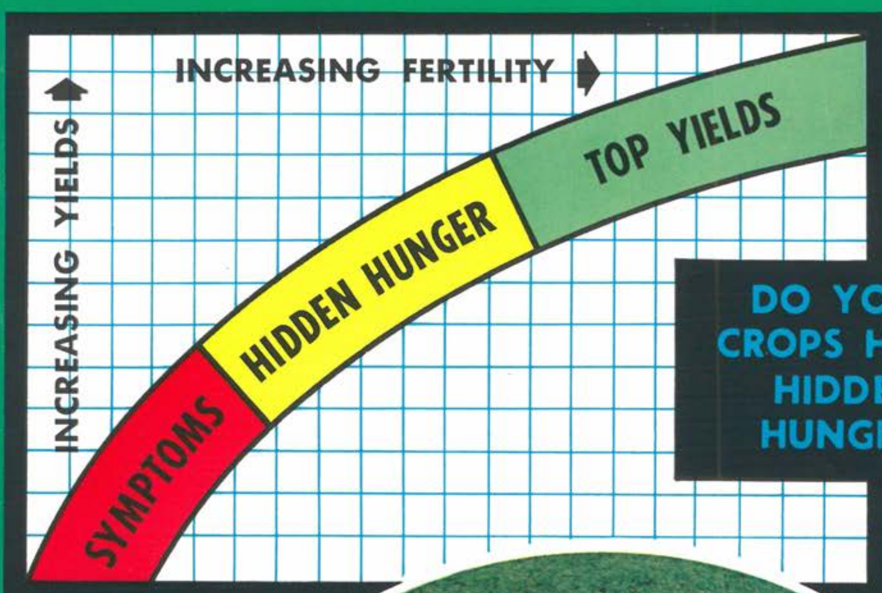
Better Crops

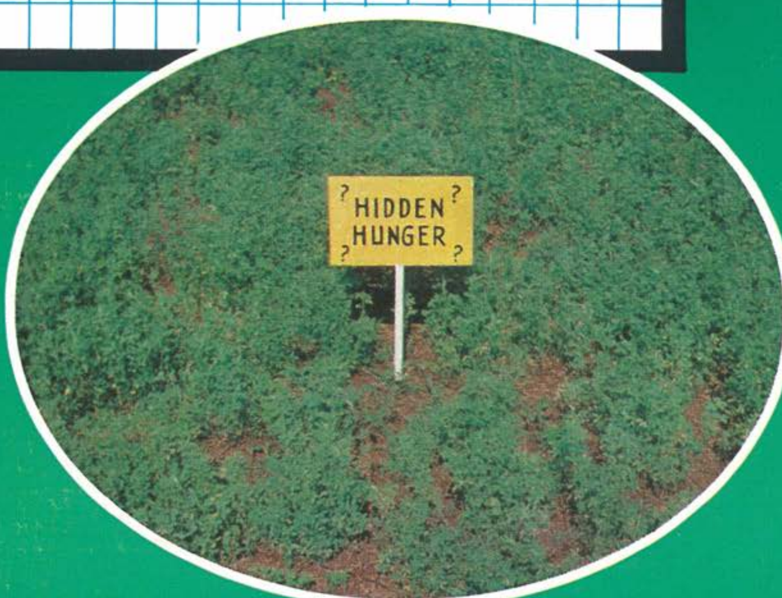
WITH PLANT FOOD

May, 1958

10 Cents



DO YOUR CROPS HAVE HIDDEN HUNGER?



Cauliflower: left, boron treated; right, brown curd with boron deficiency

Alfalfa yellows and rosetting due to boron deficiency

EXAMPLES OF BORON DEFICIENT CROPS

Apples with external cork cracks, necrotic areas and dwarfed

Tobacco with die-back of terminal bud rolling of upper leaves

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ON THE COVER . . .

. . . we see that crops, like people, can suffer from *hidden hunger*.

For years, we have spent much effort identifying, describing, and publicizing plant food deficiency symptoms in various crops. Such symptoms are important for diagnostic purposes. But, in concentrating so thoroughly on obvious hunger, we have seemed to say—or ask—"Why worry about *hidden hunger?*"

The graph and picture on our cover answer why. They show deficiency symptoms are a good guide when deficiencies are *very great*. But toward the top of the yield curve—where increasing fertility is increasing yield potential—external symptoms may disappear *although the crop does not have enough nutrients to produce top yield and quality*. This is *hidden hunger* which, no doubt, is limiting the full performance of many crops.

On the yield curve, the first unit of fertilizer applied returns more per $1 invested, but the last unit gives the *greatest net profit per acre*. This is in the *hidden hunger zone* toward the top of the yield curve, where farming is most efficient.

The picture, below, shows an alfalfa stand demanding diagnostic tools other than symptoms to find its "next limiting factor." Something's wrong. The stand is thinning. Yields aren't high enough. Plants are somewhat stunted. But there are no *recognizable leaf symptoms*.

Is this *hidden hunger?* What diagnostic tool should we use? Tissue tests? Soil Tests? Plant Analysis? Field Trials? And what economic factors help determine yield goals and the most profitable fertilizer treatments?

To help answer some of these questions, the Potash Institute has invited several authors—authorities in their fields—to explain how various research tools can be used to guide farmers through the *hidden hunger zone* toward the most profitable yield levels.

Better Crops WITH PLANT FOOD

The Whole Truth—Not Selected Truth

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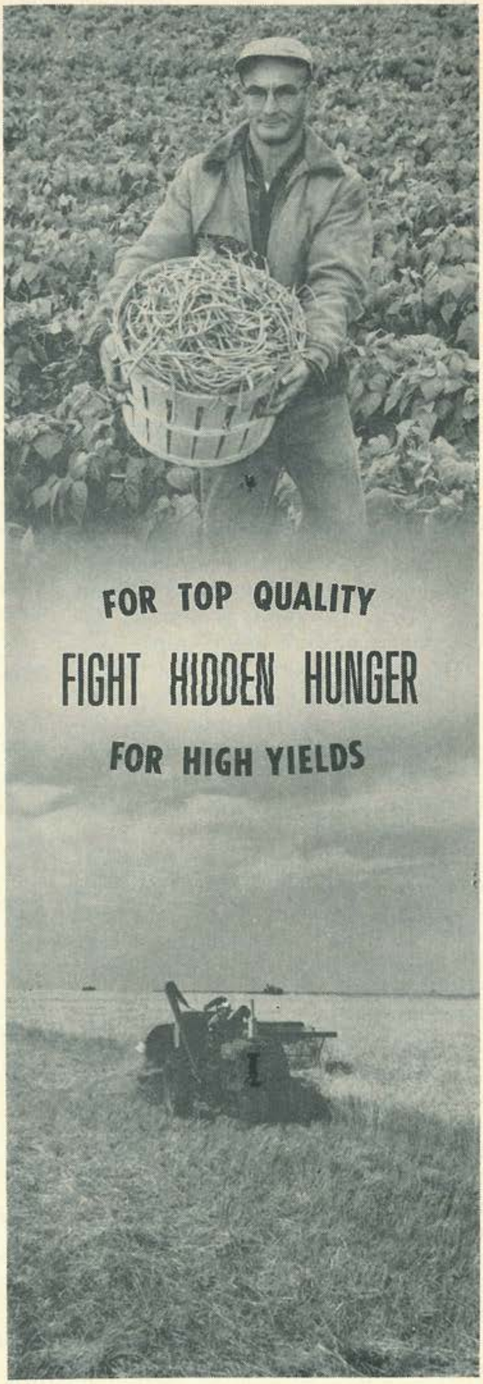

Better Crops with PLANT FOOD

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Plants Can't Wander Around . . .

LOOKING FOR RICHER SOILS

Jeff McDermid

(ELWOOD R. MCINTYRE)

FINDING and correcting the hidden hunger of plants is the first step in a long, complex chain of reactions aimed at creating proper nourishment in animals and mankind.

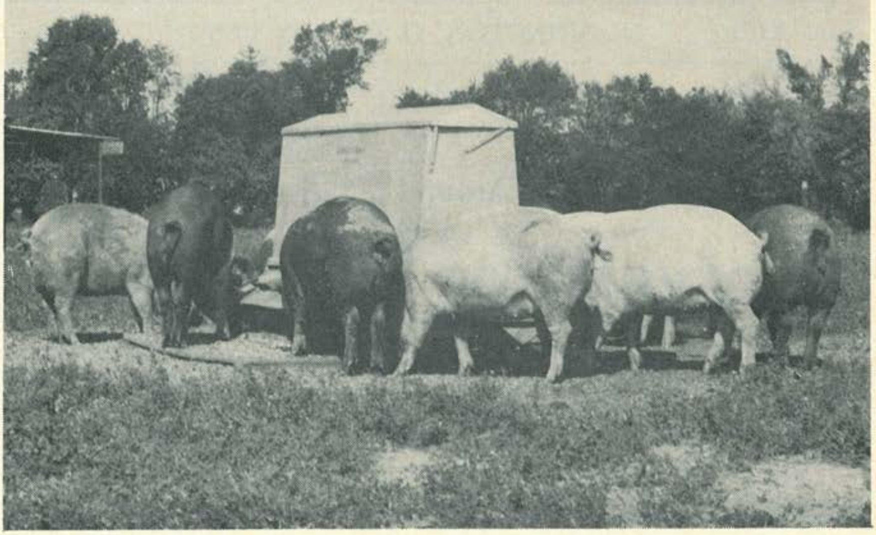
Faulty, unbalanced nourishment begins with food and feed crop plants and may eventually carry directly into the life cycles of milk- and meat-making livestock—and from there to the household larder and family diet.

Plants are at a disadvantage in this crisis, for they can't wander around and establish themselves in a better nutrient supply zone. With them, what goes on underground makes or breaks their healthy, normal growth and sound maturity.

Plants can't choose their victuals much beyond the limited reach of their characteristic root systems. So they rely solely upon the alert farmer or gardener who grows them for himself or others or for livestock provender. He, in turn, depends on the steady progress of our soil and plant scientists to point the practical way through soil and tissue tests and analyses. This makes fertile land one of our most universal objectives.

(Continued on page 22)

DO YOUR CROPS HAVE HIDDEN



Fertile soil has been compared to a self-feeder by some agronomists—a self-feeder where crops can get the plant foods they need when they need them, like hogs that select a balanced diet when it's readily available. Plant food demands (or removals) increase during the growing season, according to both plant sizes and numbers "eating" from the soil.

HIDDEN hunger is the kind of nutrient deficiency that keeps the crop from producing its maximum yield, *although no external abnormalities can be seen in the plants or in the quality of the products.*

There is nothing new about this *hidden hunger* idea. Dr. A. L. Kenworthy, of the Michigan State University Horticulture Department, issued a "Nutrient Element Balance Chart" (Figure 1) in 1949, consisting of five concentric rings. These rings represented (1) visible deficiency symptoms, (2) hidden deficiency, (3) optimum levels of plant nutrients, (4) approaching excess or hidden toxicity, (5) excess or visible toxicity.

Names of 10 nutrient elements were placed around this chart, designed to record chemical analyses of crops. After chemical analyses were made of a plant, black lines were drawn from the hub of the circle toward the outside, forming the spokes of a wheel. The lengths of the lines represented the supplies of N, P, K, Ca, Mg, B, Mn, Fe, Cu, and Zn relative to the needs of the plant.

Before looking at *hidden hunger* as the insidious phenomenon it is, perhaps we should first ask, "What is a deficiency symptom?" There are many

"An ideal nutritional environment indeed may be one in which all nutrient elements are available to the point of slight luxury

By H. L. GARRARD

HUNGER?

Homewood, Illinois

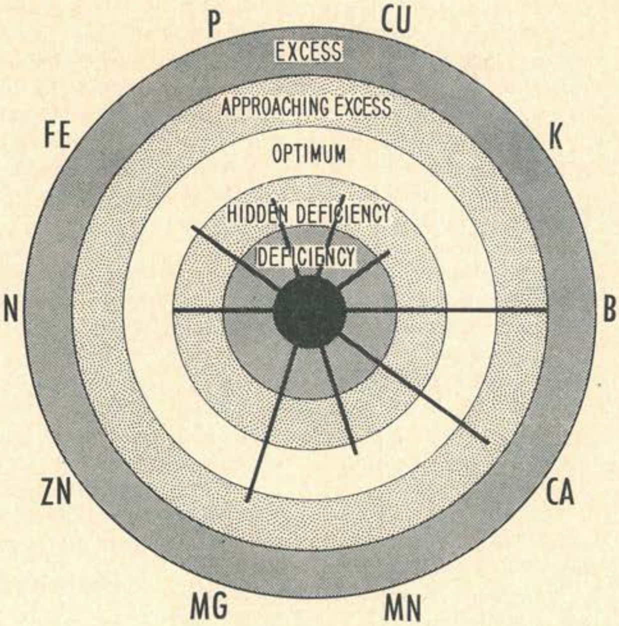


Figure 1—There is nothing new about the Hidden Hunger idea. This nutrient element balance chart was produced by Dr. A. L. Kenworthy of Michigan State in 1949, with lengths of lines drawn from center indicating supplies of nutrients.

degrees of nutrient hunger:

1. Complete crop failure at seedling stage.

2. Severe stunting of plants.

3. Specific leaf symptoms appearing in different degrees at varying times during season.

4. Internal abnormalities, such as clogged nodes.

5. Delayed or abnormal maturity.

6. Obvious yield differences, with or without leaf symptoms.

---

consumption at all times."

A. G. Norman, Past President
The American Society of Agronomy

---

7. Poor quality of crops including unseen chemical composition differences, as in protein, oil, or starch contents; in keeping qualities, etc.

8. Yield differences which can be detected only by careful experimental work. Here surely is hidden hunger.

Symptoms Alone Not Enough

Deficiency symptoms—or hunger signs—alone are not enough to diagnose nutrient needs, because (1) the problem is to *prevent* hunger rather than *correct* it; (2) when yields rise, as in the graph on the cover, visual symptoms become *less obvious* or *disappear;* (3) no outstanding symptoms have been identified for certain deficiencies; (4) symptoms appear only at extremely low levels; (5) some symptoms appear late in the season.

Determining symptoms—what they mean, what they are from, why they exist—is not an easy job, often full of contradictory factors. For example:

Few plants show phosphorus hunger leaf symptoms. The main symptom is usually slow growth *from seedling to maturity, although leaves or stems of some crops—such as corn, tomatoes, red beets, etc.—may turn a purplish color early in the season.*

Neither nitrogen nor potassium hunger in grasses and grains is always definite and distinguishable. On the narrow leaves of such crops, these symptoms may be confused with leaf discolorations caused by disease and weather damage.

On the other hand, large-leafed plants, like tobacco, exhibit more definite deficiency patterns.

Sometimes hunger symptoms may not appear until the middle of the growing season, as on corn, when it is too late to correct the deficiency for that year. Take corn fertilization trials on low-potash soil, for example. Only 10 lbs. K_2O equivalent in fertilizer may make an outstanding growth difference for the first six to eight weeks; after that, symptoms begin to appear; and final yields are disappointing. But high potash treatment alongside will help carry the crop to a normal maturity.

Corn is a good example of how a crop can run out of available plant food at any time but show the signs when it's too late. Take nitrogen, for instance. Corn can run out of nitrogen at any time, but often the yellow-tipped bottom leaves don't appear until the flush of growth just about tasseling and earing time. In dry seasons, it may be called "dry weather firing," but water-logged soils also produce the same nitrogen starvation.

Changing Theories and Goals

Changing theories on soil fertility are interesting. Some experimenters once advised the farmer to avoid liming costs by growing lespedeza instead

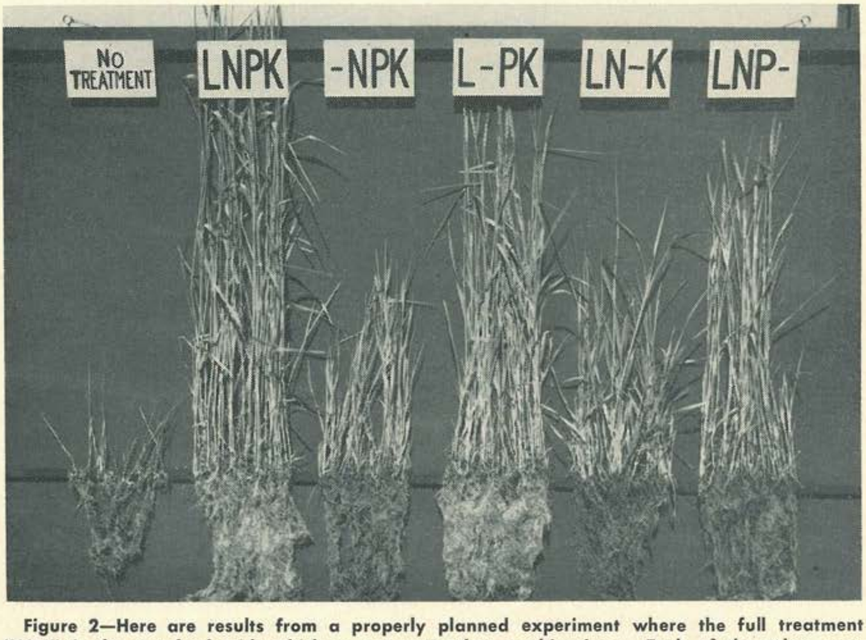


Figure 2—Here are results from a properly planned experiment where the full treatment (LNPK) is the standard with which to compare other combinations. Each of the other combinations—except the "no treatment" results—is minus one factor. In one treatment, lime is missing; in another, nitrogen; in another, phosphorus; and finally potash.

of alfalfa. But others found really good lespedeza could not be grown without liming.

And there was the time wheat and oat varieties were grown or eliminated according to their abilities to produce a fair yield on existing fertility levels. Some varieties even lodged under high fertility conditions. Today small grains are selected for their ability to stand erect under high nitrogen treatments.

