability are soil texture (the proportion of sand, silt and clay-sized particles in a soil), clay mineralogy (the type of soil clay), and soil structure (the physical arrangement of soil particles).

The soils of Missouri vary widely in their inherent soil fertility and suitability for crop production. Information about the specific soil resources on your farm can be obtained by consulting your regional extension specialist or your county Farm Service Agency office or by using the Center for Agricultural Resource and

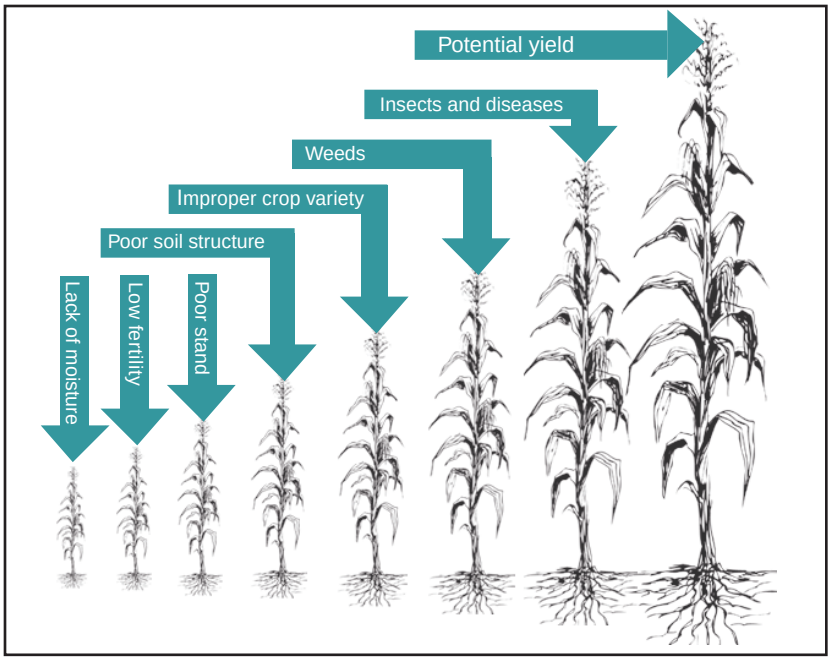


Figure 1. Low soil fertility is only one of several factors that can limit crop yields.

Environmental Systems (CARES) Web site (www.cares.missouri.edu).The parent material of some soils may contain a large amount of certain plant nutrients (e.g., potassium, calcium and magnesium) and, therefore, the possibility of a plant response to additional fertilizer sources of those nutrients may be reduced. In addition, certain soils have natural soil physical and chemical restrictions that can limit potential crop productivity. A prior knowledge of your soil resources will help you to develop a successful nutrient management program.

Primary and secondary macronutrients are often limiting factors for crop production in Missouri depending on soil conditions and prior management. Most soils in Missouri have sufficient amounts of micronutrients to supply plant needs for crop production, but individual crop species may have special micronutrient requirements, and soil properties may vary.

Factors such as soil pH and moisture can affect the solubility of nutrients or interfere with the ability of plant roots to absorb nutrients (Figure 2). Deficiencies of micronutrients occur most often in soils with high pH (with the exception of molybdenum). Phosphorus availability is reduced by soil acidity and alkalinity. Low soil pH increases the availability of aluminum and manganese, which can result in toxic levels of these elements.

# VISUAL SYMPTOMS

Nutrient disorders may appear in many ways in a plant, including stunting or reduced growth, off-colored leaves (often white, yellow or purple); abnormally shaped leaves, stems, and roots; and a breakdown of certain parts of the plant, including the root system. “Chlorosis” is a type of deficiency or toxicity symptom characterized by yellowing that can be generalized over the whole plant, localized over individual leaves or isolated between some leaf veins (interveinal chlorosis). “Necrosis” is a type of deficiency or toxicity symptom characterized by death of plant tissue sometimes in spots. Yield and quality of grain or fiber may suffer when nutrition is inadequate.

When inspecting plants for symptoms of nutrient disorders, compare plants displaying symptoms with normal ones and examine new and older leaves. Nutrient deficiencies generally appear first in the oldest leaves when nitrogen, phosphorus, potassium, and magnesium are limiting. These nutrients move from one part of the plant to another as needed.

Younger leaves and terminal buds show a deficiency when sulfur, iron, calcium, zinc copper, boron, manganese or chlorine are limiting. These nutrients do not readily move about in the plant.

As a deficiency becomes more severe, visual symptoms may spread to the whole plant, leaves may become more chlorotic or bleached in appearance, or stunting, deformity and death of plant parts may become more extensive. Deficiencies of certain nutrients, such as sulfur and phosphorus in corn, may also be visible only early in the growing season because of immature root development or cold weather, and then become less apparent as the plant matures and the weather warms up.

Symptoms of nutrient toxicity vary, depending on the element and the crop. Essential nutrients that can be toxic to plants include manganese, copper, boron and chlorine. Excessive quantities of other nutrients in the soil may cause nutrient imbalances in plants, resulting in poor growth and crop quality.

Visual symptoms of nutrient deficiency or toxicity can be confusing because of problems with more than one nutrient. Symptoms associ-

ated with different nutrients may resemble crop injury caused by herbicide damage, insect damage, or the effects of plant diseases. Listed below are nutrient deficiencies that may be difficult to determine without laboratory tests.

## Sulfur–Nitrogen

Symptoms of sulfur deficiency in crops are similar to those of nitrogen deficiency. The main difference is that sulfur deficiency may cause leaf yellowing, beginning in the younger leaves, whereas nitrogen deficiency starts in the older leaves and then spreads to the whole plant. In some environments, sulfur and nitrogen deficiencies can cause yellowing between the leaf veins. Without tissue testing, these similarities may cause misdiagnosis of the problem. Tissue testing effectively determines whether nitrogen or sulfur is in short supply.

