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BETTER CROPS

with plant food

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SPECIAL ISSUE:

The Diagnostic Approach

BETTER CROPS with plant food

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Contents

Our cover: The illustrations on our cover represent various aspects of "The Diagnostic Approach", the subject of this special issue.

Introduction

MODERN AGRICULTURE must use every available tool and practice to produce efficiently and at a profit. One important aid is "The Diagnostic Approach".

This edition of *Better Crops* deals entirely with that topic. The style of presentation is such that it can be useful as an educational aid.

The use of soil testing and plant analysis, and the understanding of visual symptoms are practices that are important to scientists and laymen alike.

It is hoped that this publication will be useful to teachers of high school and introductory college courses, to extension specialists and county agents, to members of the fertilizer, agrichemical and seed industry, to soil conservationists, and to consultants. Farmers could find it helpful in understanding better the whole diagnostic approach. To order copies of this publication, see page 39.

The Diagnostic Approach

IN MODERN HIGH YIELD AGRICULTURE all scientific methods and information are put to use. This includes:

1. Tillage practices best suited to an area.
2. Moisture conservation and efficient use.
3. Proper chemical environment by liming or reducing salinity and alkalinity.
4. Correct amount and kind of fertilizers.
5. Variety – best suited to the conditions.
6. Proper plant spacing.
7. Pest alerts.
8. Herbicides – for weed control.
9. Pesticides – to control insects and diseases.
10. Correct method and time of planting and harvesting.
11. Timeliness in all operations.
12. Careful records and economic evaluation.

It also includes the "diagnostic approach" – the use of all knowledge and tools to study conditions in the field and to find out how a soil can produce better.

Diagnosis requires experience and knowledge. There are many pitfalls. To do a good job, the diagnosis should begin with observations made in the field. This often requires more than one trip to the same field. The diagnostician should have:

- ► a spade – to look at roots and environment;
- ► a knife – to look at internal tissues;
- ► a soil tube – to look for compaction and profile;
- ► a hand lens – to look for diseases or insects;
- ► a notebook – to record history and symptoms;
- ► an "open mind" – to avoid preconceptions and bias.

The diagnostician should also have knowledge of:

- ► visual symptoms;
- ► soil testing;
- ► plant analysis.

The three approaches listed above are becoming widely used as diagnostic aids. They are extremely helpful, yet are not without limitations. The purpose of the following articles is to acquaint the student and people involved in crop production with

(continued on next page)

these three valuable diagnostic tools:

1. **Visual symptoms as indicators of plant disorders.**
2. **Soil tests for high yield agriculture.**
3. **The use of plant analysis and tissue testing in identifying nutrient disorders.**

Top farmers are recognizing more and more the necessity for top profit yields. Reaching these yields and profits calls for the use of every practice that will help attain them. So the importance of the diagnostic approach is ever increasing. ■

Part 1: The Diagnostic Approach

Be A Complete Crop Diagnostician

TO BE A COMPLETE DIAGNOSTICIAN, you must look beyond fertility problems, beyond the soil test for phosphorus (P) and potassium (K) and other nutrients. Know your plant environmental conditions.

Such knowledge may help you pinpoint a problem that is inducing, or magnifying apparent nutrient shortages. Look at all factors that influence crop growth, response to fertilization, and yield.

1. Root zone – The soil must be granular and permeable enough for roots to expand and feed extensively. A crop will develop a root system 6 feet or more deep on some soils to get water and nutrients. A shallow or compacted soil does not offer this root feeding zone. Wet or poorly drained soils result in shallow root systems. Proper drainage is of key importance in early crop growth.

2. Temperature – Cool soil temperatures reduce organic matter decomposition. This slows the release of nitrogen (N) and other nutrients. Also, nutrients are less available in cool soils, increasing deficiency potential. P and K diffuse more slowly in cool soils. Root activity is decreased.

3. Soil pH – Acid soil conditions reduce the availability of calcium (Ca), magnesium (Mg), sulfur (S), and molybdenum (Mo), as well as P and K. Acid conditions increase the availability of iron (Fe), manganese (Mn), boron (B), copper (Cu), and zinc (Zn). Nitrogen (N) is most available between pH 6.0 and 7.0.

4. Insects – Don't mistake insect damage for deficiency symptoms. Examine roots, leaves and stems for insect damage that may look like a nutrient deficiency.

5. Diseases – Close study will show the difference between plant disease and nutrient deficiency. The disease can often be detected with a small hand lens.

6. Moisture conditions – Dry soil conditions may create deficiencies. Boron, Cu and K are good examples. This is why crops respond so well to such nutrients when they are present in dry periods. Drought slows movement of nutrients to roots.

7. Soil salinity problems – Soluble salts and alkali are problems in some low rainfall areas. These conditions may occur in just part of the field – usually where a high water table exists or where poor quality water has been used for irrigation.

8. Weed identification — Herbicides and mechanical controls are more important today than ever before. Weeds rob agronomic plants of water, air, light, and nutrients. Some weeds may even release substances that inhibit crop growth. Learn to identify weeds and to know the materials used to control them.

9. Herbicide damage — Under certain conditions plants may suffer from carryover herbicides or those applied the current year. Learn the symptoms.

10. Tillage practices — Some soils develop hardpans and require deep tillage. This calls for more P and K to build up fertility. In conservation tillage much of the fertilizer is broadcast and is on or near the surface. Here more P and K may be needed to build fertility and band placing of some of the fertilizer near the seed may be helpful. Also in some cases, it is desirable to know the fertility level of the subsoil.

11. Hybrid or variety — Yield potential and adaptability to a given environment affect how a crop performs.

12. Plant spacing — Row width, uniform spacing of plants in the row, and number of plants per acre are important in yields.

13. Water management — Adequate drainage, either surface or tile, is the key. With irrigation, time and amount of watering are of prime importance in good crop growth. Learn what the irrigation program has been.

14. Date of planting — This will affect crop appearance and optimum growth. Get the information.

15. Fertilizer placement — Under many conditions a small amount of fertilizer near the roots is important for a fast start. The fertilizer may have been applied broadcast or too deep. Strip or deep banding may be effective under some soil and environmental conditions.

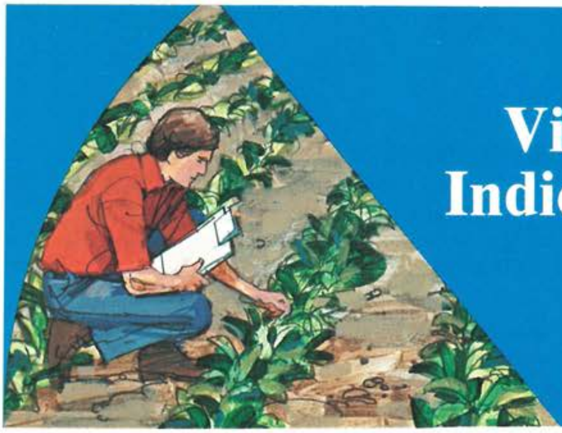
Importance of cultural practices

Knowing what has been done in a field before you go into that field can be one of the most important diagnostic techniques you will develop.

Get the facts! On field cropping histories. On planting dates. On seeding rates. On varieties. On row widths. On tillage practices. On depth and method of planting. On past fertilizer and liming practices. On past weather conditions, if you can.

Remember: The more you know about a field before you go into it, the better you may diagnose its problems.

Get the facts systematically. And record them! A checklist will avoid forgetting key information. ■



Part 2 — Visual Symptoms Can Indicate Plant Disorders

FOR GENERATIONS, the appearance of a plant has been used by scientists and by laymen, by gardeners and by farmers to help indicate plant health.

The plant speaks through distress signals. The message may tell us there is simply a shortage of water or there is too much water and, hence, a shortage of air. Or the signals may tell of a disease caused by an organism such as a virus or bacteria.

The plant may be complaining because it is being attacked by nematodes, insects or rodents, either below or above ground. And there may be injuries from frost, lightning, pesticides, or mechanical equipment.

If there is an excess of some chemical that can be toxic to the plant, this condition is also indicated by plant appearance. Finally, if one or more of the essential nutrients is not present in an adequate amount, the plant will do its best to tell us this.

So we have learned to use visual plant symptoms as indicators of mineral nutrient deficiencies. At the same time, we must realize visual symptoms tell many more stories than just mineral deficiencies. It is not always easy to know just what the plant is trying to tell us.

The purpose of this section is to help us find out what is limiting production of a plant and, especially, to learn how to tell one symptom from another.

This calls for great patience and study and, most of all, experience. It requires knowledge of what the healthy plant should look like. It means using the other diagnostic tools to help identify or confirm the visual symptoms. This is brought out in the companion sections on soil testing and plant analysis.

The modern farmer or scientist will use a soil test or plant analysis or both, to help identify the symptom. This is especially necessary when one is just beginning to study visual symptoms.

Then, as one learns symptoms, he must be aware of the hazards in relying on his knowledge and must be aware of the possibility of errors. This involves going beyond the field of agronomy and plant nutrition and including the areas of plant diseases, insect damage, and weather and environmental factors.

A good diagnostician must be broad in his knowledge and meticulous in his approach. But when all of this is done, it provides a valuable aid for profitable crop production.

Another very important point should be kept in mind. Often a plant will border on deficiency of a plant nutrient and yet not show any symptoms. This condition is frequently called *hidden hunger*. Here there are no visual symptoms, but the plant is not producing at its capacity.

This is one of the dangers of relying on symptoms. When the plant reaches the level where a symptom appears, the yield may already have been greatly reduced. Too many areas of the world are being farmed in the *hidden hunger* zone.

In this section, the general symptoms of various factors that limit production will be described.

The Plant Nutrients

Scientists have determined that 16 elements are necessary for plant growth. Some of these come from the air, some from the water, and others from the soil or from fertilizers and lime.

