In Pursuit Of The Better Soil Test

A soil probe can turn up variations in soil types in one field. This variation across a state or region can make generalized soil test recommendations inaccurate.

Predicting a crop's nutritional needs from a laboratory analysis of soil is still more art than science.

WILLIAM F. BRINTON, JR.

OVER A CENTURY has elapsed since the German chemist Justus von Liebig formulated the Law of the Minimum—that plant growth is limited by the necessary nutrient present in the soil in least amount. Liebig's discovery led to the birth of modern agricultural chemistry and the use of soil testing, for it marked the beginning of the belief that soil nutrient composition influences plant growth.

A century later, soil testing is still an art. More than one-hundred years of world-wide research has failed to conclusively prove or disprove Liebig's theory. And despite the urgings of many scientists, efforts to standardize soil testing internationally have all but failed.

Does this imply that soil testing is meaningless? Not necessarily. The confusing variation among research findings and on-the-farm soil test results are themselves important clues to the diverse ways plant growth is affected by soil condition—bothersome clues for those seeking a simple formula to explain crop growth. These clues, however, have helped researchers evolve broader and more realistic means for assessing the suitability of soils for agricultural use.

The soil testing market has grown considerably in recent years, and with it the type of services offered. A survey conducted in the north central U.S. for the ten year period before 1970 revealed a marked increase in private soil testing services. Almost all of them were using the *basic cation saturation ratio* (BCSR) concept to interpret their tests, in contrast to the *sufficient level of available nutrient* (SLAN) approach employed in most state and university services. At the risk of oversimplifying, the BCSR method may be thought of as measuring balances between nutrients stored in the soil while the SLAN method measures nutrients which relate more directly to crop yields. By 1970 the majority of farmers were sending soils to private labs which used the newer measurement of stored nutrients.

Have these private services with a new approach brought farmers new measures of success? Not always. To be valuable a soil test must be properly understood and applied in the right place at the right time. As one soil chemist put it, "There is no way to test an unknown soil." In other words, the usefulness of a soil test depends on how well understood a particular soil is before it is tested. To be reliable, soil tests for agricultural fertility must be fit regionally to soil type, climatic conditions and known relationships of individual crops to the specific nutrients being examined. Field trials are needed to supply this kind of information. Knowledge of this relationship is evolving constantly and as long as it does keep changing it is fair to say that the real value of soil tests is never fully known.

Testing For Available Nutrients

Soil tests which measure available nutrients are still widely used by state university testing services. The theories used to explain this approach to soil testing have changed since Liebig proposed his "Law of the Minimum" in 1840, but Liebig's concept is still the simplest expression of the dependency of crop yields on soil nutrients. It is often illus-

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Mobile vs. Immobile Nutrients in Soil Testing

	MOBILE	IMMOBILE
	Nitrogen (Nitrate) Sulfate	Phosphorus Potassium Calcium Magnesium
Sufficient level determined by:	expected uptake for maximum yield.	concentration needed to maintain maximum growth.
Usually limiting for:	later growth and high yields competitive crops.	early growth when high concentration in crop is needed.
Affects yields in:	an absolute way (quantity yield)	a relative way (percentage yield).
Any exceptions?:	usually not.	yes—in sandy soils immobile nutrients may act like mobile nutrients.
Associated with:	Liebig's law or the barrel concept of fertility.	Mitscherlich's law.

trated with a drawing of a barrel made of uneven staves. Each stave represents a soil nutrient needed by the crop. Water in the barrel represents the crop's yield. The water level, or crop yield, is determined by the shortest stave—the nutrient most deficient in the soil. As each deficiency is made up, the yield moves to the next highest level defined by another limiting nutrient.

This limiting nutrient concept has proven misleading. It implies that all nutrients, regardless of the form in which they exist in soils, affect yields in the same manner. It pays little heed to the law of diminishing returns or the possibility of excessive nutrients being toxic.

The shortcomings of Liebig's law were brought to light in the 1930s when more than 27,000 field experiments were laid out in different locations in Germany to test the relation of nutrient levels to yields of a variety of crops. This research resulted in the Mitscherlich Law, named after its chief proponent, E. A. Mitscherlich, who recognized the diminishing effect of increased soil nutrient levels on crop yields.

