Chapter 5 Foliar Testing and Sampling in Berry Crops, Visual Symptoms of Deficiencies - *Dr. Marvin Pritts, Cornell University*

Let's review

Soil testing is most useful prior to planting to adjust pH and nutrient levels. Leaf analysis is most appropriate once the planting is established. Determining what the plant itself has taken up is a more accurate assessment of nutrient status than estimating availability in soil using a chemical extractant, which only mimics what the root may take up from soil. Foliar testing is particularly important for perennial plants that may accumulate and store up nutrients over a period of years.

Foliar analysis – a simple principle

Foliar analysis is based on a simple principle where nutrient levels in the leaf tissue are compared to a pre-determined standard. Similar to a cholesterol test at the doctor's office, your level is compared to a normal range and if it's too high or too low, appropriate steps are taken to adjust it accordingly. Standard leaf nutrient ranges have been established for many crops including berry crops such as strawberries (*Table 14*).

Table 14. *Standard foliar nutrient ranges for strawberries*

Element	Range (PPM)	Element	Range (PPM)
Nitrogen (N)	2.0 – 2.8	**Manganese** (Mn)	50 - 200
Potassium (K)	1.5 – 2.5	**Iron** (Fe)	60 – 250
Phosphorus (P)	0.25 – 0.40	**Copper** (Cu)	6 - 20
Calcium (Ca)	0.7 – 1.7	**Boron** (B)	30 – 70
Magnesium (Mg)	0.3 – 0.5	**Zinc** (Zn)	20 – 50

What is the basis for these standard nutrient ranges? The analysis for leaf tissue, unlike soil analysis with its various extractants, is the same from lab to lab as it is based on inductively coupled plasma spectrometry (ICPS). A specified amount of leaf tissue is heated to really hot temperatures; the various minerals present in the tissue glow different colors as they are heated. The spectrophotometer measures the resulting color ranges, spectra, and intensities, correlating these with the amount of a specific element present in the tissue.

Nitrogen and sulfur are the exceptions to ICPS testing. These minerals are better tested using other methods including digestion and methods of quantifying amounts present such as colorimetric spectrophotometry, specific ion electrodes and/or combustion. Results from these methods are pretty closely correlated so not of concern. This is especially true for sulfur, particularly as it is rare to have a sulfur deficiency.

The most desirable method for nitrogen would be to determine the amount of biologically active nitrogen (NH_4+) as opposed to NO_3- or total N but determining NH_4+ is expensive ; the nitrate (NO_3-) concentration in plants is pretty low, thus using total N is the least expensive method for evaluating N and assuming it is highly correlated with the biologically-active NH_4+.

Standard tissue ranges used today are derived from healthy plants; they are not usually empirically derived. That means they are not a result of nutrient experiments where plant response is measured to various nutrient levels. To do this type of testing for each crop and nutrient would be entirely too time-consuming and expensive.

Instead, they are an average of those values obtained from testing a large pool of healthy leaf samples for a given crop.

When should leaf samples be taken?

It is important to note leaf samples should be taken at a time when leaf nutrient values are relatively stable. The time to sample is not when plants are growing rapidly in spring or when fruit expansion is ongoing as leaf nutrient levels may change rapidly during these times and not be representative. For strawberries, the best time to sample for leaf analysis is after harvest at renovation when the new leaves begin to grow in late July to early August. For either summer or fall-bearing raspberries, the best time for sampling would be in early August when most of the rapid plant growth is completed for both and summer raspberries have finished fruiting and fall raspberries haven't begun fruiting. For both it is best to sample leaves from primocanes. August is also the best time to sample blueberries for the similar reasons.

Which leaves should I select?

Select the most recently mature leaves for analysis are the best indicator of nutrient status. Older leaves are those produced during the period or rapid growth or fruit expansion and may not be representative. Collect 30 to 50 leaflets without petioles. Randomly sample the area of interest. This may be done on a diagnostic basis (plants not performing well or on a routine basis routine to document nutrient status. Choose young leaves exposed to sun.

How do I prepare collected leaves for analysis?

Rinse in distilled water to remove dust, soil or fungicide residues. Dry for a couple days in a brown paper bag before sending to the lab. There is no need for the leaves to be kept moist and/or green as they may begin the decomposition process in transit to the lab. They are routinely dried prior to testing so it's best to begin the drying process immediately. There's also no need for rapid drying using heat or fans; just room temperature drying on a non-metal surface will suffice.