They are needed in different amounts, from as much as several million pounds of water to very small traces of some of the elements. A general guide is shown in **Table 1.**

Table 1. Elements essential for plant growth

Element or material	Chemical symbol	lb/A
Supplied by air and water:		
Hydrogen (as water)	H_2O	2 to 6 million
Oxygen	O_2	5,000-8,000
Carbon (as carbon dioxide)	CO_2	15,000-25,000
Primary or major elements supplied by soil and fertilizers:		
Nitrogen	N	60-300
Phosphorus	P	10-200
Potassium	K	20-400
Secondary elements supplied by soil, fertilizer or lime:		
Calcium	Ca	20-400
Magnesium	Mg	20-400
Sulfur	S	10-200
Micronutrients needed in small amounts:		
Iron	Fe	1-5
Manganese	Mn	0.5-5
Boron	B	Trace*
Chlorine	Cl	Trace*
Zinc	Zn	Trace*
Copper	Cu	Trace*
Molybdenum	Mo	Trace*

* Usually measured in parts per million

These amounts of nutrients are broad approximations and depend on the crop being grown and, especially, on the yield of the crop.

Nutrient balance

Even more important is the interrelationship of one element to another. A high quantity of phosphorus in the soil or in the plant may result in a deficiency of zinc. A high amount of potassium may result in a deficiency of magnesium.

And then there is need for more of one element as more of another is added. When we add more nitrogen, we create the need for more potassium because the yield is greater and the plant's needs increase. A farmer might not see potassium deficiency in one field where he has added only a small amount of nitrogen; but on an adjoining area where he has applied more nitrogen, he sees potassium deficiency.

This whole science of interrelationships, of the effect of one element upon another, is a complex one. It is mentioned here so the grower can be aware of pitfalls when using visual symptoms.

This does not suggest that we should not learn to use symptoms. But it would warn the user that the symptom simply tells us what the limiting factor is at that time. When this limiting factor is corrected, another may then turn up, so one must be aware of these interrelationships. ■

Part 2: Visual Symptoms

Factors Affecting Symptoms

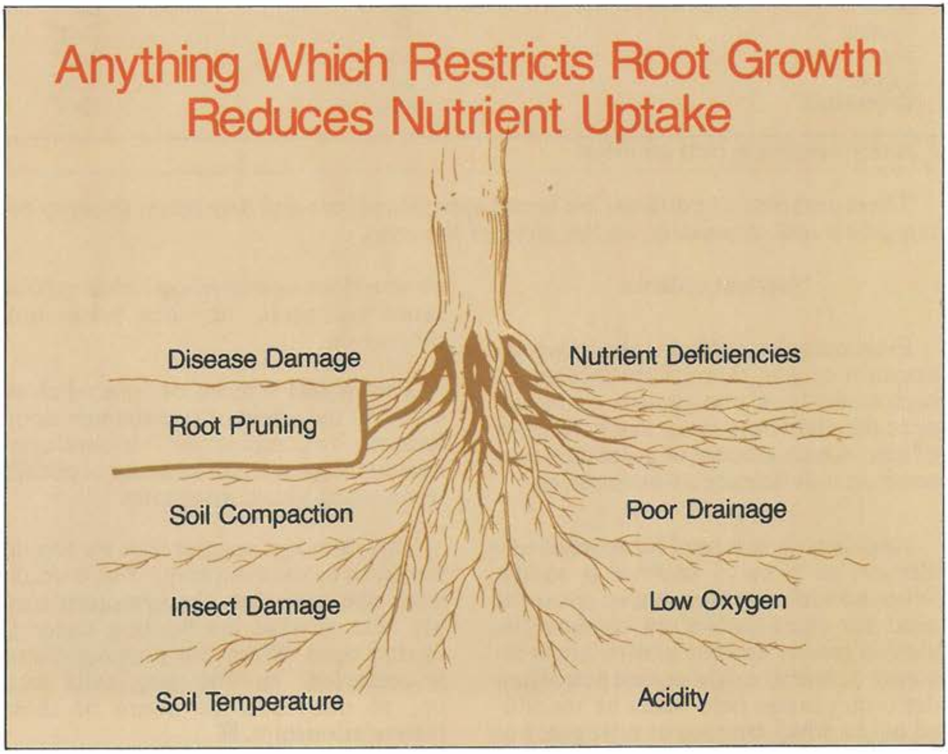
WHY DO SYMPTOMS of a plant nutrient deficiency occur? Because there is not enough of that nutrient present in a form the plant can take up and use.

Often this is simply because the soil is infertile and not enough of that nutrient was added. But we must recognize that there are various other factors that affect uptake and hence lead to the appearance of symptoms.

Root zones

Crops differ a great deal in the extent of their root systems. And even the same crop will vary in the amount of roots, depending on the environment in which it grows. Since some of the plant nutrients do not move very far in the soil, the extent of the root system will determine whether the plant gets enough of a nutrient. Indeed, if conditions are such that root growth is rather shallow, a plant may show a deficiency symptom even when the soil actually contains a good supply of that nutrient.

When a deficiency symptom is noted, you should always examine the root zone



to see if a greatly restricted root zone may be contributing to the deficiency.

Temperature

Many growers have seen a visual symptom when the plants are young, only to see the plant "grow out" of this symptom as the season progresses. Often this is caused by a combination of temperature and root growth. If the soils are cold and the air temperature is cold, the plant just does not grow, root systems are small, and plant nutrient uptake is low.

Also, when air temperatures are too low or too high, photosynthesis and respiration rates are affected. For example, if temperatures are too high at night, respiration continues at a high rate, burning up sugars, while photosynthesis stops at night. Thus, temperatures could create visual symptoms.

Acidity or alkalinity

When a visual symptom is noted, you should look especially into the degree of acidity or alkalinity of the soil in which the plant is growing. Very often this is closely related to the cause of the symptom.

The solubility and the availability of many plant nutrients depend on the soil pH. When the pH value of the soil goes above pH 6.0-6.5, elements such as iron (Fe), manganese (Mn), zinc (Zn) and boron (B) decrease in solubility, often to the point where the plant is deficient and shows symptoms. And in contrast, when the soil pH is on the acid side (pH below 6.0), molybdenum (Mo) becomes less soluble and a deficiency of this element may be evident.

Because of the influence of pH on plant nutrient availability, it is essential to learn the liming history of a field, or even a small area, where a symptom is observed. Over-liming is easy to do on acid, sandy soils. When these soils are overlimed, deficiency symptoms of iron, manganese or zinc are likely to appear.

In some parts of the world the soils are not acid, but are naturally alkaline. This is often the case in arid regions where alkaline salts have accumulated or even in areas of more rainfall where there are outcroppings of limestone and the soil pH is above 7.0. In such soils, it is not uncommon to see iron, manganese, or zinc deficiency symptoms.

Variety – genetic factors

Sometimes a deficiency symptom may be noticed in one variety of a crop but not in another. This is not uncommon, but it is often overlooked. Difference in genetic makeup may affect the ability to take up and utilize plant nutrients. One variety may show symptoms of magnesium deficiency while another variety growing beside it may not show the symptom.

Stage of maturity

As a plant nears maturity, it shows signs of "old age." This may be a reddening, or browning, or tip or edge "burn." But it often looks like a deficiency symptom and the grower may mistake it for such.

In fact, there is a relationship, because as a plant grows older, it may "run out" of nitrogen or potassium and therefore may "mature" before it has reached its full yield potential. In some crops there is a delicate balance between the amount of nitrogen required for full yield and amount that may be too little or too much. Visual symptoms help us to recognize the correct amount. ■

Part 2: Visual Symptoms

Symptoms Identify Deficiencies

A SYMPTOM will usually occur over an area and can be related to such properties in the area as wet spots, sandy conditions, infertile areas, or areas treated differently in the past. If a symptom is found on a single plant, consider disease, injury, or a genetic variation. Also, the earlier symptoms are often more useful than late mature symptoms.

It is helpful to keep in mind that some nutrients are relatively "immobile" in the plant, while others are more "mobile."

In general, the symptoms caused by deficiences of an "immobile" nutrient will occur on the upper or younger leaves. The older leaves will remain green and free of symptoms because these "immobile" nutrients do not move or translocate from them.

Typically, the "immobile" nutrients are calcium, iron, zinc, copper, boron, manganese and molybdenum.

In contrast, when there is a deficiency of a "mobile" nutrient, the symptoms usually occur in the lower or older leaves of the plant. This is because the "mobile" nutrients move out of the older leaves to the younger part of the plant.

Typically, the "mobile" nutrients are nitrogen, potassium, phosphorus, magnesium, and sulfur.

However, it should be emphasized that this pattern does not always follow the rule. The plant is a complex material and symptoms may appear on the upper and lower leaves. Too, moisture supply may enter in the picture.

It is also necessary to consider **excesses** of certain elements since these can produce specific symptoms. The most likely are:

Boron – chlorosis leading to necrosis of tissue along margins of older leaves;
Sodium – usually no chlorosis but necrosis of the leaf tips and margins;
***Manganese** – crinkling of the plant – known as "crinkle-leaf";
***Aluminum** – marginal leaf scorch and stunting.
(*Manganese and aluminum excesses are usually under very acid conditions.)

For More Information . . .

THERE ARE MANY excellent publications that contain illustrations of plant nutrient deficiency symptoms. Typical of these is the complete and classic book, *Hunger Signs in Crops*, now being revised. Other books and bulletins published over the past 45 years contain fine illustrations.

In addition, symptoms of plant diseases and insect damage are in print.

Color slides which depict all these symptoms in detail are available from various sources.

The illustrations shown here are simply examples of the type of material that is available. Those who are interested should acquire a file of these symptoms. ■

Individual Symptoms

PHOSPHORUS (P). Plants are often small and growth is stunted, but in many crops the leaves are darker green than normal. The leaves and sometimes the stems may develop a reddish-purplish cast, especially during early stages of growth.

Maturity is delayed and fibrous root development restricted. Petioles, leaves, and leaf margins may take an upward direction. Frequently the only symptom may be smaller plants.

MARGINAL PURPLING of corn leaves is a classic symptom of phosphorus hunger. However, deficiency can slow growth and delay maturity without purpling evidence.

ADEQUATE PHOSPHORUS made this difference toward better growth and yield of wheat.