The new Mitscherlich Law created an international stir by suggesting an entirely new way of relating soil nutrient levels to crop yields. Liebig believed that a certain quantity of nutrient was necessary for each quantity of yield. But Mitscherlich's discovery suggested that a given quantity of soil nutrient would be sufficient for a certain percentage of yield, regardless of the size of the yield. These two approaches are practically opposite. Which one should be used for soil testing?

An Illinois agronomist, Roger Bray, resolved the conflict. He discovered that soil nutrients can influence yields in either of the two ways depending on their mobility in the soil. Mobile nutrients aren't bound to soil particles because they have the same negative electrical charge as surfaces of clay and organic matter particles. Just as the two negative poles of magnets repel each other, these negatively charged nutrients—called anions—are not attracted to negatively charged soil particles. Good examples of anions are nitrates, chlorides and sulfates. Water in the soil diffuses these nutrients rapidly into zones where they have been depleted by feeding roots. Because of this it is possible for crops to extract mobile nutrients very thoroughly from a large soil volume. Depletion of them will limit yields in the absolute sense of Liebig's law, since once they are gone further plant growth is impossible.

Other nutrients have restricted

mobility because they are attracted to soil particles. This group of immobile nutrients includes the cations (positively charged elements) such as calcium, potassium and magnesium. Since cations have the opposite electrical charge from negative soil particles, they are attracted to clay and humus much as the opposite poles of magnets attract each other. Phosphorus, an anion, is also a relatively immobile nutrient because it chemically reacts with soil minerals such as iron and calcium. These nutrients diffuse very little through soil layers, and if plants are to get them, their roots must in some way forage for them. It is impossible, of course, for roots to explore the entire soil volume and consequently impossible for a crop to use up a soil's immobile nutrient supply. Therefore, it is unlikely that an immobile nutrient could limit yields in the absolute way suggested by Liebig's barrel concept. A crop can deplete a soil's supply of the mobile nutrients such as nitrogen. When that happens, growth stops, just as the shortest stave in a barrel limits the barrel's water level. But with immobile nutrients like potash and phosphorous, as long as root expansion keeps pace with above-ground growth, the crop will continue to forage for them. If the soil has low levels of immobile nutrients, the crop won't reach maximum growth, but it won't stop growing, either.

These principles of soil fertility are of little use to farmers without regional confirmation through field tests. Each crop's ability to take up nutrients differs. And the accuracy of a soil test's recommendations can only be checked by growing that crop with several rates of fertilizer application—and on the types of soils to be tested. Normally, state soil test services run these field trials at several experiment stations. Often, however, only major crops such as corn, soybeans and wheat are tested, while many others may be placed in general groups with similar nutrient requirements. If a farmer chooses to grow an unusual crop for which no experiments have been conducted, then the soil test can't be used to make accurate recommendations for fertilizer applications.

A similar problem arises where soil types vary within a small area. In regions where soil type is uniform over large areas, as in some midwestern states, university field trials used to interpret soil tests may be valid over wide areas. In regions such as the Northeast, where soils are not uniform and all soil types can't be tested, unreliable generalizations may be used to interpret soil tests from unknown soils.

Unusual soils, such as those which are very sandy or high in organic matter, often do not give good correlations for soil test calibrations and are therefore almost never used in the field trials that test crop response to fertilizers. For example, nutrients that are normally immobile, such as potassium, may be fairly mobile in some sandy soils. Sand doesn't attract and hold such nutrients in the way that soil minerals and organic matter do. In those kinds of soils immobile nutrients may act to limit yields in the same absolute way as such mobile nutrients as nitrate. This means that much lower levels of soil nutrients might be adequate for crop growth. Growers located on unusual soils should read their soil test recommendations with caution. In Florida a special soil test had to be devised because so many agricultural soils were sandy.

Some Soil Test Terms

Anion—a negatively charged nutrient such as nitrate, sulfate and phosphate. Because particles of clay and organic matter are also negatively charged, they tend to repel anions in much the same way that like poles of a magnet repel each other. This is why anions leach easily from most soils. Only phosphate, which is more chemically reactive than other common soil anions, tends to link up with elements such as calcium and iron, becoming fixed in the soil and unavailable to plants.

Cation—a positively charged nutrient such as calcium, potassium and magnesium. Cations are attracted to negatively charged particles of clay and organic matter and less likely to be lost by leaching.