## Zinc–Magnesium–Iron–Manganese

Deficiencies of zinc, magnesium, iron, and manganese all typically cause yellowing of the tissue between leaf veins. Deficiencies of iron and manganese usually occur in high-pH soils, but these are rare in Missouri. Zinc deficiency is most common in corn, and the bleached area can spread to include the veins, but the midrib and leaf edges usually stay green. With magnesium deficiency, yellowing between veins will be seen mainly on older (lower) leaves, while zinc, iron and manganese deficiency symptoms will be seen mainly on younger (upper) leaves. Magnesium deficiency is best diagnosed with a soil test.

## Others

Use care to distinguish among various underlying causes of crop deficiency symptoms. Insect damage may look like a nutrient deficiency. Herbicides sometimes affect root, stem and leaf development, thereby impairing nutrient uptake. Diseases also can impair nutrient uptake by roots or the translocation of nutrients in the plant. Examine stems and stalks, root systems and the ears or grain. Split the stalks and study the internal circulation system. If you observe potassium deficiency symptoms in cotton, always check inside the stalks for discoloration from *Verticillium* or *Fusarium* wilt. Likewise, check for soybean cyst nematodes on soybean plants with potassium deficiency symptoms. Do not overlook possible contributing causes: disease, insects, herbicides, temperature, physical soil conditions and moisture conditions. Plants stressed from lack of nutrients are often more susceptible to diseases and some insects.

The following pages depict nutrient deficiency and toxicity symptoms in corn, soybeans, rice, cotton, wheat and alfalfa.

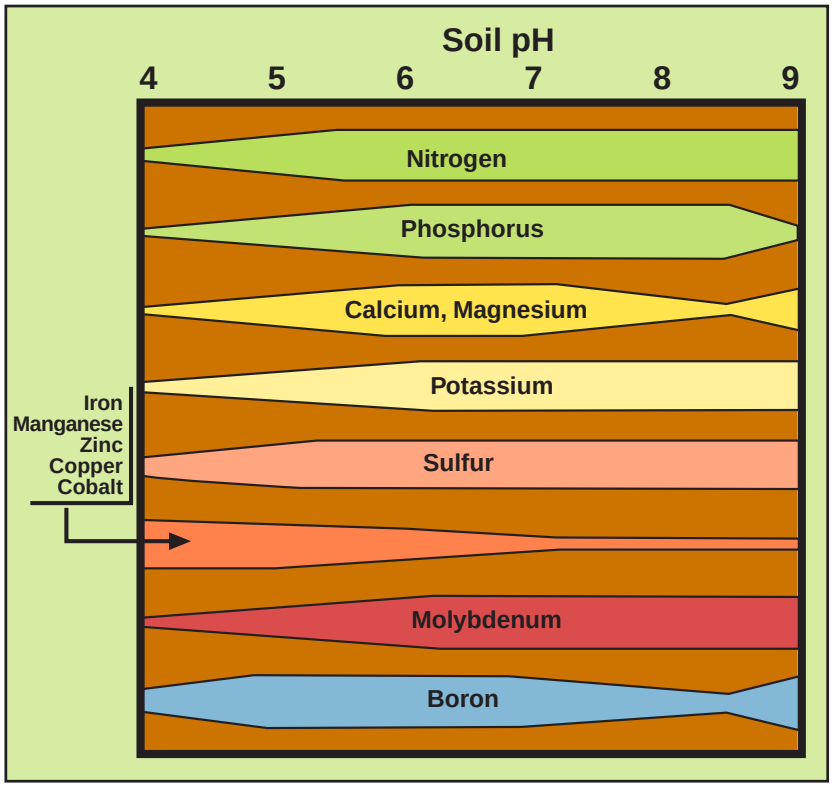



Figure 2. The relative availability of nutrients to plant roots depends on the pH level of the soil.

## Nitrogen deficiency

Yellowing from leaf tip and along midrib while edges remain green (oldest leaves affected first); spindly stalks; stunted growth; small ears (fail to fill at tip); ear tip pinched off: kernels have glossy luster (low in protein, but high in fats); light brown stover at maturity; poor yields (Figures 3 and 4).

Figure 3. Yellow or brown midribs indicate nitrogen deficiency.

Figure 4. Nitrogen-deficient corn plants have pale green or yellow leaves.

## Potassium deficiency

Firing or drying at tips and along leaf edges (oldest leaves affected first); leaf edges ragged; iron accumulation in joints; weak stalks and excessive lodging; short internodes; poorly filled ear tips; chaffy nubbins (starchy, dull-colored kernels); roots weak (rot off); slow maturity (Figures 5 and 6).

Figure 5. Corn with potassium deficiency is stunted and easily lodged. Photo: Gerald Bryan.

Figure 6. Potassium deficiency in corn causes bronzing and yellowing along edes of lower leaves.

## Phosphorus deficiency

Stunted, slow early growth; purplish stalks and leaf tips of young plants (may be characteristics of some varieties); weak stalks; shallow root system; delayed emergence of silks; imperfect pollination and barren stalks; missing rows of kernels on ears: small twisted or curved ears; retarded maturity (Figure 7).

Figure 7. Phosphorus-deficient corn plants sometimes have purple leaves.

## Zinc deficiency

Narrow yellow or white stripes between veins of upper leaves (Figure 8). Stripes may join together to form a bleached area between midrib and leaf margins, which remain green.

Figure 8. Zinc deficiency causes yellow stripes in the upper corn leaves.

