BETTER CROPS

WITH PLANT FOOD

Spring 1993

Featured in this issue:

Crop Residue Management Raises Soil Fertility Questions

Starter Fertilizer and High Residue

Soybeans Respond to Better Management Thinking

. . . and much more

BETTER CROPS With Plant Food

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Contents

Our Cover: Soybeans planted in residue of the previous crop look healthy at this site near Redfield, South Dakota. Increasing importance of fertilizer management with reduced tillage is discussed in this issue. Photo by Dr. Larry S. Murphy.

Starter Fertilizer and High Residue: A Profit-Building Combination

By Paul E. Fixen

Farmers are managing more crop residue on the soil surface as a result of less tillage and higher yields. There is a good case for starter fertilizer use under these conditions.

THE CONCEPT of starter fertilization hasn't changed for centuries, but our agriculture has. Modern high yields resulting from better management and improved varieties place increased nutritional demand on the crop's root system. Higher yielding crops produce more residue. Reduced tillage leaves more of that residue on the soil surface. Net effects are conditions that increase potential responses from starter fertilization . . . placement of nutrients in a concentrated band near the row.

Advances in planting equipment and banding attachments have reduced the inconvenience and time requirements of starter use. **Benefits of starters have increased while the agronomic costs have decreased.**

CONSERVATION TILLAGE systems increase plant nutrient needs early in the growing season and emphasize the role of starter fertilizer.

Starter Effects on Crops and Crop Management

Young root systems must have sufficient nutrients early in the growing season. Starter effects are most noticeable during this period. Starter fertilizer can:

- ➠ Enhance plant development, resulting in
  - earlier cultivation
  - increased competition with weeds
  - quicker soil cover, decreasing erosion potential
  - reduced heat stress during pollination
  - earlier harvest.
- ➠ Reduce grain moisture content at harvest.
- ➠ Improve nitrogen (N) use efficiency.
- ➠ Increase yield and crop quality.

Is Starter a Good Investment for Me?

Many factors influence responses to starters.

Residue level. High levels of residue on the soil surface from the previous crop result in larger and more frequent responses to starters (**Figure 1**). Residues reduce surface evaporation and increase water

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infiltration, leading to wetter, colder soils. This means increased response to starter fertilization. Surface concentrations of soil phosphorus (P) and potassium (K) that occur with limited tillage increase the potential for response to subsurface bands. Cool soil temperatures and a higher potential for N immobilization in crop residue can boost the need for starter N.

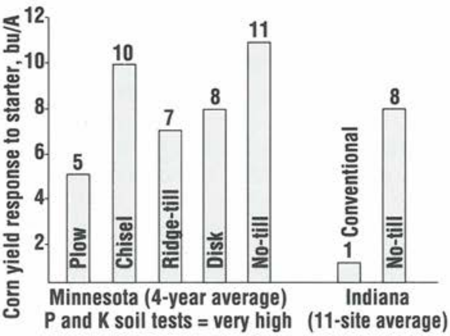

Figure 1. High residue farming increases the importance of starter fertilizer for corn.

Soil and weather conditions. Starter response is greatest when environmental conditions result in high plant nutrient demand relative to the root system's capacity to absorb nutrients. For example:

Cold soils decrease root absorbing power, nutrient movement from roots to shoots, carbohydrate movement to roots and soil nutrient movement to root surfaces. Starter responses in **Figure 2** were caused, at least partially, by cold soils. Grain moisture at harvest was also reduced by as much as 10 percent with starter P.

Root growth restrictions reduce the root system's ability to absorb nutrients. Factors include compaction (**Tables 1, 2**), soil acidity, high salinity and herbicide carryover.

High early season air temperatures and adequate soil water increase shoot to root ratios and the amount of nutrient that must be absorbed per unit of root length. Starter responses in years with warm springs are often due to such effects.

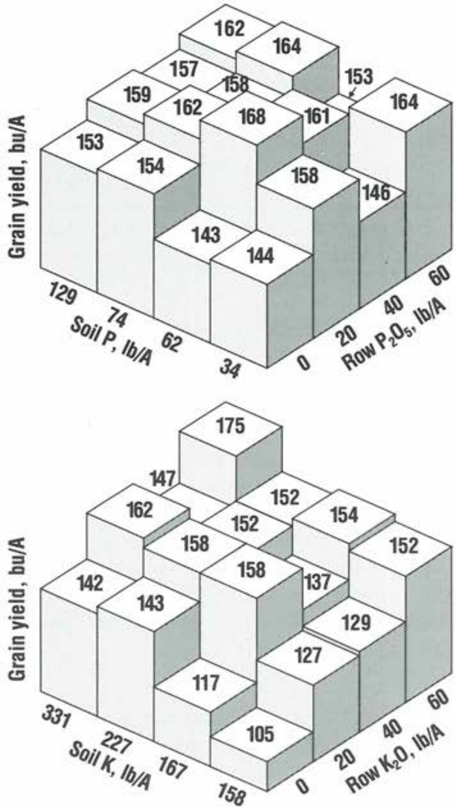

Figure 2. Corn grain yield increased with starter P and K, even on high testing soils. (Wisconsin)

Table 1. Higher soil bulk density (more compacted soil) leads to diminished P uptake by corn.

Soil texture	Bulk density, g/cm³	Shoot P, %
Silt loam	1.10	0.41
	1.35	0.35
	1.60	0.28

Ontario

Table 2. Soil compaction increases corn yield response to starter K.

	Row K_2O, lb/A	Corn yields, bu/A at compaction levels of (tons): <5	9	19
Year 1	0	132	114	111
	45	162	152	159
Year 2	0	169	168	147
	45	175	176	169

Soil test K = 204 lb/A — Wisconsin

HIGH SHOOT TO ROOT RATIOS, common in warm springs, place added stress on roots to take up nutrients early in the growing season. Starter responses are likely under such conditions.

concentration at the 4 to 5 leaf stage approaches 0.5 percent. In many soils it is nearly impossible to attain that concentration without a starter band.