Cation Exchange—the process that makes cation nutrients available to plants. One cation—hydrogen, for example—can replace another—such as potassium—that is bound to a clay particle. This exchange of cations makes the potassium available to a plant root.

Cation Exchange Capacity (CEC)—a soil's total number of exchangeable cations, in other words, the amount of negative electrical charge in that soil. Soil tests usually report CEC in milli-equivalents per 100 grams of soil. Soils rich in clay or organic matter have high CEC values, sometimes 50 meq/100 grams or more: sandy soils have low exchange capacity, in the range of 1 to 10 meq/100 grams.

Basic Cation Saturation Ratio—(Sometimes called "percent base saturation ratio") is the amount of a soil's cation exchange capacity taken up by each of the basic elements or cations in that soil. Because some cations exchange more readily than others, they are considered more desirable. For example, many labs recommend that calcium make up 60 to 70 percent of the base saturation.

Sufficient Level of Available Nutrients—the concept that elements essential for plant growth must be present in the soil in the right amount for maximum yields. If one element is deficient, it will limit the beneficial effects of the others.

Basic Cation Saturation Ratio

Another approach to soil testing makes use of the principle of cation exchange to interpret soil fertility. This approach shouldn't completely replace testing for available nutrients because it concerns itself principally with cations. Nutrients not involved in cation exchange—phosphorus and nitrogen, for example—must still be tested in the customary manner.

The idea that soil particles such as clay and organic matter are capable of holding cations such as calcium, magnesium and potassium in a form which is immobile yet potentially available to plants was not clearly understood until relatively recently. Research conducted in the 1930s by

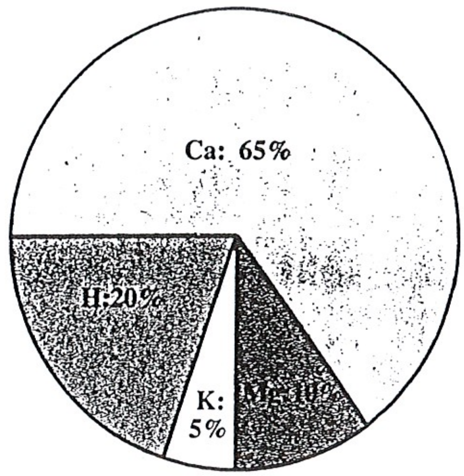
Missouri soil scientist William Albrecht and others suggested that the principle of soil cation exchange could be useful for interpreting a soil's fertility for crops. Ideal saturation ratios for soils were drawn from a limited number of experiments and used to interpret appropriate soil tests.

In the cation exchange process positively charged minerals such as calcium and potassium are held by negatively charged surfaces of soil minerals and organic matter. The extent to which a soil is able to hold cations is referred to as "cation exchange capacity" (CEC) and varies with the type of soil and its humus content. Nutrients that are cations are not available to plants until other cations "exchange" for them on the soil particles, releasing the bound cations into solution.

Some cation elements are more easily exchanged for plant use than others. This is known as the complementary ion effect. If an easily exchanged cation is present on soil particles it will tend to become available to plants much more readily than will a cation which is strongly held.

The complementary effect of cations on each other can be pronounced enough to be antagonistic. For example, potassium typically inhibits magnesium release, and large amounts of potassium in soils may cause magnesium deficiency in plants even when the soil's magnesium level appears sufficient. Magnesium deficient forages are the cause of widespread grass tetany disease in cattle. Other complementary effects include sodium and ammonium depression of calcium, magnesium and potassium release, magnesium depression of calcium release and even hydrogen depression of calcium and magnesium release on very acid or high organic matter soils. Because calcium has the least antagonistic effect on the release of other cations it is the most desirable element to have occupying most of the negatively charged surfaces of a soil's minerals and organic matter. This explains in general how researchers have arrived at "ideal" saturation ratios for soils.

The chemistry of cation reactions is complicated by the diversity of soil. Research has shown that the nature of cation exchange varies with the type of minerals which make up a soil and there is some evidence that cations associated with humus are more available than those bound to soil minerals. Such facts limit the extent to which specific recommendations can be made for different soils, and until the approach is tested regionally it probably can only be used in the generalized way which most labs apply it.