Around 1923, some of the first experiments on corn inbreds and hybrids planted across different fertility levels in Indiana showed that inbreds and hybrids do not rate the same under high and low fertility levels. Today, corn hybrids are rated by testing them under very high fertility conditions.

Some people once thought "spoon feeding" crops by starter fertilizers was all that was ever needed. But as yield goals rose and soils were depleted, corrective or soil building treatments became more popular, especially for those aiming for top yields.

Soil Like a Self-feeder

Keeping a soil fertile, with so-called "balanced" supplies of each nutrient, might be compared to using a self-feeder.

Top crop yields demand adequate and *constant* supplies of nitrogen, phosphorus, potassium, calcium, etc. The problem is to make those nutrients available at the right time, without injuring the crop by application mechanics.

The critical nutrition period of most crops comes 1, 2, or 3 months after planting.

For example, corn absorbs its greatest amounts of nutrients about two or three months after planting—at least one month after it could be sidedressed practically—so the plant foods must be stored in the self-feeder soil where the roots of the growing plant can reach them.

Another example is wheat. Fall-seeded wheat needs its first supply of nutrients during the first few weeks after planting before freeze-up, when

Figure 3—Long-time investments for limestone, or corrective applications of phosphates or potash, can be evaluated only by long-term experiments. These should be considered capital investments. Here we see how limestone makes the difference between alfalfa or weeds.

the plants become dormant during 2 or 3 months of winter. In the spring, 5 to 6 months after planting, a new surge begins, using its greatest amounts of nitrogen, phosphorus, and potassium. To meet these needs, sufficient phosphates and potash should be applied in the root zone at or before planting, while spring topdressings can supply nitrogen.

Most row crops need a fast start, to give the seedlings a good chance. We often advise banding fertilizers near, but not in touch with, most seeds. Plowed-under fertilizers are safely stored in properly limed silt and clay soils. The organic matter, the silt and clay particles, act as storehouses for water, for minerals, and even nitrogen.

Before our guest authors discuss the various research tools used to guide farmers through the *hidden hunger zone*, we would like to comment briefly on the philosophy, background, and usage of diagnostic tools.

The different diagnostic methods and their purposes are:

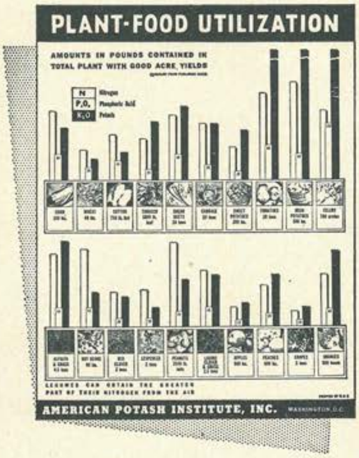


Figure 4—Total plant food utilization for top yields is predicted by chemical analyses of plants from high-yielding experiments. Charts, as above, indicate general total needs of different crops at specific yield levels. Make sure your calculations of plant food needs are based on high enough yield goals.

1. *Field trials* come first, to show possibilities and trends, or to test theories.
2. *Soil tests* indicate immediate needs.
3. *Chemical tests on plants*—including tissue tests, leaf analyses, and total plant food contents—all help to show deficiencies and guide to adequacy.
4. *Plant physiology studies* show effects of below-adequate nutrient supplies.
5. *Economic studies* prove practicality of short-time and long-time investment in fertilizers, lime, and related soil fertility management practices.

Field Trials Come First

Field trials—experiments or demonstrations—are used to calibrate soil tests or tissue tests and to indicate immediate responses to fertilizer treatments, (Figure 2). In the Lang and Aldrich article, page 14, long-time trends give valuable lessons for those planning soil improvement programs.

It takes long-time trials (Figure 3) to evaluate long-time investments in limestone (8 to 10 years) and in corrective applications of phosphate and potash. Such corrective applications are capital investments by land owners and their bankers. Short-term trials cannot always measure residual effects of fertilizers, although residual values often pay the entire fertilizer bill.

Soil Tests

Soil tests, so far, have been the most important tool for making field by field recommendations of lime and fertilizer on most crops. They are used to interpret research results back to the individual fields, where the fertility needs may vary because of soil type differences or man-made changes.

Mitscherlich's percent yield curve concept was used by R. H. Bray of the University of Illinois to calibrate phosphorus and potassium soil tests.

Table I shows how crops vary in their relative percent of yield at the same soil test levels. This means crop needs, as well as extractable or so-called "available" potassium, must be carefully considered when interpreting soil test results.

For those seeking very high yields, recommendation rates are usually raised even with the same soil test. For example, in Minnesota, recommendations are made for *average* and for *extra* corn yields. Look at these recommendations on loams and finer with medium P and K test (corn more than one year away from legumes and manure).

	N	P_2O_5	K_2O
	lbs/A	lbs/A	lbs/A
For Average yields......	55	40	40
For Extra yields.........	80	80	80

Plant Analyses

Plant analyses as diagnostic tools are divided into three main groups or uses:

1. *Chemical analyses* of *entire plants* to indicate total requirements per acre at specific yield levels. The main usage of total analyses is illustrated by the chart, (Figure 4).
2. *Percentage composition of selected portions* of plants, termed foliar analysis, leaf analysis, etc., to indicate by relative composition the possible deficiencies, (Figure 5).
3. *Plant sap analyses*, mainly quick tests on tissues or sap extracts, to indicate relative supplies of nutrients present in sap at critical growth periods, (Figure 5).

Current practices indicate tissue tests and leaf analyses will be used more in the future to guide high yield attempts and interpret mistakes.

For orchards and vineyards, leaf

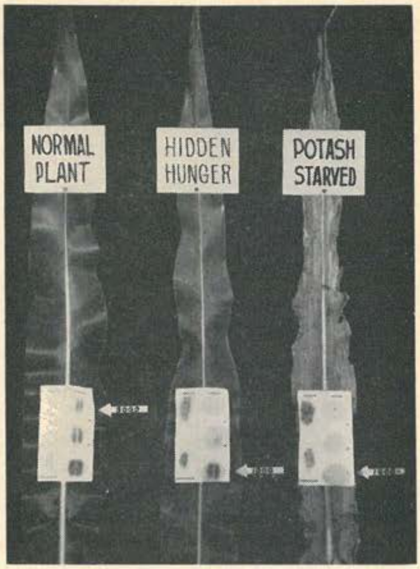


Figure 5—Properly calibrated tissue tests can detect hidden hunger NOW, right in the field. Here we see tissue tests on filter papers with spots (right half) impregnated by different concentrations of dipicrylamine to detect 1,000, 2,000, and 3,000 ppm. of K in plant sap. Tests for unassimilated nitrates and phosphates have been made on the left halves.

analyses are now a standard diagnostic tool, as reported elsewhere. Chemical analyses of leaves, no doubt, will be the major method of checking on forest nutrition, which is a coming field.

Right now one of the problems in leaf analyses is conflicting terminology. There seems to be some disagreement on terminology used to express degrees of adequacy or deficiency of nutrients. For instance, the term *critical* has been used to describe the level below which yields definitely decline and also the level below which symptoms usually appear.

There seems to be confusion, too, over the terms *optimum*, *adequate*, *threshold luxury*, and *safety* level.

Most research will show a point (as about 1.4% K in alfalfa) that might be considered optimum or adequate to produce good yields in certain years.

But to be safe in *all* seasons, it might be best to maintain K slightly above adequate or the safety level. Some have suggested 2 to 3% K to help alfalfa compete in mixtures with grasses.

There has not been enough work on satisfactory levels for quality or stand persistence (in case of legumes), as well as yields. Excessive luxury consumption, of course, is wasteful.

Perhaps more logical terms might be used—such terms as:

	Alfalfa Example
Safety level: % composition aimed to supply slightly above adequate nutrients, to prevent temporary or prolonged deficiencies in variable seasons.	2.0+% K
Barely Adequate level: % composition below which yields definitely decline . . .	1.4% K
Deficiency Symptom level: % composition below which definite deficiency symptoms appear.	1.0% K

The *tissue test* is a quick test. It gives results now, right in the field, where plant and soil variables can be considered firsthand while interpreting test results.

G. N. Hoffer, a pioneer in adapting *quick tests,* first started using the diphenylamine test for nitrates in corn. While in charge of corn breeding at Purdue University, he adapted the thiocyanate test for showing iron accumulations in corn nodes grown on low potash soil. A platinic chloride test in the laboratory confirmed variations in potassium concentrations.

S. F. Thornton, at Purdue University, first calibrated the ammonium molybdate test for measuring phosphates in plants. Then he calibrated a tissue test for potassium, using the cobaltinitrite method. Later these two tests, along with pH indications, etc., were combined into a portable testing kit for use in the field for both plants and soils.

Others have developed methods for quick tests on sap. A. C. Richer of Pennsylvania calibrated a test to detect concentrations of potassium (K) in the sap, by using a dipicrylamine solution. S. W. Melsted, R. H. Bray, et al. of Illinois developed filter papers with three spots impregnated with different concentrations of dipicrylamine solution to detect concentrations of K in plant sap, (Figure 5). On the same paper, they also ran a phosphate test by the molybdate method and a nitrate test by a powder also developed by Dr. Bray.

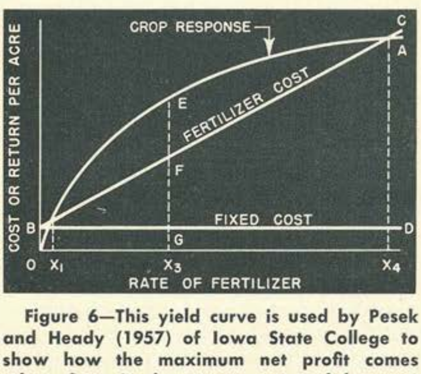


Figure 6—This yield curve is used by Pesek and Heady (1957) of Iowa State College to show how the maximum net profit comes when there is the greatest spread between the fertilizer cost line and the crop response curve—points F and E.

There is one major difference between foliar analyses and sap analyses:

In foliar analyses, all nutrients both in the sap and built into tissues are measured. In sap analyses for nitrates (NO_3) and phosphates (PO_4), only unassimilated portions of these elements are detected. Results may not compare with foliar ash analyses. Since potassium is never fixed in the plant, results from both methods are more comparable for this nutrient.

Interpreting Related Facts

Interpreting all the related facts revealed by these various methods is a challenging job. Every young scientist hopes to develop accurate methods. But experience soon teaches him that the most accurate data must be interpreted back into relative terms before being most useful.

Table I. Relation between percent yield without added potash and soil test values for available potassium.

Available Potassium	Percent yield without Added Potash*		
	Corn or clovers	Soybeans	Wheat or oats
lbs. per A.	percent	percent	percent
40	45	51	66
60	60	65	80
80	70	76	90
100	78	83	94
130	85	90	97
150	90	93	98
200	95	97	—
300	98	—	—

*Soil test calibrations made largely from Illinois experiment fields where yield with adequate potash equals 100 percent.

He soon learns that crops vary in their ability to grow at different pH levels, that crops vary in their total requirements for different elements, and that varieties of specific crops differ in their total requirements and their abilities to get adequate nutrients from the same root environment.

He soon learns the size, rate of growth, and especially numbers of plants per acre may determine whether a certain rate of nitrogen release from soil may be adequate or deficient. He learns, also, that the rate of nitrogen release from soil may vary according to "weather."

He learns the chemical availability of potassium may be reduced by poor aeration in the soil. Anything that restricts root growth will reduce its positional availability because potassium absorption depends largely on actual contact of root hairs and soil particles.

Because of all these variables, the exact requirements for any one year may be difficult to predict.

Why good judgment is so important for interpreting most data was best answered by Prof. Emil Truog of Wisconsin, a pioneer in soil testing: "When you go fishing, you may not catch all the fish within the range of your tackle, for various reasons."

The same truth applies to plants. No plant will get, within a short growing season, all the nutrients that might be chemically extractable from a soil. No soil test will state the exact amount of nutrients available to a crop. Both chemical availability and positional availability of nutrients in a soil and those added by fertilizers must be considered.

Economic Studies Set Yield Goals

Through economic studies, we determine that last unit of plant food which is profitable to apply.

Mitscherlich's so-called "Law of Di-

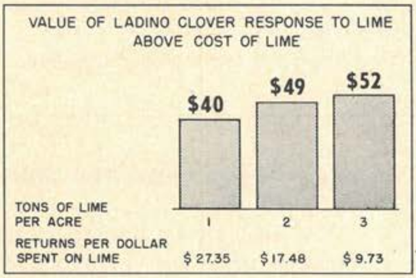


Figure 7—Net returns per acre above costs are more important than returns per dollar invested as a guide to deciding on rates of lime or fertilizers to be added. (4-year average on Bladen silt loam in North Carolina, pH 4.8. 200 pounds per acre of P_2O_5 at seeding and 100 pounds P_2O_5 annually; 200 pounds per acre of K_2O annually. N. C. Agri. Expt. Sta. Bul. 385, 1953.)

minishing Returns" may be misleading unless it is interpreted properly. That is, one might seem to make the most returns per $1 on smaller fertilizer investment, although the maximum yields are so low that acreage returns are below the overall cost of operation.

A top yield must be high enough to make efficient production per bushel or per ton. Many of the costs, up to harvest time, are static regardless of yields:

Static Costs	Variable Costs
Interest	Better seed
Taxes	More seed
Plowing	More fertilizer or lime
Discing	Better fertilizer machinery
Planting	
Weed control	Extra harvesting costs of extra yields
Insect control	
Harvesting costs (Unfertilized)	

In some people's minds, there may be some misconceptions over the best way of deciding how much fertilizer and/or lime will be profitable. The net return per acre above the cost of materials is most important, rather than the returns per $1 spent for the treatments, (Figures 6 and 7).

You do not buy fertilizers or lime to make a large percentage return on the investment, but rather to get yields up to the most profitable and efficient production levels.

The need for high yields has been expressed in other ways. Illinois economists recently said it costs $65 per acre to grow a crop of corn. Purdue recently estimated an owner-operator should grow more than 44 bushels and a tenant above 49 bushels of corn per acre to "break even" on first year corn.

It's easy to "sell" a grower on the first $1 invested in fertilizers when he has seen starvation symptoms and when the crop responds rapidly to fertilizer treatment. But above the symptom level toward the top of the yield curve in the *hidden hunger zone,* the last unit of plant food that may be profitable is not easy to "sell."

The eye cannot see small but profitable differences caused by fertilizer treatments, especially at the higher yield levels. For example:

In an Illinois corn yield guessing contest, 1,267 farmers estimated the yield of a block of corn. The average guess was nearly 5 bushels under the actual yield of 94.4 bushels—with 47% missing the yield by 10 bushels or more, 72% missing it by 5 bushels, 83% missing it by 3 bushels or more.

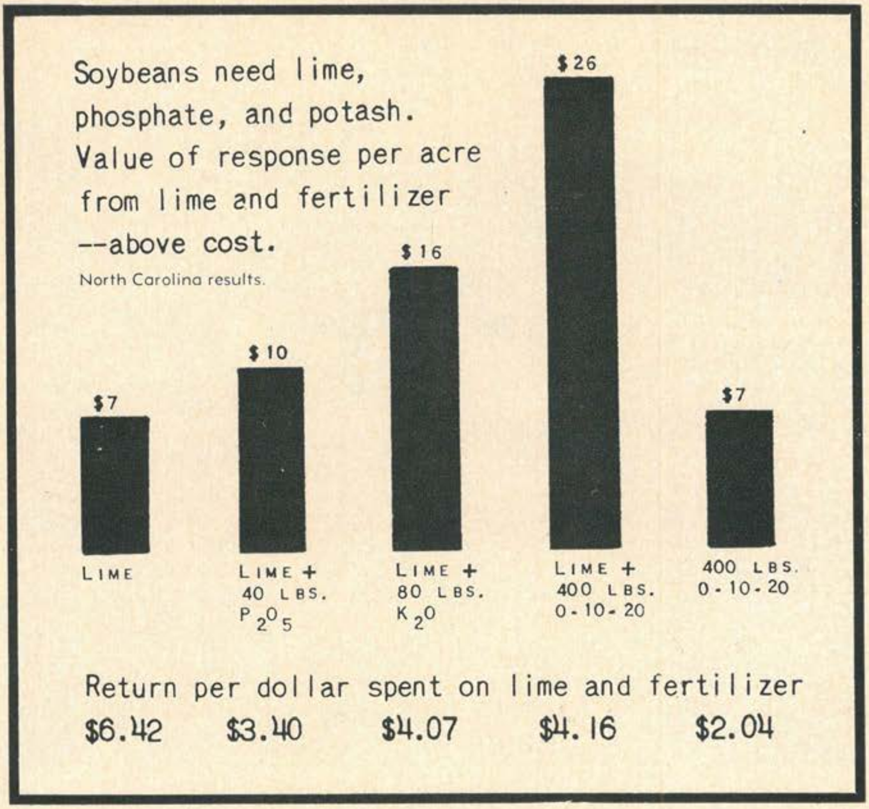
The point is, so many factors are involved in crop yields that significant differences cannot be measured by the eye alone. It takes very accurate experimental work to measure small but profitable increases from various practices.

But such increases are what make successful farmers—the *net* returns at the top of the yield curve. ◄◄◄

Crop Requirements And Roots Challenge Tests

The well-known ability of grasses to "steal" potassium from legumes, when the two are growing in mixtures with roots intertwined, is one example of the nutrient differences in species. Both the different total requirements and the varied root absorption capacities between species makes another problem in the interpretation of soil tests into fertility prescriptions, especially from the rotation standpoint.

The problem *begins* in the "hidden hunger" zone.



"UNWISE TO WAIT"

Soybean yields are often considerably reduced by a potash deficiency even before symptoms are noticeable. Therefore, it is unwise to wait for potash deficiency symptoms to appear before applying fertilizer.