Local research and experience. There is no substitute for local experience with starter use. Interacting factors influence starter response and make prediction in specific situations difficult. However, the trends in crop production (conservation tillage, early planting, high yield hybrids) increase starter response probability.

Soil test levels. The need for starters is often expected to decrease as soil test levels increase **(Table 3, Figure 3)**. But many other factors influence starter response regardless of soil test level **(Figures 1, 2 and 4).** Substantial yield responses have occurred at soil test levels that are more than three times the level required to be classified as very high.

Table 3. Corn response to starter decreased as soil test P increased in Iowa (32-year average).

Broadcast[1] P_2O_5, lb/A	Response on two soil types, bu/A Primghar	Webster
0	12	17
46	4	9
92	2	4
138	1	7
Starter	6-23-12	6-23-23

[1]Applied once every three years.
Soil test levels: 0 P_2O_5 = very low; 138 lb/A P_2O_5 = medium.

Yield potential and cultural practices. Cultural practices can have a major influence on starter response. For example, a Nebraska study demonstrated a 33 bu/A response when irrigated corn was planted on May 8 and only a 7 bu/A response when planting was delayed to May 22. Generally, practices that lead to high yield potential increase the probability of response to starter. The full yield potential of corn growing in high yield environments cannot be achieved unless shoot P

Starter Effects on Profitability

Net returns. Net returns to starters can be impressive when weather conditions and cultural practices are both favorable for response. A cool, moist growing season combined with reduced tillage (spring disk) contributed to a $48 net return to starter P on corn on a very high P testing soil **(Figure 4)**. Return at a nearby site with a soil test level more than twice as high was lower, but still substantial. Increased returns were due to higher yields and lower drying costs. A 3-year Wisconsin study with four planting dates

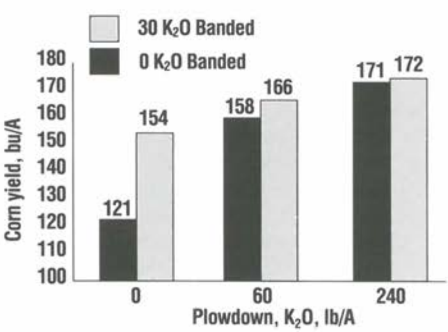

Figure 3. Responses to starter K decrease as soil test K increases. (Iowa)

and two tillage systems resulted in a profitable starter response in 19 of 24 comparisons, with an average increased net return of $12.00 per acre (data not shown).

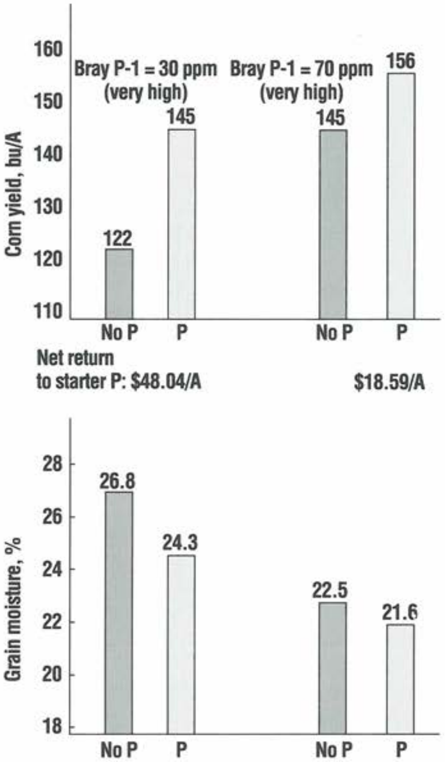

Figure 4. Cool, moist growing seasons amplify the importance of starter P even at very high soil test levels.

Data extracted with permission from the University of Minnesota Blue Book (A Report on Field Research in Soils, 1991, pp 313-316, John Moncrief, et al.)

Non-nutrient starter costs. Estimating net return to starters calculated solely on the cost of nutrients in the starter may not be appropriate if soil tests are near optimum and nutrients in the starter would have been applied, regardless of starter use, to maintain soil test levels. In such cases, the true cost of the starter involves the extra equipment required and any planting delays incurred due to starter use. These costs vary markedly and have to be determined on an individual basis.

Catastrophic crop loss. An entire crop can be lost if full season varieties are used where unusual weather has the potential to prevent crop maturity. Starter fertilizer can reduce the probability of such catastrophic crop loss by enhancing development during cool weather. Starter fertilization may also allow use of longer season varieties with higher yield potential.

Starter Placement and Equipment Alternatives

For maximum effectiveness, starter bands should not be placed more than about 3 inches to the side of the row and, preferably, below seed depth. When the normal growth angle of most roots originating from the seed is considered, the standard location of 2 inches to the side and 2 inches below the seed is nearly ideal for root interception. This usually places the band 3 to 4 inches below the soil surface, where soil moisture is likely to be favorable for nutrient uptake by roots. Placement with the seed for corn can give good early growth response, but the amount of N and K that can be safely applied is limited by the potential for salt injury. **Follow local guidelines on maximum rates for seed placement that are specific for crop and soil conditions.**

Great improvement in starter banding equipment has occurred in the last decade. Modern starter attachments offer options that are more durable, give more consistent performance, cause less soil disturbance, tolerate more residue, and frequently have lower power requirements than the conventional double disk opener of the past.

Starter Composition

Phosphorus has been the nutrient emphasized in starter fertilizers, but evidence now supports use of a starter containing N, P, K, sulfur (S) and possibly other nutrients, depending on conditions. Studies have indicated that N, especially ammoniacal N, can enhance the response to P applied in bands. Soils with low levels of plant-available N near the surface are good candidates for high N starters.

Early growth response to starter S has also been observed in soils with low levels of S in the surface. Cold temperatures and winter precipitation may combine to cause low availability of S early in the season. Growth responses to starter zinc (Zn) are likely in soils testing low in Zn. Zinc requirements may be increased by banded P.

