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USING PLANT ANALYSIS AS A DIAGNOSTIC TOOL[1/]

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The information provided through plant analysis helps farmers with decisions on fertilizer effectiveness, the need for additional nutrients, and planning fertilizer programs for future years. If used properly, plant analysis can be an important guide to efficient crop production because it provides a nutritional profile of the growing plant at the time that the sample was taken.

Essential Elements

Plants require 17 elements for normal vegetative growth and reproduction. In addition, there are some elements that improve plant growth in some situations but are not essential. Table 1 shows the main function of the essential elements and their primary sources. Different amounts of each element are required by different plant species. Plant growth is restricted when: 1) not enough of one or more elements is present; 2) too much of one or more elements is present, including toxic levels of nonessential elements such as aluminum, arsenic, selenium, or sodium; 3) the levels of one or more elements are adequate but out of balance with other elements.

The first result of nutrient deficiency, toxicity, or imbalance is a reduction in plant growth. If the condition persists, visible symptoms of deficiency or toxicity appear, and plant yield is reduced even further. A nutrient deficiency or imbalance may result in a yield reduction without showing visible symptoms but is detectable by plant analysis.

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Table 1. Concentration, function, and primary source of essential plant elements.

Element (chemical symbol)	Approximate concentration in plants	Main function in plants	Primary sources
		Essential plant nutrients	
Carbon (C)	45%	Part of all organic compounds	Carbon dioxide in air
Hydrogen (H)	6%	Forms main structural components	Water
Oxygen (O)	43%	Forms main structural components	Water, air
Nitrogen (N)	1-6%	Components of proteins, chlorophyll, nucleic acids	Soil organic matter; microbial fixation of atmospheric nitrogen (legumes)
Phosphorus (P)	0.05-1%	Energy transfer; metabolism, nucleic acids, phospholipids	Soil organic matter, soil minerals
Potassium (K)	0.3-6%	Protein synthesis; translocation of carbohydrates; enzyme activation; universal cation	Soil minerals
Calcium (Ca)	0.1-3%	Structural component of cell walls; cell elongation; affects cell permeability	Soil minerals, limestone
Magnesium (Mg)	0.05-1%	Component of chlorophyll; enzyme activator; metabolism; cell division	Soil minerals; dolomitic limestone
Sulfur (S)	0.05-1.5%	Constituent of proteins; involved in respiration and nodule formation	Soil organic matter; rainwater
Iron (Fe)	10-1000 ppm	Chlorophyll synthesis; oxidation-reduction reactions; enzyme activator	Soil minerals; soil organic matter
Manganese (Mn)	5-500 ppm	Oxidation-reduction reactions; nitrate reduction; enzyme activator	Soil minerals
Copper (Cu)	2-50 ppm	Enzyme activator; nitrate reduction; respiration	Soil minerals; soil organic matter

Table 1. (continued).

Element (chemical symbol)	Approximate concentration in plants	Main function in plants	Primary sources
		Essential plant nutrients (continued)	
Zinc (Zn)	5-100 ppm	Enzyme activator; regulates pH of cell sap	Soil minerals; soil organic matter
Boron (B)	2-75 ppm	Cell maturation and differentiation; translocation of carbohydrates	Soil organic matter; tourmaline
Molybdenum (Mo)	0.01-10 ppm	Nitrate reduction; fixation of atmospheric nitrogen by legumes	Soil organic matter; soil minerals
Chlorine (Cl)	0.05-3%	Photochemical reactions in photosynthesis	Rainwater
Nickel (Ni)	0.1-10 ppm	Metal component of urease; seed fertility	Soil minerals
		Enhancing or beneficial nutrients	
Sodium (Na)	0.05-2%	Influences mesophyll chloroplasts of come C_4 halophytes; substitutes for K; increases cell expansion	Soil minerals
Silicon (Si)	0.1-10%	May affect spikelet fertility of some species; contributes to cell wall stability	Soil minerals
Cobalt (Co)	0.01-10 ppm	Nitrogen fixation, component of vitamin B_{12}	Soil minerals
Selenium (Se)	2-1000 ppm	Component of enzyme co-factor responsible for peroxide in animals; essential for animals; insect defense	Soil minerals
Aluminum (Al)	10-1000 ppm	May alleviate toxicities from other elements	Soil minerals

What is Plant Analysis

Plant analysis is the quantitative determination of many of the essential nutrients in plant tissue. Carbon, hydrogen, and oxygen are not analyzed routinely because they come from air or water and plant analysis is not helpful for these elements. Chlorine is normally sufficient under field conditions, but it may become excessive in saline soils. It is usually analyzed in special cases only. Similarly, molybdenum and nickel deficiency or toxicity are rare, and these elements are not analyzed routinely. Thus, plant analysis usually refers to analysis of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and boron (B). Aluminum (Al) and sodium (Na) are sometimes included even though they are not essential elements. Aluminum can be toxic in very acid soils, and sodium can improve the quality of some crops such as beets and celery.