Advantages and shortcomings of foliar testing

Foliar analysis offers some major advantages, not least of which is the standardization of analyses across labs. Foliar analysis is also a better indicator of nutrient status than a soil test. Additionally, it can identify a potential nutrient deficiency to be redressed ***before*** it results in visible symptoms or reduced growth and yield. Leaf analysis can also be used to help in crop diagnostics; often nutrient problems may have similar symptoms to those caused by diseases and/or pests; leaf analysis may be used to confirm or rule out deficiencies as a probable cause.

Some of the shortcomings of foliar testing, while relatively minor, include the fact it provides the total amount of an element, not the amount that is biologically active. Iron is probably one of the most important of these. For example, Fe++ is the active form for plants vs. Fe+++ which is not as biologically active; unfortunately the ICPS gives only a value for total iron. Thus there may be an iron deficiency occurring even when the leaf analysis indicates sufficient iron is present. Another shortcoming is that the prescribed sampling time of late July to early August when these elements are most stable may not be most ideal for all elements. Additionally, leaf analysis does not negate the need for a soil test; rather, an accompanying soil test is needed for leaf analysis results to be meaningful as they are soil pH dependent. And finally, leaf analysis does not measure interactions among elements that can affect activity and bioavailability. Examples of this include: 1) High potassium (K) levels in the plant decreases Magnesium (Mg) activity, 2) iron (Fe) and phosphorus (P) are antagonistic, 3) zinc (Zn) and phosphorus (P) are antagonistic and 4) Calcium (Ca) and iron (Fe) are antagonistic in blueberries.

A caveat to our discussion of nutrient deficiencies is that frequently more than one nutrient is deficient at a time. Usually the conditions that affect the level of a specific nutrient can impact multiple nutrients simultaneously. For example, a high pH from an improper lime application can induce deficiencies of iron, manganese, copper, boron, zinc and phosphorus.

The role of essential nutrients in plant growth and development

Nutrients play many roles in essential plant functions (*Table 15*). Potassium is the only one of these essential elements not directly incorporated into plants. Note however it is important in catalyzing more than 50 enzymatic reactions in plants, and in osmoregulation.

Table 15. *Essential elements in plants and their functions*

Element	Function
Nitrogen (N)	Amino acids; cation-anion balances; osmoregulation
Phosphorus (P)	DNA/RNA structure; energy transfer; metabolism
Potassium (K)	Osmoregulation; metabolism; enzyme activation (50+); photosynthesis
Calcium (Ca)	Cell walls; cell extension; enzyme modulation, vacuole pH
Magnesium (Mg)	Chlorophyll; protein synthesis; enzyme activation; vacuole pH
Manganese b	Oxygen evolution; enzyme activation
Iron (Fe)	Chloroplast development; redox systems; protein synthesis
Copper (Cu)	Strongly bound; lignification; enzyme activation; pollen formation
Boron (B)	Cell elongation; lignification; xylem differentiation; auxin activity
Zinc (Zn)	Root cell elongation; pollen germination

Other essential nutrients in plants are among the most recently discovered due to the difficulty in working with them in the small amounts required in a laboratory setting. These include Molybdenum, Chlorine and Nickel. Sodium, Selenium, Cobalt and Silicon are essential nutrients for some plants and/or plant families; but not for berry crops. In the case of Sodium and Selenium they may have a negative impact on berry crops if present in excess. Table 16 shows the relative concentrations for essential elements in plants.

Table 16. *Adequate relative concentrations of elements in healthy plant tissue.*

Element	Atoms	Element	Atoms
Nickel (Ni)	1	Silicon (Si)	30,000
Molybdenum (Mo)	1	Sulfur (S)	30,000
Cobalt (Co)	2	Phosphorus (P)	60,000
Copper (Cu)	100	Magnesium (Mg)	80,000
Zinc (Zn)	300	Calcium (Ca)	125,000
Sodium (Na)	400	Potassium (K)	250,000
Manganese (Mn)	1000	Nitrogen (N)	1,000,000
Boron (B)	2000	Oxygen (O)	30,000,000
Iron (Fe)	2000	Carbon (C)	40,000,000
Chlorine (Cl)	3000	Hydrogen (H)	60,000,000

One of the challenges of leaf analysis is coming up with a test that measures various elements across such a wide, wide range of concentrations. For example Nickel at 1 atom and Iron at 2,000, vs. Magnesium at 80,000 and Carbon at 40,000,000. We are fortunate to have technology capable of doing so today.