## Magnesium deficiency

White or yellowish streaking or bleaching between leaf veins; mainly on lower leaves. When rubbed, the affected tissue may reveal a distinctive slickness (Figure 9).

Figure 9. Magnesium-deficient corn will have white or yellow stripes on the lower leaves.

## Manganese deficiency

Leaves are mostly yellow, gradually becoming dark green next to veins; deficient plants are usually on dark sandy soils that tie up manganese. Foliar or banded applications of manganese fertilizer are used to minimize fixation (Figures 10 and 11).

Figure 10. Leaves on right are from manganese-deficient plants. Manganese toxicity is common on low-pH soils.

Figure 11. Manganese deficiency causes yellowing between veins.

## Boron toxicity

Leaves have scorched appearance and eventually fall off the plants (Figure 12).

Figure 12. Boron toxicity causes brown areas on soybean leaves.

## Potassium deficiency

Irregular yellow mottling on leaflet edges, drying and curling downward (older leaves affected first); dead leaf tissue falls away from leaf edges leaving ragged appearance; shriveled, poorly shaped seed; delayed maturity and poor yields (Figure 13).

Figure 13. Potassium deficiency in soybeans causes yellow areas along leaf margins between veins.

## Salt toxicity

Seasonal changes in soil moisture affect salt tolerance; plants may be healthy in spring; as soil becomes dry, salt causes plants to wilt and die; soil may have a white or light gray-colored crust on the surface (Figures 14 and 15).

Figure 14. Dead areas in this soybean field were caused by sodium toxicity.

Figure 15. White crystals on soil surface usually indicate toxic levels of sodium for soybeans. Photo: Steve Hefner.

## Potassium deficiency

Red or brown discoloration on tips and margins of leaves; severity of condition varies by variety; leaf symptoms usually develop after internode elongation (Figure 16).

Figure 16. Potassium-deficient rice will have yellow or brown areas on leaf tips and edges.

## Nitrogen deficiency

Poor tillering; leaves and stalks pale yellowish green with extreme yellowing of lower leaves on young plants; spindly stems and short heads; yellowing starts at leaf tip of older leaves; plants do not form a complete canopy over water; poor yields (Figures 17 and 18).

Figure 17. Nitrogen-deficient rice is pale green in color and does not form a full canopy.

Figure 18. Tools such as the plant area board (above) and the cholorphyll meter can be used to monitor the nitrogen status of rice.

## Zinc deficiency

Leaves begin to turn brown after flooding fields; plants float limply on the water surface instead of standing erect. If well water has calcium carbonate, the problem is most acute at the water inlet or other high pH locations in fields; if the field is not drained quickly, rice plants will die (Figures 19 and 20).

Figure 19. Zinc deficiency causes flooded rice seedlings to starve for oxygen.

Figure 20. If the water is not drained from fields with zinc deficiency, rice plants will die.

## Phosphorus deficiency

Slow, dwarfed growth; may not be noticeable until sick plants are compared with healthy plants of the same age; abnormal bluish green color of foliage; slow maturity; poor yield and milling (Figure 21).

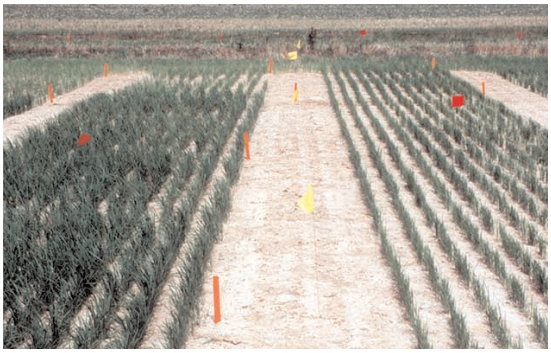


Figure 21. Rice plants on the right did not receive preplant phosphorus fertilizer.

## Nitrogen deficiency

Yellowish green foliage; older leaves dry up and shed prematurely; stunted growth; fruiting branches fail to develop (Figures 22 and 23).

Figure 22. Light green strips in this cotton field indicate poor distribution of nitrogen fertilizer.

## Magnesium deficiency

Magnesium deficiency causes purplish red leaves with green veins; symptoms late in season can be easily mistaken for normal aging; appears first in lower leaves (Figure 23).

Figure 23. Magnesium deficiency causes purplish leaves in cotton.

## Low soil pH

Poor germination and emergence; death of seedling plants; new leaves are "crinkled" as in thrips insect damage; yellowish green foliage color; limited and delayed fruiting; bending and collapse of leaf petioles; underdeveloped root system; delayed maturity (Figure 24).

Figure 24. Cotton grown on acid soil can have aluminum and manganese toxicity. The crinkle leaf symptom is often mistaken for insect damage. Photo: Mike Milam.

## Boron deficiency

First symptom is usually dark rings on leaf petioles; as the season progresses, some leaves may become deformed (Figure 25).

Figure 25. Chronic boron deficiency on cotton terminal. Photo: Woody Miley, Arkansas Cooperative Extension Service.

## Potassium deficiency

"Rust" starts with yellowish white mottling of leaves; tip and margin of leaves scorch and curl downward; whole leaves turn reddish brown, die and shed prematurely; dwarfed immature bolls; plants are more susceptible to wilt diseases (Figures 26 and 27).

Figure 26. Cotton leaves with potassium deficiency have yellow or bronze edges.

Figure 27. Potassium deficiency in cotton at midbloom.

## Potassium deficiency

The leaves of wheat with potassium deficiency are yellow or brown along the tips (Figure 28). Potassium deficiency in wheat is difficult to diagnose without supporting tissue test results. Symptoms from K deficiency are similar to symptoms caused by disease and injury from blowing sand (Figure 29).