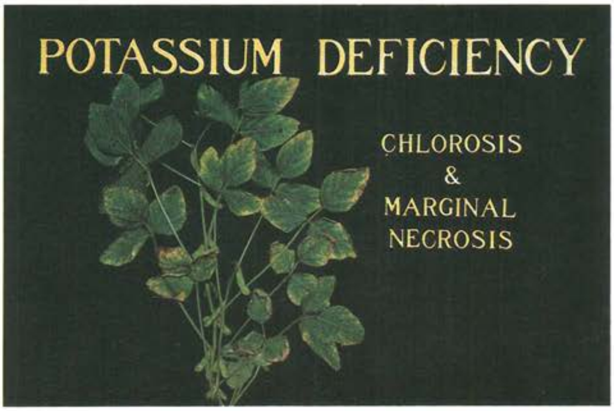
(continued on next page)

POTASSIUM (K). Scorching or firing along leaf margins is the most common symptom. This usually appears first on the older leaves. Plants grow slowly, have poorly developed root systems. The stalks are weak and lodging is common.

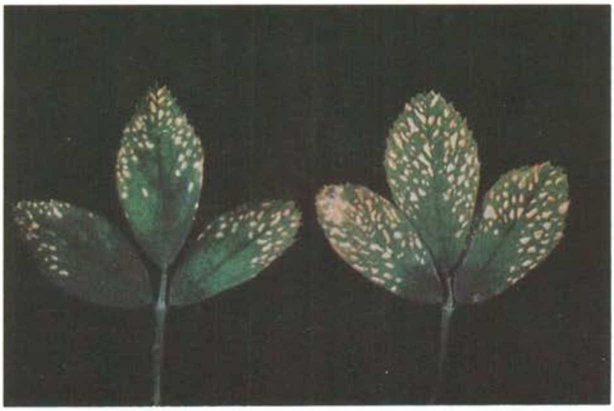
Seed and fruit are small and shriveled.

Plants possess low resistance to disease.

In the case of legumes, the first signs of potassium deficiency are often small white spots or yellowish dots around the outer edges of the leaves. Later the edges turn yellow and die.



POTASSIUM (K) HUNGER in soybeans begins as firing or scorching on outer edges of leaves. When leaf tissue dies, leaf edges become broken or ragged, with delayed maturity and slow defoliation.



THE FIRST SIGNS of potassium hunger on alfalfa leaves show up as small white or yellowish dots around the outer edges of the leaves. As deficiency increases, these edges turn yellow, become brown, and die.

LOW-K CORN ages too fast . . . cells die . . . tissues deteriorate . . . inviting stalk rot. Potassium builds strong stalks and more brace roots . . . helps prevent decaying stalks.

NITROGEN (N). Plants are light green and growth is stunted. The lower leaves may be affected first, but other leaves follow, with later yellowing and drying up or firing and final shedding of the lower leaves.

In tree crops, the leaves are often small, pale in color and may appear on any part or all of the plant.

NITROGEN (N) DEFICIENCY symptoms appear on this corn leaf.

MAGNESIUM (Mg). Magnesium deficiency symptoms appear first on lower (older) leaves. It appears first as a light, yellowish, faded discoloration with the veins remaining green. In crops such as corn the leaves are yellowish or very light green striped while veins remain green. In some crops, as the deficiency progresses, a reddish-purplish color develops with green veins.

The pattern is distinct and characteristic and can usually be identified after some experience in observation. It is more likely to occur in acid soils.

MAGNESIUM (MG) DEFICIENCY caused these effects on grapefruit.

CALCIUM (Ca). Calcium deficiencies are not often seen in the field because secondary effects, associated with high acidity, limit growth first.

Leaves may be cup-shaped and crinkled, and the terminal buds deteriorate with some breakdown of petioles.

Fruits may break down at the blossom end. Calcium deficiency is known to be associated with "blossom-end rot" in tomatoes and other crops.

IRON (Fe). Iron deficiency shows up as a very light pale leaf color with veins remaining green, usually first appearing on younger leaves; but severe deficiency may result in the entire plant showing such symptoms.

It can easily be mistaken for manganese and also occurs on high pH soils. The interveinal chlorosis in iron is often whiter than manganese.

(continued on next page)

SULFUR (S). Plants are pale green and look very much like nitrogen deficient plants. The symptoms generally appear first on the upper leaves while nitrogen-starved plants generally show up first on the lower leaves; however, in sulfur deficiency the entire plant can take on a pale green appearance.

Leaves tend to shrivel as the deficiency progresses and plant stems grow thin and woody.

Sulfur deficiencies occur most often on sandy soils low in organic matter and in areas of moderate to heavy rainfall. It occurs early in the season and the symptoms may disappear as roots penetrate the subsoil and into areas of higher sulfur content.

SULFUR (S) DEFICIENCY on corn may be confused with effects of low N.

ZINC (Zn). Symptoms appear first on the younger leaves and other plant parts. Some crops are much more likely to show the symptoms, and they have been defined on these.

In corn, the deficiency is called "white bud" because the young bud may turn white or light yellow while the leaves show bleached bands, or a striping.

Other symptoms include bronzing of rice; rosette of pecans; "little leaf" of fruit trees; brown spots with yellowing leaf tissues in legumes; and small, pointed, yellow mottled leaves in citrus.

ZINC (Zn) DEFICIENCY symptoms are shown on these leaves of an orange tree.

COPPER (Cu). Organic soils are most likely to be copper deficient, since copper is fixed in unavailable forms in these soils.

Common symptoms of copper deficiency include dieback in citrus and blasting of onions and vegetable crops. When vegetable crops show copper hunger, the leaves lose turgor and develop a bluish-green shade before becoming chlorotic and curling. Also the plants may fail to flower, and there is often excessive leaf shedding.

MANGANESE (Mn). Symptoms first appear in younger leaves, with yellowing between the veins – and sometimes brownish-black specks.

The deficiency is sometimes confused with magnesium; however, it usually appears first on the newer (upper) leaves while magnesium occurs on older or all leaves. Best way to distinguish is to check soil properties. Manganese deficiency is more likely if the soil pH is higher and in soils higher in organic matter during cool spring months when soils are waterlogged. Liming history is important.

MANGANESE (Mn) DEFICIENCY is shown in various degrees of severity on these soybean leaves.

BORON (B). Boron deficiency generally stunts plant growth – the growing point and the lower leaves first.

In many crops the symptoms of boron deficiency are well defined and quite specific, such as crooked and cracked stem in celery, corky core in apples, black heart in beets, hollow heart in peanuts, and ringed or banded leaf petioles in cotton.

Alfalfa is especially susceptible to boron deficiency, which is shown by rosetting, yellow top, and death of the terminal bud. With experience, this can be distinguished from potash deficiency or leafhopper damage.

BORON (B) DEFICIENCY caused the condition called hollow heart in peanuts.

MOLYBDENUM (Mo). Molybdenum deficiency symptoms show up as general yellowing and stunting of plant. In fact, this deficiency can cause nitrogen deficiency in legumes because the soil bacteria on legumes must have molybdenum to help fix nitrogen from the air.

A soil test helps because molybdenum becomes more available as the soil pH increases. So liming may often correct the deficiency.

This is not an easy deficiency to identify just from visual symptoms without a soil or plant test and a history of treatment. ■

Part 2: Visual Symptoms

Distinguishing Deficiency Symptoms from Other Symptoms

THE NECESSITY for study and experience has been stressed in learning to detect symptoms due to plant nutrient deficiencies. It is especially important to learn to tell the difference between these symptoms and other visual symptoms that may be present.

Herbicide Injury

The use of herbicides has been a tremendous boost to efficient crop production. Occasionally, herbicides may be misused and plant injury may result. This may be mistaken for a nutrient deficiency symptom. The history of field treatment should be reviewed.

Diseases and Insects

If the symptom is one of a deficiency that is well known to the examiner, then there may be no problem. But often when a plant shows distress signals, the average person has a hard time deciding, "Is it a deficiency or is it a disease? If it is a disease, is deficiency partly responsible for the disease? Could it be nematodes?"

Maybe it's none of these but a matter of too hot, too much water, or too little water.

Frequently these questions are hard for the inexperienced to answer. That's why we do not rely on visual symptoms alone but use every available tool.

First, look for insects by examining the roots, leaves, and stems. At the same time use a small hand lens and look for evidence of disease. Of course, to be sure, plants should be taken to a plant pathologist or an entomologist.

A plant analysis, a tissue test, and a soil test are very helpful in arriving at the answer.

General Features

While symptoms differ for different crops, there are some general clues for nutrient deficiencies and some specific symptoms for the individual element deficiencies that can serve as a guide for all crops. A nutrient deficiency should be suspected when these conditions occur:

1. Very poor growth at seedling stage
2. Plants badly stunted in early growth
3. Root growth restricted or abnormal
4. Internal discolorations or abnormalities
5. Maturity too soon or too late
6. Difference in growth from adjacent crops, even without leaf symptoms
7. Poor quality crops — appearance, taste, firmness, moisture content
8. Specific leaf symptoms that may appear at different times during growth. ■

Nutrient Deficiency Guide

Note: This drawing shows how some nutrient deficiencies might affect plants. It is not intended as a complete guide.