Environmental conditions that cause uptake problems for one nutrient, such as P, can also lead to problems for other nutrients. Starters should be tailored to the needs for specific situations. However, extra assurance of nutrient availability can be purchased at minimal costs by using a complete starter containing N, P and K, and, where soil conditions suggest, S and Zn.

Summary

A logical argument can be made that in high residue cropping systems, a portion of the maintenance nutrients should be applied in a starter band. When producers manage more surface residue, as a result of higher yields and less tillage, starter fertilizer is a best management practice that can help improve the potential benefits of modern residue management by increasing yields and profits . . . and providing better environmental protection. ■

Saskatchewan

Yield Response of Canola to Nitrogen, Phosphorus, Precipitation and Temperature

IN THIS 16-year study, researchers measured the response of canola to nitrogen (N) and phosphorus (P) fertilization in relation to soil tests for these nutrients. Tests were conducted on a silty clay which had been previously cropped to spring wheat. Nitrogen was applied at rates of 40 and 120 lb/A in factorial combination with P_2O_5 rates of 0, 20, 40, 60 and 80 lb/A.

Both grain and straw responded to N and P fertilization, but the N by P interaction was not significant. The interaction effects of year by fertilization (both N and P) were significant. This indicates a wide range of response to fertilization because of precipitation, temperature and nutrient effects.

Researchers concluded that soil tests for N and P accounted for much of the variation in response to fertilization despite large yield differences among years. ■

Source: W.F. Nuttall, A.P. Moulin and L.J. Townley-Smith. Agron. J. 84:765-768 (1992).

North Carolina

Ranges in Soil Phosphorus Critical Levels with Time

THE AUTHOR points out that mathematical functions used to determine critical levels result in different soil test interpretations for phosphorus (P). Interpretations also differ because the critical soil P level may not be the same from year to year.

The long-term study from which the conclusions were drawn included nine years of crop production . . . corn (five crops), soybeans (four crops) and wheat (three crops). The soil was a Portsmouth, with a low P-fixing capacity. Yield responses to soil P were excellent. Two mathematical functions, as well as economic analysis, were used to interpret results.

Considerable ranges in critical soil P levels were formed with each crop and with each mathematical function. The author concluded that recognition of these ranges gives some justification for recommending P fertilizer on soils with P levels 50 percent greater than the average critical level for a crop grown on similar soils. ■

Source: Cox, F.R. 1992. Soil Sci. Soc. Am. J. 56:1504-1509.

Crop Residue Management Raises Soil Fertility Questions

By Harold F. Reetz, Jr.

Residue management is an important consideration as farmers move toward reduced tillage to control erosion and meet other conservation plan objectives on highly erodible land (HEL). Determining the actual percent residue cover can be a challenge. The photos with this article illustrate different amounts of corn and soybean residue. Some soil fertility considerations are discussed.

IN RECENT YEARS, the soil-saving value of crop residue has gained importance. Recent changes in management systems result in more residue remaining on the surface of fields.

Color photographs featured here show actual field situations. The photos were provided by the Soil Conservation Service (SCS) state office in Illinois, to illustrate varying percentages of corn and soybean residue cover after planting. The photos should be useful for estimating residue cover by comparison.

Actual measurement is a more reliable method of determining whether a field's residue cover is in compliance with HEL conservation plan requirements. The "line-and-point method," using a 50 ft. tape marked in 6-inch increments (or a rope with knots tied at 6-inch intervals) is an easy, accurate way to estimate residue cover (**Figure 1**).

Increasing residue left on the soil surface through reduced tillage raises several questions relative to soil fertility management. Research is ongoing to help provide answers and establish management guidelines. Following are some of those questions and some points for consideration.

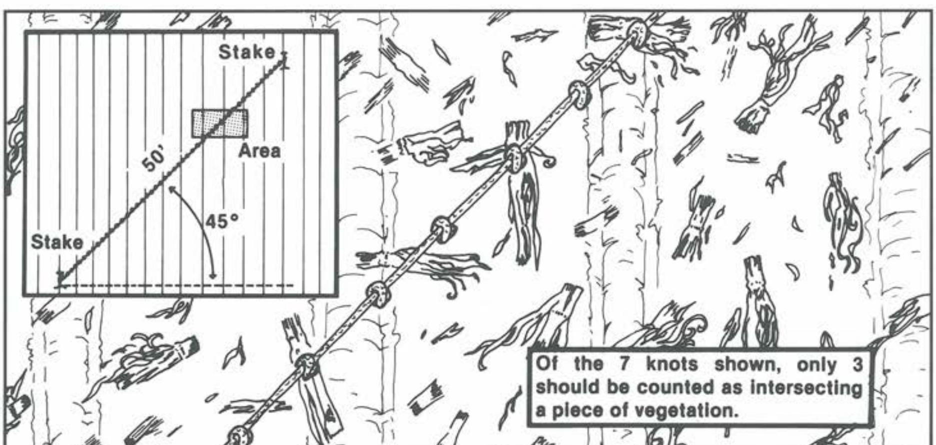

Figure 1. Overview (insert) and closeup of the line-and-point method of determining percentage of surface residue covering.

Dr. Reetz is Midwest Director of the Potash & Phosphate Institute, Monticello, IL.

Crop Residue Management

Corn

High Residue (80 percent)

Medium Residue (35 percent)

Low Residue (10 to 15 percent)

Soybeans

High Residue (60 to 65 percent)

Medium Residue (40 percent)

Low Residue (10 to 15 percent)

How does leaving more residue on the surface affect soil test levels and nutrients available to crops?