Visual symptoms of nutrient deficiencies

It is important to note that certain nutrients (N, P, K, Mg, and S) are extremely mobile in the plant; this characteristic can help diagnose visual symptoms that you might see. Mobile nutrients tend to move from leaves into the phloem and then to actively growing points; therefore older leaves exhibit deficiencies first. When older leaves exhibit odd colors or look strange and new leaves appear healthy then most often it's the result of a deficiency in N, P, K, Mg, or S. If you see the opposite, where younger leaves look oddly colored or showing deficiencies while older leaves look healthy, most likely it's one of the other essential micronutrients, not N, P, K, Mg, or S.

Table 17 below gives nutrient ranges for sap. Remember, xylem is what comes up from the roots into the leaf; phloem is what comes out of the leaves. For example, there may be no sugar in the xylem; but lots of sugar coming out of the phloem. Nitrate is the reverse of sugar in this respect. It moves from the soil water into the roots then the leaves; none of it comes out of the phloem during the growing season. Nitrate doesn't move through the phloem; in the leaf it's converted by nitrate reductase into amino acids and/or ammonium compounds.

Table 17. *Typical nutrient ranges for plant sap*

Element	Xylem (mg/L)	Phloem (mg/L)
Sugars	0	140,000 – 210,000
Amino Acids	200 – 1,000	900 – 10,000
Ammonium (NH_4+)	7 – 60	45 – 846
Nitrate (NO_3-)	1500 – 2000	0
Phosphorus (P)	70 – 80	300 – 550
Potassium (K)	200 – 800	2,800 – 4,400
Calcium (Ca)	150 – 200	80 – 150
Magnesium (Mg)	30 – 200	100 – 400
Boron (B)	3 – 6	100 – 400
Manganese (Mn)	0.2 – 0.6	0.9 – 3.4
Copper (Cu)	0.1 – 2.5	1 – 5

There has been some work on determining nitrogen needs by measuring petiole (xylem) sap concentrations of nitrate. This has been done particularly with strawberry to see if a good correlation exists. The problem is that nitrate sap concentration is not necessarily correlated with the amount of active N (amino acids and NH4- are in the phloem). The nitrogen is coming in, but not going out of the plant. Moreover, the nitrate concentration is very dependent on the water flow in the xylem; values change on a day–to-day basis. For this reason this test has not really caught on in perennial crops like berries, as it has in annual crops like corn (but see page 156).

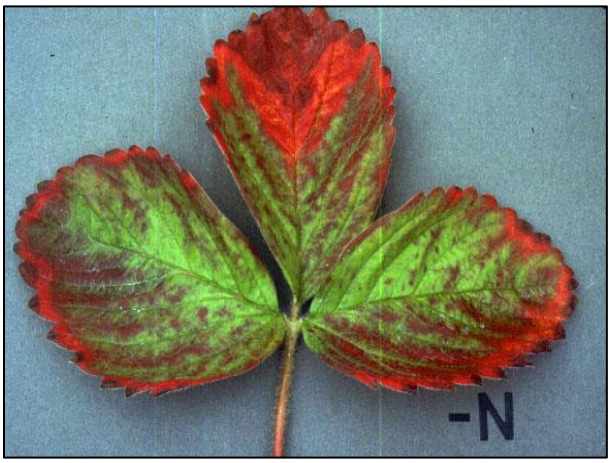
Phosphorus comes into the plant at a low concentration in the xylem and goes out of the leaf through phloem at a relatively high concentration, and is not very mobile. Potassium is very mobile, but calcium is not. When looking for deficiencies of Ca, they are found at the extremities of the plant.

Examples

Nitrogen deficiency. Nitrogen deficiency often appears on the plant as lighter green leaves; in the case of blueberries nitrogen deficient leaves are smaller, yellower in color (*Figure 9a*). Nitrogen deficiency in strawberries has a slightly different appearance (*Figure 9b*) with leaf yellowing moving into reddening.