Idealized cation saturation levels for soil. Ideal saturation levels vary with the soil and crops grown. The above levels were originally found to be ideal for alfalfa grown in New Jersey.

The cation approach has other hurdles to cross before it can be used alone to recommend fertility levels for crops. It has had very little field testing under varying conditions, although laboratories using the method in different areas of the country nonetheless use almost identical calculations to arrive at recommendations. This is because the same idealized soil saturation ratios are used to interpret the tests. Private labs using the approach may not be in the position to set up experiment stations to test the approach for different soils. It seems too good to be true that one general formula could fit different growing areas.

Despite these shortcomings, the concept of cation exchange has been widely accepted. More than half the soils tested in the United States are interpreted according to this approach. An increasing amount of research on the method is being conducted by state Extension services and some state soil testing labs, such as the one at Pennsylvania State University, are using it.

For farmers, recommendations from the basic cation saturation ratio test are likely to result in higher fertilizer bills than recommendations for sufficient nutrient levels. This is especially true in the case of over-zealous testing services that seek to "fine tune" a soil to idealized saturation levels not proven to give higher yields. Corn, for example, is a crop for which no ideal cation saturation ratios are known. Consequently, if a lab always recommends the idealized levels, as many do, they most likely can't guarantee increased yields. A University of Nebraska survey of the results of fertilizing corn and sugar beets according to the conventional and the cation ratio methods on five locations showed yields remaining similar although fertilizer costs for the cation approach were doubled. However, cation ratio recommendations which properly account for crop variation should not result in increased fertilizer costs.

It is probably true that the basic cation saturation ratio is most valuable in correcting imbalanced soils, assuring the proper potassium-magnesium ratio—particularly where animal forages are grown. Increased research and close rapport between growers and soil consultants may improve the usefulness of this method.

Nitrogen—The Transient Nutrient

Every nutrient has its particular cycle in the soil yet none has been harder to pin down for soil testing

Adapting soil tests to organic methods

FARMERS WHO CHOOSE not to use conventional soluble fertilizers have an added problem when interpreting soil tests—determining application rates for partially effective fertilizers. Although organic fertilizers are used with more than nutrient content in mind plant nutrient needs must still be met as efficiently as possible. Recommendations from conventional tests are made by using an efficiency factor based on field tests with soluble fertilizers. Although most labs and farmers will convert these conventional recommendations using NPK tables for organic materials, the new recommendations are guesswork. The efficiency factor for organic soil amendments varies widely and often depends on soil type. And prewar field trials with natural amendments have not been correlated with modern soil testing methods, with a few exceptions. Until agricultural researchers fill these information gaps, private and state labs and organic farmers will continue to rely on NPK tables and guesswork.

The following table highlights some of the facts about efficiency of nutrients contained in organic soil amendments (excluding rock powders):

Effectiveness of Nutrients in Organic Materials

	Effectiveness	Comments:
Nitrogen	Medium	In fresh manures 40–70% effective, less in stabilized materials such as composts. Carryover effects in 2nd & 3rd years (rule of thumb for manures: 50% release 1st year, 25% 2nd, 10% 3rd)
Phosphorus	Medium-high	Usually very effective in presence of organic materials. The Dutch extension service reports 100% effectiveness in most manures.
Potassium	Very high	Almost always 100% effective from plant and animal sources.
Calcium	Medium	Less effective if potash and sodium are high
Magnesium	Medium-High	Less effective if potash and sodium are high

Note on rock powders: efficiency of release is normally highest in the presence of soil acids. If soils are near neutral the efficiency can be improved by adding the rock powders to manures in advance of spreading.