- Residue on the surface ties up nutrients for a short time until that residue can decompose, possibly increasing the amount of fertilizer needed for the current crop. This residue can also be a slow release nutrient source in some situations.
- As the residue decomposes, there is a tendency for phosphorus (P) and potassium (K) to accumulate at or near the surface. Fertilizer P and K are also likely to accumulate at the surface. Under residue mulch with no-till, there is more root mass in the top 3 inches to utilize these nutrients. In dry years or low rainfall areas, nutrients may be "positionally

unavailable" to the growing crop.

- There may also be a tendency to deplete nutrient levels . . . especially P and K . . . lower in the root zone where the decrease is not detectable by the standard 6 to 8-inch soil sampling depth. Shallower sampling in compacted soils may give inaccurate, high soil test readings.
- Often, pH will be lower near the surface due to acid produced by nitrification and by the decomposing crop residue. However, when lime is applied, the surface pH may remain unusually high. At either extreme, herbicide and nutrient availability may be adversely affected. Applying half the amount of lime twice as often will help to alleviate this problem.
- Occasional tillage to incorporate lime and mix nutrients into the root zone may be an acceptable part of a conservation plan for a given field. Consultation with local SCS offices will help determine the options available. Explore deep placement and timing alternatives to have least impact on residue cover.

How does soil fertility level influence the amount of residue produced by a crop?

- As yields increase, residue production may increase. Each extra bushel of corn is accompanied by about 56 lb of added stover production. It is easier to get 35 percent residue cover with a 200 bu/A corn crop than with a 100 bu/A corn crop.
- Higher fertility produces higher yield potentials. Set a realistic yield, then build and maintain soil tests to support that yield.
- Higher yielding crops produce more extensive root systems, which more efficiently utilize water and nutrient resources and also help hold soil in place.

How does increased residue affect fertilizer requirements?

- Residue on the surface insulates the soil, making it slower to warm up in the spring. A concentrated nutrient supply, such as starter fertilizer close to the seedlings, may help to get optimum stands established and early crop growth, even when soil test values are high. Conditions later in the season will determine whether these early advantages are translated into yield increases.
- Having more nutrients tied up in crop residue may increase the short-term fertilizer requirement, especially in the first 3 to 5 years.

Table 1. Guide to estimated percentage of soil covered by crop residue after field operations.

Predict the effect your till/plant system will have on crop residues by multiplying the percentages for each operation you use. These are broad ranges. Speed, depth and soil moisture can affect the amount of residue left.

Tillage operation	Corn/Small grain	Soybeans
After harvest	90-95	60-80
Over-winter decomposition	80-95	70-80
Moldboard plow	0-10	0- 5
Paraplow	80-90	75-85
Combination secondary tillage tool	50-75	30-60
Chisel (twisted points)	50-70	30-40
Chisel (straight points)	60-80	40-60
Disk (off-set, primary >9" spacing)	40-70	25-40
Disk (tandem, finishing 7"-9" spacing)	30-60	20-40
Anhydrous applicator	75-85	45-70
Field cultivator (as secondary operation)	60-90	35-75
Row planter	85-95	75-95
No-till drill	55-75	40-60

Here's an example of how to estimate how much residue cover will be left after each tillage operation.

$$95\%\left\{\text{after corn harvest}\right\} \times 60\%\left\{\text{fall chisel twisted points}\right\} \times 90\%\left\{\text{after winter}\right\} \times 45\%\left\{\text{spring disk tandem}\right\} \times 90\%\left\{\text{planting}\right\}$$

$$= 21\%\left\{\text{residue cover after planting}\right\}$$

How does the residue requirement affect fertilizer placement options?

- Any injection or incorporation method will reduce the amount of residue left on the surface. So placement systems such as surface banding or broadcast will cause least disturbance of residue. **Table 1** shows how to estimate residue cover loss from various field operations.

- The option of building soil test levels before going to reduced tillage is even more important as a means of supplying adequate nutrients throughout the root zone.

Residue management for conservation compliance is good business. It preserves the basic soil resources of the farm while helping protect water resources from contamination. Coupling sound agronomic management with responsible environmental protection can result in long-term optimization of profits. Farmers working in cooperation with their fertilizer dealer, their SCS representative, their Extension adviser and other consultants can develop a management plan that meets all of these goals. ■

How to Measure Crop Residue on Fields

- **Use a 50-ft. rope** equally divided into 100 parts. A 50-ft. tape measure using each 6-inch and 12-inch mark also works well.

- **Stretch the line** diagonally across the rows. Count the number of marks, tabs or knots that have residue under them. It is important to use the same point under each mark for accuracy. If a piece of residue is smaller than one-eighth of an inch, don't count it.

- **Walk the entire length** of the rope or tape. The number of marks with residue under them equals the percentage of cover. If your rope or tape has only 50 marks, then multiply your count by two.

- **Repeat the above steps three** times in different areas of the field. Add the scores together and divide by three to find the average percentage of cover for the field.

12 Ways to Leave More Crop Residue

1. **Use high residue producing crops.** Plant crops such as corn in your rotation.
2. **Spread residue evenly.** Spreaders on harvesting equipment will help.
3. **Skip fall tillage,** especially after soybeans. Fall-tilled soybean ground is very vulnerable to erosion in late winter and early spring.
4. **Make fewer tillage passes.**
5. **Use cover crops.** Rye and wheat are good options when you grow low-residue crops such as soybeans.
6. **Set chisels and disks to work shallower.** Residue will be buried to about one-half the tillage depth.
7. **Don't use a moldboard plow.**
8. **Drive slower on tillage operations.** Tilling at higher speeds throws more soil and covers more residue.
9. **Use straight points and sweeps on chisel plows.** Twisted points may bury about 20 percent more residue.
10. **No-till drill soybeans.** No-till drilling keeps more crop residue on the soil surface and produces a canopy faster than row planting.
11. **Go no-till on sloping land or ridge-till on flatter land.** Both disturb only the crop residue in the rows.
12. **Don't till when soil is wet.** Tilling wet soil will cover more residue than tilling when the soil is dry.