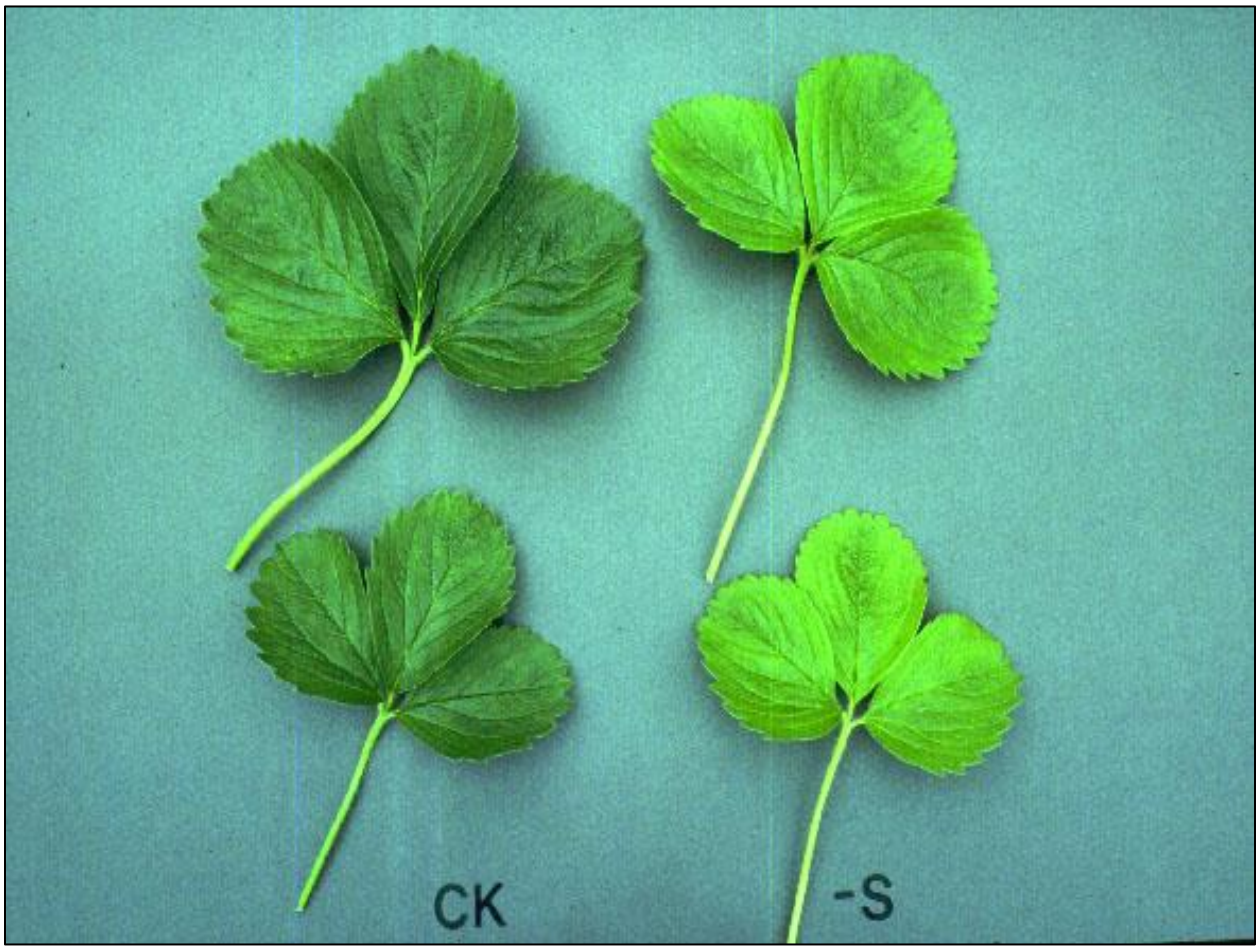
Figure 9a. *Blueberries (left) – healthy (left side of photo) vs. nitrogen deficient (right side of photo). Photo courtesy M. Pritts.*

Figure 9b. *Nitrogen deficient strawberries in complete nutrient solution minus N (left) and in the field, after harvest without N application, (right); note reddening in strawberries. Photos courtesy Michigan State Univ.*



Sulfur deficiency. Sulfur is a deficiency that mimics nitrogen (*Figure 10*); both are essential for amino acid formation. Sulfur and sulfates are ubiquitous in soils so sulfur is not a common deficiency. It occurs most frequently on very sandy soils with high rainfalls.