Figure 28. Leaves with yellow tips becoming scorched along the edges indicate potassium deficiency.

Figure 29. Blowing sand can cause scorched leaf tips resembling potassium deficiency, but the rest of the plant will usually be of normal size and color.

## Sulfur deficiency

Sulfur deficiency in wheat usually occurs on sandy soils with low organic matter. Wheat plants with low sulfur have pale green leaves and fail to "green-up" when more nitrogen fertilizer is applied. Tissue testing is usually needed to distinguish between nitrogen and sulfur deficiency (Figure 30).

Figure 30. Wheat leaves with pale green or yellow color indicate sulfur deficiency.

## Nitrogen deficiency

Wheat plants with nitrogen deficiency have reduced plant height and produce fewer tillers than healthy plan. Leaf color in nitrogen-deficient plants is pale green or yellow, resembling the symptoms of sulfur deficiency (Figure 31).

Figure 31. Nitrogen-deficient wheat is stunted with yellow leaves.

## Phosphorus deficiency

Mild phosphorus deficiency in wheat can only be characterized by stunted growth with no distinct leaf symptoms. In severe cases, phosphorus-deficient plants become purple or brown (Figure 32).

Figure 32. Stunted wheat plants with purple leaves and dead leaf tips are signs of phosphorus deficiency.

## Potassium deficiency

Yellow leaf color in alfalfa may be caused by potassium deficiency. This deficiency begins at the bottom of the plants with small white spots on leaf edges. As potassium deficiency progresses, the tissue between the spots turns yellow or brown and the leaves become ragged. Second and third cuttings are usually affected the most by potassium deficiency (Figure 33).

Figure 33. White spots on edges of lower alfalfa leaves are caused by potassium deficiency; as plants get older leaves turn yellow.

## Phosphorus deficiency

Alfalfa plants with phosphorus deficiency have retarded growth and small leaves (Figure 34).

Figure 34. Stunted alfalfa growth caused by phosphorus deficiency.

## Boron deficiency

The deficiency of boron is more common in alfalfa than in other legumes. The upper leaves develop a reddish yellow rosette appearance (Figures 35 and 36). Injury from potato leafhopper is often confused for boron or potassium deficiency (Figure 37).

Figure 35. Boron deficiency causes yellow areas in alfalfa fields.

Figure 36. Closeup of boron-deficient alfalfa.

Figure 37. Leafhopper injury can be confused with boron deficiency but causes a yellow “V” at the tip of a leaf.

# PLANT TISSUE TESTING

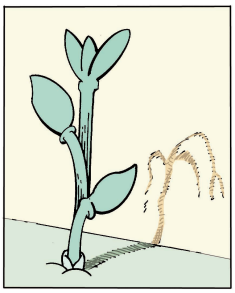


Figure 38. "Hidden hunger," caused by mild nutrient deficiencies, can be detected only by soil or tissue analysis.

Soil testing is the foundation of a sound nutrient management program and will help prevent the development of crop nutrient deficiencies. Soil and plant testing are also valuable diagnostic tools when possible nutrient deficiency symptoms are seen. Similar visual symptoms may be caused by different nutrient deficiencies or toxicities and by herbicide injury, diseases, insect damage or environmental conditions. As a result, diagnosis based on symptoms alone is much less reliable than diagnosis based on symptoms plus additional evidence, which may include soil test results, plant tissue test results or knowledge of other factors that are associated with deficiencies of particular nutrients (see Table 2).

Plant tissue testing is the most accurate of all diagnostic tools for nutrient deficiencies, particularly when paired samples are taken. Plants with possible deficiency symptoms should be compared with nearby plants that appear to be healthy.

Tissue testing is also the only way to detect "hidden hunger." Mild nutrient deficiencies may not produce obvious visual symptoms, such as leaf yellowing or chlorosis. However, significant reductions in crop yields can occur with these deficiencies. Steps for successfully using tissue tests are shown in the box below.

**Table 2. Environmental conditions associated with selected crop nutrient deficiencies.**

| Nutrient | Conditions favoring deficiency |
|---|---|
| **Macronutrients** | |
| Nitrogen | • Wet currently, or wet since fertilizer application<br>• Surface application of urea<br>• Broadcast N solution on high-residue surface |
| Phosphorus | • High or low soil pH<br>• High soil clay content |
| Potassium | • Dry or wet soil<br>• Compacted soil |
| Sulfur | • Sandy soil low in organic matter<br>• Cool, wet weather |
| **Micronutrients** | |
| Zinc | • Very low soil organic matter (terrace channels, cut areas in leveled fields)<br>• Cool, wet weather<br>• High soil pH |
| Iron | • High soil pH |
| Manganese | • High soil pH |

## Sampling plant tissue

Nutrient analysis of plant tissue at different growth stages is a major tool for determining which nutrients are limiting growth. Plant monitoring with tissue testing is especially important with high value crops. Plant nutrient content will vary depending on the type of plant being sampled, the specific plant part sampled, and the stage of growth of the plant.

Tables 3 and 4 provide guides for suggested stages of growth and plant parts to sample for

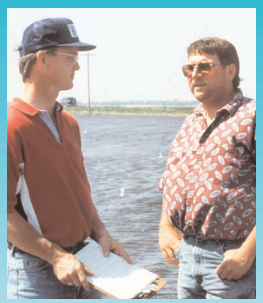
## Five steps in plant tissue testing

1. Determine correct plant part to sample and how many plants to sample (see Table 3). Collect samples from affected plants and from nearby healthy plants.

2. Handle samples properly after collection to avoid contamination and potential molding.

3. Clearly label all sample bags and maintain records of sampling date, field name or number and any other identifying information.