It is apparent from the above chart that maximum net returns were obtained when money was spent for lime, phosphate, and potash. A soil test will help determine what combination of these three important essentials are required for any particular condition.

Adequate fertilization of soybeans, as recommended by the various agricultural experiment stations can mean producing additional soybeans for considerably less than $1 per bushel. It also provides an opportunity for realizing an additional $10 to $20 profit per acre. As the yields go up, cost of production per unit is decreased.

—*THE SOYBEAN DIGEST*

Proving Ground for Scientific Concepts

FIELD EXPERIMENTS

On America's oldest experimental plots—Morrow Plots at Illinois—slower drying surface soils on untreated sections (dark areas) reflect more compact soil structure and slower drainage than on treated sections. Quite often, in wet springs, untreated areas cannot be plowed until several days after properly treated plots could have been plowed and planted.

By A. L. Lang and Samuel R. Aldrich

FIELD experiments are the ultimate guide to economical long-term soil fertility programs and to current fertilizer applications, especially for those wanting to grow above-average yields.

A. L. Lang, Professor of Soil Experiment Field Research at Illinois, is nationally known in the field of relating hybrid corn varieties to soil production and fertilizer response. He is active on national committees dealing with soils, fertilizers, and related crop problems.

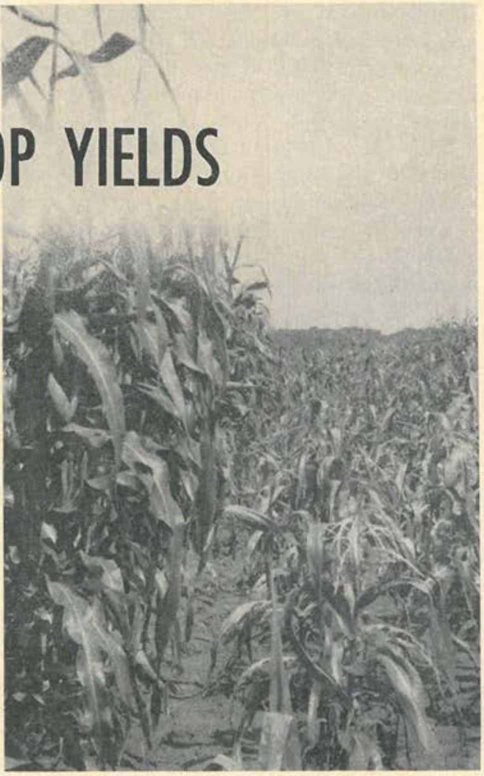
In one sense, all other diagnostic approaches are substitutes whose justification lies in the fact that they are faster or that they cost less than a fully adequate field experiment program.

Several types of field trials, including long-time or short-time experiments, one-year trials, and even demonstrations on farms, all help indicate ways to get higher yields. These are the *proving grounds* for scientific concepts. Of course the final test of any theory, any plan or recommendation is the actual economical production of high yields on large acreages of farms year after year.

Land is a fairly stable commodity.

► By making proper agronomic comparisons, where "full treatment" plots are *the standard*.

POINT WAYS TO TOP YIELDS



► By trying more than enough fertilizer—so results on top yields can be fully interpreted.

► By making treatments in long-time plots more flexible—in varieties, planting rates, cultural practices, proper fertilizer placement, etc.

► By making maximum numbers of physical and chemical measurements, as well as observations.

► By using good locations and conducting experiments that can be statistically analyzed.

Fertilizers in field trials have produced results that have caused more and more farmers to use plant foods of higher total analysis—often for reasons as striking as above. Left, fertilizer; right, no fertilizer.

Department of Agronomy • University of Illinois

The immediate effect of management practices may be startling or apparently non-consequential. Nevertheless, a management practice, if continued, may have a *long-time measurable impact* upon the soil and the economic welfare of land owners or operators.

Long-Term Experiments

Long-term field experiments measure cumulative residual effects of treatments with respect to chemical, physical, and biological properties of soils, and the resulting influences on yields and qualities of the crops grown.

In Illinois, long-time soil experiment fields have been in operation in all major soil associations and on many major soil types, as well as over a wide range of climatic conditions.

Many were started about 1910. Other more elaborate regional re-

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search stations are now in operation and others are planned. Of course the Morrow Plots at Urbana, the oldest long-time experiment in America, were started in 1876.

First, let's look at trends shown by some of these long-time trials with various soil conditions.

Only 16 years of soil improvement (1940-1955) on the acid, gray silt loam soil at Brownstown Soil Experiment Field have shown interesting trends in the first four rotations, (Figure 1). The full treatment consists of limestone (L), nitrogen (N), phosphorus (P), and potassium (K), in a rotation of corn-soybeans-wheat-mixed hay. Since most crops on this soil respond to all four treatments, interactions show *that we must supply enough of each and every nutrient required in a well-balanced program.*

The series of four graphs (Figure 1) illustrate both (1) gradually increasing returns for the proper use of limestone, nitrogen, phosphorus, and potassium over several rotations, and (2) that returns are greater when used in proper combination than when used alone.

A study of these yield increase trends indicate (1) why farms within the same soil type vary in present productivity, (2) why we may expect variable responses from any one nutrient or combination on individual farms when starting with different soil conditions due to man-made variables.

So, it is not surprising that demonstration results or short-term trials do not always show uniform positive results as hoped for or expected. There

Table I. Increases in Corn Yields from Potash at Various Stages in 14 Different Experiments in Three Soil Groups.

Location	First 4 years	First 8 years	Second 8 years	Third 8 years	Fourth 8 years	Fifth 8 years
			Light colored soils			
Ewing	3	8	15	27	30	34
Toledo	4	6	15	25	32	43
Oblong	2	2	13	19	25	30
Raleigh	1	4	7	7	17	25
Enfield	0	4	4	12	21	19
Brownstown*	6	10	22			
Average	3	6	13	18	25	30
			Intermediate Dark-colored soils			
Carlinville	2	3	5	6	10	13
Carthage	2	1	4	2	3	6
Clayton	2	2	5	7	8	2
Lebanon	1	2	7	5	7	11
Average	2	2	5	5	7	8
			Dark-colored soils			
Dixon	5	3	3	7	6	8
Joliet	6	4	5	1	6	5
Kewanee	6	4	3	−2	−2	2
Mt. Morris	−1	1	3	2	7	0
Average	4	3	3	2	4	4

* Brownstown—only 16 years, 1940–1955.

may be other limiting factors also.

Potash Needs Increase

Average increases from potash are greater a few years after soil improvement programs begin on most soils. These trends are shown in Table I, by running averages at 4- and 8-year periods, from 14 long-time Illinois fields.

Similar trends are illustrated in Figures 1, 2, and 3. The necessity for continued applications is demonstrated in Figure 2.

Of course, average increases expected from added potash under favorable conditions vary according to the soil origin or type, as indicated by this summary, Table I. Compare average increases at individual fields within the three soil groups.

Nitrogen Responses May Vary

Nitrogen usually is applied on a one-year basis. But nitrogen responses are quite variable from year to year on any soil where we depend partly on nitrate releases from native or residual organic matter.

In Table II, we see corn yield increases from 100 pounds of nitrogen each year for 12 years on the Carlinville Soil Experiment Field. The soil is dark colored, slowly permeable, with a medium amount of organic matter. There were extreme variations in responses even on low-yielding plots without legumes. Also there were substantial increases from nitrogen in 3 out of 12 years on the higher-yielding plot with legumes. Average increases must be used in such cases to decide what fertilizer investments probably will be profitable. There are some residual values from nitrogen applications.

Renovation Requires a Long Time

A subsoil renovation study started in 1936 by Ohio Agricultural Experiment Station is typical of problems requiring long-term trials.

To find how fast eroded soils could

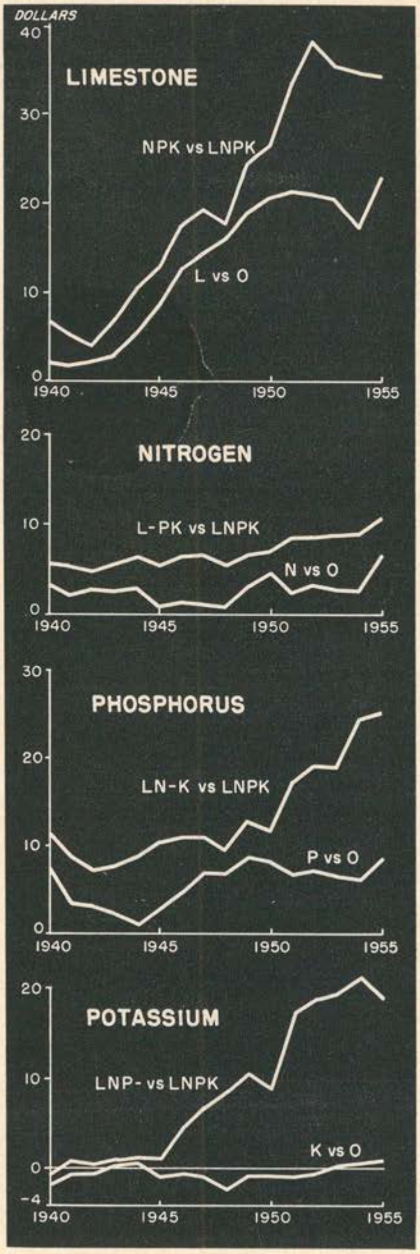


Figure 1—These four graphs show (1) gradually increasing returns for the proper use of limestone, nitrogen, phosphorus, and potassium over several rotations and (2) returns are greater when used in proper combination than when used alone.

Table II. Annual Yields of Corn and Increases from 100 lbs. Nitrogen per acre per year. Carlinville Soil Expt. Field.

Year	Without Legumes		After Legumes	
	Yield Bu.	Increase Bu.	Yield Bu.	Increase Bu.
1946	64	2	103	6
1947	46	18	79	−4
1948	40	50	105	16
1949	62	−1	99	−1
1950	51	18	103	3
1951	63	8	122	−2
1952	53	16	106	4
1953	51	25	95	−2
1954	49	19	68	26
1955	58	−2	70	0
1956	46	28	99	10
1957	83	2	101	−2
Averages	55.5	15.3	95.8	4.5

be renovated, they first removed 7 inches of topsoil from one plot and spread it on an adjacent strip. This provided three conditions—normal soil, no topsoil, and double topsoil. This was done on two soil types, one with friable subsoil and another with higher clay content. Soils were limed to about pH 6.5, and a moderate fertilization program was started on a corn-oats-wheat-clover rotation.

Even on the most friable soil it required much expense and many years to get yields on the improved subsoil to approach those of plots with normal topsoil. See Table III.

The rate of improvement was still slower on soil with a higher clay content.

Depleted Soils Can Be Revived

The principal weakness of long-term experiments is that the rigid treatments required to measure long-term depletion or residual effects *may become somewhat obsolete or at least unable to answer all questions arising from changing conditions.*

Several long-term experiments, which are of great historical value because they have provided valuable information, *have been revised recently.* That is, by sub-dividing plots or changing treatments these old experiments become even more useful in guiding us toward *higher yield possibilities.*

For instance, Sanborn Field, at Uni-

Table III. Relative Per Cent Yields with No Topsoil (Normal Topsoil = 100 per cent)

Crop	First Year %	Fifth Year %	Ninth Year %	Thirteenth Year %
Corn	38	59	74	86
Oats [1]	20	50	86	—
Wheat [2]	31	42	48	—

[1] Oats yields are for the 2nd, 6th, and 10th years.
[2] Wheat yields are for the 3rd, 7th, and 11th years.

versity of Missouri (1888), has had certain plots converted to "full treatment," where treatments are varied according to what is thought to be adequate for the present but ever-changing needs required to produce top yields.

Treatments on the Jordan Plots at Pennsylvania State University (1881) have been revised. In 1953, the plots were split lengthwise.

One half continued to receive the long-established treatments.

The other half received basic lime, phosphorus, and potassium treatments as indicated by soil tests to be necessary to bring the plow layer to proper pH and high levels of available phosphorus and potassium. Since 1954 this half of each plot has been fertilized according to current recommendations made to Pennsylvania farmers.

These new treatments on an old experiment led to this conclusion by Richer, et al.:

"Land made infertile by previous mismanagement (depletion and not erosion) can be quickly brought back to a high state of productivity *by proper lime and fertilizer treatments.* In 1956, corn yields were *46 bushels* per acre on the *check plots* and *128 bushels* per acre on the new *modernized treatments.* Oat yields on the *check plots* were raised *from 28.5 to 63.7 bushels* per acre by applying *recommended treatments.*"

Morrow Plots

Likewise, revised treatments on the Morrow Plots, have demonstrated some amazing yield improvement possibilities on depleted soils (Table IV.)

1955 treatments boosted yields by 50 bushels per acre, from 36 to 86 bushels, on depleted land which had grown continuous corn for 80 years

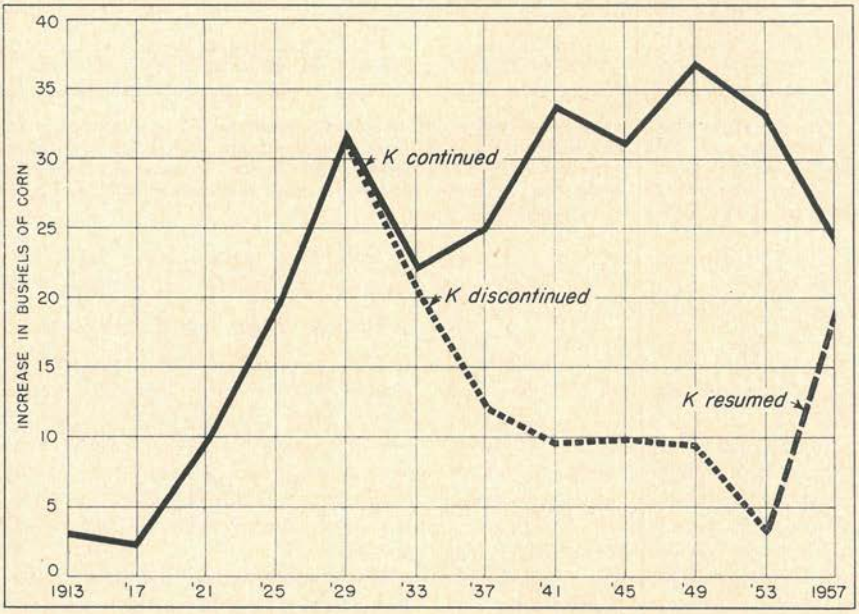


Figure 2—Here we see the necessity of continued potassium applications on "low" potassium soils—increases in bushels of corn per acre from potash (RLP vs RLPK). From Ewing Soil Experiment Field 1910-1957, the data are 4-year running averages. Low yields from very dry seasons in 1930, 1936, 1954, and very wet in 1957. Fifty lbs. K_2O per acre per year had been applied from 1910 to 1929. In 1929, a plot was split and potash was discontinued on one half. The dotted line indicates the reduced yield trend where no extra potash was applied from 1930 to 1953. Treatment was resumed in 1953 and yields increased.

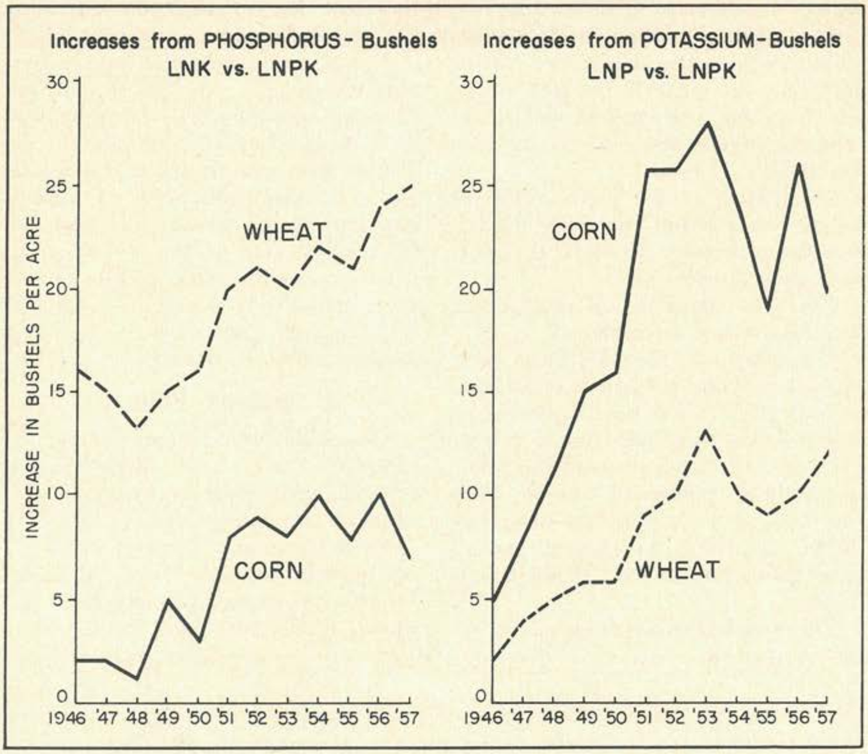


Figure 3—Corn and wheat respond differently to added phosphorus (P) and potassium (K) on the same soil. This chart shows bushels of increase in both corn and wheat from phosphorus and potassium at Brownstone Soil Experiment Field. Notice: (1) generally increasing responses, especially during the first few years; (2) corn responds relatively more to potassium while wheat responds more to phosphorus.

without treatment and with all residues removed. The 3-year average increase was 66 bushels, or from 36 to 102 bushels. (Results might be quite different on soils which contain less organic matter and less favorable soil textures.)

When that portion of the continuous corn plot which had been previously treated with manure, lime, and phosphorus was also heavily fertilized, it yielded 116 bushels. Hence MLP was worth 14 bushels when compared with the check plus heavy fertilization.