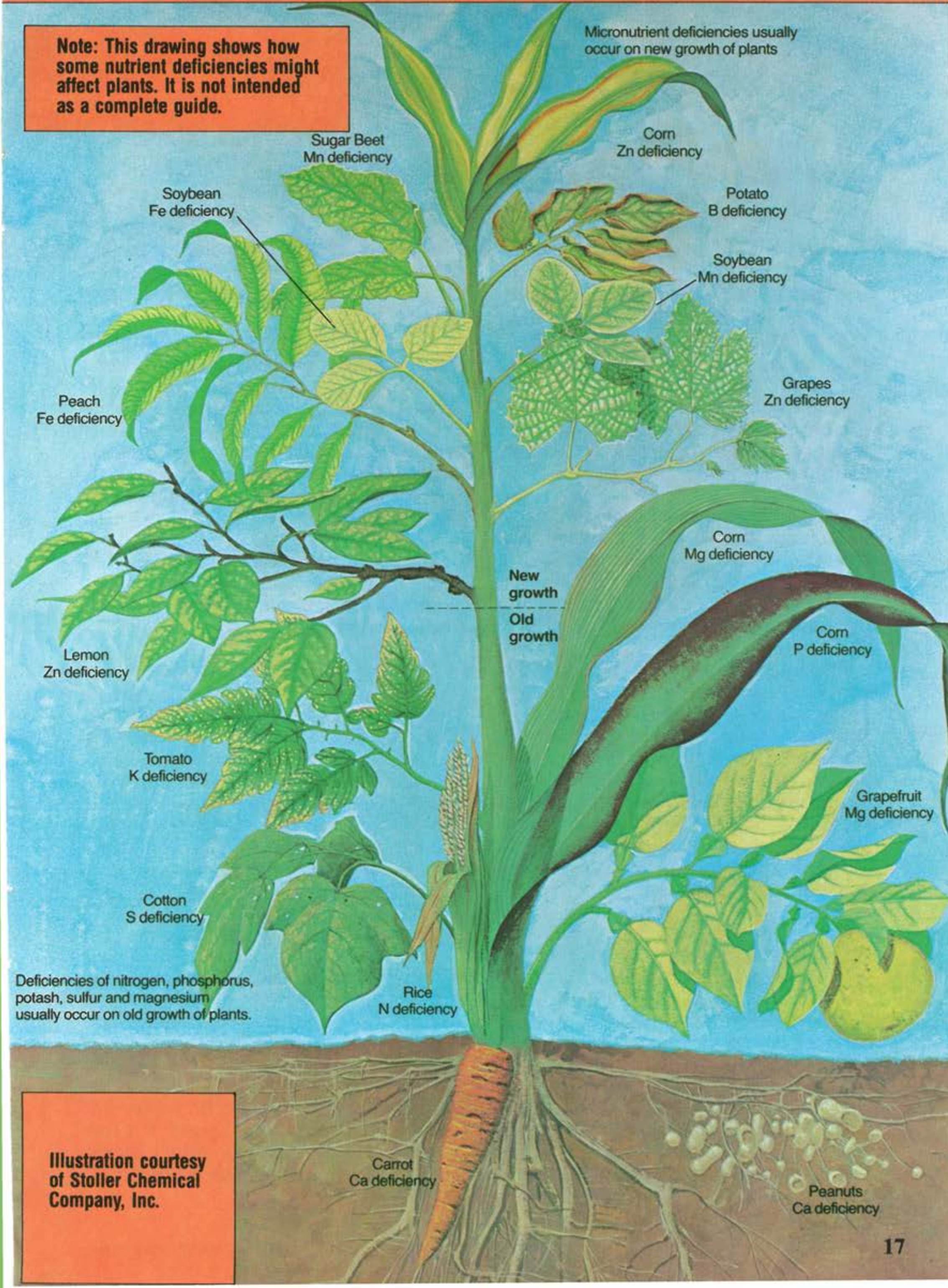


Illustration courtesy of Stoller Chemical Company, Inc.

Part 3 – Soil Tests for High Yield Agriculture

SOIL TESTING is an important tool in high yield farming. Three to four million soil samples are analyzed each year in the U.S. The results are very helpful in monitoring the soil fertility status. When used along with other information, soil tests are useful guides in arriving at recommendations for fertilizer and lime.

In these tests, a chemical extractant is used. It is in contact with the soil for a few minutes, to extract an amount of a nutrient that is indicative of the amount available to plants during their growing period.

Confidence in soil tests must be maintained. Yet, we must avoid creating the impression that soil tests and the resulting fertilizer recommendations are "miracle workers." The soil test is a helpful diagnostic tool just like the thermometer or the stethoscope for the doctor. But all such tools require skill plus common sense in their use and interpretation – plus a realistic approach to the needs and goals of the growers.

In 1949 a National Soil Test Work Group was established. The report of this group pointed out two factors that called for more attention in soil testing: (1) Obtaining representative samples and (2) correlation studies to interpret the results. These problems are still not completely solved.

To use soil tests most effectively in modern high yield agriculture, many points must be recognized:

1. Keep research up to date in high yield age.

Research is needed to determine the plant nutrient level necessary for **continuous** top profit yields. Field and greenhouse experiments must be constantly conducted to calibrate or standardize soil tests. Many field research studies have not provided data at high yield levels, and, hence, have limited value for correlation.

For example, soil tests calibrated for 135 bushels of corn per acre, when farmers are interested in 185 bushels, are behind times.

Some of our present correlation data information that relates crop yields to soil nutrient status goes back to Dr. Roger Bray. His data were collected from 1938 to 1941. Top corn yields ranged from 40 to 103 bu/A. So when we use these correlations to predict nutrients required for 200 bu/A corn, we could be in error. This emphasizes the need for new high yield tests to serve as a research basis for soil test correlation.

2. Time and method of sampling can be important.

While there has been improvement in sampling, still one of the problems in soil testing is failure to get a sample that is truly representative of the conditions that we are trying to measure.

There have been scientific studies of sampling techniques that point out the possible errors that can result from: Failure to include enough borings per composite sample; failure to properly divide the fields; failure simply to cover the whole area properly — and, in fact, errors from just plain carelessness or laziness.

One should take into account the time of sampling, and the location of the boring with regard to time and method of fertilizer placement, and depth of sampling as related to tillage.

How often should the soil be sampled? In many areas the suggestion is made to check the levels every 2 or 3 years. But on sandy soils, especially where rainfall or water additions are high, it is recommended that samples be taken at least annually and sometimes even more frequently. Many labs test annually for nitrates.

Also, there is the question of subsoil sampling . . . and drying the sample. Many labs now want to test the subsoil also.

3. How, then, do you get a good soil sample?

The best practice is to follow carefully the instructions of the laboratory to which the sample is being sent. These instructions are usually quite detailed and explicit. The problem is not the instructions but the failure of so many to follow them. Sampling according to maps of soil types is often of help.

4. Laboratory methods promote accuracy.

Improved laboratory equipment, refined techniques, and newer methods have been a great help to soil testing. The use of spectrophotometers, spectrographs, better pH meters, and better understanding have increased the speed and precision of laboratory determinations.

Laboratories run check samples periodically to be sure the apparatus and solutions are OK.

In the past, soil test improvements usually referred to the development of new and better lab tests. There was no point in developing other phases of

HIGH YIELD FIELD TRIALS are necessary to calibrate soil tests. To test response to a plant nutrient, all other controllable limiting factors should be eliminated. A field test for P or K response, when N may become limiting, is wholly misleading.

(continued on next page)

testing until the accuracy of laboratory tests was assured.

But with the development of precise laboratory tests for the major nutrients and for most of the secondary and micronutrients, the researchers now are more concerned with issues such as:

(a) Extraction procedure — type of extractant, length of time and method of extraction. Whether to use one extraction for all elements or several extractions. Whether to use one extractant for all areas of a state or region, or several extractants.

(b) Analyses for "sorption" or "fixation" of the various elements. This information indicates the degree of reduction in the availability of an element when it is added to the soil — information useful in arriving at the amount of an element that is needed to attain an optimum level in the soil.

(c) Meaning of the figures obtained in the determination.

Sometimes in our efforts to refine our laboratory procedures we overlook the fact that the results obtained by all procedures are empirical. Nutrient assimilation by plants is greatly influenced by many factors such as moisture, light, temperature, other elements, age of plant, etc. So trying to duplicate a plant's uptake of nutrients by using a chemical extraction of the soil is practically impossible. That is why correlation studies must be the basis for using the results of the extraction to measure soil fertility levels and plant needs.

5. What tests are usually run?

This depends on the laboratory making the analyses, on the nature of the soil and crops to be grown, and on what problems may be encountered with the soil or crop.

All laboratories will run pH, lime requirement (or excess lime), phosphorus and potassium. Many labs also determine organic matter, calcium, and magnesium and often cation exchange capacity and percent base saturation.

Other determinations are optional with many labs, though commercial labs frequently include them. These include sulfate-sulfur, nitrate-nitrogen, and micro-nutrients such as zinc, manganese, copper, boron, and iron. And where there are possible problems, it may be desirable to run tests for sodium and soluble salts. Greenhouse soil tests often include these.

6. How about nitrogen tests?

Tests for total nitrogen are usually not run. The information is of limited value in routine soil testing. However, tests for nitrate-nitrogen are becoming more common in areas of relatively low rainfall, and in areas where irrigation is practiced. This test calls for special sampling procedures and these are supplied by the laboratory that will make the analyses and the recommendations.

The most reliable tests are generally assumed to be for pH and lime requirement and for extractable phosphorus and potassium. There is more research information behind the interpretation of these tests and, hence, more confidence in them.

7. Other elements.

As yields go up and soil depletion increases, more emphasis must be focused on plant needs for secondary and micronutrients. This opens a relatively new soil testing field.

It calls for a vigorous research program to evaluate the possibilities of using routine soil tests to determine needs for these elements.

Many labs determine extractable calcium and magnesium and use the information along with pH to determine lime status as well as needs for calcium or magnesium. Also sulfate-sulfur is determined, but sulfates are mobile, like nitrates, and the data call for careful interpretation. Often the texture of the soil, the amount of organic matter, and the rainfall pattern are more useful than the sulfate-sulfur level in predicting need for sulfur.

Although research work on tests for micronutrients is underway, there are still some labs that do not feel they have reached the stage where routine soil tests can predict with great accuracy the need for certain of the micronutrients. In general, however, these tests do give additional data upon which to base micronutrient needs. In the hands of the expert, one is usually better off with these determinations than without them.

Specifically, tests for manganese, zinc, and boron may be helpful in making recommendations. These tests should be considered along with other analyses and along with a description of the soil type plus a complete history of the field. Of particular help in the case of micronutrients are tests for pH and organic matter, depth of profile, water conditions, and history of liming and any plant symptoms.

Many agronomists feel that plant analysis is more useful than soil analysis for monitoring nutrients such as sulfur and certain micronutrients.

8. Lime Recommendations.

Lime recommendations are generally considered to be the most reliable recommendation that can be made on the basis of soil tests. They should be, because many of the determinations help arrive at the lime requirements: pH and buffer pH, cation exchange capacity and percent base saturation, calcium and magnesium levels, organic matter, and soil texture — all of these relate to lime needs. So the soil tester has a wealth of data upon which to base this recommendation.

In some instances amounts of lime recommended have not produced expected results.