4. Complete plant sample information forms for submission of samples to your regional soil and plant testing laboratory.



5. Maintain records of plant tissue test results and consult regional and local extension agents if you have questions about the results and the test interpretations.

**Table 3. Guide for plant sampling of selected agronomic crops.**

| Plant | Stage of growth | Plant part | Number of plants to sample |
|---|---|---|---|
| Corn | Seedling (<4 inches in height) | Whole aboveground plant | 20–30 |
| | Early growth (>4 inches in height to tasseling) | Entire leaf fully developed below the whorl | 15–25 |
| | Tasseling/bloom | Earleaf | 15–25 |
| | Maturity | Earleaf | 15–25 |
| Soybean | Seedling | Whole aboveground plant | 20–30 |
| | Early growth and flowering | Most recently matured trifoliate leaves | 20–30 |
| Small grains | Seedling to tillering | Whole plant | 50–60 |
| | Before heading | Upper 1/3rd of plant | 50–60 |
| Alfalfa | Before bloom (1/10th bloom) | Top 6 inches or top 1/3 | 40–50 |
| | Harvest | Top 6 inches or top 1/3 | 40–50 |
| Sorghum | Head fully emerged but before pollination | Most recently matured and fully expanded leaves | 15–25 |
| Cotton | First square to midbloom | Fourth petiole from the top of plant | 30–40 |
| Rice | First tiller (preflood) | Whole aboveground plant | 25–35 |

**Sources**:
Campbell, C.Ray (ed.) 2000. Reference sufficiency ranges for plant analysis in the Southern Region of the United States. Southern Cooperative Series Bulletin #394, Raleigh, N.C.
Mills, Harry A., and J. Benton Jones, Jr. 1996. Plant Analysis Handbook II, MicroMacro Publishing, Inc., Jefferson City, Mo.

**Table 4. Guide for plant sampling of selected vegetables, fruits and trees.**

| Plant | Stage of growth | Plant part | Number of plants to sample |
|---|---|---|---|
| Apples | July 15 to August 15 | Leaf from middle of current terminal shoot | 60 |
| Asparagus | Mature fern (August) | Fern from 17 to 35 inches up | 20 |
| Beans, snap | Initial flowering | Young mature trifoliate | 50 |
| Beans, table | Mature | Young mature leaf | 20 |
| Blueberries | First week of harvest | Young mature leaf | 50 |
| Broccoli | Heading | Young mature leaf | 15 |
| Cabbage | Heads, 1/2 grown | Young wrapper leaf | 15 |
| Cantaloupe | Early fruiting | Fifth leaf from tip | 25 |
| Carrots | Midgrowth | Young mature leaf | 25 |
| Cauliflower | Buttoning | Young mature leaf | 15 |
| Celery | Half-grown | Young mature leaf | 20 |
| Cherry | Summer | Mature leaves from new growth | 50 |
| Cucumbers | Early fruiting | Fifth leaf from tip | 20 |
| Grapes | Flowering | Petiole from young mature leaf | 75 |
| Lettuce | Heads, 1/2 size | Wrapper leaf | 20 |
| Onions | Midgrowth | Top, no white portions | 25 |
| Peaches/nectarines | Spring at fruit set | Midshoot leaf | 20 |
| Peas | First bloom | Recently matured leaflet | 50 |
| Pecan | 56–84 days after terminal bud set | Leaflet pairs from new growth | 25 |
| Peppers | Early fruiting | Young mature leaf | 20 |
| Plum | Summer | Whole leaf from midshoot growth | 25 |
| Potatoes | 40–50 days after emergence | Young mature leaf | 20 |
| Pumpkin/squash | Early fruiting | Young mature leaf | 15 |
| Radishes | Midgrowth to harvest | Young mature leaf | 40 |
| Raspberries | First week in August | Leaf 18 inches from tip | 50 |
| Spinach | 30–50 days old | Young mature leaf | 35 |
| Strawberries | At flowering | Young mature leaf | 20 |
| Sweet corn | Tasseling to silk | Ear leaf | 10 |
| Tomatoes | First mature fruit | Young mature leaf | 20 |
| Walnut (black) | Summer | Mature leaf from new growth | 5 |
| Walnut (English) | Summer | Center leaflet from mature leaf | 25 |
| Watermelons | Midgrowth | Young mature leaf | 15 |

common agronomic and horticultural crops in Missouri. When the recommended plant part is sampled at the designated stage of growth, the soil and plant testing laboratory can compare the results of the tissue test with established nutrient sufficiency ranges for the crop.

If specific sampling instructions are not found in the selected crops, the rule of thumb is to sample upper, recently matured leaves. The recommended time to sample is just before the beginning of the reproductive stage for many plants. More specific information on plant tissue sampling procedures and available nutrient sufficiency ranges can be obtained by consulting your regional soil and plant testing laboratory.

In sampling plants for tissue testing, it is critical to obtain a representative sample. Take separate plant samples from an area in which plants are growing well and from another area in which the plants are affected by a suspected nutrient disorder. This comparison can assist in diagnosing specific nutrient problems, especially when nutrient sufficiency ranges are not available for a specific crop, growth stage or plant part. Plant tissue samples from one plant may not be representative of all the plants in a field with a similar problem. To obtain a representative sample, avoid collecting plants that have insect damage, are infested with disease, are covered with dust or soil or foliar-applied sprays, or are border row plants. If possible, take random plant samples from several plants distributed throughout the affected area of the field.