Only one year's data are available so far in the corn-oats-clover rotation, but 1955 yields were not improved much above the 100-bushel level on the old MLP section. Likewise, two years' results with corn-oats MLP and an intercrop legume have shown no gain for the heavy fertilization.

Future High Yield Research

The principal goal of high-yield research is to identify specific factors which limit crop yields, in order to predict needs for future crops. One exasperating fact is that *many of the highest corn yields have been in farmers' fields rather than on experimental plots.*

What combination of favorable factors enabled a 300-bushel corn crop to "happen" once on a southern farm?

Why are corn yields mostly limited to the 120- to 150-bushel range on experimental farms in the best years and the so-called best soils of the corn belt?

Enough 200-bushel yields or more have been produced to raise our goals.

New *Maximum Yield Experiments* at Cornell University are designed to *determine* and then *eliminate* known limiting factors, if possible.

First, fertilizer treatments, crop varieties, and cultural practices will be changed whenever research indicates improvements can be made.

Second, complete data on weather, soil moisture, and temperatures are recorded. Crop growth is logged, likewise tissue tests and soil tests. All diagnostic techniques are used to estimate the annual needs for the next crop or crops.

Planning New Experiments

All new fertilizer experiments can be enhanced by:

(1) *Making proper agronomic comparisons* where the "full treatment" plots are *the standard* with which to compare all other treatment combinations.

(2) *Trying more than enough fertilizer.* Failure to include high enough treatments to supply slightly more than enough for top yields is a common weakness. The heaviest rates tried have sometimes been what were estimated to be near the practical economic level for that time. Failure to bracket *the full fertilizer response curve* results in yields still going up with the highest treatment. Thus, results cannot be fully interpreted. What is most economical for the future may depend on the ratio between relative fertilizer costs and crop prices.

(3) *Providing for flexibility of treatments in long-time plots.* That is, include extra plots, large plots, or reserve adjacent areas on which new practices can be tried out in direct comparison to the original treatments. Do not allow original treatments to become "sacred" and unalterable. Provide flexibility also as to varieties, planting rates, over-all cultural practices, proper fertilizer placement, etc.

(4) *Making maximum numbers of physical and chemical measurements,* as well as observations. Save plant and soil samples for chemical analy-

Table IV. Recent Corn Yields with Revised and Regular Long-Time Treatments. Morrow Plots, University of Illinois

Rotation	Long-time Treatment	Corn Yields with Revised Treatments				Corn Yields on Regular Treatments			
		1955	1956	1957	Ave.	1955	1956	1957	Ave.
Continuous Corn	0	86	113	106	102	36	29	42	36
	MLP	98	128	121	116	79	96	91	89
Corn-Oats	0	97		125		43		48	
	MLP (Le)	107		126		98		133	
Corn-Oats-Clover	0	102				63			
	MLP	101				100			

MLP = Manure, limestone, phosphates.
(Le) = Legume intercrop.

Additional Treatments

	N* lbs/A	P_2O_5 lbs/A	K_2O lbs/A	LIME
1955.........	200	150	100	5 tons
1956.........	200	40	30	
1957.........	200	40	30	

* Only 100 lbs. N on MLP in corn-oats (Le) and corn-oats-clover rotations

ses at regular intervals during the experiments.

(5) We assume that layouts will allow statistical analyses of data. However, *statistical treatment cannot improve the accuracy of experimental work* or correct errors in agronomic comparisons or poor choice of locations. *Good agronomic judgement is the first requirement for planning and conducting* worthwhile *experiments.*

Coordinated Field Experiment Program

The Illinois field experimental program is planned to evaluate interactions of soil, climate, fertility, cropping, and other soil management practices related to high yields and largest net income for most farm situations.

How this can best be done with the money available is the problem always confronting administrators.

The general program includes:

(1) *Central experiment stations.* These are specifically adapted for research requiring difficult technics, close observations, and complex installations. Usually there is too little opportunity of choice of site.

(2) *Regional research centers.* These represent the important soil and climate variations within the state. They are well suited for *long-time* field experiments, while furnishing a center of operations for *short-time* experiments on the more detailed problem areas. These are useful for field days and keeping in close contact with farmers.

(3) *Farm field experiments.* These are short-term experiments to increase the amount of information on specific localized conditions.

(4) *Field trials and demonstrations.* Extension personnel or local county workers handle this type. Such trials provide additional opportunity for farmers, agricultural leaders, and local business representatives to observe fertilizer responses. These trials play an important role in supplementing research results. ◄◄◄

JEFF—*Continued from page 3*

Plants probably have appetites just as we and our animals do. But they can't vary their available foods at will to match their appetites for balanced menus. Some plants, no doubt, are forced into over-eating certain plentiful elements in a sort of luxury way. At the same time, they go on almost a starvation diet for other nutrients needed to furnish them health and steady growth. Like wartime refugees, they *can live* on potatoes and bread, but they lose their pep and vigor. They also resemble a very fat person who looks well fed and extremely hearty, even though he persists in eating too much and too often of the wrong things for his own welfare.

But here the plant always has the sound excuse that it is unable to hustle out to get enough of what it needs. And it has no "free choice," self-feeding system such as self-indulgent humanity and fattening hogs enjoy.

Conversely, the droopy, emaciated plant victim of soil depletion has been equally unable to pick and choose the right body-building diet, like thin persons can if they so desire—that is, short of poverty, deprivation, or wasting disease.

Why wait until the season's crops show ring-streaked, speckled, spotted signs and blotchy discolorations? Why not get somebody well qualified to help beforehand? He can make soil tests and take tissue tests from the living plant to detect nutrient deficiences even before the plants show visible changes in their appearance on leaf and stem.

Yet we know that a perfect, fool-proof way to determine the amount of available plant food in soils has not yet been devised to work under *any and all situations.*

One also hears soils men say that finding an answer to the next question is often perplexing: "How much of each mineral element should be added to guarantee a heavy, healthy yield of any specified crop?"

If the soil were blank and lifeless, unchanging and inert, our task of analyses might be more simple. But in that case, we'd lose the dynamic, mystic forces therein and get about the same results as trying to grow crops on concrete or silica sand beds.

Nevertheless, our rapid soil testing in laboratory or afield is especially useful when accompanied by plant tissue tests and careful scanning of growing crops for visible signs and portents of hunger and other troubles. The amount of soluble plant food in specified organs or parts of the growing plants is a good index of the adequacy of the food supply reaching them.

Then the radioactive isotope method of the past decade enables us to tell what part of the plant's nutrients came from the extra added fertilizer or from the natural content of elements already available in the soil. Each year sees new processes perfected by men who are themselves as dynamic, forceful, and active as the underground factories with which they deal.

Feeding folks and animals indefinitely on rations from just one cereal source was shown long ago to be dangerous and disruptive of production and reproduction. Similarly, *no one morsel of a certain plant food* can take over all of the manifold functions that keep plants satisfied and normal. *Each of the major elements and many of the "trace" substances play a necessary role in the scheme of plant life.*

Insect ravages often cause symptoms resembling those which indicate a lack of plant nutrition. The scars of insect damage may even mask the true hunger of the plants affected. Plant diseases often prevent the proper identification of a real hunger warning. Or again, diseases may interfere with the plant's ability to use nutrients in the soil and thereby cause a deceptive sign of plant food scarcity to appear.

Underground battles and antagonisms between soil organisms and different soil chemicals must also be recognized as more "foolers" in the constant campaign against plant starvation. Animal bodies also undergo similar internal disturbances that often make choice of the right treatment difficult.

Objectives of the farmer play a part also. One farmer may put on fertilizer mainly to get increased crop yield. Another one may prefer to apply enough plant food to raise the available nutrient in a soil up to a level that will carry all crops in the rotation in use. Then, too, the carryover or residual benefit from extra nutrients placed in the plant's larder is something to be reckoned with in meeting farm needs on a practical basis. ◄◄◄

PLANT ANALYSIS

By Albert Ulrich
University of California

IT is good business to anticipate the fertilizer needs of crops *before deficiency symptoms can be seen on the crop itself*.

When the nutrient content of the crop drops so low that deficiency symptoms appear on the plants, the grower is already suffering a loss in yield and quite often also a reduction in quality of the crop.

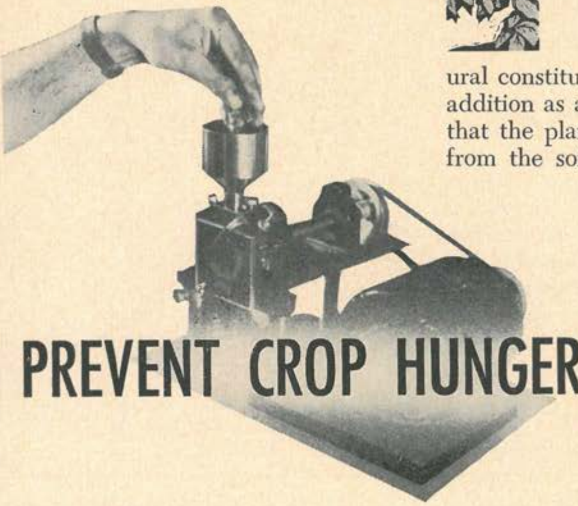
In present-day farming, the real problem is to know how well a particular fertilizer program is meeting the needs of the crop. Soil testing can help, but the results of chemical soil tests are just one step short of telling what the plant is *actually getting from the soil*.

Dr. Albert Ulrich, Plant Physiologist at the University of California, has spent many years developing and applying leaf analysis techniques to California crops. His research on factors affecting the sugar content of beets is widely known.

The mere presence of a nutrient as a natural constituent of the soil or even the addition as a fertilizer is not a guarantee that the plant is getting that nutrient from the soil. Because they can only apply to a limited area on the farm, field tests likewise fall short of supplying an answer to the real problem. "How well is my fertilizer program meeting the needs of the crop?" This question is often asked. Waiting for a deficiency *to develop* is perhaps the poorest practice of all, for by then crop losses have already taken place.

In many business enterprises, the question, "How well am I doing," is easily answered by taking inventory of the goods on hand in the warehouse. Such periodic checkups indicate whether goods are accumulating, are in balance, or are in short supply. Adjustments in purchases are made in accordance with these inventories.

In much the same way, the farmer



CAN PREVENT CROP HUNGER

can help himself by inventorying the nutrient status of his crops as they grow under field conditions. If the crop is verging on a deficiency, more fertilizer should be added; if just right, the same fertilizer program would be used again; and if there is a surplus, less would be applied the following year.

Thus, at all times, *the crop itself* would determine what steps should be taken to avoid nutrient deficiencies or even excesses.

The modern way of anticipating the fertilizer needs of crops is through a systematic sampling of the plants for chemical analysis during the growing season of the crop. This system is referred to as leaf analysis, but more generally as *plant analysis* in contrast to soil analysis.

Once the farmer has embarked on a fertilizer program, its value in meeting the needs of the crop from year to year can be estimated through plant analysis. In using plant analysis, the nutrient concentrations for each field

The mere presence of a nutrient as a natural constituent of the soil or even its addition as a fertilizer is no guarantee that the plant is getting that nutrient from the soil.

To determine how well a particular fertilizer program is meeting the needs of a particular crop, the *crop itself* should determine what steps should be taken to avoid nutrient deficiencies or even excesses.

The modern way to anticipate fertilizer needs of crops is through a systematic sampling of the plants for chemical analysis during the growing season—known as leaf analysis, but more generally as plant analysis in contrast to soil analysis.

Plant analysis is a tool that can detect any change in fertilization or even in management that may need correcting before symptoms appear and it is too late—whether we've used the right nutrients, if they've been applied correctly for the root zone, whether moisture is adequate or excessive, etc.

are plotted on graph paper and the results compared to previously established "critical concentrations"* and to "safe levels."**

**The "critical concentration" may be defined as that nutrient concentration where plant growth begins to decrease in comparison with plants above the critical concentration. Often visual deficiency symptoms appear at approximately the same concentration as the critical level, although for some nutrients and crops this may not necessarily be true.*

***The "safe level" is that concentration which under normal conditions would be considered adequate for the remainder of the growing season. In practice, the "safe level" is set well above the critical concentration, to insure an adequate supply of nutrients until the crop is harvested.*

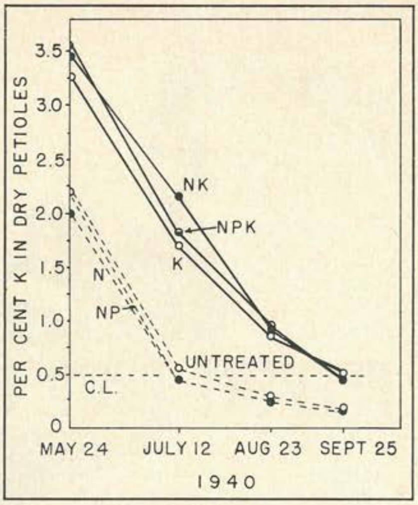


Figure 1—Potassium concentration of petioles of recently "matured" leaves taken from fertilized plots of Petite Sirah grapes, Alexander Valley, California, for the 1940 season (N = ½ pound of ammonium sulfate; P = ½ pound treble superphosphate; K = 1 pound potassium sulfate per vine applied each year from 1935 through 1938). The grape yields in tons per acre for 1940 and 1941 were as follows: untreated, 3.10, 2.92; N, 3.31, 3.18; K, 3.87, 3.98; NK, 3.76, 3.66; NP, 3.01, 3.29; NPK, 3.83, 4.02. This represents an increase in yield of 25 and 36 per cent for the K-treated plots over the untreated plots in 1940 and 1941, respectively. C. L. = Critical level. (Ulrich, Proc. Amer. Soc. Hort. Sci. 41: 204-212, 1942).

If an impending deficiency is discovered early in the growing season, then emergency applications of fertilizer may be made to correct the deficiency. However, with more experience and consistent use of plant analysis, emergency applications of fertilizers will become a rarity or even completely unnecessary.

Minor adjustments in the fertilizer program are often limited to increasing the use of one nutrient or lessening that of another or even of adding other elements just becoming short in supply.

Changes in timing or in the method of fertilization, to meet more fully the needs of the crop, are other benefits derived from systematically inventorying the plant nutrients of crops in the field.

After each fertilizer addition, the nutrient changes within the crop can be observed intimately. Often, this may reveal (1) the wrong form of a particular nutrient has been applied or (2) the materials have been applied incorrectly in relation to the root zone or (3) moisture was insufficient to make the materials effective.

At other times, plant analysis may reveal that excessive moisture may have washed the materials from the root zone. In brief, any change in fertilization or even in management—such as spacing of plants—can be detected by means of plant analysis. If the nutrient trend turns downward, the practice can be changed long before deficiency symptoms appear and a loss in yield takes place.

What is learned on one crop through plant analysis can often be applied to a succeeding crop even though the crops may differ considerably from each other. For example, low-phosphorus

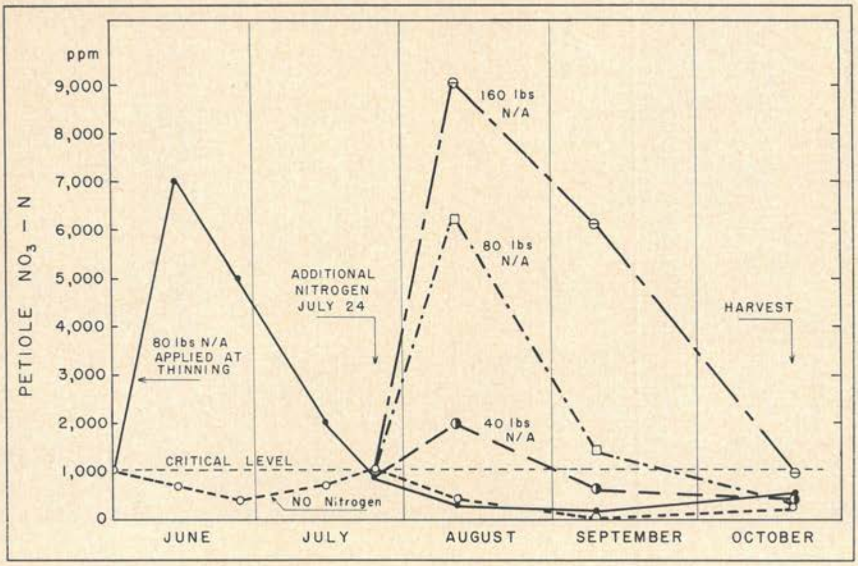


Figure 2—Effects of fertilization on the nitrate-nitrogen content of sugar beet petioles, Davis, California. The first petiole samples were taken on May 31—four days after fertilization but before water had been applied to the beets. The second set of petiole samples were taken after the beets had been irrigated.

The petioles tell the nitrogen story: Nitrate rises in the petioles sharply after nitrogen fertilization but drops again as it is used up by growing plants. The information shown here tells the grower that a second 80-lb. application is ideal for an October 20 harvest. With a 40-lb. application the harvest would have to be planned earlier; with a 160-lb. application later. (Ulrich, Ririe, Hills, George and Morse, Plant analysis: A guide for sugar beet fertilization. Calif. Agr. Exp. Sta. Bul. In press.)

alfalfa that has responded to phosphorus applications may very well indicate that sugar beets on the same land might require phosphorus as well.

By having phosphorus information on the last cutting of alfalfa, the plants in essence have sampled the soil, providing information for use on the next crop.

If, however, by use of phosphorus fertilizers, the phosphorus levels in the plants have been built up, then the need for phosphorus on the beet crop would be less than if the alfalfa on the last and preceding cuttings were deficient in phosphorus.

The same line of reasoning holds for potassium, magnesium, boron, and other nutrients that are likely to be deficient in both crops.