Plant analysis is distinguished from tissue testing in that it is a quantitative laboratory analysis, whereas tissue testing refers to semi-quantitative or quantitative “quick” tests of crushed tissue or plant sap carried out in the field for trouble-shooting purposes.

The general relationship between plant tissue nutrient levels and crop growth is shown in Figure 1. When a nutrient is deficient, addition of that nutrient results in increased crop growth and usually an increase in the concentration of that element in the plant. As the level of the deficient nutrient increases, crop growth increases until some maximum yield is reached. Further additions of the element will cause the concentration of that element in the plant to rise more rapidly because it is not being diluted by added dry matter accumulation. Eventually, toxicity of that element may occur.

Uses of Plant Analysis

Plant analysis has proven useful in confirming nutrient deficiencies, toxicities or imbalances, identifying "hidden hunger," evaluating fertilizer programs, determining the availability of elements not tested for by other methods, and studying interactions among nutrients.

Determining nutritional problems — One of the major uses of plant analysis is troubleshooting crop problems. Plant analysis defines nutrient problems more precisely than does an examination of deficiency symptoms, soil tests, or quick tissue tests. In addition to confirming suspected deficiencies, plant analysis can also detect toxicities or hidden deficiencies when visible symptoms are not evident. The second most common use is corp monitoring to evaluate potential nutritional problems while they can still be corrected or so they can be avoided in subsequent seasons.

Evaluating fertilizer programs — Scientists and others use plant analysis to study uptake from fertilizer or other nutrient sources and to evaluate different methods and times of fertilizer application. Farmers can also use plant analysis to determine whether their fertilizer program is performing according to expectations. Adding nutrients is no guarantee that they have been utilized as other factors may restrict uptake. Plant analysis can establish treatment effectiveness.

Determining nutrient availability where soil tests are not available — Most laboratories routinely test soils for lime needs, phosphorus, and potassium. Some have optional tests for calcium, magnesium, and some of the minor elements. However, reliable soil tests have not been developed for all of the elements. Furthermore, a test for iron developed in one state is not necessarily applicable to the soils of another state until the test has been calibrated for the soils in that state. Plant analysis can be particularly advantageous in determining the availability of nutrients for which there are no reliable soil tests, or for those areas where soil test calibration has not been done.

Deficiencies of most micronutrients and sulfur are identified more accurately by plant analysis than by soil test. The soil test commonly used for sulfur, for example, measures only the amount of sulfate-sulfur present in the sampled area at that point in time. It does not include possible contributions from other sources such as rainfall. A high sulfur soil test indicates adequate sulfur is present, but a low test may mean either the sulfur is not there or it was not measured by the soil test. Plant analysis gives an accounting of all of the sulfur available to the plant.

Studying nutrient interactions — Plant analysis helps detail the relationships among essential elements. This use may have rather limited applicability for most routine users.

Plant Analysis Complements Soil Testing

Sometimes adequate nutrient levels may be present in the soil, but because of other problems—such as cool temperatures at planting, insect feeding, or root damage—inadequate amounts of nutrients get into the plant. Plant analysis along with soil tests can help pinpoint the problem. For example, plant analysis of corn ear leaf samples from central Wisconsin may show high levels of manganese present, but the soil analysis identifies the actual problem is very acidic soil resulting in excessive manganese availability.

Soil tests normally are calibrated for the average depth of plowing. If a subsoil is high in a particular nutrient, the subsoil contribution will go undetected unless a subsoil sample is also analyzed. A plant analysis will not tell how much of the nutrient in the plant came from the subsoil, but it will measure the integrated effect of the entire root volume, which may include several cubic feet of soil.

The results of plant analysis alone cannot be used to make fertilizer recommenda-tions. Although plant analysis can provide substantial additional information, plant samples should be accompanied by soil samples taken from the same area as the plants. If the plant and soil samples are taken from an abnormal area of a field, the results are applicable to that area only. Unless a field is sampled in detail, the soil sample accompanying a plant sample usually is not very representative of the entire field. Emergency recommendations for an abnormal area in a field can be made from soil and plant analyses, but field-scale recommendations should be based on appropriate soil sampling and analysis (see Extension Publication #A2100, “Sampling Soils for Testing”).