This may not be the laboratory's fault. It may be brought about by many factors such as quality and fineness of lime, how recently it was applied, mixing and depth of plowing, time of year for sampling, and use of high amounts of N fertilizers.

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For example, most recommendations have been based on 6-2/3 inch plow layer. But more and more farmers are plowing 10 inches or deeper which calls for 50% more lime. This depth must also be considered in P and K recommendations in a "build-up" program.

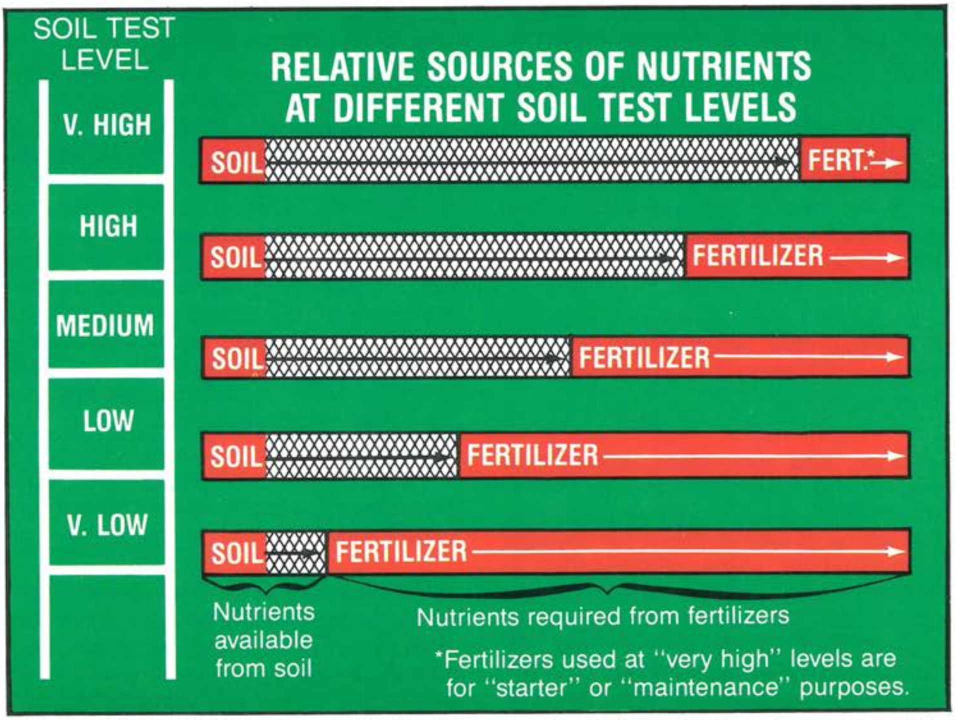
9. What do the numbers mean?

When the soil test results reach the dealer or farmer or county agent, the numbers are often misunderstood and create confusion. There are several reasons:

(a) The soil test value is empirical and actually is an index. Some laboratories report the number in terms of amounts of "available" plant nutrients. Others more properly call the figure "extractable" plant nutrients. The soil test does not pretend to extract an amount of a nutrient that is exactly the amount that is "available" but rather one that is **related** to the amount that is or will become available to the plant.

(b) Whether the value reported is considered high, medium, or low depends on calibration (or standardization or correlation) with carefully conducted field experiments over a period of years. These experiments involve different rates and combinations of fertilizer. Both yield and quality should be measured. And response may be obtained with one crop but not with another, one year and not another, or at one yield level but not another. Hence, it takes skill and experience in field research to calibrate soil tests with expected response.

(c) Different labs report the numbers in different ways. And the micronutrients are often reported



AS THE SOIL TESTS HIGHER in a plant nutrient, the amount needed from fertilizers becomes less. But even at high levels, some nutrients come from fertilizers — to maintain fertility and provide insurance.

in different terms than the major elements. The nutrients may be reported as:

pounds per acre (lb/A)
parts per million (ppm)
milliequivalents per 100 grams (m.e./100g)

Parts per million are frequently multiplied by 2 to give pounds per acre, since the average soil weight to a depth of 6-2/3 inches equals about 2 million pounds.

Milliequivalents per 100 grams may be a more scientific means of reporting results and has certain advantages, but is harder for the laymen to understand. It is used often to report cation exchange capacity.

(d) Different labs use different extractants or methods and, hence, get different numbers for the amount of extractable nutrients. This disturbs the farmer or dealer, but remember the number is an index number and must be calibrated with field tests. Thus, a figure of 60 lb/A with one extractant could mean the same as one of 100 lb/A with another. Both could be "medium."

(e) Since the figure is empirical, it is not possible to take the number as an exact figure. If a soil test report shows 60 lb/A of a nutrient and the plant needs 100 lb of that nutrient to produce a good yield, it is **not** possible to simply subtract 60 from 100 and conclude that 40 lb/A should be added. The numbers are simply index ones.

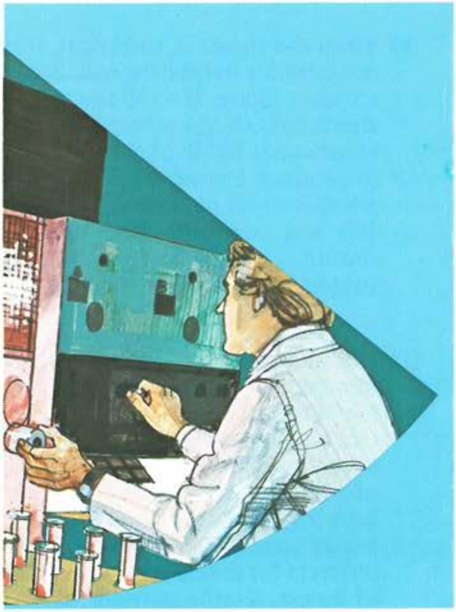
(f) Another cause for confusion in the numbers is that one lab may report the nutrients in the elemental form (such as lb/A P or lb/A K) while another reports the results in terms of the oxide (such as lb/A P_2O_5 or lb/A K_2O). Either is acceptable, but of course the **numbers** will be different for the exact same amount of an extractable nutrient. ■

Part 3: Soil Tests

Interpreting Soil Tests: The Pay-off

THE PAY-OFF COMES when the soil test is used, along with other background information, to make recommendations designed to eliminate soil fertility as a limiting factor.

Emphasis should be placed on the use of soil tests to monitor the soil fertility level rather than just to make a recommendation for a particular crop in a particular year. By keeping records it can be determined if the soil is being depleted, maintained or built-up. Then, for a recommendation, consideration would be given to the crop requirement at the determined soil fertility level.



When interpreting the test, several things should be kept in mind:

1. The chances of getting a profitable response to fertilization are much greater on a soil that tests low in a given nutrient than on one that tests high.

2. This does not rule out the possibility of a profitable response from fertilizer application at a high level of fertility, if other production factors are optimum. Likewise, a profitable response on soils of low fertility is not assured when other factors such as climate or management are poor.

3. Interpretation of soil test results and recommendations often becomes a matter of how to improve the fertility status of the soil. How much will be needed to change the soil from low to medium or high in that element? What will be the most economical level at which to maintain the nutrient status of the soil?

Purdue indicates that with a low soil test, there is a 70 to 95% chance of getting a yield response. With a high test there is a 10 to 40% chance. Minnesota indicates that with row-applied fertilizer the probability of response with a high test is 30 to 65%.

4. With top level management practices, yields increase and the probability of a response at any given soil test likewise increases.

There are many unanswered questions in soil testing as related to high yield levels. Many think we have arrived when we have only begun to learn what the possibilities are.

Basic question: What does the farmer want?

Some interpreters use soil tests to see how much fertilizer can profitably be applied. Others use soil tests to see how little fertilizer the farmer can get by with.

Tomorrow's farmer should receive fertilizer recommendations for the maximum economic or top profit yield. At the same time, a soil test gives good opportunity for making needed suggestions on crop management other than fertilizer and lime.

Since farmers today must strive for higher and higher yields, this requires evaluation of all the factors in the yield equation to determine those upon which he can exert some control. Among these is soil fertility. The old philosophy was to test the soil and predict the response from addition of a nutrient. But this does not answer the question of today's farmer. He wants to keep his soil in shape to produce high yields. He doesn't want yields to decrease due to a deficiency or imbalance of elements. He does not want to fall back to an "average" yield and then get response to nutrient application. Rather he wants to build his nutrient level to an optimum and maintain it there.

Thus, the soil test of the future may be used to determine the optimum level of an element required to reach high yields, the amount to be applied to reach this level, and then the amount needed to maintain it. It has been suggested that the farmer should never let his soil drop to the level where he gets response to nutrients other than nitrogen. ■

Part 3: Soil Tests

Making Recommendations Based on Soil Tests

AT ONE TIME recommendations from soil tests were made only by highly trained technical people who also ran the chemical tests. Now other groups can make these recommendations after receiving special training.

This offers certain advantages. It can permit recommendations from a person with first-hand knowledge of the farmer and his problems – a person who can follow up on results obtained.

Also, many farmer-businessmen want more than a fertilizer recommendation. They want a complete set of plans to meet a high yield goal. This calls for the inclusion of all relating factors – proper variety, cultural practices, time of planting, proper use of pesticides, etc.

Under these circumstances consulting agencies may be used by farmers to sample the soil and also the plant and to monitor the crop throughout the season. This adds a new dimension to soil tests. But the consultant should be well informed and experienced in the use and interpretation of soil tests.

In most cases, industry and commercial laboratories are just as well equipped as state labs to run soil tests with precision. The numerical results that one lab reports may differ from that of another lab, but this does not mean that one lab is correct and the other wrong.

The numerical figure is relative, and its meaning in terms of high, low, or medium depends on the calibration system and also the philosophy of making recommendations.

Two scientists could recommend different rates of nutrients from the same soil test, depending on many factors such as yield goals, building or depleting plans, and especially the type of farmer for whom the recommendations are being made.

For this reason, the use of computers for making recommendations must be carefully handled. The computer readout should be subject to modification by those who know the past history, the management practices of the farmer, and the many local facts that are part of yield determination.

It is hard to visualize a medical doctor making a diagnosis on the basis of a blood sample mailed in by a patient, analyzed, and run through a computer. The doctor would want to see the patient, ask questions, get a history, and use the blood analysis as a diagnostic aid.