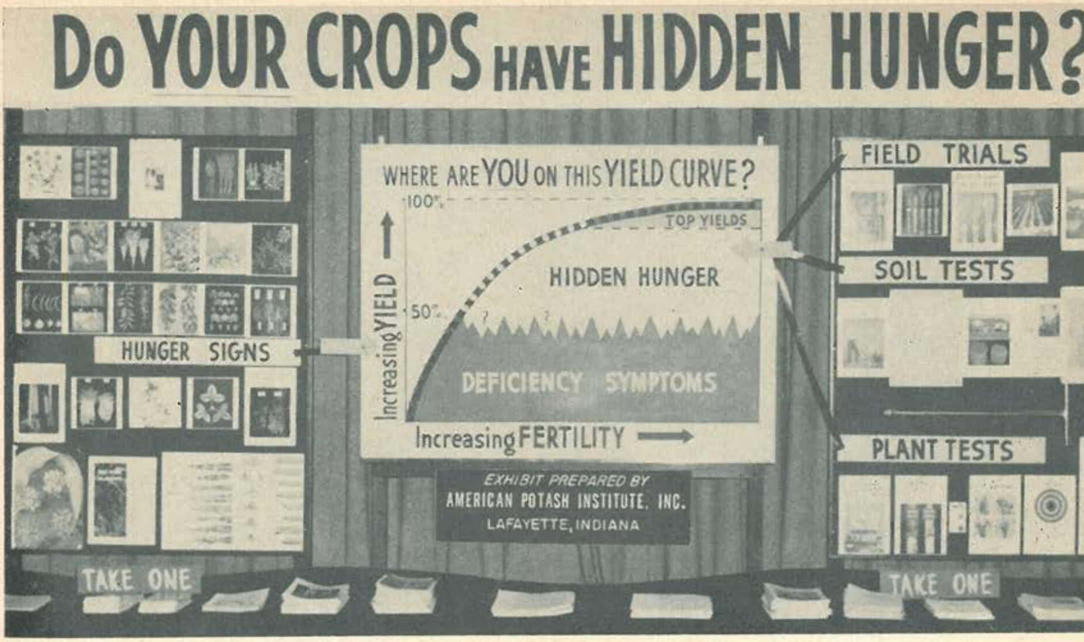
In the case of nitrogen, information gained from one non-leguminous crop may well be applied to another non-leguminous crop—sugar beets followed by tomatoes, corn, cotton, etc.

Thus far, plant analysis has been a useful tool in studying nutritional problems. It offers a means of keeping up-to-date on the plant nutrient status of the growing crop. It is our most important means of indicating how well the nutrient levels are *holding up* and whether some nutrient is *approaching* the deficiency level in the crop.

In other words, by taking plant nutrient inventories periodically, the results tell us whether the crop is adequately supplied or will soon need an adjustment in the fertilizer program.

Here is a tool, then, that tells us what we want to know before the symptoms appear and before it is too late.

(Continued on page 35)



FROM THE SEEN . . . TO THE

THE father of Agricultural Extension, Dr. Seaman Knapp, once said, "What a man sees, he believes."

Upon that principle, American agriculture has developed—because most of the farming practices used today were adopted *after* some mighty convincing results were demonstrated to curious, and often suspicious, viewers.

When he *saw* 100 pounds more potash per acre take the scorch out of his corn, the farmer believed it—and *used* it.

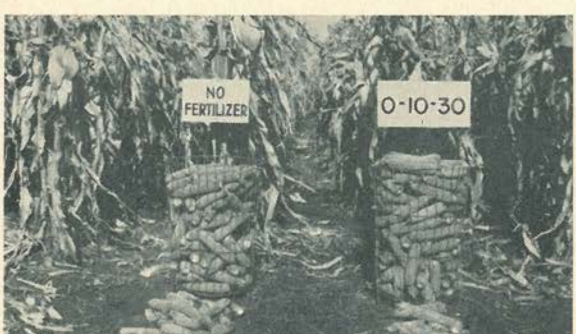
When he *saw* 100 pounds more nitrogen and phosphate raise his stalks with green new life, he believed it—and *used* it.

But when are we going to realize deficiency symptom agriculture is negative farming? It is defeatist farming—the kind that pinches and scrapes and economizes in the wrong direction, in the direction of middlin'-poor yield, poorer quality, and even poorer net returns. The kind that seems to say, "Keep the hunger signs from *showing* and you'll have no hunger." The kind that maintains fertilizer recommendations just above the symptom level and no further.

The United States Department of Agriculture put i effectively in its 1957 Ye on Soil:

"You may not be able tice any deficiency effe plants that have moderat adequate levels of potassi cause the usual symptom degree of deficiency is a reduction in growth. T not easy to detect unle compare the size of the with that of others th growing in a similar pla are getting enough potas

"Furthermore, *this is a deficiency symptom for nutrients.* Analyses and



Sixteen bushels *more* corn per acre—from 86 to 102 bushels—resulted from row fertilization, although no differences in the *looks* of the plants were obvious.

"It is always easy to sell the obvious, and plant deficiency *symptoms* are readily understood in terms of nutrient needs. But basic research has demonstrated that much greater efficiency of production can be had if *hidden hunger* deficiencies are remembered in the fertilization program. *Hidden hunger* can be determined by soil and plant tissue tests and the experience of well constructed field experiments. The American Potash Institute exhibit as an educational aid in this important area is a very fine instrument, pointing up the emphasis that should currently be given toward recognition of the *hidden hunger* phenomenon."

Dr. W. P. Martin
Head of Soils
University of Minnesota

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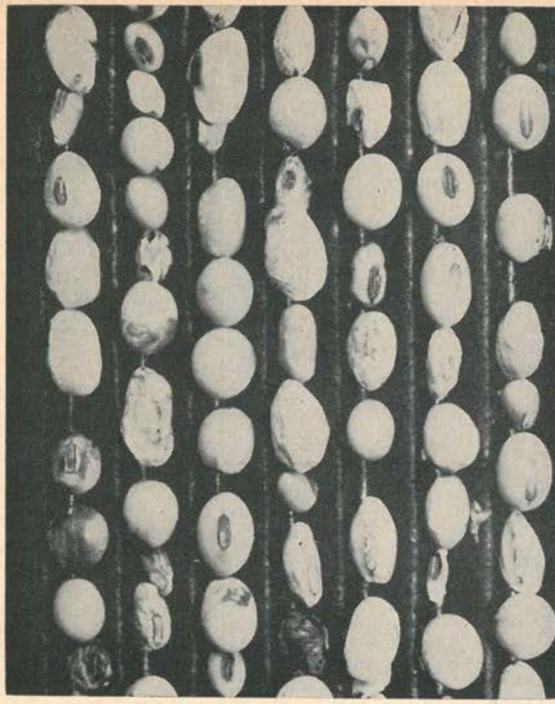
the soil and plant may reveal a potassium deficiency.

"The onset of characteristic *visual symptoms*, which signifies a more severe deficiency, means that production has *already been seriously impaired*. The application then of fertilizer potassium cannot overcome the damage already incurred, especially in the annual quick-growing crops."

For years, the farmer could take deficiency symptom farming in his stride—fertilizing enough to correct or keep down hunger signs, with a bag or two more, and taking his yield as it came.

But in today's economy, he must *net* every dollar he can. This means preventing symptoms before they appear. And it means more. It means fertilizing his crop to bear its *maximum* yield per acre, produce its *finest* quality, and bring its highest *net* return.

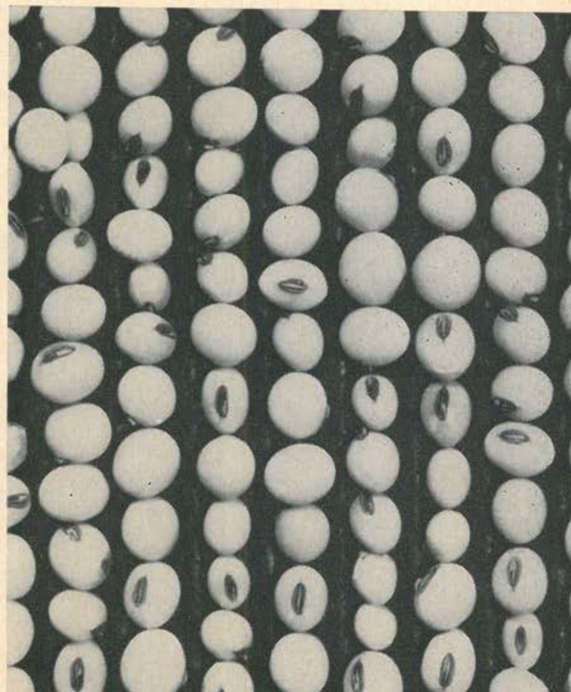
To obtain such yields, quality, and profits in this age requires as much attention to *unseen hunger* as we once gave to *seen hunger*. ◄◄◄



▲
From Hidden Hunger

From Right Nutrients
▼

You may lose hundreds of dollars from *hidden hunger* before quality differences like this show up in your soybeans. The beans above needed more potash—but didn't *show* it until yield time.



By W. D. BISHOP,

Extension Service,
University of
Tennessee

INTERPRETING SOIL TESTS FOR TOP YIELDS

By following a regular program of soil testing, the farmer can avoid loss of yields and low profits brought on by *hidden hunger*.

Soil testing becomes very important in isolating areas where no apparent deficiencies occur, yet top yields are seldom obtained.

Although sufficient quantities of fertilizers have been used to adjust the soil level to a medium or high level, the soil resources should be constantly checked.

Numerous alfalfa demonstrations conducted in Tennessee over the past 5 years have turned up the need for more liberal potash applications.

It is important to use sufficient quantities of fertilizer to build up and maintain rather high fertility levels in the soil.

Top yields are best obtained by adjusting the fertilizer use to suit the individual situation.

RAPID chemical soil tests are made by most of the Land-Grant Colleges and many commercial organizations.

In general, such chemical tests are used to make sound fertilizer and lime recommendations to farmers. Such recommendations are normally based upon numerous well-planned field studies.

Field experiments are used to establish two main relationships: (1) the chemical method which gives the greatest reliability, (2) the relative amounts of plant nutrients needed at different soil test levels.

Soil Test—A Diagnostic Tool

Soil testing is one of the best diagnostic tools available for determining nutrient requirements. Through this "tool," we can obtain information about the relative level of plant nutrients in the soil and predict the amount of each nutrient needed. Soil testing is the most popular technique used in making fertilizer and lime recommendations.

Dr. William D. Bishop is head of the Extension Agronomy Department at the University of Tennessee. He earned his B.S. and M.S. at Tennessee, his Ph.D. at Purdue and has spent 10 years in Extension work, largely in soil fertility and soil testing programs.

Before soil testing reached its present development, many farmers waited for deficiency symptoms to tell them they were running out of a plant nutrient—an *inefficient, dangerous method.* When plants reached this stage, profits had been declining for some time.

We now realize that even though plants do not show signs of deficiency, they may be producing *below* the *most profitable* level. We say they are suffering from *hidden hunger.*

How can one recognize such a stage if the plant shows no visible signs? This is where soil testing really serves its best purpose. By following a regular program of soil testing, the farmer can avoid loss in yields and low profits brought on by *hidden hunger.*

Most soil tests reveal about four or five different fertility conditions—*very low, low, medium* and *high.* Many states divide the high group into high and very high. In discussing these groupings, we must consider the crop in question.

For example, a report stating that the soil tested *medium* in potash carries different recommendations for different crops. In this case, a *low* fertilizer recommendation would be made for wheat, *medium* for corn, *high* for alfalfa, and *very high* for tobacco.

What type of plant growth can be expected at each soil fertility level? Most crops grown on soils of very low fertility produce low yields of poor quality. Plant nutrient deficiencies or hunger signs will often be evident on such soils. Through the use of sufficient amounts of plant nutrients, the deficiencies will be corrected and yield increases obtained.

Likewise, an increase in crop yields will result when soils of low to medium fertility levels are properly fertilized. However, many crops grown on such soils will not have striking hunger signs. Therefore, *soil testing becomes very important in isolating areas where no apparent deficiencies occur yet top yields are seldom obtained.*

Table I points out the importance of using the best diagnostic tool available—soil tests—in planning a sound soil fertility program.

Build Up Soil Fertility Levels

Production cannot be as high on soils of very low or low fertility as on medium to high fertility soils. This makes it important to build up the fertility level for profitable yields.

In many parts of the United States, nitrogen cannot be stored in the soil very long. Therefore, nitrogen fertilization is normally based on the needs of a particular crop for one year or, to be more specific, on the crop needs during a certain time of its growth.

Phosphorus and potassium levels can be maintained at high levels in many soils. *These plant nutrients are needed in rather large amounts by most plants.* Alfalfa fertilization experiments conducted during 1953-1956 at the Middle Tennessee Experiment Station by Dr. W. L. Parks showed approximately 50 pounds of K_2O removed per ton of hay.

In the same experiment, potassium levels in the soil were increased from approximately 200 pounds of ex-

Table I

Soil Test Level	Extent of Hunger Signs	Amount of Fert. Needed	Response to Fert. Applications
Very low	Marked	High	Very good
Low	Very slight	High	Good
Medium	Hidden	Medium	Moderate
High	None	Low	Little

Man-made fertility variations within soil types, as well as differences among soil types, can be detected by soil tests. Soil type alone is no longer a safe basis for making lime and fertilizer recommendations.

changeable potassium per acre in 1954 to over 450 pounds in 1956 *where 200 pounds of K_2O were applied annually.*

Many field experiments clearly show phosphorus levels can be increased in the soil where fairly large rates of phosphate fertilizers are used. Although plant removal is not as high with P_2O_5 as it is with K_2O, the efficiency with which plants utilize phosphorus is normally considered low.

In the experiment referred to above, a total of 70 pounds of P_2O_5 was removed while 240 pounds of K_2O were removed in the entire production of the 1956 alfalfa hay crop. In other experiments, phosphate levels increased from *low* to *medium when 60-120 pounds* of P_2O_5 were applied annually and to *high* when *180 pounds* were used.

Through the use of chemical soil tests, the fertility level of the soil can be maintained at the desired level. Even though sufficient quantities of fertilizers have been used to adjust the soil level to a medium or high level, *the soil resources should be constantly checked.*

Numerous alfalfa fertilization demonstrations have been conducted in Tennessee for the past five years. *These demonstrations have shown the necessity of applying liberal applications of potash.* Not only has this been essential for maintaining the level of potassium in the soil but also for maintaining high yields and good stands.

On established alfalfa stands where soils tested high in potassium, soil potassium levels dropped from high to medium or low after two or three years of crop removal. The fertility level of alfalfa was maintained by applying *100 pounds of K_2O per acre per year where yields of three to four tons of hay were removed.*

Even more striking perhaps, is to compare the fertility level of various counties with the yields of various crops grown in each.

Approximately *50 per cent* of the soils in Shelby County test low or very low in phosphate, while only *35 per cent* of the soils in adjoining Tipton County test low or very low in phosphorus. Each county grew between 30,000 and 35,000 acres of corn and between 40,000 and 45,000 acres of cotton during the past five years. *Yet, Tipton County produced about five bushels more corn and 50 pounds more lint cotton per acre in 1956 than Shelby County.* This difference, of course, is not due entirely to phosphate levels, but it is unlikely that the difference can be explained by any other single production factor.

It becomes important, therefore, to use *sufficient quantities of fertilizers to build up and maintain rather high fertility levels in the soil.* Whether we consider the individual field, the farm, or an entire area, soil testing is the most desirable method for evaluating the existing soil resources and determining the fertility program necessary to insure a profitable operation.

Get Top Yields

Soil fertility as measured by chemical tests must also be interpreted based on yield potential or management. Several states suggest two or more levels of fertilization. For example, Iowa suggests three levels of fertilization for corn—minimum, intermediate, and optimum. Minnesota suggests average and extra yields of corn and certain other crops.

Last year Tennessee recommended three levels for corn and cotton. These levels were based on yield potential or soil type. Research conducted by Dr. F. F. Bell and complete production demonstrations conducted by members of the Extension Agronomy Department revealed the information shown in Table II.

It is very important to consider *the potential* before making fertilizer recommendations. For example, an *average recommendation* for corn would provide enough nutrients for only 50 to 60 bushels of corn. On soils having a yield potential of 100 or more bushels per acre such a recommendation would be insufficient to obtain this yield. *Top yields are best obtained by adjusting the fertilizer use to suit the individual situation.*

Most farmers using soil tests today are not interested in recommendations for average production. The mere fact that they use soil tests indicates they are above average farmers and, therefore, are interested in obtaining top yields consistent with the economic framework in which they are operating.

The average farmer realizes very little net return on the 30 bushels of corn that he produces per acre. *However, the yield average for the top corn producers returns a nice profit.*

Approximately 50 farmers conducted complete corn production demonstrations in Tennessee during 1956 and *averaged about 85 bushels* per acre while the state average was *only 31 bushels* per acre.

According to the best research information available, the average cost of producing 31 bushels of corn per acre in Tennessee is approximately $1.15 per bushel and only $0.55 per bushel where 85 bushels per acre are grown.

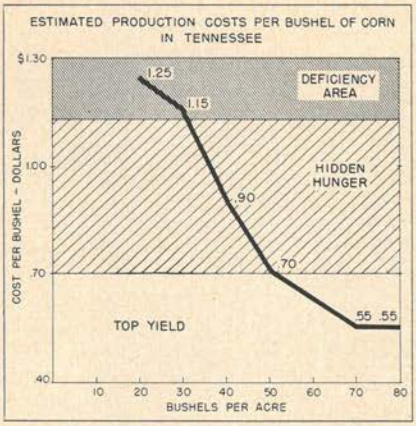
Summary

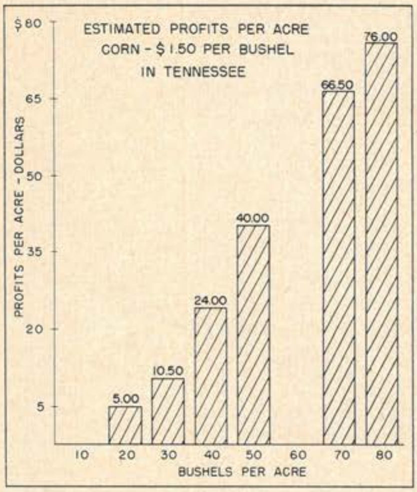
Soil testing is one of the best diagnostic techniques available to farmers for determining the fertility needs of their farms.