Soybeans Respond to Better Management Thinking

By William K. Griffith

Generally, soybean producers are aware of the many inputs and management decisions which must be made when growing the crop. Production information is obtained from dealer contacts, producer meetings, farm magazines, neighbors, the Extension Service and other sources. Most often lacking is the farmer's ability to package this information into a high-yielding soybean production system for specific farm or field conditions. This article describes a different approach which might help. Let's call it "better management thinking" (BMT).

IT IS NOT UNUSUAL for neighboring soybean growers with identical soils and fixed costs to have a big difference in yields and profits. The explanation almost always means that one farmer used better management thinking (BMT).

Like all high-yield cropping systems, there must be an integration and balance of all controllable inputs. But it is usually the improper management of several of these inputs which explains why one farmer profits more than another; a single input is seldom responsible. The BMT technique outlined here can improve grower yields and profits. Yields and profits do go hand-in-hand. That's because higher yields reduce production costs per bushel by spreading fixed cost, such as those for land and machinery, over more bushels per acre.

Step by Step

The path to BMT starts with a positive and realistic yield goal. A good rule of thumb is to set a yield goal 10 to 15 percent higher than the previous high for the field. Set aside 5 or 10 acres to try BMT techniques. Then adopt those practices that prove best for your specific conditions to the entire soybean acreage. Once a yield goal has been achieved, then set a new, higher goal.

The second step to BMT begins after harvest and before planting. This step involves listing all the controllable factors you can think of for soybeans. Following are a few examples of key controllable factors which are essential for top yielding, full-season soybeans. There are many others . . . some may be quite specific for the conditions on your farm. Along-side these factors, jot down the visual problems and yield or profit consequences which will result if each factor is not managed at optimum levels. Think about each factor and list the recommendations you plan to follow which are best suited for your location, soils and yield goals. Your local agribusiness dealer or farm advisor can help you list the factors and select the optimum recommendations for your farm. Keep reviewing these strategies and be flexible in changing recommendations as yield goals increase, as new varieties are released, and as new management technology is discovered.

Better Management Thinking for Soybeans

Planting date factor. Timely planting is the biggest economic bargain for full-season soybeans. It costs no more to plant on the optimum date than at any other time. For each day past the optimum planting date, expect soybean yields to decrease an average of one-third to one-half bushel per acre. Ohio data show a 6 bu/A loss in 15 days from delayed planting (**Table 1**). That's $36 per acre off the bottom line for $6 soybeans. **BMT strategy:** Have the planter ready, seed purchased, fertilizer in place and be ready to plant on that

Dr. Griffith is Eastern Director, Potash & Phosphate Institute, Great Falls, VA.

Table 1. Late planting reduces soybean yields.

Planting date	Soybean yield	Yield loss after May 10
	------------- bu/A	--------------
May 10	49	—
May 25	43	6
June 10	34	15
		Ohio

optimum date. Only an uncontrollable factor such as unfavorable weather or soil conditions should change the plan.

The variety factor. The variety chosen sets the genetic yield potential on a particular farm. Variety trials across the country show differences at any one location of 15 to 20 bu/A between the top and bottom varieties. **BMT strategy:** Don't use a variety just because it is being used or sold by a neighbor. Monitor variety trial results and remember that the most useful tests are those that are conducted under top management. Make a point to grow a few rows of several varieties to see which varieties are best for a particular location and farming system.

The row width factor. Narrower row widths almost always increase yields over wider rows and seldom hurt if weather doesn't cooperate. This is true across all soybean producing areas. Beans benefit from better sunlight interception, greater moisture efficiency and reduced pressure from weeds that escape control measures. Expect full-season soybean yields to increase 3 to 4 bu/A for every 10-inch reduction in row widths down to a 7-inch drill width. **BMT strategy:** Give serious consideration to reducing soybean row widths down to 15, 10 or even 7-inches. Match this row width reduction with careful variety selection and plant populations. Remember that non-branching varieties respond more to narrow rows. Remember too that determinate semi-dwarfs do better in narrow rows with high populations.

The rotation factor. Expect soybeans to yield 3 to 5 bu/A more if produced in rotation versus continuous beans. Rotations are also good for the soil, help with pest control problems, and increase the yield potential for the other crops in the rotation. **BMT strategy:** Design a crop rotation system that reduces the number of times soybeans are grown after soybeans.

(continued on next page)

ROTATING corn with soybeans offers advantages for both crops.

NARROW ROWS for soybeans offer greater yield potential.

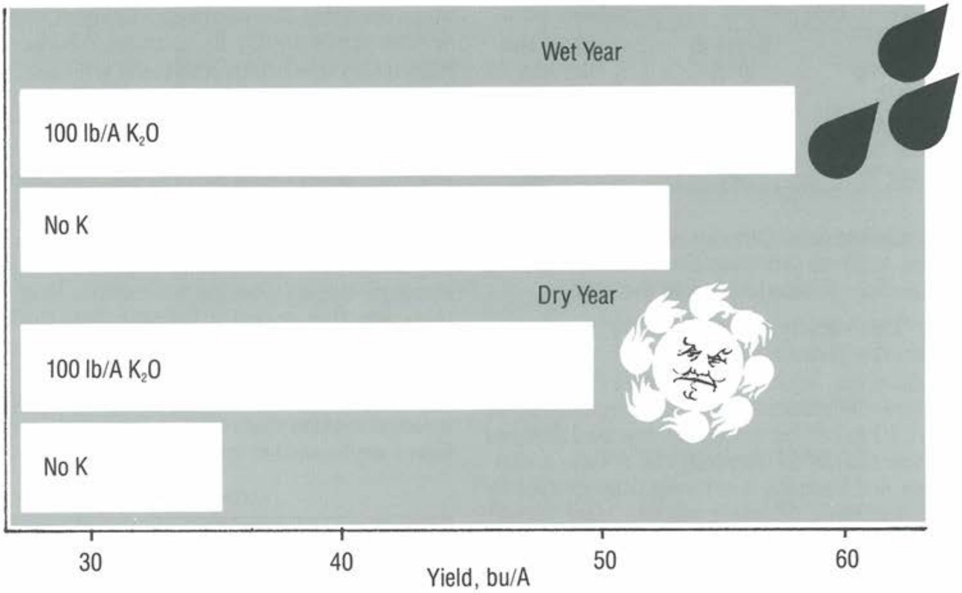

Figure 1. Soybean response to K may be greatest in a dry year.