Limitations of Plant Analysis

Interpretation difficulties — In general, good relationships can be developed between soil nutrient supply, nutrient levels in the plant, and crop yield for a given plant part, time of sampling, and location in any one year. However, differences in location, variety, time, and management often cause variations in these relationships and make them difficult to interpret. Nutrient levels in plants differ depending on the plant part sampled, stage of maturity, hybrid, and climatic conditions. Interpretations of plant analysis must take these factors into consideration. For this reason, most plant analysis interpretations are based on a specific plant part sampled at a definite stage of develop-ment. Greater detail on plant sampling for tissue analysis is provided in Extension Publication A2289 “Sampling for Plant Analysis.”

For corn, the ear leaf at silking is most commonly used for diagnostic analysis. In most situations, this is too late for remedial treatment. The results of the analysis, then, can only be used to guide future management decisions. In many cases, it may be possible to identify nutrient disorders at an earlier stage of crop development if plants from a normal growing field at the same growth stage are also analyzed for comparison. The normal/abnormal

comparison is especially important for plants in early growth stages since sampling the entire plant tends to mask the differences in key plant parts, or for specialty crops that may not have an adequate calibration database developed.

Interrelationship of other factors — Interpreting plant analysis assumes that the chemical composition of the plant reflects its nutrient supply in relation to the growth of the crop. There are situations, however, when the nutrient concentrations in the plant are not the primary factor responsible for the amount of plant growth obtained. For example, any factor that limits growth may cause non-limiting nutrients to accumulate at higher than normal concentrations in the plant. In this case, there is not necessarily a direct relationship between nutrient supply and plant growth.

Progressive deficiencies — Plant analysis usually detects only the one element that most inhibits plant growth. Rarely are two or more elements acutely deficient at the same time. A corn plant, for example, may be deficient in K, but because K is limiting growth, there may be sufficient P for the reduced amount of dry-matter production even if the soil P supply is low. However, when K is added as a remedial treatment, dry-matter production increases sharply; then P becomes deficient. Nitrogen stress, on the other hand, can limit the uptake of phosphorus and some of the micronutrients to the extent that they appear to be "low."

Secondary deficiencies — If plant growth is limited because of something other than a nutrient shortage (i.e., insect feeding or lack of water), the nutrient deficiency symptoms expressed may be a secondary effect. Adding more nutrient in this case will not increase nutrient uptake or plant growth.

Sample contamination — Contamination of a plant sample with soil particles or pesticide residue can lead to erroneously high results for iron, aluminum, manganese, zinc, or copper. Washing the sample to remove contamination can introduce other contam-inants if a detergent or tap water are used. Appreciable potassium can be lost by washing.

Sample deterioration — Decomposition of a plant sample before it reaches the laboratory will result in a loss of carbon (as CO_2 through respiration and microbial activity) and the concomitant increased concentration of most other elements, thereby giving erroneously high readings. This can be prevented by refrigerating the sample until it is delivered to the laboratory or air-drying to 15 to 25% moisture.

Interpretation of Plant Analyses

Critical value and sufficiency range approaches — For most diagnostic purposes, plant analyses are interpreted on the basis of "critical or sufficiency levels" for each nutrient. The critical level has been defined as that concentration below which yields decrease or deficiency symptoms appear. For many nutrients, yield decreases even before visible deficiency symptoms are observed. Because the exact concentration of a

nutrient below which yields decline is difficult to determine precisely, some define the critical level as the nutrient concentration at 90 or 95% of maximum yield.

The nutrient composition of a plant changes as the plant matures and with the portion of the plant sampled; therefore, critical levels are defined for a specific plant part at a specified stage of maturity. For corn, the ear leaf from the period from tasseling to silking is most commonly used. For most crops, there is an optimal range of concentration over which yield will be maximized rather than a single point. Growers, therefore, usually strive for operating in the sufficiency range that corresponds to the yield plateau illustrated in Figure 1. Most nutrients have fairly broad sufficiency ranges.

Nutrient ranges representing deficient, low, sufficient, high, and excessive concentra-tions for corn and alfalfa used by the University of Wisconsin Soil and Plant Analysis Lab. are given in Table 2. For some nutrients, excessive nutrient levels have not been well-defined because growth is not depressed by excessive uptake. These ranges are useful guidelines for interpreting plant analyses, but they must not be used dogmatically. Knowledge of hybrid requirements, unusual soil or climatic conditions, or other extenuating information should be considered.

DRIS or nutrient ratio approach — The Diagnosis and Recommendation Integrated System (DRIS) simultaneously considered nutrients on a ratio basis in relation to crop growth. The DRIS approach to interpreting the results of plant analysis involves creating a database from the analysis of thousands of samples of a specific crop. The nutrient ratios corresponding to the highest yielding portion of the population are established as the standard (norms) and used as the basis for comparison. A ratio of plant nutrient concentrations by itself cannot be used to diagnose plant problems, but combinations of different nutrient ratios can be combined mathematically to determine what nutrients are most likely to limit yield. The results of such calculations are the “DRIS indices.”