Fertility levels can be maintained

Table II

	Soil Groups			
	Excellent	Good	Fair	Poor
Cotton (lint/acre)	750	600	450	275
Corn (bushels/acre)	100	75	50	30
Tobacco (pounds/acre)	2300	1900	1400	800





and built up by using information obtained from soil tests.

Soil testing provides farmers with the latest research information available on lime and fertilizer use.

By following a regular program of soil testing, one can avoid loss in yield and low profits resulting from *hidden hunger*. ◄◄◄

PLANT ANALYSIS—*Continued from page 27*

Here is a tool we can use to determine accurately the nutrient status of our crops for the vital purpose of keeping the plant nutrients up to safe levels. This procedure is always more profitable than waiting for trouble to arrive and then trying to overcome it. ◄◄◄

Harvest Results. Davis, California, 1952.

Lbs. of N, P_2O_5, or K_2O per acre		Ton beets per acre	% sugar	cwts. sugar per acre	Increase in dollar return per acre [2]
May 27 [1]	July 24				
0	0	21.1	15.9	66.8	....
80N	0	23.6	15.5	72.8	$11.50
80N	40N	25.9	15.1	78.2	28.25
80N	80N	28.5	14.7	84.0	44.25
80N	160N	30.4	14.0	84.8	38.00
200P_2O_5, 80N	160N	29.7	13.6	80.6	....
200P_2O_5, 200K_2O and 80N	160N	28.4	14.1	80.2	....
Significant...........	(19:1)	2.3	0.7	10.0	....
Difference...........	(99:1)	3.1	0.9	13.4	....

[1] Applied shortly after thinning.

[2] Represents net gain over return from beets receiving no nitrogen. (Ulrich, Ririe, and Hills, "The application of petiole analysis to sugar beet fertilization," mimeographed circular, 1953, Table II.)

By T. L. JACKSON,
Soils Extension,
Oregon State College

FERTILIZING

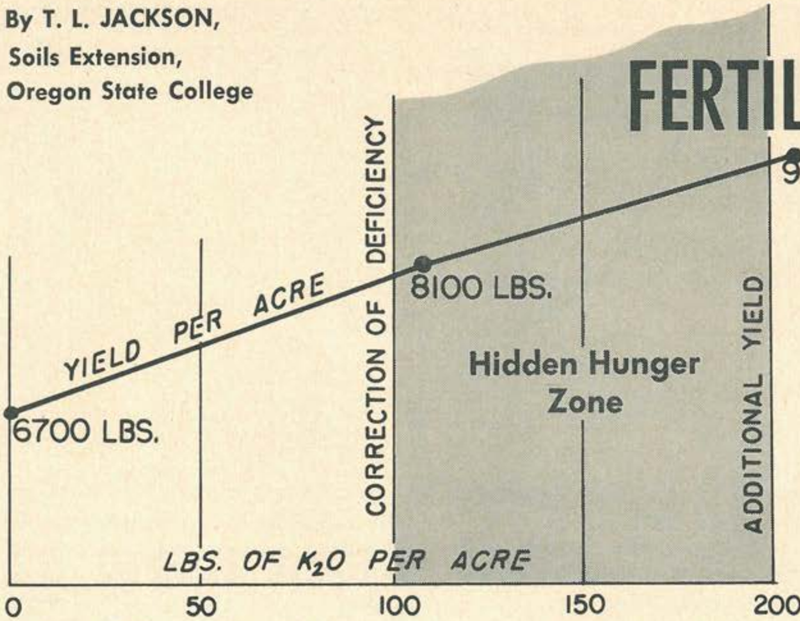


Figure 1—When supplied enough potassium to overcome *hidden hunger*, this crop produced another half ton of fine quality alfalfa. Potash deficiency symptoms were eliminated with the first 100 pounds of K_2O per acre, increasing the yield from 6,700 pounds per acre to 8,100 pounds per acre. The second 100 pounds of K_2O produced an additional 1,000 pounds yield after the deficiency symptoms were corrected.

THE management of farming operations "to produce the maximum profitable yields" has become an increasingly complex problem.

This short phrase "to produce the maximum profitable yield" means balancing a number of factors.

First, the right kind and amount of fertilizer must be combined with high-yielding, adapted varieties planted at the right plant population. Diseases, weeds, and insects have to be controlled. The crop must be managed correctly and adequate soil moisture must be present for growth.

One of the most complex parts of this problem is to determine the proper fertilization program to produce the most profitable yields. Figure 1 shows the value of a proper fertilizer program compared to no fertilizer on the Red Hills Experiment Station at Oregon City. Application of lime to correct soil acidity was essential for establishing alfalfa. The combination of fertilizer—phosphorus and potas-

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WHO SUGGESTS ....

FOR MAXIMUM YIELDS

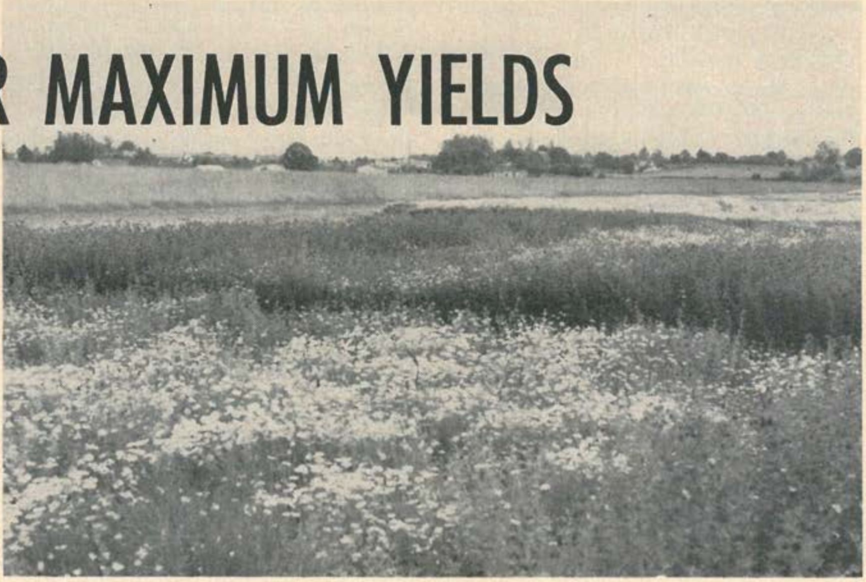

Figure 2—Experiments on the Red Hills Experiment Station at Oregon City saw PKCa transform the forage from weeds (foreground) to a high yield of fine quality alfalfa hay (background). The combination fertilizer—phosphorus and potash—with lime increased the yield from 500 pounds of weeds on the check plot to 9,000 pounds of good alfalfa hay in the fertilized plot.

sium—with lime increased the yield *from 500 pounds of weeds* on the check plot *to 9,000 pounds of high-quality alfalfa hay* on the fertilized plot.

Doing an efficient job of fertilizing for maximum yields means being able *to predict the fertilizer needs* for each crop on an *individual field basis.* Some of the tools for making such a prediction are:

1. Crop requirement.
2. The soil type on which the crop is grown.
3. Visual deficiency symptoms.
4. Soil testing.
5. Leaf analysis.

The total amount of nutrients removed from a field by a crop and the total amount of nutrients required to produce a crop can be calculated fairly easily from the chemical composition of high-yielding crops. This gives us a place to start in figuring fertilizer needs.

There are wide differences, however, between crop requirements and the amount of nutrients removed from

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To do an efficient job of fertilizing for maximum yields, we must be able to predict the fertilizer needs for each crop on an individual field basis. Such prediction takes such tools as . . .

1. *Crop requirement*
2. *The soil type on which the crop is grown*
3. *Visual deficiency symptoms*
4. *Soil testing*
5. *Leaf analysis*

---

a field by different crops.

For example, 10 to 20 pounds of potassium per acre will be removed by a 500-pound crop of bentgrass seed in the Willamette Valley, while the neighbor's alfalfa crop in the field across the fence could easily remove *200 pounds of potassium* per acre in 5 tons of hay.

Crop requirement alone does not tell us how much of these nutrients can be supplied or will be supplied by the soil, nor does it recognize the varying abilities of root systems in different crops (such as bentgrass versus alfalfa) to utilize the nutrients present in the soil.

Predicting fertilizer needs on a crop removal basis does not recognize the *variability* in fertility levels or the supply of nutrients in different soil types or in individual fields.

Fertilizer Needs on a Soil Type Basis

The supply of plant nutrients in various soil types differs greatly, especially when we compare soils developed from different parent materials and soils developed under wide variation in climatic conditions.

These factors—variation in parent material and climate—develop different types of clay minerals. In some states, like Oregon, the soil organic matter can range from .5 to 1 percent levels in the central part of the state where the soils were developed under semi-arid conditions to 12 and 15 percent levels along the coast where the rainfall averages 80 to 100 inches a year.

Certainly, the differences in the supply of plant nutrients in the acid soils needing lime and in the calcareous soils developed in low rainfall areas are very marked.

These two approaches—crop requirement and the difference between soil types—leaves out a major factor: *the present fertility level on an individual field basis*.

The fertility level of each field is the product of management systems, the growth and production of different crops, and the use of fertilizer and lime during the last 100 years or so. Proper fertilizer usage recognizes these variations within soil types and between fields, and the differences in crop requirements.

Visual Deficiency Symptoms

Deficiency symptoms developed on the leaves and foliage of plants have been used to identify starvation signs in some areas.

However, we need to recognize the major weaknesses in using this as a diagnostic tool for proper fertilizer application.

First, by the time the growth and development of a plant has deteriorated so that visual deficiency symptoms appear *there has been a substantial loss of yield*. Very often this loss in yield cannot be recovered by later fertilization.

Second, on some plants the only visual deficiency symptom for some nutrients *is poor growth and lack of vigor*.

The zone of *hidden hunger*—where just enough fertilizer has been applied to correct the visual deficiency symptom and plants do not show deficiency symptoms—lies between *the starvation signal* and *the maximum yield of a crop*.

Proper Fertilization Through Soil Tests

Through a soil test we can inventory the fertility status of each field before a crop is planted. This gives us a basis for predicting fertilizer needs and the response we might expect from fertilizer applications.

By recognizing the differences in crop requirements and fertilizing each field on the basis of a soil test, we can avoid the so-called *hidden hunger* and yield losses that occur when we wait for the appearance of deficiency symptoms.

We do need to recognize that any

reliable and usable soil testing program has to depend on many years of extensive fertilizer experiments in that particular area.

It is an easy job for a chemist to use different extracting solutions and measure the amount of phosphorus or potassium released to this solution by a soil sample. This answer *by itself* has little or no meaning unless it is correlated and compared with soil samples from fields where experiments have been conducted and response from fertilizer application has been measured. This correlation between the laboratory analysis and response or lack of response from application of fertilizer is an essential step in any reliable soil testing program.

A soil test is one way of comparing the fertility status of an individual field with the fertility status of fields where experiments have measured yield differences following application of fertilizer.

It would be a mistake to leave the impression that soil tests are perfect and foolproof. It will be some time before we approach perfect correlations between soil test values and response from fertilizer applications on all important crops in an area and for all of the essential plant nutrients.

However, *soil tests are an excellent tool when based on a sound research program and when used properly.*

Also, we need to recognize the soil's fertility is *just one* of the factors—certainly an important one—but just one of the factors that determines the final yield of a crop.

A soil test is of limited value for predicting the fertilizer needs for fruit trees. A tree grows in one spot for many years, the roots penetrate a large area of surface soil and subsoil, and fertilizer applications can influence the growth of trees for several years. All of these factors make fertilization of fruit trees a very complex problem.

Figures 1 and 3 illustrate the use of soil tests in determining proper fertilizer application on an individual field basis. Lime was the main factor influencing the yield of alfalfa shown here. Lime, with potassium, increased the yield from 3,400 pounds per acre to 9,200 pounds per acre. Potassium increased the yield from 6,700 pounds per acre to 9,400 pounds per acre where soil acidity had been corrected with lime. Potassium deficiency symptoms were eliminated with the first 100 pounds of potassium (K_2O) per acre—increasing the yield from 6,700 pounds per acre to 8,100 pounds per acre. The second 100 pounds K_2O produced an additional 1,000 pounds' yield after the deficiency symptoms were corrected.

The soil test showed a low level of potassium and calcium and a soil pH

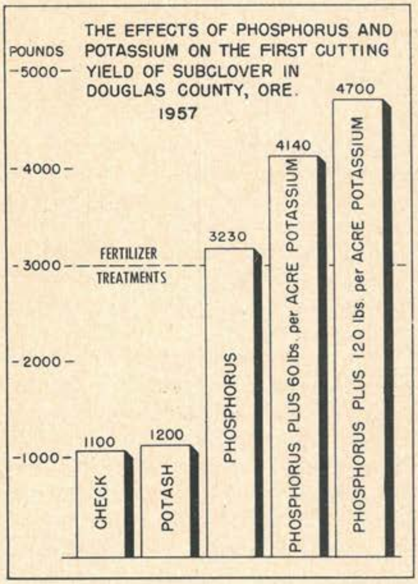


Figure 3—Interactions between plant nutrients are important in proper fertilization. This yield data from a spring harvest of subclover shows how important interaction really is. It also gives us two good examples of hidden hunger. The combination of phosphorus plus 60 pounds of potash (K_2O) per acre eliminated the potash deficiency symptoms, but it took *120 pounds* of K_2O per acre to produce the *top yield* on this cutting.

too low for good alfalfa growth on this soil.

Proper Fertilization Through Leaf Analyses

Leaf analysis is our best way to inventory the nutritional status of fruit trees. Used in many places throughout the United States, this approach has been very successful in determining the needs for nitrogen, phosphorus, potassium, and several of the minor elements.

Like a soil testing program, any reliable leaf analyses project must be supported with an extensive research program. Response from fertilizer application must be correlated with the chemical analyses of a plant part, and we must establish the best time during the growing season to take plant samples.

Some problems must be recognized if leaf analysis information is going to be used:

(1) It has worked very successfully on perennial plants where you can analyze samples of the vegetation during the growing season to plan the use of fertilizer for the production of next year's crop.

(2) It is very useful in diagnosing soil fertility problems that appear while a crop is growing and in evaluating the effectiveness of the current year's fertilizer program.

(3) But leaf analysis is of limited value for the annual crops that require application of fertilizer before the crop is planted.

The work of Dr. Mack in the Horticulture Department at Oregon State College evaluating optimum phosphorus application for producing beans is an excellent example of *hidden hunger* in this crop.

The main phosphorus deficiency symptom in the bean plant is low yields. There is no striking purpling of the leaves as we have on phosphorus-deficient corn plants, nor is there any burning of the leaf margin as we have from potassium deficiency. The bean leaves have a fairly good color, but the plants *just don't grow*.

This work also shows the relationship between yield increase from application of phosphorus and the phosphorus composition of the bean plants —the plant samples were taken as the first trifoliate leaf developed.

Interactions Between Plant Nutrients

The necessity of having an adequate supply of each of the 16 chemical elements essential for plant growth has to be recognized when making fertilizer recommendations.

While most of our fertilizer recommendations call for nitrogen, phosphorus, potassium or sulfur, the individual making these recommendations must know that there is an adequate supply of the remaining chemical elements necessary for optimum production of the crop.

Very often Liebig's "Law of the Minimum," published in the mid-nineteenth century, is forgotten. This Law states "the growth of a plant will be limited by that plant nutrient element present in the smallest quantity, all others being present in adequate amounts."

This idea or law tells us that the benefits from application of one element, such as nitrogen or phosphorus or potassium, will not be realized if there is not an *adequate supply* of the *other essential plant nutrients*—thus, *the response from one nutrient is affected by the relative supply of another nutrient.*

This relationship between nutrients and the effect of one nutrient on another is an *interaction.*

We need to recognize the importance of *interactions* between plant nutrients in proper fertilization. This point is well illustrated by the yield data from a spring harvest of subclover in a Douglas County fertilizer experiment shown in Figure 3.

The check plot (Figure 3) showed

Yield and Phosphorus Content of Beans as Influenced by Phosphorus Fertilization

		Treatment lb/A N-P_2O_5	Yield Tons/A 1952	Yield Tons/A 1953	% P in Plants 1952	% P in Plants 1953
	1.	50–0	8.99	10.53	.18	.25
Vegetable Crops	2.	50–60		11.38		.40
Farm—Oregon State	3.	50–120	12.17	11.39	.44	.45
College 1952–1953	4.	50–240	12.33		.48	

no potassium deficiency symptoms and potassium *alone* had no influence on yield. Subclover does not develop easily recognizable phosphorus deficiency symptoms.

Phosphorus alone increased the yield one ton per acre and caused *typical potassium deficiency symptoms*—phosphorus was no longer the nutrient present in "smallest quantity." The combination of phosphorus plus 60 pounds of potassium (K_2O) per acre eliminated the potassium deficiency symptoms, *but it took 120 pounds of potassium (K_2O) per acre to produce the top yield on this cutting.*

This experiment gives us two examples of *hidden hunger.* The severe phosphorus deficiency on the check plot limited production so that there was enough potassium supplied by the soil to eliminate deficiency symptoms at this low yield. But after phosphorus plus 60 pounds of potassium (K_2O) had been applied the potassium deficiency symptoms had been eliminated. The lack of phosphorus deficiency symptoms on the check plot and potash plot is another case of *hidden hunger.*

Summary

1. To prevent *hidden hunger,* we need to recognize the importance of an adequate supply of each of the essential plant nutrients.