The potassium factor. If soybeans don't have adequate potassium (K), the crop will have poorly developed roots, uneven maturity, weak stalks, more shriveled and diseased seed, fewer nitrogen (N) fixing nodules and much greater susceptibility to drought. In fact, K responses are frequently better under moisture stress conditions (**Figure 1**). **BMT strategy:** Soil test ahead of planting and maintain a high soil test K level. This build-up application can be made ahead of the previous crop, but make sure that the soil K test or K availability is high for the soybean crop. Soybeans remove about 1.4 lb K_2O per bushel of yield. Apply a maintenance amount of K based on expected yield goal.

The phosphorus factor. Low phosphorus (P) levels cause the soybean crop to lack the energy needed for rapid vegetative growth and uniform grain fill. Phosphorus-deficient beans will not ripen uniformly and will be more susceptible to drought and disease stress. **BMT strategy:** Plant high-yield soybeans into a soil that is testing high in P. Apply a maintenance amount of P based on the fact that each bushel of soybeans removes about

POTASSIUM deficiency symptoms.

0.8 lb of P_2O_5. Make sure that soil pH is at the recommended level because efficient P use and optimum N fixation are dependent on proper soil pH. Phosphorus can be applied to a preceding crop. But be sure that enough P, and K, are applied for both crops (**Table 2**).

The weed factor. Weeds rob soybeans of yield and profit. They are fierce competitors for nutrients and moisture. When fertility or moisture levels are marginal, losses to weeds are even greater. **Table 3** shows some losses which occurred at one location from various types of weeds. **BMT strategy:** Routinely scout fields for

Table 2. Adequate P and K interact to boost soybean yields.

P_2O_5 lb/A[1]	K_2O lb/A[1]	1992 Yield, bu/A	5-year avg., bu/A
0	0	65	66
0	60	68	67
30	0	69	67
30	60	81	69
60	0	76	68
60	60	80	69

[1]P_2O_5 and K_2O for corn prior to soybeans. Kansas

potential weed problems. Scouting for a soybean crop begins during the growth of the preceding crop. Identify problem weeds and problem areas and begin planning for control in the future. Good management practices for all the other inputs go a long way in reducing the pressure from weed competition.

Summary

This highlights full-season soybean "better management thinking" for several controllable inputs. Expand the list to include tillage practices, planting depth, population, harvest management, soil acidity control, secondary nutrient needs, micronutrients, insect and disease pests and all the other inputs over which you have some control. Then integrate these into a new soybean production package. That's the kind of thinking that raises yield levels and profit potentials. If BMT works for you, then try it for other crops in the rotation. ■

PHOSPHORUS response in soybeans.

Table 3. Control weeds for better soybean yields.

Problem weed or grass	Plants per foot of row	Yield reduction %	Yield reduction bu/A	Income loss $/A
Giant foxtail	6	10	4	28.00
Fall Panicum	1	20	8	56.00
Pigweed	0.25	30	12	84.00
Morningglory	1	52	20.8	145.60
Cocklebur	1	10	4	28.00
	2	28	11.2	78.40
	3.50	43	17.2	120.40

Assume 40 bu/A yield and $7.00/bu soybean price — Illinois

RESEARCH NOTES

Oregon

The Influence of Tillage and Cropping Intensity on Cereal Response to Nitrogen, Sulphur and Phosphorus

IN THIS 6-year study, cereal responses to nitrogen (N), sulphur (S) and phosphorus (P) were determined under conventional-till (CT) and no-till (NT) for cereal/fallow and cereal/cereal. Semi-dwarf white winter wheat was alternated annually with either fallow or spring cereal (barley or wheat). Fertilizer treatments were none, N, NS and NP.

The cereals showed a strong response to fertilization, averaging 16.5, 13.8 and 7.0 bu/A, for N, S and P, respectively. Both N and S were more deficient in NT and when soils were cropped annually than was P.

Adequate fertility was a prime prerequisite for efficient yields for CT, NT and crop rotation, but was most critical with NT and the cereal/cereal rotation. ■

Source: P. E. Rasmussen and C. L. Douglas, Jr. 1992. Fertilizer Research 31:15-19.

Nitrogen Loss from Corn Plants During Grain Fill

By Dennis Francis

Nebraska research has shown that substantial amounts of nitrogen (N) can be lost from corn plants prior to plant maturity. These volatile N losses are not clearly understood and can lead to over-estimation of N losses via leaching and denitrification.

WHILE THE MERITS of N fertilizer for increasing crop productivity are well understood, our knowledge of the various ways N can be lost from the soil-plant system and the associated environmental impacts is fragmented. Some pathways for N loss have been known for decades, while others have only recently been recognized. Calculations for N fertilizer use efficiencies are typically based on the amount of N found in the crop at maturity. It is commonly perceived that maximum accumulation of N by plants occurs at maturity. However, it is more typical for maximum N accumulation of many grain crops to be reached sometime between pollination and maturity.

Agronomists have been aware for some time of numerous reported instances where the total amount of N in the aboveground parts of grain crops actually decreased before maturity. In cases where loss occurs or even when N level remains static, the questions become: 1) Did the crop cease taking up N during grain fill? 2) If N uptake continues, why doesn't total plant N content increase? 3) What is the pathway and fate of any N lost from living plants?