An index of 0 is considered optimum; however, although finer-tuning may be possible, DRIS indices are normally calibrated so that those within the range of about -15 to +25 are considered normal and in balance. A DRIS index less than -25 indicates a likely deficiency, whereas those between -15 and -25 represent a possible deficiency. Values greater than +100 may be an indication of possible nutrient excess. The greater the magnitude of the nutrient index, either positive or negative, the more likely that element is out of balance in the plant.

The principal advantages of the DRIS system are that stage of maturity, plant part, and cultivar are less important than they are for the critical level or sufficiency range approaches to interpreting plant analyses. Thus, by using DRIS as a interpretative approach, it is possible to sample alfalfa at the pre-bud stage and obtain meaningful results, rather than waiting until first flower.

Table 2. Interpretive ranges for plant nutrients used by the University of Wisconsin Soil and Plant Analysis Lab.

	Tissue nutrient interpretative level				
Nutrient	Deficient	Low	Sufficient	High	Excessive
			Corn ear leaf at tasseling to silking		
N, %	<1.75	1.75-2.76	2.76-3.75	>3.75	--
P, %	<0.16	0.16-0.24	0.25-0.50	>0.50	--
K, %	<1.25	1.25-1.74	1.75-2.75	>2.75	--
Ca, %	<0.10	0.10-0.29	0.30-0.60	0.61-0.90	>0.90
Mg, %	<0.10	0.10-0.15	0.16-0.40	>0.40	--
S, %	<0.10	0.10-0.15	0.16-0.50	>0.50	--
Zn, ppm	< 12	12-18	19-75	76-150	>150
B, ppm	<2.0	2.0-5.0	5.1-40.0	41-55	>55
Mn, ppm	< 12	12-18	19-75	>75	--
Fe, ppm	< 10	10-49	50-250	251-350	>350
Cu, ppm	--	<3	3-15	16-30	>30
			Top 6 inches of alfalfa at first flower		
N, %	<1.25	1.25-2.50	2.51-4.00	>4.00	--
P, %	<0.20	0.20-0.25	0.26-0.45	>0.45	--
K, %	<1.75	1.75-2.25	0.26-3.40	3.41-4.25	>4.25
Ca, %	--	<0.70	0.70-2.50	>2.50	--
Mg, %	<0.20	0.20-0.25	0.26-0.70	>0.70	--
S, %	<0.20	0.20-0.25	0.26-0.50	>0.50	--
Zn, ppm	--	<20	20-60	60-300	>300
B, ppm	< 20	20-25	26-60	>60	--
Mn, ppm	< 15	15-20	21-100	101-700	>700
Fe, ppm	--	<30	30-250	>250	--
Cu, ppm	--	<3.0	3.0-30.0	>30.0	--

DRIS norms are not available for all crops and some users of the DRIS system tend to interpret the results too dogmatically. Some regard every negative index as representing a deficiency and pay no attention to positive indices. Since not all of the nutrient norms used to develop DRIS indices have been evaluated under field conditions, experience has shown that the evaluations should not be made disregarding nutrient concentrations altogether. The University of Wisconsin recommends that the two interpretative approaches be used together.

PASS — The Plant Analysis with Standardized Scores (PASS) was developed at the University of Wisconsin to combine the strengths of the sufficiency range (SR) and DRIS methods. The SR provides easily interpreted, categorical, independent nutrient indices. The DRIS gives difficult to calculate, easily interpreted, numerical, dependent nutrient indices, and a ranking of the relative deficiencies. The strengths of the SR are the weaknesses of the DRIS and vice-versa. The PASS system combines an independent nutrient section and a dependent nutrient section. Both types of indices are expressed as a standardized score and can be combined to make more effective interpretations. Research has demonstrated that PASS results in more correct diagnoses than either of the other two systems. To date, however, the PASS system has been developed only for alfalfa, corn, and soybean.

Summary

Plant analysis is a powerful tool for confirming nutrient deficiencies, toxicities and imbalances, identifying “hidden hunger,” evaluating fertilizer programs, studying nutrient interactions, and determining the availability of elements for which reliable soil tests have not been developed. The results can be misleading, however, if initial plant sampling, handling, and analysis of the sample are faulty. Experience with interpreting the overall plant analysis report is essential because of the many interacting factors that influence the concentration of any one element in plant tissue. After assessing the status of each nutrient by both interpretative methods, one needs to review possible causes of the effects observed. Thus, cropping history, sampling techniques, soil test data, environmental influences, and a knowledge of nutrient concentrations all need to be considered in the final diagnosis. If properly done, plant analysis can point the way toward more efficient nutrient management and crop production programs.