2. We need to use soil tests to give a basis for evaluating the fertility status of a field before the crop is planted.

3. We should use leaf analyses to take an inventory of the nutritional status of a growing crop.

4. We should use all of the information thus developed to predict the need for fertilization of individual fields so that safe levels of fertility may be maintained. ◄◄◄

LAST UNIT IS TOUGH

It is easy to "sell" a grower on the need for the first $1 per acre to be invested in fertilizers, but it is difficult to "sell" that *last* unit of plant food needed to grow top yields.

Modern research on grasses and legumes shows . . .

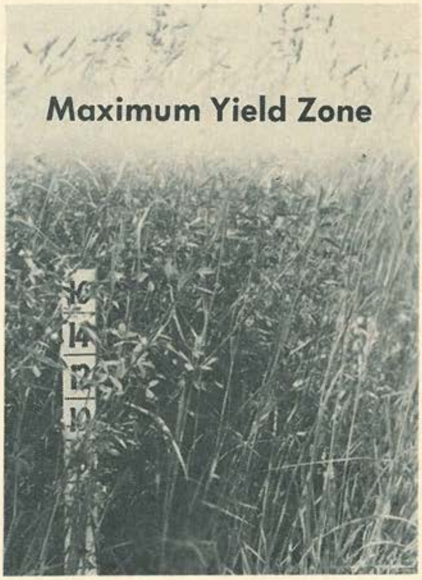
That fertilizer practices delayed until deficiency symptoms of leaves appear cause low yields, lower crop quality, stand losses, and the encroachment of weeds.

That high yield responses to fertilizer in the **hidden hunger** area indicate a fertilizer deficiency, although leaf deficiency symptoms are not present.

HIDDEN HUNGER IN GRASSES AND LEGUMES

That plant maturity influences the mineral and protein content of grasses and legumes more than fertilization, which can mean fertilizer practices based on mineral uptake of plants may be misleading.

That yields and maintenance of balanced stands of grasses and legumes are the best criteria for measuring needs in forage programs.



This series of pictures (above and facing page) shows an alfalfa-orchardgrass mixture that was limed and fertilized liberally with phosphorus. This is the first spring crop in

By R. E. Blaser, C. Y. Ward, and

LONG survival and high yields of grasses and legumes for pasture, silage, and hay depend on:

(1) Proper liming and fertilization.

(2) Selection of the best adapted varieties and species.

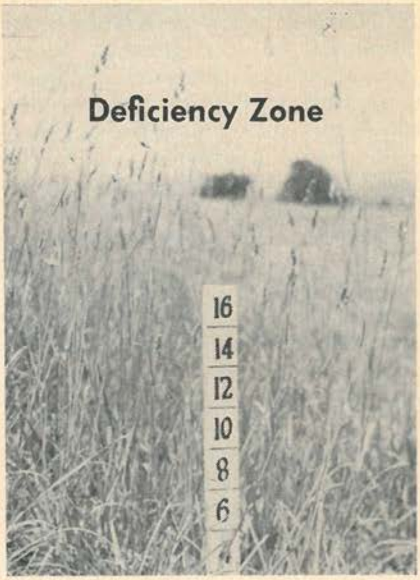
(3) Using mixtures suited to specific soil conditions on farms.

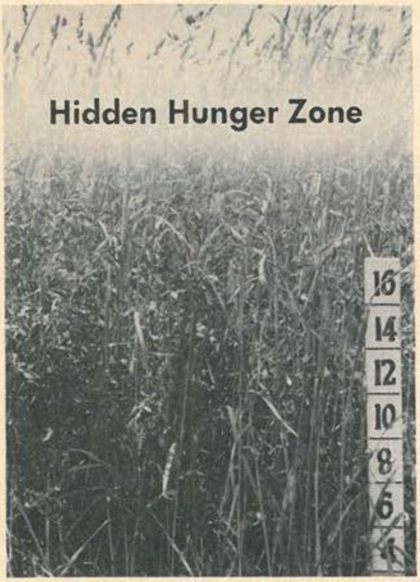
(4) Cutting and grazing practices to obtain high yields of nutritious forage.

(5) Insect control measures when needed.

A farmer's failure to consider any one of these limiting factors that affect plant growth is like "throwing a monkey wrench into the works." Of course, the yields and longevity of stands also depend on rainfall, temperature, day length, and other natural factors that cannot be controlled.

We shall limit this discussion to fertilizing grasses and legumes. It is





1953, the third harvesting season. The mixture in the *Deficiency Zone* switched largely to grass *where potash was not applied*. The *maximum yield* zone received 400 pounds of K_2O annually. The *hidden hunger* zone received 200 pounds of K_2O *yearly*. See Figure 4 for actual yields.

W. W. Moschler • Virginia Agricultural Experiment Station

necessary to begin with a lime and fertilizer program that will produce high yields. In balanced fertilization, any and *all* of the fertilizer elements that many improve yields should be applied. If a low amount of *available soil potash* causes low yields, this shortage *cannot* be corrected by adding more phosphorus or nitrogen.

There is no easy way to decide how much lime and fertilizer a farmer should apply. Yield increases as influenced by added amounts of a given fertilizer are the only sure and practical way to determine how much fertilizer should be applied. Foliar deficiency symptoms, nutrient absorption (dry or green tissue analyses), soil tests, and field histories are useful tools, but they often give unreliable results. To *delay* in applying a given fertilizer until the plants showed deficiency symptoms would cause low yields. Let us now look at *yields*, *mineral uptake*, and *deficiency symptoms* of forage plants with different fertilizers.

Zone of Hidden Hunger

Experiment I: The potash requirements of orchardgrass were studied in a green house experiment, Figure 1. Potassium deficiency symptoms were

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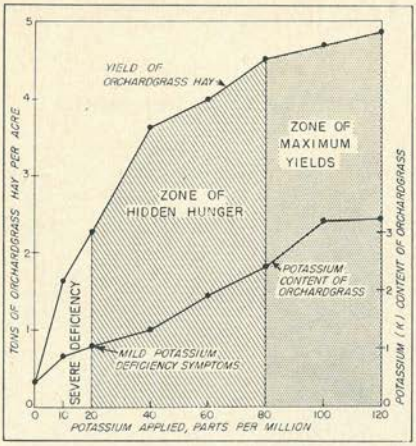


Figure 1—The yield (16% moisture) and potassium content of orchardgrass as influenced by potassium fertilization in a greenhouse experiment.

present when the grass ranged from 0.37 to 0.89% K and the hay yields ranged from 0.26 to 1.63 tons per acre. By adding potash fertilizer, the yields increased up to 4.86 tons and the potassium content of plants rose to 3.34%. As more potash was added, the yields increased much faster than the potassium content of plants. These yield increases from additional potash fertilization *when foliar deficiency symptoms were not present* are called the *zone of hidden hunger,* shown in Figure 1.

The highest applications of potash in this experiment, 100 and 120 ppm., caused consistent but small yield increases of hay as more potash was applied.

This region is called the *zone of maximum yields.* The yields obtained from a pound of fertilizer here were less than for the *zone of hidden hunger.* Notice (1) that fertilizing to satisfy mineral deficiency symptoms would have resulted in low yields and (2) that yields increased much faster than potassium content of orchardgrass.

Experiment II: Yield increases of Coastal bermudagrass were measured for added amounts of nitrogen, Figure 2.[1] The exact region on the yield curve when Coastal bermudagrass leaves *showed* nitrogen deficiency symptoms were hard to define. Nitrogen fertilizers turned the foliage from a lemon yellow without nitrogen to a darker green color and also increased the number of shoots and rate of growth.

The yield with 100 pounds of nitrogen per acre was 4.42 tons. The *zone of hidden hunger* shows large increases in yields as more nitrogen was added. The yields from 300 and 600 pounds of N were 7.46 and 9.3 tons, respectively. In the *zone of maximum yields,* the curve began to flatten as more nitrogen was applied. Note that protein content would not have been a good fertilizer index, as with added nitrogen, the yields increased much faster than the per cent protein content.

Experiment III: Alfalfa yields were obtained from different amounts of phosphorus. The hay yields during three years from different amounts of phosphorus on a limestone soil are given in Figure 3. Alfalfa without phosphorus was stunted *but typical phosphorus deficiencies were not present, even for the low yields of two tons of hay per acre during the*

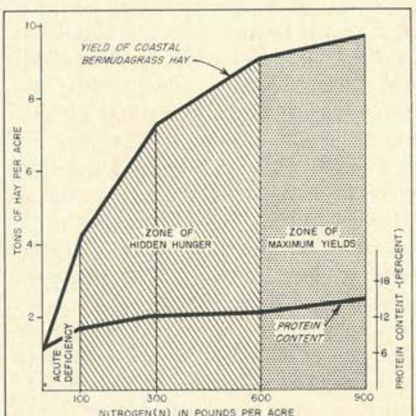


Figure 2—The yield (16% moisture) and protein content of Coastal Bermudagrass when fertilized with different rates of nitrogen.

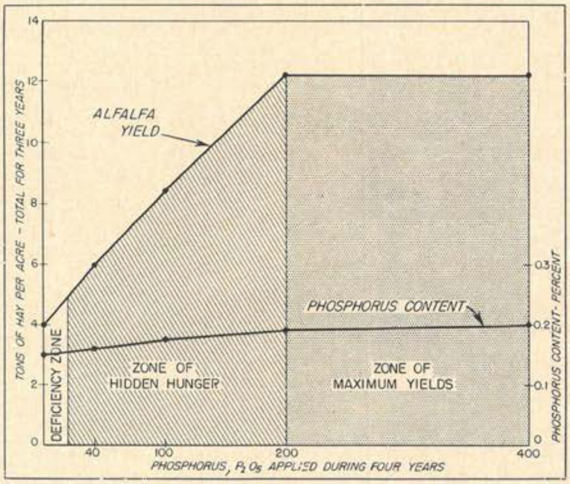


Figure 3—Phosphorus deficiency symptoms of alfalfa are not clearly displayed. The large yield increases in zone of *hidden hunger* are not usually associated with large increases in phosphorus content of plants.

three-year period. Deficiency symptoms of phosphorus are almost useless in ascertaining growth responses of alfalfa and other forage plants as typical symptoms rarely occur under good farming. The alfalfa yields increased from about 4 to 12 tons of hay per acre as the amount of P_2O_5 was increased up to 200 pounds per acre during the three-year period. This *zone of hidden hunger* again shows large yield increases as more phosphorus was added.

The phosphorus (P) content of plants without P_2O_5 fertilizer averaged 0.15 as compared with 0.20% when 400 pounds of P_2O_5 were applied. *These data show that phosphorus analyses of plants would have been useless in predicting growth responses from added amounts of P_2O_5.*

Hidden Hunger in Grass-Legume Mixtures

Grass-legume mixtures should be fertilized to keep a balanced stand of legumes and grasses to get high yields. Mixed stands of grasses and legumes often revert to grasses and weeds because legumes are set back by *(1) low fertilizer and lime applications, (2) mismanaged cutting and grazing practices, (3) damage from disease and insect pests and/or (4) adverse weather conditions.*

Clovers and alfalfa have higher pH, lime, phosphorus, and potassium, and minor element needs than grasses.

Experiment IV: Alfalfa-orchardgrass, ladino clover-orchardgrass, and ladino clover-tall fescue mixtures were grown on two soils—Piedmont and an Appalachian limestone—with plenty of fertilizer, Table I.

The grass grown with a legume in each of the three mixtures for both soils was higher in potassium content than the legumes. For all mixtures on the two soils, the grasses averaged 30% higher in potassium content than the legumes. The potassium content of the grasses averaged 3.19% as compared with 2.44% for the legumes in the mixtures on the Piedmont soil. The grasses on the limestone soil averaged 3.60% potassium as compared with 2.77% for the legumes.

The average mineral and protein content of the legumes and grasses grown on each of the two soils is given in Table II. The legumes were 24% to 61% higher in magnesium than the grasses, but the legumes absorbed 455% to 579% more calcium than the grasses. The phosphorus absorbed by grasses and legumes was similar. The legumes were 27% to 75% higher in protein content than the grasses.

Table I. The potassium content of grasses and legumes grown in mixtures on two soils. [1]

Legume-Grass Mixtures	Piedmont Soil Grass %	Piedmont Soil Legume %	Limestone Soil Grass %	Limestone Soil Legume %
Alfalfa grown with orchardgrass......	3.41*	3.00	3.77*	2.70
Ladino clover grown with orchardgrass	3.19*	2.34	4.01*	2.71
Ladino clover grown with tall fescue...	2.96*	1.97	3.03*	2.89

* Significant differences of the species in mixtures.
[1] Cecil soil in Piedmont and Groseclose soil in the Appalachian Limestone Region of Virginia.

The legume stands in mixed seedings with grasses are often lost because: *(1) the legumes require higher rates of certain fertilizer minerals or (2) the aggressive grasses rob the soil of certain minerals.*

Although legumes need more magnesium than grasses, the amount absorbed is low so competition among grasses and legumes is not serious. Competition for calcium is not important since soils have a large reserve in lime. Furthermore, the legumes absorb more calcium and magnesium than the grasses.

On the other hand, legumes are often lost in mixed stands *because they cannot compete with grasses in potassium absorption. Potassium needs are high. The potassium taken in by the legumes was higher than that for magnesium, calcium, and phosphorus all together, Table II.*

Competition For Potash in Legume-Grass Mixtures

Experiment V: In an alfalfa-orchardgrass mixture, near Blacksburg, the yield was increased from *1.21 tons without potash* to *4.25 tons per acre with 400 pounds of potash per acre,* Figure 4.

These yield increases are attributed to the stimulated growth of alfalfa in

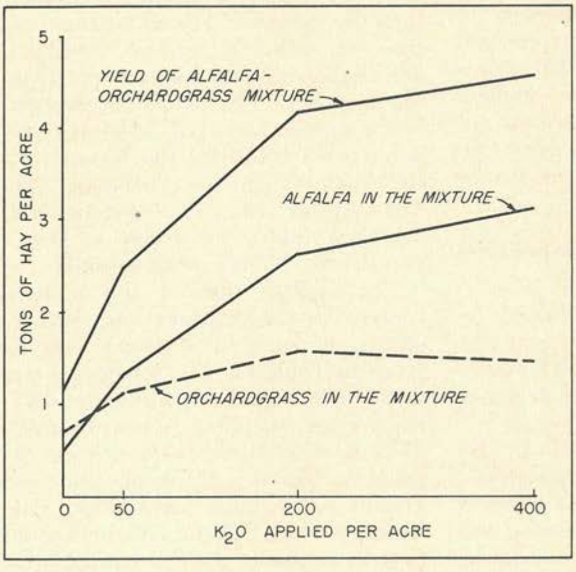


Figure 4—The yield (15% moisture) of an alfalfa-orchardgrass mixture and the alfalfa and orchardgrass as influenced by potash fertilization (See Figure 9). Data from a limestone soil near Blacksburg.

Table II. The average composition of three grass-legume mixtures grown on two soils (average values for the mixture given in table III.)

Fertilizer Element	Piedmont Soil		Limestone Soil	
	Grass %	Legume %	Grass %	Legume %
Potassium	3.19*	2.44	3.60*	2.77
Magnesium	0.38	0.47*	0.18	0.28*
Calcium	0.33	1.15*	0.32	1.88*
Phosphorus	0.52	0.50	0.42	0.43
Protein	21.2	26.8*	16.5	28.9*

* Significant differences of species.

response to potash fertilization. Notice that when compared with alfalfa, orchardgrass gave low yield increases from potash applications, Figure 4. The alfalfa yield was quite closely associated with the total yield; the yields increased as 50, 200, and 400 pounds of K_2O were applied. Orchardgrass responded less than alfalfa to potash fertilization, the yield of grass was increased slightly with 200 pounds of K_2O, but not for 400 pounds of K_2O per acre.

The hay yields of the alfalfa-orchardgrass mixture and the potassium content of the orchardgrass and alfalfa for Experiment V, are given in Figure 5. Under low potash fertilization, alfalfa could not compete with orchardgrass. This is so because alfalfa was much lower in K content than orchardgrass at low-potash as compared with high-potash fertilization. Alfalfa leaves were spotted and potassium deficient at 0 and 50 pounds of K_2O per acre, but orchardgrass leaves did not show potassium deficiency symptoms. The yield of alfalfa and the total yield of the mixture along with the increased potas-

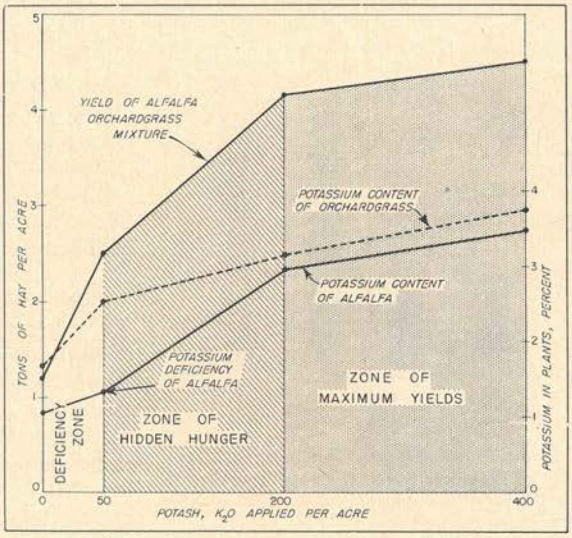


Figure 5—Potash fertilization as it influences the yield (10% moisture) of an alfalfa-orchardgrass mixture and the potassium content of orchardgrass and alfalfa. Using potassium deficiency symptoms would have resulted in low yields as shown by the *hidden hunger* and *maximum yield* zones. Fertilization of a grass-legume mixture depends on the response of the legume (See Figure 6).