Nitrogen Loss from Plants

Published research over the last decade has shown relatively large amounts of volatile N compounds (mainly ammonia, NH_3) can be lost from aboveground vegetation of various grain crops. These losses largely occurred during grain development. Reported volatile N losses have been as high as 69 lb/A for winter wheat and 40 lb/A for soybean. Generally, N losses increased as the amount of applied fertilizer N increased.

Under favorable growing conditions, many corn hybrids achieve maximum N accumulation between silking and the grain's milk stage (**Table 1**). During kernel fill, large amounts of N can be translocated from vegetative tissue to the grain. One method of monitoring N translocation to the grain and determining if additional N is being taken up from the soil is by the use of isotopically labeled N fertilizer (^{15}N). Isotopic techniques provide a means for differentiating and tracing N coming from the various sources (soil, fertilizer, etc.). By being able to trace its fate, the interactions of labeled N within the soil-plant system can be studied.

Nitrogen balance studies using isotopically labeled N have been a valuable aid in expanding our knowledge of N interactions in various cropping systems. In labeled N balance studies it is common to have 5 to 25 percent of the applied fertilizer missing or unaccounted for from the soil-plant system at the end of the growing season. Previously, leaching and volatile N losses from the soil, mostly thought to be associated with denitrification, were assumed to be major reasons for this missing N. Recent findings indicating that substantial N loss can occur from plant tops do not translate into increased amounts of N being lost from soil-plant systems. Rather, these data identify another mechanism to explain some of the unaccounted for N loss noted above.

Dr. Francis is Research Associate, USDA-ARS, Soil and Water Conservation Research Unit, Lincoln, NE, currently working with the Management System Evaluation Area (MSEA) project.

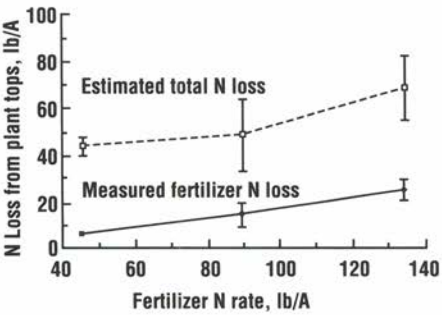

Figure 1. Measured post-anthesis fertilizer N losses from aboveground biomass of corn and the estimated total N losses using ^{15}N depleted fertilizer. Bars denote standard errors of the means.

Nebraska Studies Quantify Losses

One objective of our study was to quantify, under field conditions, N loss from corn plants during grain fill. Two irrigated corn studies, which had isotopically labeled N fertilizer applied, were used to determine the amount and location of labeled N in the aboveground plant parts. At site 1, fertilizer N rates of 45, 89 and 134 lb/A were applied at the three-leaf stage as labeled ammonium nitrate (NH_4NO_3) to Stauffer S7767 corn hybrid.

The total amount of N in the corn plants reached a maximum at the blister stage and remained constant for all treatments through maturity. However, for the three labeled treatments, isotope data showed that 15, 17 and 20 percent of the labeled N that was in the plants at the blister stage was missing by maturity. If one assumes that non-labeled N is lost at the same time and rate as labeled N, then total N losses from the aboveground plant material for the three treatments would be 44, 49 and 70 lb/A of N (**Figure 1**). Net N in the plant tops remained constant after the blister stage for these plots, which means that similar amounts of N were taken up as were lost during the final 55 days of grain fill.

At site 2, labeled N treatments of 67, 134, 201 and 268 lb/A were applied at the six-leaf stage to Pioneer corn hybrid 3379. In this case maximum N accumulation occurred when the grain was at the milk stage (**Table 1**). For the three highest fertilizer rates, total plant N decreased before maturity was achieved. Labeled N losses from the plant tops across the four N rates ranged from 6 to 31 lb/A, which extrapolates to total N losses of 40 to 72 lb/A. All four fertilizer treatments showed that less than half of the labeled N that left the leaves and stalks between the milk stage and black layer development was translocated to the grain.

(continued on page 19)

Table 1. Labeled fertilizer N in different plant parts of corn at milk and black layer growth stages (mean of four replications at site 2).

Fertilizer N rate, lb/A	Growth stage	Labeled fertilizer N in plant parts, lb/A		
		Leaves	Stalks	Grain
67	Milk	14 ± 2[1]	4 ± 1	8 ± 2
	Black layer	3 ± 1	2 ± 1	11 ± 2
134	Milk	35 ± 5	12 ± 3	21 ± 4
	Black layer	6 ± 1	5 ± 1	28 ± 4
201	Milk	39 ± 6	21 ± 5	26 ± 5
	Black layer	8 ± 3	10 ± 2	40 ± 2
268	Milk	52 ± 5	33 ± 3	35 ± 3
	Black layer	13 ± 1	18 ± 4	64 ± 3

[1]Mean ± the standard deviation.

Corn Yield Challenge Improves Efficiency and Profitability

By Ron Akin

A dealer-organized Corn Yield Challenge has aided farmers in learning more about new techniques for corn production and how to produce higher, more profitable yields while conserving soil resources.

FARMERS Grain and Agri-Center of Union City, TN, has sponsored a Corn Yield Challenge for its farmer customers for seven years, dating back to 1986. The objective of the Yield Challenge was to demonstrate to farmers how their production input practices influenced corn yields and profitability, and how those practices compared to other systems. The Yield Challenge has taught farmers to plan and develop production input programs, learn all they can about new production techniques and to keep records.

One of the objectives of the Yield Challenge has been the generation of highest net return, not just highest yield, so entrants must plan their inputs to keep yields high and production costs per bushel low . . . emphasizing production efficiency. Fixed costs were not included because of variation among entrants.

Rules of the Yield Challenge do not permit irrigation, but do require soil tests of the challenge area and records on all inputs. The yields are certified by a staff member of the local cooperative Extension office or Farmers Grain. Either no-till or conventional tillage systems are eligible. The entrant must select 10 acres in one contiguous block for yield measurements.