Figure 10. *Sulfur deficient strawberry leaves from plants in complete nutrient solution minus S (right) and in the complete nutrient solution plus S as a control (left). Photo courtesy M. Pritts.*



Phosphorus deficiency. P deficiency is characterized by darker green colored leaves with dark red coloration developing around leaf margins (*Figures 11a and 11b*). Not particularly common in the NE region where there is a

lot of dairy manure spread on fields. Symptoms will appear in the older leaves first. Note: during cold springs, blueberries often develop similar coloration; this disappears as temperatures warm. Do not mistake this for P deficiency in blueberries.

Figure 11a. *Phosphorus deficient strawberries in complete nutrient solution minus P. Photos courtesy M. Pritts.*

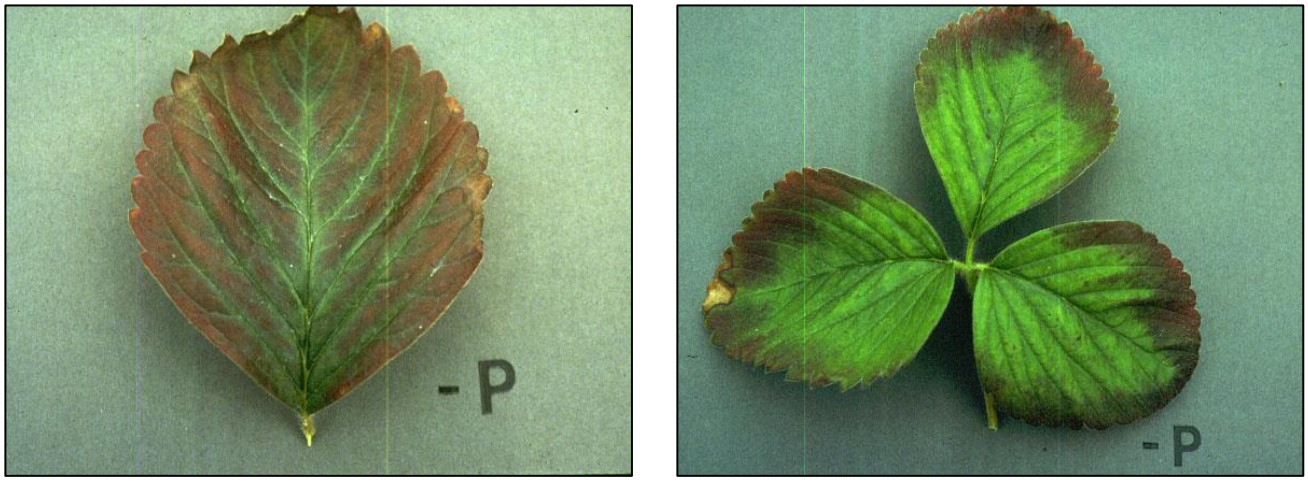
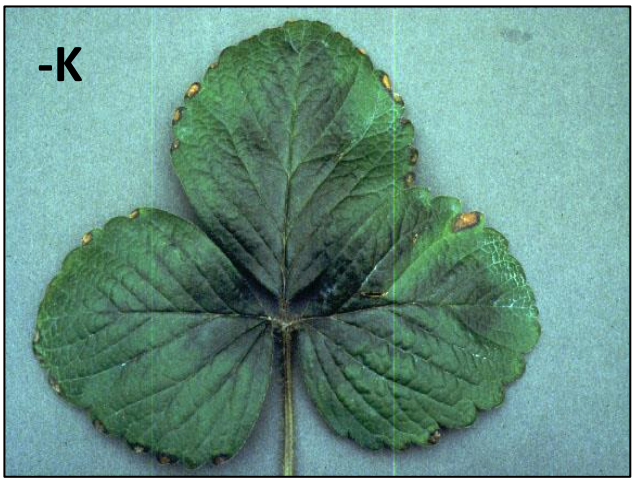


Figure 11b. *Phosphorus deficiency symptoms on blueberry in the field. Photo courtesy M. Pritts.*

Potassium deficiency. K deficiency is more common than P. Slight browning where leaflets attach to petioles is pone symptom of this deficiency. Another is leaves have a light and dark green blotchy appearance (*Figure 12a*); this is often followed by margin burning of leaves (*Figure 12b*). For blueberries, marginal burning is observed (*Figures 12c and 12d*). Remember symptoms will appear on older leaves first.

Figures 12a, 12b. *Potassium deficient strawberries in complete nutrient solution minus K (left) and in the field, (right).*



Figures 12c, 12d. *Potassium deficiency symptoms on blueberry in the field. Photos courtesy M. Pritts.*

Calcium deficiency. Symptoms of this deficiency (*Figures 13a, b, c*) include growing points of leaves turning brown and leaf cupping as leaf tips are not able to expand at same rate as older portion of leaves.