**Sample Plant Testing Report**

**MU Extension**

**Soil and Plant Testing Laboratory**
**Department of Agronomy**
**University of Missouri**

**23 Mumford Hall**
**Columbia, MO 65211**
**Phone (573) 882-0623**
**Fax (573) 884-4288**

**Plant Analysis Report**

To: John Doe
1000 Anywhere St.
Anywhere, MO 64506
Phone: 111-222-4444
Fax:

Date received: 05/26/00
Date completed: 06/02/00
Lab No: 200345
Sample ID:

Crop: Corn
Sampling Time: 12"
Plant Part: top plant

Firm:
Outlet:
File Name: mark1.doc

| Elements | Content | Sufficiency Range | Nutrient Level Position Low | Optimum | High |
|---|---|---|---|---|---|
| Nitrogen (N) | 3.73 % | 3.50 – 5.00 % | | x | |
| Phosphorus (P) | 0.32 % | 0.30 - 0.50 % | | x | |
| Potassium (K) | 0.61 % | 2.50 – 4.00 % | x | | |
| Calcium (Ca) | 0.85 % | 0.30 – 0.70 % | | | x |
| Magnesium (Mg) | 0.71 % | 0.15 – 0.40 % | | | x |
| Zinc (Zn) | 34 ppm | 20 – 60 ppm | | x | |
| Iron (Fe) | 401 ppm | 50 - 250 ppm | | | x |
| Manganese (Mn) | 108 ppm | 20 – 300 ppm | | x | |
| Copper (Cu) | 19 ppm | 5 – 20 ppm | | x | |
| Sulfur (S) | | 0.15 - 0.50 % | | | |
| Boron (B) | | 5 - 25 ppm | | | |

**RECOMMENDATIONS:**

The corn plant sample tested low in potassium (K). The accompanying soil sample tested had a medium level of soil test K. The K deficiency symptoms are favored in wet and compacted soils or dry soils. The drought that prevailed in the state during the early growth period of corn is most likely the cause for K deficiency. Even though the soil test recommends 30 lbs of $K_2O$/ac, applying 50 to 60 lbs of $K_2O$/ac as a side dress application would be beneficial.

Manjula V. Nathan, Director- MU Soil & Plant Testing Laboratory

## Submitting samples for testing

Remove any soil or foreign matter on the collected plant material by wiping with a clean damp cloth or rinsing directly with water while the material is still fresh. Place the collected plant tissue samples in a clearly labeled paper bag. If the plant part is collected and stored in plastic bags for more than several hours, be sure to refrigerate it to prevent the plant material from molding. Air dry the plant sample for 12 to 24 hours before mailing it in an envelope or dropping it off at your regional soil and plant testing laboratory or extension office.

Maintain records of the sampling date, field location, submission date to the soil and plant testing laboratory and any prior results of tissue or soil testing. These records will help you to keep track of your samples and assist you in monitoring the effectiveness of your fertility management program over time.

Your regional soil and plant testing laboratory will have forms for submission of samples for plant tissue testing (see the Plant Analysis Information Form for the University of Missouri Soil and Plant Testing Laboratory, page 18). Providing the requested information on the forms is crucial for interpreting analytical results from plant tissue testing. You may wish to consult your local or regional extension agent or the soil and plant testing laboratory as to the appropriate analytical tests for your situation.

## Interpreting the test report

You will be sent your plant sample test results within about five working days after the MU soil and plant testing laboratory receives your plant samples (times may vary for other labs). An inter-

pretation of the results will also be included based on crop and management information, available nutrient sufficiency ranges, available soil test information, and (when paired samples are submitted) comparison of test results from affected and healthy areas (see the example of a plant tissue test report on page 14).

The sufficiency level for a particular nutrient may depend on genetic and environmental factors. The sample from the healthy area of your field establishes the tissue nutrient levels needed for healthy plants, given the genetics, soil type, and weather specific to your field.

Only nutrients with substantially different test levels between the affected and healthy areas should be considered as possibly deficient and contributing to the observed symptoms. If the observed symptoms are typical for a particular nutrient deficiency, and if the tissue levels are higher for that nutrient in the healthy area than in the affected area, then deficiency of that nutrient is strongly indicated. For example, if browning of the edges of older (lower) leaves is observed, and tissue potassium levels are higher in healthy plants than in affected plants, then potassium deficiency is a solid and convincing diagnosis.

If you do not submit healthy plants, the results from your affected plants will instead be compared with a large database of tissue test results for your crop to determine which nutrients may be deficient or excessive. Once a diagnosis of nutrient deficiency is made, the appropriate nutrient may be applied immediately or for the next growing season. Your local or regional extension specialist can assist you in understanding the report and determining its significance for your future management.

# DIAGNOSING NITROGEN NEED FROM PLANT COLOR

Nitrogen is one of the most commonly deficient plant nutrients because large amounts of this element are required to produce amino acids and proteins in the tissue and because nitrogen is easily lost from the soil during wet conditions. Nitrogen-deficient crops are lighter green in color than healthy crops. The lighter the green, the more severe the deficiency and the more nitrogen fertilizer will be required to correct the deficiency. Crop color can be used as a guide to how much fertilizer to apply to correct deficiencies.

There is also pressure, for environmental reasons, to reduce overapplication of nitrogen fertilizer. Diagnosing nitrogen need from plant color has the potential to give accurate nitrogen rate recommendations that will ensure optimal crop yield while reducing overapplication of N.

## Measuring greenness

The simplest way to measure plant color is by visual comparison to a color scale. The University of California has developed a leaf color chart to measure the “greenness” of crops (Figure 39), and has developed interpretations of the color chart to guide midseason nitrogen applications for rice.