This does not suggest that the use of computers is undesirable. Indeed, computers have provided tremendous labor savings in data handling, and result in fewer errors in the mechanics of calculating and reporting values. Also, computer storage of soil test values has facilitated annual summaries of soil test data.

The computer is extremely useful but caution should be exercised when expecting it to make all judgment decisions.

Recommendations when levels are high

One might ask, "If my soil tests high in a plant nutrient, should I add more?" This depends on what is meant by "high." If it means very high, that there is an abundance of the element present in the available state, then it might be well to leave it off, at least for the current crop.

Some laboratories assign the value "high" not to such very high conditions but to a level at which the odds point to little or no response to applications of that nutrient that year.

At the same time, failure to apply any of this nutrient will surely result in a depletion of that plant food. Also, under some conditions crops will respond profitably to a nutrient even with a high test. For example, on early planted corn the addition of P and K as a row application may produce response on soils testing high.

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Often farmers fail to place a price tag on residual fertility. While immediate return on the fertilizer investment is important, the better farmers are interested in big returns over the years.

Some laboratories and soil testers suggest adding a plant nutrient, even if the level is high, to avoid depletion of that plant food. Such depletion can occur fairly rapidly in some soils if yields are high.

For example, in Tennessee the K level in a soil dropped from "high" at the beginning to "low" at the end of one season as a result of cutting 4 to 5 tons of alfalfa hay.

What do soil tests mean?

In the 1940's, 50's and 60's soil fertility levels and yield levels were low and fertility level was an important controlling factor in crop yields.

Now fertility and yields are higher and as the better farmers strive for even higher yields and quality, other factors become increasingly important along with fertility. The goal is to build soil productivity, as well as fertility.

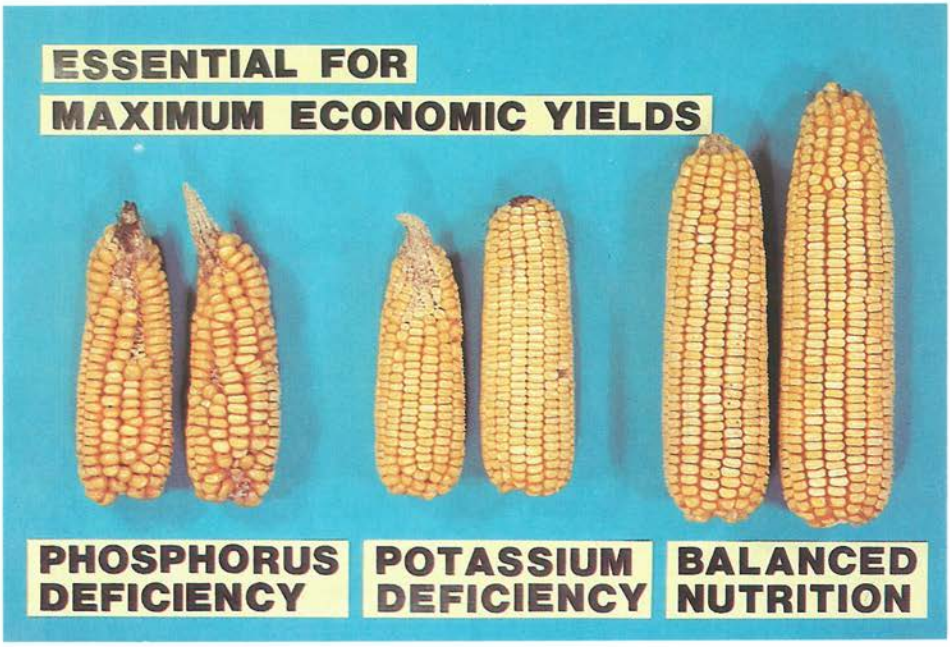
Long-term fertility trials are essential if soil test calibrations are to be meaningful. Most farmers operate on a long time basis.

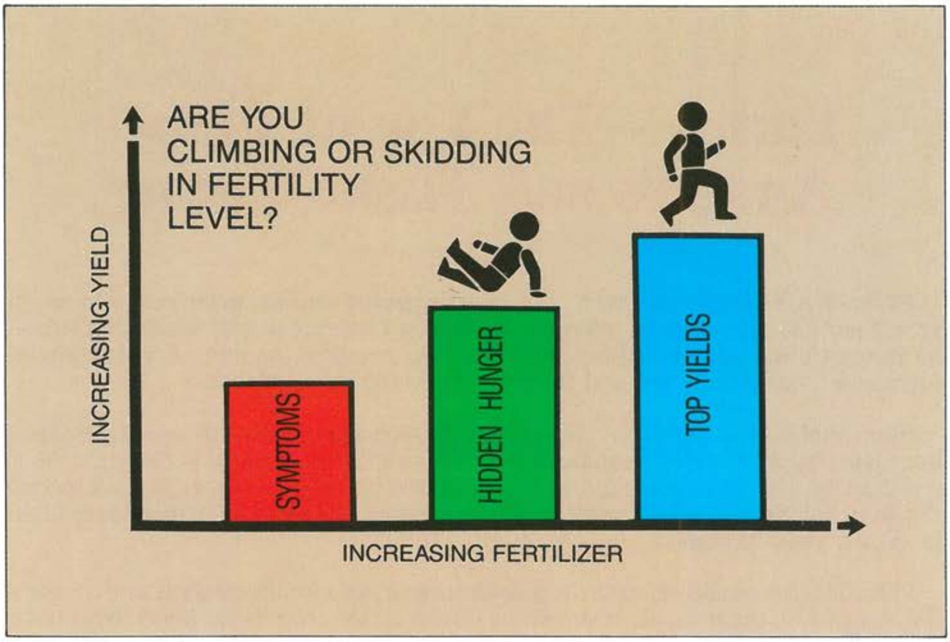
Soil tests are very useful diagnostic tools. And that is just what they are — tools. To consider a soil test as an infallible miracle worker is to misuse it.

The fact is the value of the soil test itself is seldom questioned. It is in the interpretation of the tests that the differences in philosophy occur.

In Summary

1. A soil test measures the relative soil fertility level.
2. Maximum yield research must determine the fertility levels of the entire





soil profile at which most profitable yields are consistently produced.

3. When interpreting a soil test, the goal should be to maintain the plant nutrients at that level where the supply cannot be a limiting factor at any stage from germination to maturity.

4. For soil testing to be even more helpful and more reliable in high yield agriculture, there must be more long-term correlation research at high yield levels. Also, more attention must be devoted to proper sampling time and techniques.

5. Soil tests are important in planning a long time fertility program. Sampling periodically and maintaining records of fertility levels, yields and all management practices is a must. ■

Final Note on Soil Testing

IN THIS DISCUSSION no attempt has been made to present the theories behind various extraction procedures. Nor are there any specific instructions on soil sampling or analysis.

There are many good soil testing laboratories throughout North America and the world. These include state supported laboratories and those operated by private industry. They offer literature that describes their services in detail.

Anyone involved in having his soils analyzed should select a laboratory in which he has confidence, and follow all the instructions from that laboratory. Then monitor the soil test levels over the years. ■

Part 4 — The Use of Plant Analysis and Tissue Testing

PLANT ANALYSIS has been used as a diagnostic tool for many years. In recent years there has been renewed interest and activity. There are several reasons for this — improved techniques for making plant analysis, increased amount of calibration information, and greater demand from farmers and their advisors.

Plant analysis is based on the concept that the concentration of an essential element in a plant or part of the plant indicates the soil's ability to supply that nutrient. Thus, it is directly related to the quantity in the soil that is available to the plant. A second aspect is that, up to a certain point, as the percentage content of a nutrient in the plant increases, yield increases.

Plant analysis usually refers to the quantitative analysis for the total amount of essential elements in plant tissue. It should be distinguished from rapid plant tissue tests, which may be made in the field. These will be discussed later.

Plant analysis and soil testing go hand in hand.

Reasons for using plant analyses

1. **To diagnose or confirm diagnoses of visible symptoms.** Symptoms are often difficult to identify because a number of factors may cause symptoms that may look alike. Often analyses are used to compare normal and abnormal plants.

2. **To identify "hidden hunger".** Sometimes a plant may be suffering from a deficiency but show no symptoms. A plant analysis looks beyond the appearance of a crop.

3. **To indicate if applied nutrients entered the plant.** If no response was obtained to applied nutrients it might be concluded that the nutrients were not lacking. However, such factors as pests, unfavorable placement or soil chemical properties or moisture stress might have prevented uptake.

4. **To indicate interactions or antagonism among nutrients.** Sometimes the addition of one nutrient will affect the amount of another taken up by the plant. For example, zinc uptake may be reduced with high rates of phosphorus.

5. **To study trends during the year or over the years.** Periodic sampling during the season may help to determine if a nutrient is becoming deficient. Sampling a crop over the years monitors trends in the levels of fertility in the soil. Many of the more common nutrient deficiencies are the result of long-term improper lime and fertilizer practices. Plant nutrient deficiencies or excesses can be detected before they appear as visual symptoms or reduce yields and quality.

6. **To suggest additional tests or studies to identify problems in a field.** Analyses can be useful in locating areas for fertility trials.

Calibration with yield and nutrient supply in the soil

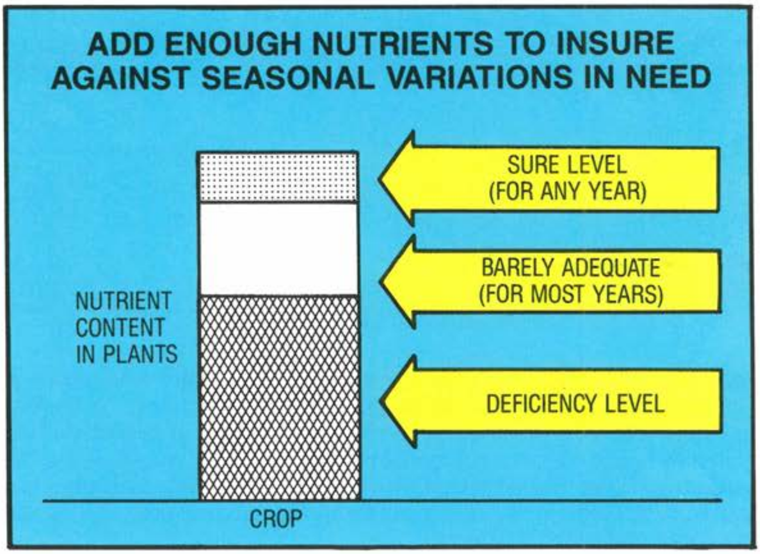
Of prime importance is how the plant analyses relate to available nutrient levels in the soil and/or to nutrients applied. Studies involving rate of a nutrient at various levels of that nutrient in the soil are essential in defining the relationship. While many such studies have been conducted, yield levels have often been relatively low. There is an urgent need for carefully controlled experiments at modern yield levels and up to the maximum yield for a given soil and environment.