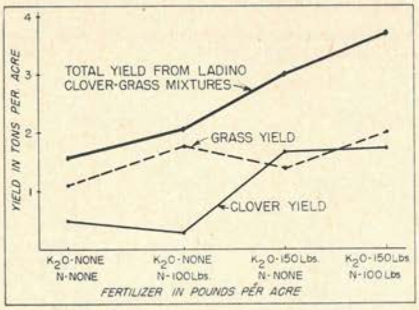


Figure 6—The total grass and ladino clover yield (16% moisture) as influenced by nitrogen and potash fertilization on a limestone soil near Blacksburg. Lime and phosphorus were applied liberally.

sium content of alfalfa, (Figure 5), point out that *the fertilization program of a grass-legume mixture should be based on the performance of the legume. Withholding potash applications at or near deficiency symptoms of alfalfa would have caused very low yields.*

Potash applications based on orchardgrass deficiencies would have caused even lower yields. In the *zone of hidden hunger,* there were large increases in alfalfa yields and potassium intake as fertilizer applications were increased up to 200 pounds of K_2O per acre.

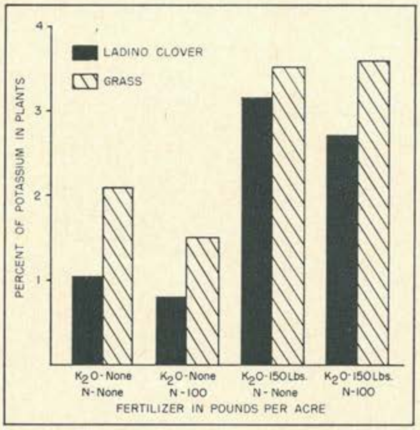


Figure 7—The nitrogen and potassium content of ladino clover and grass as influenced by nitrogen and potash fertilization. Yields are given in Figure 6.

Competition For Potassium Stimulated By Nitrogen

Experiment VI: Three grass-clover mixtures were grown separately (ladino clover with orchardgrass, with Ky. 31 fescue, and together with both grasses) on a limestone soil near Blacksburg. Lime and phosphorus were applied liberally, and two amounts of potash were used with each of two amounts of nitrogen for each of the three mixtures, Figure 6. The yields for the three mixtures were averaged together, but are given as total, grass and clover yields.

Nitrogen without potash increased the mixed yield because the grass yield increased but the clover yield was reduced by nitrogen. Potash without nitrogen gave a large increase in yield because there was a big response by clover—but the grass was also stimulated. *The largest yields were obtained when both potash and nitrogen were applied. Here the clover yield stayed high and the amount of grass in the mixture was also high because of the nitrogen-potash fertilizer.* The clover in the nitrogen-potash treatment stayed high because of the high rainfall.

The potassium absorbed by grass and clover for Experiment VI is shown in Figure 7. Irrespective of the fertilizer applied, the grass grown with the clover was always higher in potassium content than the clover. In the absence of potash fertilizer, clover was potassium-deficient, averaging 1.02% potassium, but nitrogen without potash reduced the potassium content of the clover to .85%. When applying potash, nitrogen fertilizer also reduced the amount of potassium in clover.

This and other experiments show that grass-legume mixtures need higher rates of potash than legumes grown alone. Adapted grasses growing at the same season with legumes are stimulated by nitrogen and become heavy potash feeders. The high potassium content and stimulated growth of grasses under nitrogen fer-

tilizer cause an extreme shortage for the legume when soil potash is low. Nitrogen fertilization thus "pulls the trigger" for increased needs of potash for grass-legume mixtures.

Spring nitrogen applications make grasses grow even earlier as compared with legume growth; hence a potash shortage for legumes in grass mixtures can be created at that season. After grazing or mowing, grasses usually recover faster than the legumes in mixtures. Here again with low-nitrogen fertilizer, grasses would be less aggressive absorbers and competitors for available soil potash than under high-nitrogen fertilization. Of course, rapid recovery of grasses under liberal-nitrogen fertilization usually retards the legumes in mixtures because of competing for water and light.

Mineral Content and Maturity of Plants

Experiment VII: Three grass-legume mixtures were fertilized with each of three rates of fertilizer. Plant analyses show that young leafy orchardgrass, about eight inches high, was made up of 33.9% protein as compared with 7.8% in a stemmy, full bloom condition, Figure 8. The protein or nitrogen content dropped very quickly as this grass produced stems, being 17.6% and 10.1% in boot and heading stages of growth, respectively. Note that the protein content of alfalfa, red clover, and bromegrass also dropped as plants got older and stemmy.

The phosphorus and potassium content of orchardgrass and alfalfa harvested at different stages of maturity are given in Figure 9. Alfalfa averaged 0.40% phosphorus when eight inches tall as compared with only half as much phosphorus, 0.19%, in the full bloom condition. The reduced phosphorus content of orchardgrass as plants became stemmy was similar to alfalfa. The potassium content of orchardgrass was 3.9% in the leafy eight-inch growth as compared with 1.87% potassium for the stemmy, full bloom growth. Note that potassium content of alfalfa followed the same trend with plant maturity, except that alfalfa was lower in potassium content than orchardgrass at all stages of growth. These changes in mineral and protein content with plant maturity occur in a short time, Table III.

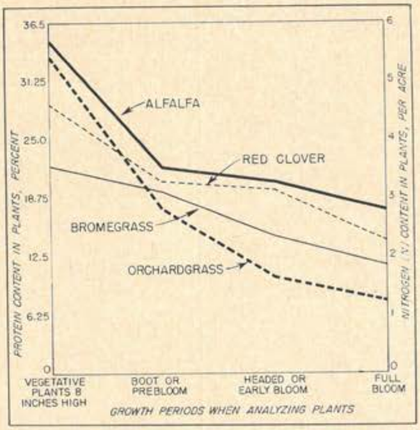


Figure 8—The crude protein or total nitrogen content of two grasses and legumes at different stages of plant growth.

The phosphorus and potassium content of an alfalfa-bromegrass mixture with three rates of fertilization is given in Table III. The amount of phos-

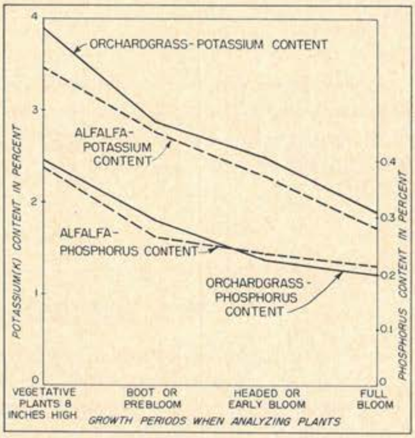


Figure 9—The potassium and phosphorus content of orchardgrass and alfalfa grown separately and harvested at different stages of growth.

Table III. The average phosphorus and potassium content of an alfalfa-bromegrass mixture as influenced by stages of growth and fertilization.

Fertilizer Pounds per acre P_2O	K_2O	April 13 (Leafy)	May 4 (Boot or prebloom)	May 20 (Headed or early bloom)	June 3 (Full bloom)	Average
				Phosphorus (P) Content		
30	30	.39	.34	.32	.29	.33
90	90	.45	.38	.34	.33	.37
180	180	.47	.40	.37	.33	.39
Average........		.44	.37	.34	.31	.36
				Potassium (K) Content		
30	30	2.77	2.58	2.22	1.65	2.30
90	90	3.43	3.36	2.84	2.22	2.96
180	180	4.04	3.74	3.14	2.65	3.39
Average........		3.41	3.23	2.73	2.17	2.89

phorus and potassium was influenced much more by stage of plant maturity than by the amount of fertilizer applied. Increasing the P_2O_5 fertilizer from 30 to 180 pounds per acre caused a 9% increase in phosphorus content for all stages of growth. Stage of growth influenced the phosphorus content in plants by 42%. Potash fertilization increased the potassium uptake by 47% and stage of growth had a 57% effect.

Conclusion:

1. Fertilizer practices delayed until deficiency symptoms on leaves appear cause low yields, lower crop quality, stand losses, and the encroachment of weeds.

2. The high yield responses to fertilizer in the area of hidden hunger demonstrate the presence of a fertilizer deficiency, even though leaf deficiency symptoms are not present.

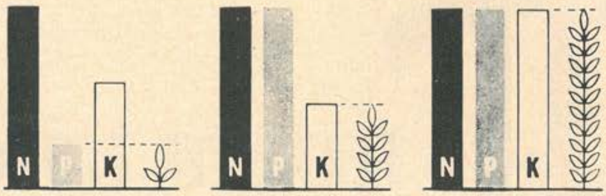
3. Because plant maturity influences the mineral and protein content of grasses and legumes more than fertilization, fertilizer practices based on mineral uptake of plants may be misleading.

4. Yields and maintenance of balanced stands of grasses and legumes are the best criteria to measure fertilizer needs in forage programs.

[1] Gordon W. Prine and Glenn W. Burton. Agronomy Journal 48:296-301, 1956, and also communication with Dr. Burton.

IT'S THE QUALITY THAT PAYS

Every tobacco planter knows that the proceeds from the sale of his tobacco crop depend more on the quality of the tobacco than on the quantity. An adequate supply of potash in conjunction with nitrogen and phosphate, besides increasing the weight of the crop, improves the quality of its color and aroma as well as its burning properties.



THE LAW OF LIMITING FACTORS

A special task has to be performed by each nutrient in the life of the plant. If a nutrient is in too short supply for the plant, its full development comes to a standstill.

According to the law of Limiting Factors (Law of the Minimum), plant growth is always limited by that nutrient which, in relation to the plant's requirements, is present in the *least amount*.

In this illustration, the development of the plant in the first example is limited by the amount of available phosphate being too small. In the second part of the picture, the nutrient potash is the limiting factor that controls the yield. To get *optimum* growth—and maximum yields—it is necessary to satisfy the needs of the crop for *all the nutrients*, as shown in the third part of the picture.

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FERTILIZER ECONOMICS IN THE HIDDEN HUNGER ZONE

$ The most promising way to increase volume of business, net profit per unit of production, and net income on most farms is to increase production per acre—*and increased use of fertilizer is the most important factor in accomplishing this.*

$ Fertilizer is partial weather insurance. It requires considerably less rain to produce a paying crop of *fertilized* corn than of *unfertilized* corn.

$ In deciding how much fertilizer to use, it should be kept in mind that each dollar spent for fertilizer this year will give two or three additional dollars to spend one year hence . . . it will pay to keep the crops out of the *hidden hunger zone.*

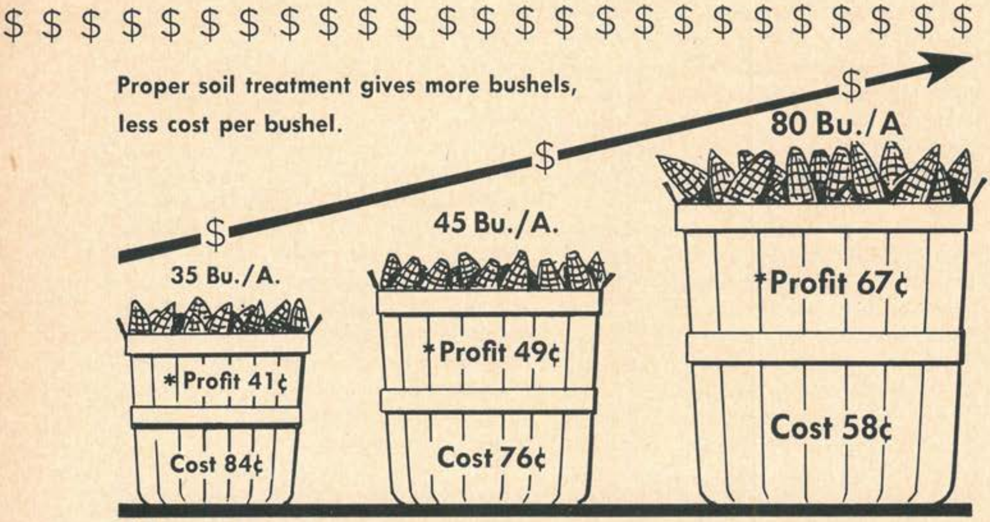
MOST of the Nation's farmers are still operating in the *hidden hunger zone* of production.

They obviously consider fertilizer a necessary expense that little more than pays for itself and not the investment of *high current return* and *residual benefits* that it is.

Today, more than ever, the farmer should consider using more fertilizer to build up the fertility of his land and put him in a position to compete successfully with other producers.

Fertilizer use, while it has been important to profitable farming for years, has assumed much greater importance in recent years.

Gordon B. Nance, Professor of Agricultural Economics at the University of Missouri, is a well-known specialist in agricultural prices. He graduated from Kentucky, did graduate work there, at Ohio State, and Missouri. In 25 years of forecasting ag prices, he has averaged 6 out of 7 correct predictions.



* With corn at $1.25

How much do you make per bushel of corn? The amount of profit neighbors get from a bushel of corn varies widely. This is due to a difference in their costs. The cost per bushel is reduced when yield is increased. This is shown above from figures cited by Missouri Agricultural Experiment Station Bulletin 675, 1956.

Some of the reasons include:

1. Costs of production have increased much more rapidly than receipts for farm products. Up to 1945, it cost a farmer about 50 cents to produce a dollar's worth of farm products. In recent years, the cost has been about 67 cents. Therefore, his cash returns must now be 50 per cent higher in order to have the same net income.

2. Profits per acre or per unit of product are narrow. To get the same net income, he must cultivate more acres or otherwise produce more units.

3. The acreage a farmer can plant is frequently limited by allotments. This reduces the volume of production that is already too small for efficient operation on many farms.

4. High prices and competition for land make it difficult or practically impossible to add additional acres to present farms.

The most promising way to increase volume of business, net profit per unit of production, and net income on most farms is to increase production per acre—*and increased use of fertilizer is the most important factor in accomplishing this.*

By

Gordon B. Nance

and

John Falloon

•

University of Missouri

John Falloon, extension specialist in soils at the University of Missouri since 1945, does general soil fertility work all over the state. He was a county agent before joining the state office in 1936 to work in conservation and as state agent until 1945.

Fortunately, fertilizer is relatively cheap. Since 1940, wages of farm labor have increased 337 per cent, prices of farm machinery 133 per cent; and the prices of all items used in production 141 per cent. But prices of fertilizer have risen only 54 per cent.

For these reasons, each farmer should figure carefully, with paper and pencil, just how *much* fertilizer can be used to add to his income—rather than how *little* he can "get by" with, as so many are now doing in farming in the *hidden hunger zone.*

The minimum fixed cash costs of growing a crop are usually the major part of total cash costs. These cash costs are for cultivation, seed harvesting, etc.—but do not include labor or interest on investments.

These minimum costs for growing an acre of unfertilized corn vary on different farms, but average perhaps near $25 per acre, exclusive of labor. In a good season, production probably would be about 40 bushels, on which returns above cash costs with corn valued $1.25 per bushel, would be about $25 for labor. In case of a total crop failure, the loss would be the entire $25 cash costs, plus labor.

If the soil were fertilized according to soil tests, the fertilizer would cost probably an additional $20, making a total of $45 cash costs (Figure 1). But, with an average year, production would be about 80 bushels per acre, and returns for labor above cash costs would be about $55.

Naturally, the cost per acre of full soil treatment varies greatly on different soils. In Figure 1, a $20 per acre annual fertilizer cost is shown. This $20 includes $1.50 each for lime, phosphate, and potash; $12.50 for nitrogen; and $3 for starter fertilizer.

What are the losses in the case of a crop failure when no fertilizer is used as compared to full fertilizer use? If no fertilizer were used, the loss would be complete—all of the $25.

If fertilizer is used, some of it would be lost too. The total loss in dollars would be more, but the percentage of the total would be less because much of the fertilizer would be carried over *to the next year.*

A liberal non-recoverable fertilizer charge in the case of a complete crop failure based upon the $20 breakdown above would be $7. This $7 would include the *$3 for starter, $1 for lime, phosphate,* and *potash* and *$3 for nitrogen.* Of course, only about one fourth of the plant food in the starter fertilizer is actually lost, but the remaining three fourths is so located that it may be of negligible net value to the following crop.

The losses with a complete crop failure look like this: Where no fertilizer is used, the loss would be $25 —100 per cent of the total costs. With full fertilization, the loss would be $32—the $25 for cultivation, etc., plus $7 of the $20 spent for fertilizer.

Thus, only about *one fifth* ($7 of the $32) of the risk in growing corn is in its fertilization, and the other *four fifths* ($25 out of $32) are in its cultivation, etc.

Conversely, the opportunities for profit are greater for the fertilizer expenditures than for the other costs. Fertilizer can be expected to return *$30 per acre profit,* while the other cultural operations will return *only* $25.

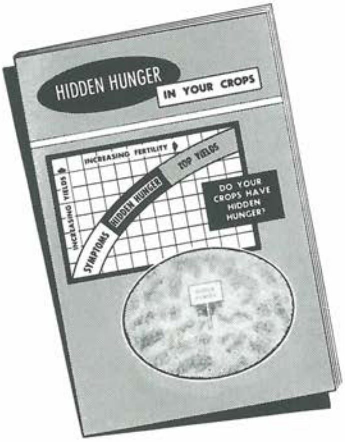
Fertilizer is partial weather insurance. *It requires considerably less rain to produce a paying crop of fertilized corn than of unfertilized.*

Fertilizer pays almost unbelievable dividends to business investors in general or to farmers. Let us consider the returns on some popular investments.

At recent prices, investments in General Motors pay 5.1 per cent; in U. S. Steel, 4.5 per cent; in Standard Oil of New Jersey, 3.9 per cent; in General Electric, 3.7 per cent; and in Du Pont, 3.6 per cent.

Yet, businessmen are investing 3 million dollars a day in these securities.

EDUCATIONAL SERVICES — AMERICAN POTASH INSTITUTE



HIDDEN HUNGER
In Your Crops

This issue of Better Crops magazine is being developed into a special handbook on Hidden Hunger in Crops. The distribution program will be announced in next month's issue at this space. If you are interested in receiving extra copies of this new booklet, please write the address below.

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