Crop color can also be measured using instruments designed for this purpose. This approach may allow greater sensitivity to small differences in color, as well as making it easier to collect enough color information to get a good field average. It can also be used to characterize the spatial variability of crop color in support of variable-rate nitrogen applications. Several differ-

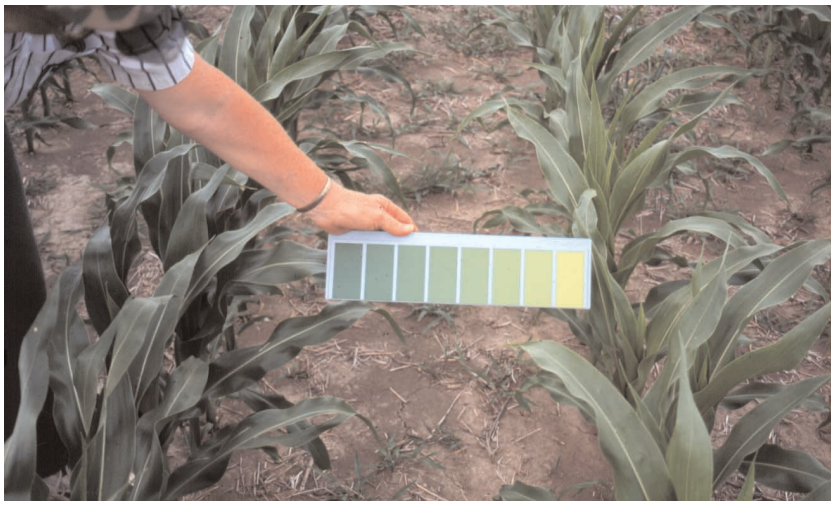


Figure 39. Visual rating of "greenness" of corn plants with leaf color chart (scale 1 to 8). The row on the right did not receive nitrogen fertilizer. Preplant nitrogen fertilizer was applied in the left row.

Figure 40. SPAD chlorophyll meter.

Figure 41. Hand-held devices such as a SPAD chlorophyll meter can be used to monitor the nitrogen status of crops.

ent types of instruments can be used in measuring crop color. One of the simplest is the Minolta SPAD chlorophyll meter, a portable hand-held device that clamps over a leaf (Figures 40 and 41). This meter measures transmittance of red and infrared light through the leaf and displays a number that is proportional to the nitrogen and chlorophyll concentrations in the leaf. As with soil or tissue samples, numerous measurements spread out evenly over the sample area must be taken to get a reliable average. Several states have developed or are developing interpretations to convert meter readings to nitrogen fertilizer recommendations.

## Radiometry

A spectral radiometer can also be used to measure crop color. Most spectral radiometers measure light intensity over a range of visible and near-infrared light wavelengths. One advantage of spectral radiometers, relative to the chlorophyll meter, is that they can be mounted on nitrogen applicators (Figure 42). The color measurements then represent a much larger amount of plant tissue, can capture spatial patterns in crop color, and can be used to guide variable-rate nitrogen applications. Norsk Hydro manufactures a system based on this concept for variable-rate nitrogen applications to small grains.

The disadvantage of spectral radiometers is that their readings are sensitive to sunlight intensity, sun angle, cloud cover and interaction of sun angle with plant geometry. A radiometer positioned to measure the intensity of incoming light, as well as the light reflected from the crop, helps to correct for these variations. Additional advances in these areas will improve the quality of the nitrogen recommendations from spectral radiometers.

Figure 42. A spectral radiometer mounted on a variable-rate applicator can reduce overapplication while delivering nitrogen fertilizer where it is needed.

Figure 43. Aerial images can assist in detecting crop stresses, including nutrient deficiency. In Missouri, nitrogen deficiency and waterlogging are the main causes of yellow-green corn.

## Aerial imagery

Aerial images acquired with film or with digital image capture from satellites or airplanes provide another way to measure crop color (Figure 43). This approach is particularly well suited for detecting for nitrogen deficiencies, because large areas can be examined quickly. Images are also well suited for detecting spatial patterns of nitrogen deficiency and producing variable-rate nitrogen recommendations. Experiments in Missouri have produced methods for interpreting images to produce nitrogen rate recommendations for corn, but capabilities for

acquiring and processing images and delivering results to producers in a timely manner remain limited. It may be difficult to detect nitrogen deficiencies from aerial images before the crop has a high percentage of ground cover.

Factors other than nitrogen deficiency can cause light-green or yellow-green coloration of crops. These factors include disease, insect damage, herbicide damage, and deficiencies of other nutrients. Automated sensors probably cannot detect the other features that allow the human eye to distinguish between these causes. Thus, these sensors are most suited to production systems in which nitrogen deficiency is by far the most common cause of light-green foliage. This would be the case when a main part of the crop's nitrogen fertilizer requirement is to be applied based on color measurements. Humid regions, with greater potential for nitrogen loss and deficiencies, will be more suited to these tools than semiarid regions. Soils with high pH may be less suited for these types of color measurements because of relatively common micronutrient (iron, manganese, zinc) deficiencies that cause a light green or yellow-green color in the crop.

## Other field quick tests

New technology and the need for rapid in-field plant testing results have stimulated an interest in "quick test kits" for determining plant nutrient deficiencies. These kits often have the advantages of being portable, less expensive than standard laboratory methods, and suitable for use by growers and consultants without extensive laboratory training.

Extensive research has been conducted, especially among horticultural crops, on several quick test procedures, including the measurement of nitrate and potassium in plant sap as indicators of plant nitrogen and potassium nutrition. Concentrations of nitrate and potassium are usually measured with an ion-selective electrode (for example, the Horiba Cardy® nitrate or potassium meters, Figure 44) or by use of colorimetric test strips (for example, Merckoquant® nitrate test strips). With the ion-selective electrode, nitrate or potassium concentrations are determined based on readings from standard solutions of known concentrations. For test strips, a calibrated color chart or a strip color reader can be used to estimate the color intensity, which is then converted to nutrient concentrations based on information supplied with the kit.