Yield level may have a distinct effect on what is considered to be an adequate level of a nutrient in the plant. A prime example is potassium in alfalfa. A number of years ago 1.25% potassium was considered adequate. As yields moved up the value was changed to 1.5, 1.75, 2.0 and 2.5%. Now some think 3.0% potassium or more is needed for sustained high yields and quality and to maintain the alfalfa stand. Examples might be cited for other crops such as corn and soybeans.

At a low yield level, factors other than plant nutrients may be limiting yields and the content of a nutrient in the plant may mean little.

Critical level. Critical level has been suggested for a number of nutrient elements in many plants. It is defined as the content of an element below which crop yield or performance is decreased below the optimum. In some instances it is considered to be the point giving 90 to 95% of maximum yield. For example, in corn, around 3% nitrogen, 0.3% phosphorus and 2% potassium in the ear leaf at silking has been considered the critical level. However, it is difficult to choose a given level because many factors affect whether a given content is sufficient or insufficient. Too, high yield farmers may not be satisfied with 90 to 95% of maximum yield.

Ranges of concentration. Ranges have been developed giving the ranges for deficiency, low, sufficiency or adequate, high and toxic for many crops. This concept is usually more useful than the critical level. In Georgia the concentration of each element is reported as less than, greater than, or within the sufficiency range. In using plant analysis as a diagnostic tool, an excessively high amount of an element may be as important as a deficiency. ■



Part 4: Plant Analysis and Tissue Testing

Factors Affecting Nutrient Concentrations in Plants

THE SOIL TEST LEVEL and amounts of nutrients added in fertilizers, manures, residues and soil amendments are key factors. However, the concentration of a nutrient within a plant is the integrated value of all the factors that interacted to affect plant growth. When one considers the multiplicity of factors that influence growth and the resulting yield of crops it is surprising that plant analysis relationships hold as well as they do. Some of these are discussed in the following paragraphs.

Soil moisture. This is very important. With low soil moisture it is more difficult for plants to absorb nutrients and the content of a nutrient will be lower. This is illustrated in **Table 1.** With moisture stress, nitrogen, phosphorus, and/or potassium in the corn plant was reduced. With application of these nutrients, more moved into the plant, but concentrations in stress periods were still below the optimum. It is important to add enough nutrients to help insure against seasonal variations in need.

Table 1. Influence of applied N, P_2O_5, and K_2O and moisture stress on percent N,P and K in corn leaves. (Dr. R.D. Voss, Iowa State University).

Nutrients applied			NPK concentration	
N	P_2O_5	K_2O	No stress days	Moisture stress
------------ lb/A ------------			%N	
0	160	50	2.0	1.5
160	160	50	2.9	2.2
			%P	
160	0	50	0.26	0.12
160	160	50	0.32	0.18
			%K	
160	160	0	1.1	0.7
160	160	50	1.6	1.2

Temperature. Low temperature reduces uptake of a number of elements including nitrogen, phosphorus, potassium, sulfur, magnesium, and zinc. In cooler climates it has been found that a higher soil test level or rate of applied nutrients must be used to achieve plant nutrient concentrations comparable to those found in warmer climates. Under cooler conditions root growth is slower and plant uptake processes are slowed. Too, release of such elements as sulfur, phosphorus and nitrogen from organic matter through mineralization is slowed.

Soil pH. This influences the availability of many nutrients. For example, a higher pH tends to reduce iron, aluminum, zinc, manganese and boron but increases molybdenum in plants. A lower pH makes it more difficult for the plant to absorb magnesium and phosphorus, but more manganese and aluminum is absorbed.

Tillage and placement. Conservation tillage practices may cause a reduced uptake of nutrients, particularly potassium in drier, cooler areas. An example from a soil medium in potassium in Wisconsin is shown in **Table 2.** The potassium concentration in the corn ear leaf from the unplowed area was lower than that from the plowed, with or without potassium. This is in part due to position availability because much of the fertilizer is broadcast and remains on or near the surface. Band placement of nutrients near the seed or deeper in the soil improves uptake by the plant.

Side band placement is effective for increasing uptake of plant nutrients in early growth stages and may influence yield.

Table 2. Effect of tillage and added potash on corn ear leaf K (Dr. E.E. Schulte, University of Wisconsin).

K_2O applied Annually for 5 years	% K in ear leaf	
	Plowed	Unplowed
lb/A		
0	0.73	0.59
80	1.40	1.04
160	1.71	1.42

Hybrid or variety. The yield of a crop is the result of the genetic capability and the environment. Hybrids or varieties vary greatly in their yield capability. For example, in an experiment in New Jersey one corn hybrid yielded 312 bu per acre and another 227 bu per acre under exactly the same environment. Obviously the total nutrient uptake would be much different.

Too, varieties or hybrids may vary widely in concentration of nutrients, and the greater the genetic variation the greater the nutrient variation. Little information is available on critical or sufficiency levels of nutrients for specific varieties and hybrids.

Interactions. High concentrations of one element may cause imbalances or deficiencies of other elements. The relationship between phosphorus and zinc is one example. A high amount of phosphorus may reduce the amount of zinc in a plant. Under a marginal magnesium supply in the soil, a high application of potassium may reduce magnesium to the deficient point in the plant. The concentration of potassium in the plant may be reduced by a high rate of ammonia nitrogen.

Stages of growth. The concentration of an element considered to be adequate changes as the plant grows and matures **(Table 3).** Hence, it is important that plants be sampled at comparable and recognizable growth stages. ■

Table 3. Effect of stage of growth of corn on sufficiency ranges for N P K (Dr. C.O. Plank, University of Georgia).

	Sufficiency range %		
	N	P	K
Whole plants, less than 12'' tall	3.5 - 5.0	0.3 - 0.5	2.5 - 4.0
Leaf below the whorl, before tasseling	3.0 - 3.5	0.25-0.45	2.0 - 2.5
Ear leaf at tasseling, before silks turn brown	2.75-3.2	0.25-0.45	1.75-2.25

Part 4: Plant Analysis and Tissue Testing

Taking and Analyzing Plant Samples

1. Mailing Kit. Many laboratories have plant analysis mailing kits. Instructions for sampling and submitting samples should be followed specifically.

2. What to sample. Sampling procedures are provided by the laboratory doing the analysis. When no specific sampling instructions are given for a particular crop, the general rule of thumb is to sample upper, recently matured leaves. The recommended time to sample is just prior to the beginning of the reproductive stage for many plants.

3. Paired samples. Where a deficiency is suspected, take samples from normal plants in an adjacent area as well as from the affected plants. Take a soil sample from each area also.

4. Washing to remove contaminates. Dusty plants should be avoided. If dust is present, brushing or wiping with a clean damp cloth may be sufficient. If not, rinse briefly in running water while the material is still fresh.

5. What not to sample.

- Diseased or dead plant material, damaged by insects, or mechanically injured.
- Plants stressed severely by cold, heat, moisture deficiency or excess.
- Roots damaged by nematodes, insects or diseases.

6. The questionnaire. This is the means of communication between the sampler and the laboratory. Completion of the questionnaire is important if the interpreter is to properly evaluate the analysis.

7. Packaging the plant tissue. Partially air dry and put in a clean paper bag or envelope. Do not put in polyethylene bags or tightly sealed containers.

Possibilities for errors

It is well to keep in mind that plant analyses are not foolproof. There are many possibilities for errors.

- Collecting the sample – plant part, stage of growth, environment.
- Analysis in laboratory.
- Interpretation.
- Sufficiency ranges may not apply to modern yield goals.
- Improperly completed questionnaire.
- Very acid or alkaline soil so that plant growth is adversely affected.
- Amounts of other nutrients. A deficiency of nutrient A may cause nutrient B to accumulate. However, when nutrient A is supplied in adequate amounts, nutrient B may be deficient.
- Additions of a nutrient may increase yield but not increase the percentage content in the plant. However, because of a larger plant the total content of the nutrient in the total plant will be greater.
- The sufficiency or adequate range at a given location may vary from one year to the next because of climatic conditions.

Use of plant analysis

With most field crops, if analyses are made as the reproduction stage begins, they are too late to be of much value for corrective applications the current year. Adjustments can be made in lime and fertilizer practices for next year's crop when used in conjunction with soil tests.

However, with nitrogen and often with potassium, and particularly under irrigation, plant analyses before the reproductive stage may indicate a deficiency of nitrogen or potassium which might be corrected in the current season for crops such as corn, cotton and tomatoes. Increased use of foliar applications, greater effort towards top profit yields, and more irrigation will increase efforts for supplying corrective applications of nitrogen during the current year as well as certain other elements such as potassium. Some micronutrients such as manganese are readily applied as a foliar spray if found to be deficient by plant analyses or by visual observation.

For many years plant analysis has been used for tree crops such as citrus, peaches, apples, pecans and other nuts and fruits. Because of the perennial nature of these crops and their extensive root systems, plant analysis is especially useful for determining their nutrient status and possibly making corrective applications the current year.

Tables are available to provide a guide for interpreting plant analyses and to relate the plant analysis results to probable causes for elemental concentrations falling outside the sufficiency range. One such example is the tables in University of Georgia Bulletin 735, Plant Analysis Handbook.

It must be emphasized that interpretations are not valid for crops infested with nematodes, insects, diseases and weeds, damaged by chemicals or mechanically injured. Too, it is difficult to interpret results from crops after a severe drought. Hence, it is important to examine the plants carefully for such problems and to be aware of the rainfall records.