Figures 13a, b, c. *Strawberries with calcium deficiency; leaves (left), growing points (center), and runners (right). Photos courtesy M. Pritts.*

Another symptom to look for is growing points turn blackish brown even before new leaves begin to expand. The symptom to look on strawberry runners is necrosis/browning of runner tips. Calcium deficiency may sometimes result from irregular or lack of irrigation. New growth displays symptoms before older leaves.

Magnesium deficiency. Symptoms of magnesium deficiency are similar to those for calcium but Mg is more mobile in plant than Ca. Mg deficiency symptoms are characteristically interveinal in all plants; green veins with reddish interveinal areas (*Figure 14a*). On strawberry, note that there is no reddish interveinal color, but interveinal browning (*Figure 14b*). New growth displays symptoms before older leaves.

Figures 14a, 14b. *Blueberry leaf showing magnesium deficiency in the field (left), strawberry leaves from plants grown in complete media minus Mg showing deficiency symptoms (right). Photos courtesy M. Pritts.*

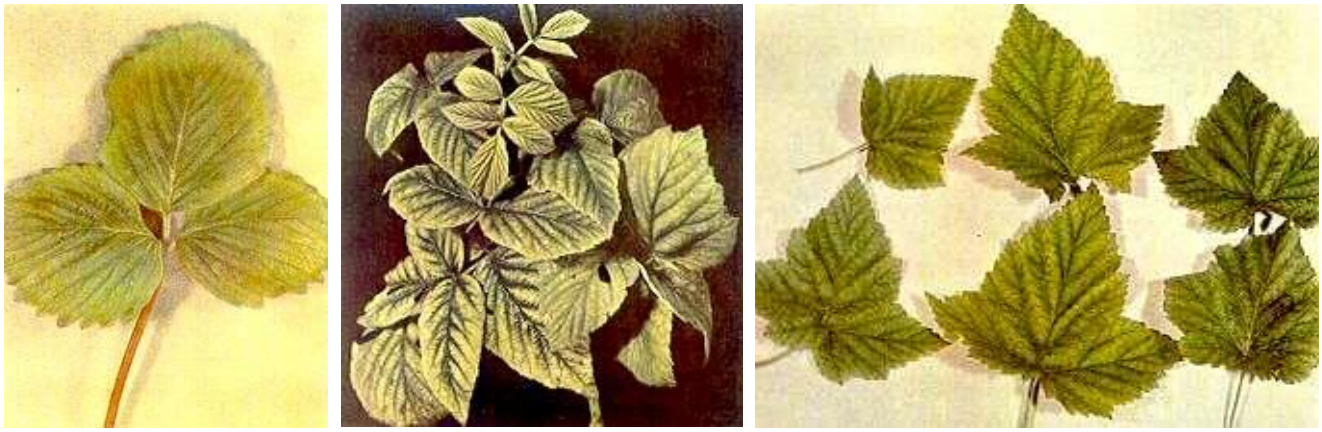
Iron deficiency. Iron deficiency shows up in the younger leaves while older leaves look fine. Yellowing associated with iron deficiency (aka "iron chlorosis") occurs in interveinal areas while the veins stay green (*Figures 15a, b, c*).

Figures 15a, 15b. *Iron deficiency symptoms in strawberry. Photos courtesy M. Pritts.*

Figure 15c. *Iron deficiency symptoms in blueberry. Photo courtesy M. Pritts.*

Manganese deficiency. This deficiency is not seen very much; when it does occur it is evident on younger leaves first. Mn deficiency symptoms are similar to those observed with iron deficiency but veinal areas are darker. This deficiency is often occurs under circumstances of too high pH; thus blueberries rarely show signs of this deficiency (*Figures 16a, 16b*)

Figures 16a and 16b. *Magnesium deficiency in strawberry (left), raspberry (center), and black currant (right). Photos courtesy: Wallace, T. 1951. The Diagnosis of Mineral Deficiencies in Plants by Visual Symptoms.*