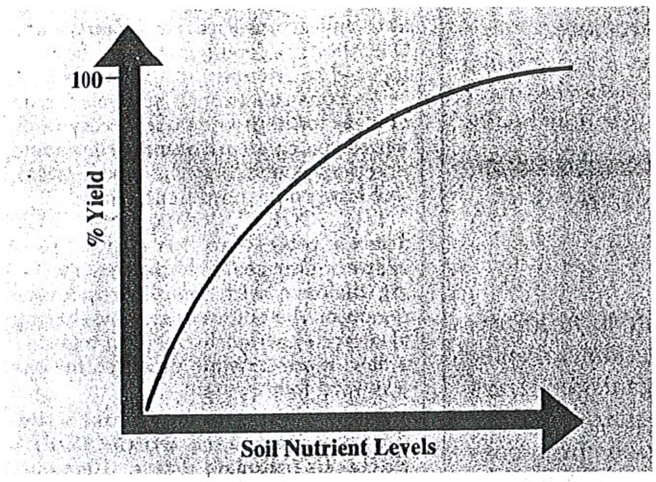
Principle Anions and Cations in Soil

ANIONS	CATIONS
Nitrate	Calcium
Phosphate	Potassium
Sulfate	Magnesium
Chloride	Sodium
Carbonate	Ammonium
	Aluminum
non-metallic micro-nutrients (Boron, molybdenum)	Hydrogen "Acidity" metallic micro-nutrients (iron, copper, zinc, cobalt)

Soil Test Methods in Relation to Soil Minerals

SLAN Method*	BCSR Method*
used to interpret:	
P, K, Mg most micro-nutrients	Ca, Mg, K, Na, H + Al exact lime requirement
Comments:	
K and Mg levels should be checked against BCSR method to assure optimum ratios	K levels should be checked against SLAN levels
May give false recommendations on very sandy soils	Problematic for high CEC soils requiring huge amounts of amendments
Recommendations based on soluble fertilizers only—difficult to convert for organic use	Recommendations based on liming materials, gypsum and soluble Mg and K salts. Often include trace minerals.

* SLAN = Sufficient Level of Available Nutrients
* BCSR = Basic Cation Saturation Ratio



The Law of Diminishing Returns Relating Soil Nutrient Levels to Percentage Yields According to Mitscherlich's Law. This type of curve has proven best for relating immobile nutrients such as phosphorus and potassium to yield levels.

than that of nitrogen. Soil testing services usually haven't directly measured nitrogen because it is known to undergo chemical and biological changes rapidly enough to make interpretation difficult.

In its available form as nitrate (NO_3^-), nitrogen is so mobile in soils as to be tremendously available to most crops and fits almost perfectly Liebig's idea of a limiting nutrient. In this sense a crop's nitrogen requirement could be considered synonymous with its total uptake, simplifying the task of recommending nitrogen fertilizers. You simply calculate the crop's expected uptake and apply that much soluble N, adding perhaps a small amount to cover losses.

This simplified approach to recommending N fertilizer rates has proven increasingly unrealistic, partly because of relatively large amounts of nitrogen within the soil's organic matter reservoir. A soil with 3 percent humus may contain as much as 3,000 pounds per acre of total nitrogen, or 5 percent of the organic matter. However, the nitrogen in this form is not directly available to plants, but a fraction of it—usually only 2-to-5 percent—will become available each year through normal decomposition of the organic matter. This relationship has been extensively studied and is so nearly perfect as to be a virtual guarantee of available N wherever soil organic matter is present.

If a soil containing large amounts of organic matter is fertilized with nitrogen without accounting for the amount of nitrogen release, then the amount of nitrogen available to crops over the growing season may be excessive. On heavy textured soils where excessive nitrate will not leach rapidly, it accumulates in sub-soil horizons. For grains, which develop extensive root systems, this nitrogen may be absorbed readily in subsequent years and may even be adequate for normal yields without additional fertilizer. If more nitrogen is applied, the grains may absorb enough to cause lodging.

Because of these problems, deep-profile testing for available N is being used increasingly in the Great Plains and the Northwest. Soil is often sampled to four feet deep, using hydraulic probes. From such soil tests, the true crop nitrogen requirement is found by subtracting from the crop's total need the available amount plus the amount of expected release. This can result in substantial savings in recommended fertilizer rates. Variations of this method are being used widely and are contributing to a nitrogen economy which is both more realistic and healthful.

Regardless of how a person farms there are inherent qualities in soils and crops which restrict the value of soil tests as indicators of true fertility. Potentially, every region contains the unknown soil for which appropriate tests cannot be devised. In fact, as long as soil testing remains a more or less centralized undertaking, regional "sore spots" will probably go unrecognized. Ultimately, it is the farmer alone who suffers from recommendations poorly suited to his own conditions. As long as fertilizers remain cheap and environmental effects minimal, such soil testing generalities can be tolerated. Yet there is already talk of future regionalized soil testing and more regional experiment stations to tailor fit agronomy more closely to farmers' needs. □