Figure 44. Using a Cardy® meter to test nitrate in cotton plants begins with extracting sap from cotton petioles with a garlic press.

Among the disadvantages of quick test kits is their sensitivity to differences in types of plants, sample handling, and the time of day when samples are taken. For example, time of day, temperature and cloudiness can affect the concentration of nitrate in plant sap and the calibration of the instrument. For consistent results, samples should be collected at a standard time of day (10 am to 2 pm) and taken indoors for analysis or in a shady area away from direct sunlight and wind. For woody plants, such as cotton, collecting sufficient sap to test can be a problem. Often it helps to freeze the sample briefly because freezing breaks down the cell walls and releases a larger volume of sap.

The usefulness of quick tests for plant nutrient management depends on the availability of research-based information for interpreting nutrient concentrations in plant sap for specific crops. In Misssouri, research is being conducted for developing interpretation information for nitrogen and potassium readings from the Cardy® meter for cotton. Interpretation tables should provide information that shows the ranges of deficient and sufficient nutrient concentrations for plant sap for the specific plant part and growth stage of the sampled crop.

Other disadvantages of many quick test kits are a lack of quality control (e.g., use of standards and blanks to ensure the test procedure is working), dependence on a single supplier for new reagents and replacement parts for the kit, and the effects of improper storage on the viability of chemicals or strips used in the procedures.

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# Plant Analysis

Soil and Plant Testing Laboratory
23 Mumford Hall, University of Missouri
Columbia, MO 65211
573-882-0623 Fax: 573-884-4288

(Please type or print)
Date Sampled _____/_____/_____

Lab # _____ Lab Use Only
Date Received

Name _____
Address _____
_____
(City) (State) (zip code)
Tel:_____ Fax:_____
e-mail address_____
County to be billed & Code_____

Firm submitting _____
Address _____
_____
(City) (State) (zip code)
Tel:_____ Fax:_____
e-mail address_____
Firm # _____ Outlet #_____

**Sample identification** _____
**Field I.D.** _____
**Stage of Growth** _____
**Moisture** _____
**When last limed** _____
**Position on landscape**_____
**Fertilizer applied** _____
_____

**Crop** _____
**Previous Crop** _____
**Accompanied by soil sample?** Yes_____ No_____
If Yes: Serial # _____
**Soil Test Results**
N_____P_____K_____Ca_____
Mg_____pH_____OM_____CEC_____
Other:_____

**Description of problem:**

| Check Tests Desired for this sample | | Analysis Cost | Total Cost |
|---|---|---|---|
| | **Regular Analysis**: Nitrogen, phosphorus, potassium, calcium and magnesium + drying and/or grinding | $17.00 | |
| | **Micronutrients: (with regular analysis)** Fe, Zn, Cu, Mn | $6.00 ($1.50 per micro-nutrient) | |
| | **Analysis Package: (Regular+Micronutrients+Boron)** N, P, K, Ca, Mg, Fe, Cu, Zn, Mn, B | $25.00 | |
| | **Individual analyses (per nutrient)** | | |
| | Nitrogen (TKN) | $10.00 | |
| | Phosphorus (P) | $5.00 | |
| | Potassium (K) | $5.00 | |
| | Calcium (Ca) | $4.00 | |
| | Magnesium (Mg) | $4.00 | |
| | Iron (Fe) | $4.00 | |
| | Copper (Cu) | $4.00 | |
| | Manganese (Mn) | $4.00 | |
| | Zinc (Zn) | $4.00 | |
| | Sulfate-S | $6.50 | |
| | Nitrate-N | $8.00 | |
| | Boron (B) | $5.00 | |
| | Chloride | $6.50 | |
| | Sample Grinding | $2.00 | |
| **Total Due for this sample** | | | |

We encourage a plant sample be taken from a poor growing area and compared to a sample from an adjacent normal area. **The testing fee for a good sample accompanying an abnormal sample will be analyzed at one-half the regular price.** Samples will be discarded after 30 days unless other arrangements are made. November 2000

## For further information

**Available from Extension Publications 1-800-292-0969**

**XPLOR [Extension Publications Library on Request]**
**on the Web at http://muextension.missouri.edu/xplor/**

EC929 – *Micro and Secondary Nutrients in Missouri*
G9110 – *How to Get a Good Soil Sample*
G9112 – *Interpreting Missouri Sil Test Reports*
G9174 – *Nitrogen in Missouri Soils*
G9175 – *Nitrogen Management for Conservation Tillage in Missouri*
G9180 – *Phosphorus in Missouri Soils*
G9185 – *Potassium in Missouri Soils*
G9804 – *Nitrate in Soils and Plants*
MP729 – *Use of a Portable Chlorophyll Meter to Manage Crop Nitrogen in Rice*
NCR326 – *Management of Urea Fertilizers*

**Other publications**

American Phytopathological Society. Nutrient Deficiencies and Toxicities of Plants CD-ROM. Web address for ordering: http://www.scisoc.org/apspress/

Bennett, William F. 1993. Nutrient Deficiencies and Toxicities in Crop Plants. American Phytopathological Society (APS). Web address for ordering: http://www.scisoc.org/apspress/.

Mills, Harry A., and J. Benton Jones, Jr. 1996. Plant Analysis Handbook II. Micro-Macro Publishing, Inc. Phone number for ordering: 1-800-500-4635, email for ordering: mmi@sockets.net.

Potash and Phosphate Institute. 1999. Nutrient Deficiency Symptoms CD-ROM. Phone number for ordering: (770) 447-0335, e-mail for ordering: Circulation@ppi-far.org.

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