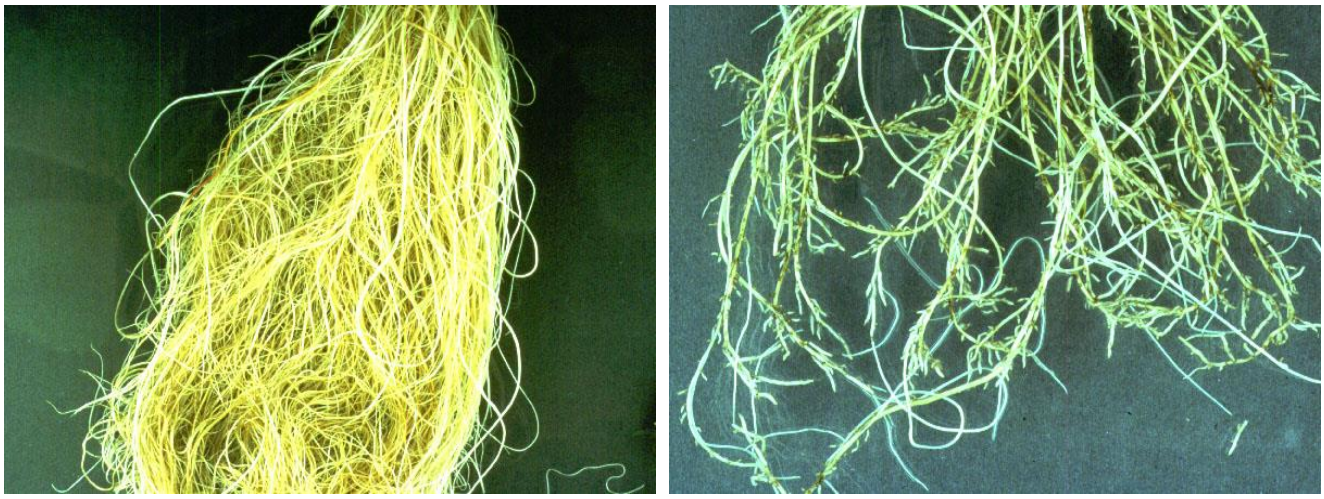
Zinc deficiency. Zn deficiency is common in tree fruit crops, particularly on sandy soils. Also known as "little leaf disease" as leaves tend to be smaller in size; internodes are shorter. Young leaves will appear yellowed and folded upward along the midribs. Zn deficiency is also characterized by interveinal yellowing similar to that of Fe deficiency. Zn deficiencies often occur when P is present in excess. (*Figure 16c*)

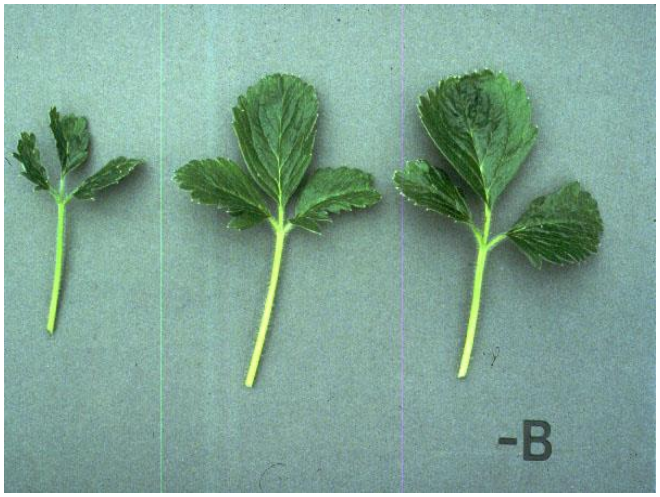
Figure 16c. *Zinc deficiency in a strawberry plant. Photo courtesy: Industry and Investment NSW.*

Boron deficiency. This is often a deficiency we see in NE soils. Often one we suggest to test for. Dieback in blueberries is similar to winter injury (*Figure 17a*). Why dieback? Boron is responsible for auxin production, stimulating root growth and elongation (*Figures 17b, 17c*). Thus root systems are compromised, other micronutrients also deficient. Another symptom in strawberry is asymmetrical leaflet growth (*Figure 17d*). Boron deficiency also may cause deformed fruits in strawberries; achenes excrete auxin; this process is boron limited (*Figure 17e*). Similar symptoms may also be caused by frost damage and/or tarnished plant bug feeding.