DRIS approach

The critical value and sufficiency range approaches have limitations. An important one is that the stage of growth greatly influences the values. So unless the sample for diagnosis is taken at exactly the right time, the critical value approach may become insensitive to the insufficiency to be diagnosed.

For example, if the leaf sample is taken earlier than it should have been, the

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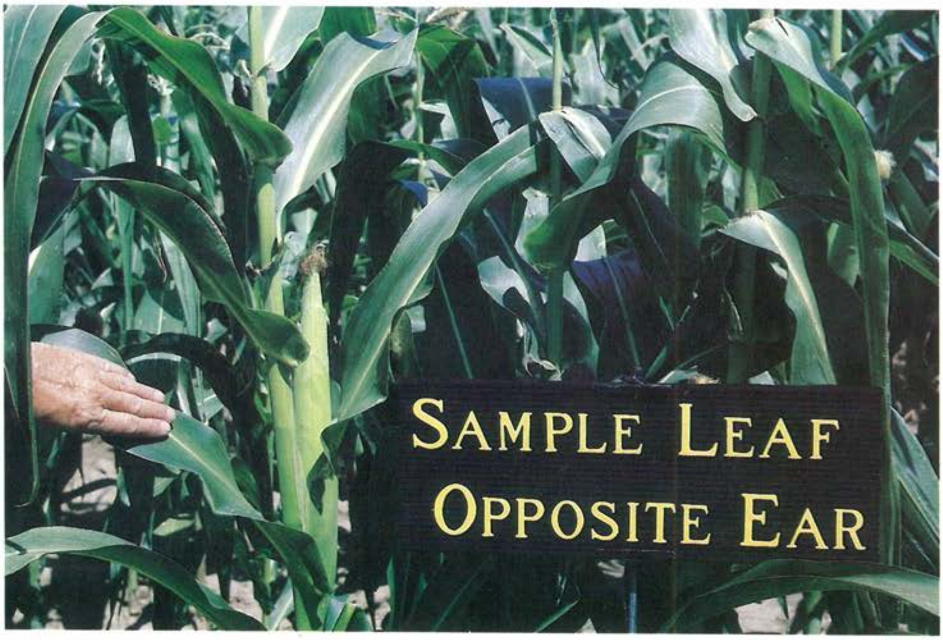

Table 3. Amounts of N, P_2O_5, K_2O, Mg and S in the above-ground portions of four crops.

	Corn			Soybeans			Wheat			Alfalfa		
	125	200	250 bu	40	60	80 bu	40	80	100 bu	4	8	10 tons
	lb/A											
N	155	266	350	216	324	432	67	134	168	225	450	600
P_2O_5	58	114	150	43	64	85	27	54	68	40	80	120
K_2O	165	266	350	95	142	189	81	162	203	200	480	600
Mg	41	65	81	18	27	36	12	24	30	20	40	53
S	21	33	41	17	25	33	10	20	25	20	40	51

(Potash & Phosphate Institute)

nutrient content may be higher than given critical values when, in fact, the plant has a deficiency. On the other hand, if the sample is taken later than it should have been, nutrients which were not insufficient may be diagnosed as deficient.

The Diagnosis and Recommendation Integrated System (DRIS) has several unique features which help overcome this problem (Dr. M.E. Sumner, University of Georgia). It is possible to make diagnoses at different ages of the crop and to classify the order in which nutrients limit yield.

In the DRIS approach, indices or norms are available for various crops. The index for a crop in a given growth situation is determined from plant analyses for several elements including nitrogen, phosphorus, potassium, calcium, and magnesium. The more negative an index value for a nutrient the more deficient that nutrient is relative to the others. Because the indices rank the nutrients in order of limiting importance, they automatically incorporate the concept of balance into the system.

The DRIS approach is not widely used as yet but it is an approach which helps answer many questions concerning plant analysis. It should be used on a trial basis with other methods of interpretation.

Total nutrient needs

Another use for plant analysis is to determine the amount of nutrients in the total above ground plant or in the harvested grain. When these data are given for several yield levels the increasing nutrient needs for higher yields are emphasized. While the fertilizer needs cannot be predicted from removal data, the nutrients must come from the soil or the fertilizer.

Approximate amounts of certain nutrients in the above ground portion for various crops at three yield levels are shown in **Table 3.** Actual amounts will vary with variety, soil and climate.

There is some emphasis on fertilizing just once in a rotation. For example, in a corn-soybean rotation most of the phosphorus and potassium may be applied ahead of the corn or soybeans with a starter fertilizer banded at planting for corn. This is satisfactory providing adequate quantities are applied to take care of both crops. The high amount of nutrients removed in forage is often emphasized. However, high amounts of nutrients are removed just in the grain of high yielding crops.

	Nutrients in grain only				
	N	P_2O_5	K_2O	Mg	S
	lb/A				
Corn — 200 bu	150	87	57	18	15
Soybeans — 60 bu	240*	48	84	17	12
Total	390	135	141	35	27

*Legumes can get most of their N from the air.

Analyses of the total plant at various growth stages throughout the season help to indicate the total amounts of nutrients needed and when. ■

Part 4: Plant Analysis and Tissue Testing

Tissue Testing

A TISSUE TEST is the determination of the amount of a plant nutrient in the sap of the plant. This is a semiquantitative measurement of the unassimilated, soluble contents of the plant sap.

Green plant tissue can be tested in the field and this helps a person to verify or predict the nutritional situation while still in the field. The results can be read as very low, low, medium or high. The purpose is not to split hairs but to assess general levels. Tests can be done for several elements: nitrate-nitrogen, phosphorus, potassium and occasionally other elements.

The tissue test is a help in verifying plant deficiency symptoms in the field and in detecting deficiencies before symptoms appear. A good approach is to compare healthy plants along with poor ones. Often the soil pH can be determined at the same time in the field, either colorimetrically or with a portable electrode, and this value is very helpful in interpreting the field tissue test.

The concentration of the nutrients in the cell sap from the green tissue is usually a good indication of how well the plant is supplied at the time of testing. The cell sap of conducting tissues might be compared with the conveyer belts in a factory. If the factory is to operate at full capacity, all the belts bringing in raw materials must be running on schedule. If one raw material is short, its belt will run empty, the other raw materials will pile up and production will be drastically reduced.

An alert factory manager will make sure there are no shortages. Likewise, an alert farmer or adviser will make certain that no nutrient is limiting crop growth and that the supplies are in proper balance.

(continued on next page)

WHEN PROPERLY USED, tissue tests can be an important diagnostic tool along with soil tests and plant analyses.

In using tissue tests, we are looking for one element (such as nitrogen) that may be limiting crop yields. If one element is low, this may allow others to accumulate in the sap because plant growth has been reduced. If the deficiency had been corrected and the plant had grown vigorously, other elements then may not have been in sufficient supply for top yields.

Materials needed for tissue tests are simple and easy to carry. The kit may include some tissue test papers, pliers, two solutions, a knife and nitrate powder. Plant Check, 4200 Woodville Pike, Urbana, Ohio 43078 or Urbana Laboratories, P.O. Box 399, Urbana, Illinois 61801 can supply kits to test for NPK. In addition, Plant Check can supply a pH test kit.

It takes **much practice and care in running the tests and interpreting the results.** The kits will have instructions. Too, the Potash & Phosphate Institute, 2801 Buford Hwy., N.E. Suite 401, Atlanta, Georgia 30329 has a slide set and script, "Field Diagnosis and Tissue Testing", which covers techniques, interpretation, and possibilities of errors.

It is important to consider:

- The ammonium molybdate solution may go bad. Hence, it must be checked frequently according to instructions.
- The potash papers deteriorate with time. They should be kept cool and a new supply obtained every three months.
- Plants damaged for any reason will give misleading results.
- Time of sampling and plant part, as for plant analysis, is important.
- Because of all these considerations, a training course in making determinations and interpreting is almost essential.

Tissue tests have not been widely used because most people would prefer to send in a plant sample and a soil sample to a laboratory rather than develop the skill to properly run and interpret the tests. Yet, properly used, tissue tests fit in nicely with soil tests and plant analysis as an important diagnostic tool.

Summary

Many factors affect uptake of nutrients. Plant analysis or tissue tests indicate what the plant was able to absorb from the soil or from foliar application. Variations from one field to another or among years on the same field are sometimes difficult to interpret. Hence, a key point is continued use to pick up nutrient trends over the years.

Plant analysis and tissue testing must be used in conjunction with other diagnostic tools. For example, soil testing, plant analysis and tissue testing go hand in hand. One is not a substitute for the other. All are useful tools in diagnosis and many good farmers and advisers use all programs. An accurate information sheet on past management practices, careful interpretation and being aware of the possibilities for errors are essential for most effective use of plant analysis and tissue testing.

Demand for plant analysis will continue to increase as farmers strive for higher, more profitable yields. The challenge will be to determine the levels of nutrients needed in the plant for top profit yields, particularly when we consider that yields will keep moving up over the years. ■

Soil Testing

SOMEONE SAID, "Soil testing is becoming quite controversial." Actually, this is nothing new. Over 40 years ago I was Director of the North Carolina Soil Testing Division. It was in the State Department of Agriculture. Top administrators in the College of Agriculture at North Carolina State at that time considered it a gimmick of unproven value, and would have no part of it. County agents were instructed to have nothing to do with this hot potato.

We've come a long way! Yes, there are those who misuse soil testing. Yes, we do need more good correlation research involving continuous high yields. Yes, we must still exercise caution in relying on soil testing alone in arriving at recommendations, especially for sulphur and micronutrients. And yes, there are many pitfalls in sampling – time of year, number of borings, mode of sampling for sod crops, tree crops, conservation tillage fields and banded fertilizer.

Too, more support for research is essential. And education should be expanded on such issues as the meaning of the values – the numbers themselves – which are often misunderstood.

But as long as we recognize that soil testing is not a miracle worker, **it is an excellent diagnostic tool,** a very useful means of monitoring soil fertility status. It is most valuable when used **along with other diagnostic tools by those with experience and knowledge.**

Let's work together to develop the full potential of this great program.

— Dr. J. Fielding Reed

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