Figure 17a. *Boron deficiency symptoms in Maine blueberry field. Photo courtesy M. Pritts.*

Figures 17b, c, d, e. *Strawberry roots in complete medium with Boron (top left) and without boron (top right) +B, -B, strawberry asymmetrical leaflets, strawberry deformed fruit. Bottom left: strawberry leaves showing signs of boron deficiency; bottom right: strawberry fruits showing the same. Photos courtesy M. Pritts.*





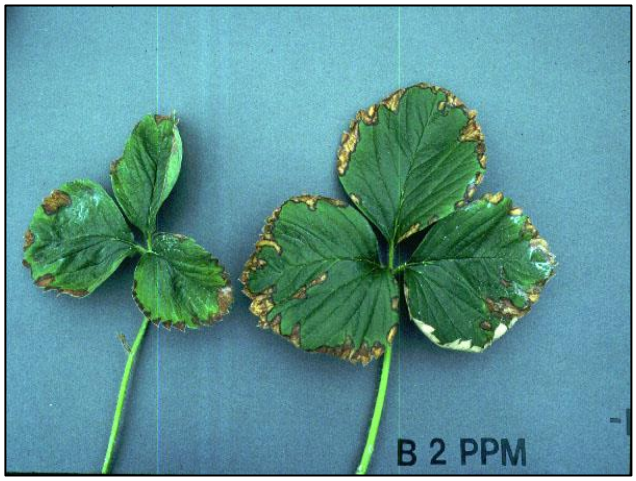
Don't be fooled!

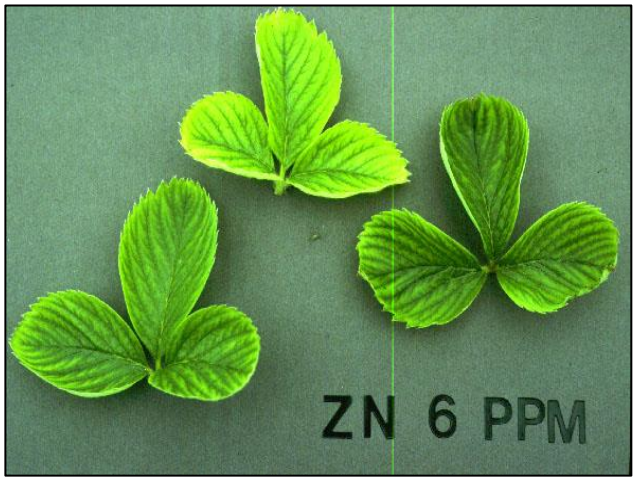
Herbicide toxicity symptoms often resemble nutrient deficiency symptoms (*Figures 18 a, b, c, d, f*). When symptoms occur, ask questions regarding history of herbicide applications in the planting. Note herbicide injury usually occurs in a regular pattern in the field (ends of rows, every third row where spray might overlap, near wet areas where tractors spin and too much herbicide deposited, etc.) Herbicide injury also usually has rapid onset. Nutrient deficiencies usually develop more slowly over time and often follow the soil type. Similar symptoms may have biological causes such as the mycoplasma that causes June Yellows (*Figure 18e*)

Figures 18a, b, c, d, e, f. *Roundup injury (top left), simazine injury (top right), Sinbar injury (center left), Solicam injury center right, June yellows (bottom left), Solicam injury (bottom right).*

It is important to recognize that over-fertilization can result in injury symptoms that may be confused with deficiency symptoms (*Figures 19a, b, c, d*).

Figures 19a, b, c, d. *Top left and right: Strawberries burned by application of too much ammonium nitrate (excess N); center left: excessive B, center right: too much Zn.*





Summary

A foliar elemental analysis is the best technology we have for assessing plant nutrient status; foliar test results need to be evaluated in conjunction with a soil analysis for accuracy of interpretation. One should try to address nutritional problems before visual symptoms occur. Visual symptoms of nutrient deficiencies are difficult to diagnose and can be confused with other causes.

Additional Resources

1. Pritts, M. and Heidenreich, C. 2012. *Cornell Berry Diagnostic Tool*. Available on line at: http://www.fruit.cornell.edu/berrytool/.
2. Wallace, T. 1943. *The Diagnosis of Mineral Deficiencies in Plants by Visual Symptoms*. Published by His Majesty's Stationary Office. Available on line at: http://customers.hbci.com/~wenonah/min-def/.
3. Domoto, P. 2011. *Recognizing and correcting nutrient deficiencies in strawberries*. Iowa State University Extension. Available on line at: http://www.iowaproduce.org/pages/fruit/files/strawberry/Strawberry_nutrition_guide.pdf