Yield and net return records of the entrants are impressive. Production costs for fertilizer, crop protection chemicals and seed are summarized in **Table 1**. Costs for 1992 were lower than recent years because of lower fertilizer prices. The net results of the seven years are summarized in **Table 2**.

In 1992, the Yield Challenge farmers had an average plant population of 23,120 plants per acre (ppa), ranging from 16,400 to 27,350 ppa. The highest yield was 226 bu/A. The average yield for entrants was 183 bu/A. The highest net return to land, machinery and labor was $360.58/A, with a yield of 210 bu/A. The winner's corn was produced in a no-till production system in 36 inch rows.

Summary

The Yield Challenge has remained popular with Obion County farmers. Each

Table 1. Average per acre expenses for Corn Yield Challenge entrants, 1986-92.

	Input cost, $/A			
Year	Fertilizer	Crop protection chemicals	Seed	Total
1992	58.89	21.10	21.10	101.09
1991	75.80	21.00	20.52	117.32
1990	80.26	19.53	20.01	119.80
1989	84.25	18.25	21.36	123.86
1988	81.64	17.21	18.95	117.80
1987	67.35	16.15	19.70	103.20
1986	67.98	17.93	21.04	106.95

Ron Akin is Agronomist for Farmers Grain and Agri-Center in Union City, TN.

Table 2. Corn Yield Challenge data summary, 7-year average.

Year	Yield, bu/A	Market price, $/bu	Revenue, $/A[1]	Expenses, $/A[2]	Expenses, $/bu	Net return, $/A[3]
1992	183	2.10	383.99	101.09	0.55	282.90
1991	145	2.50	362.32	117.32	0.81	245.00
1990	158	2.30	363.20	119.80	0.76	243.40
1989	170	2.38	403.98	123.86	0.73	280.12
1988	155	2.74	423.59	117.80	0.76	305.79
1987	168	1.53	256.75	103.20	0.61	153.55
1986	145	1.38	200.59	106.95	0.73	93.64
Average	160	2.13	342.06	112.86	0.70	229.20

[1]Yield (bu/A) x Market Price
[2]Fertilizer, Seed & Chemical Expenses Only
[3]Revenue–Expenses

year about 30 individuals participate. There are rewards for the winners with the highest yields and highest profits. There is also a prize and recognition for the highest no-till yield. This promotes conservation of the most important resource, the soil.

In the final analysis, Yield Challenge entrants have gained from the experience . . . in terms of learning more about production input efficiency, higher profitability and resource conservation. The Yield Challenge is continuing in 1993. ■

Nitrogen Loss . . . from page 17

The mechanisms and reasons why volatile N losses occur from plants is not understood. Some researchers attribute N losses mainly to inefficient N translocation and reassimilation within the plant.

However, this does not explain why large losses are noted in some studies while only negligible amounts are detected in others. Research is needed to determine which environmental and physiological factors affect or control N loss processes. Nitrogen availability and moisture stress are two factors which appear to do so.

Summary

It may seem inconsequential whether N losses are coming from the soil or plants, but it becomes important as we continue to look for ways to improve N fertilizer use efficiencies. For example, failure to consider volatile plant N losses will result in overestimation of N losses from the soil by denitrification and leaching. Proper accounting of all N losses from the soil-plant system is needed to fully assess each loss component. This information is necessary as we attempt to develop appropriate means to improve N fertilizer use efficiencies and to properly evaluate any proposed new management strategies. ■

Soil Fertility Manual Slide Sets Available

THE Potash & Phosphate Institute (PPI) released its revised and updated *Soil Fertility Manual* in 1992. The companion slide sets to the manual have also been revised and are now available, either as individual chapter sets or as a 10-chapter package.

The 10-chapter slide package consists of 320 color 35mm slides and includes printed scripts for each chapter. The slides are a true companion to the chapters in the *Soil Fertility Manual*. They help to illustrate the agronomic terms, soil-plant relationships, and principles of fertilizer and lime use addressed in the manual.

For additional information or to place an order, contact: Circulation Department, PPI, 655 Engineering Drive, Suite 110, Norcross, GA 30092; phone (404) 447-0335, fax (404) 448-0439. ■

The Law of the Maximum

By Arthur Wallace

Two different Laws of the Minimum are used to describe how limiting factors relate to crop production. Both came from Germany. One was formulated in 1843 and the other in 1909. The first carries the name of Liebig, who was the pioneer of the concept of mineral based plant nutrition. The second carries the name of the scientist who developed it–Mitscherlich.

THE Liebig Law of the Minimum says that crops yields are regulated by the factor in greatest limitation, and yields can be increased only by correction of that limiting factor. When that limitation is overcome, yields are then regulated by the next important limiting factor. Further yield increase will then occur only if that factor is corrected. This process is repeated, with step-wise yield increases, until there are no remaining limiting factors.

In a different approach, the Mitscherlich Law of the Minimum states that yields are influenced by all limiting factors simultaneously. The influence of each of the limiting factors is proportional to its degree of limitation. With this law of the minimum the yield for any given mix of conditions is related to the integrated sum of all of the remaining limiting factors. It is possible to mathematically express the degree of each limitation for each factor from laboratory and field tests. From the data, it is then possible to calculate the expected yields as inputs are made to correct the various limitations.

Actually, conditions exist where both laws of the minimum operate, and, more importantly, responses differ for each. Some limiting factors are so severe that no, or relatively little, increase in yields from inputs to correct less limiting inputs is possible unless the severe ones are first corrected. Without correction of these severe limiting factors, other less needed inputs may even cause a yield decrease. The severe limiting factors fit the Liebig law. In contrast, and only when there are no remaining Liebig-limiting factors, favorable responses can be obtained for any input that corrects a limiting factor of the Mitscherlich type. It really does not matter in which order these limiting factors are corrected as long as they are in keeping with the physiological status of the crop. The order does matter for those limitations of the Liebig type; the most severe ones must be corrected first or response to the less severe ones will be minimal.

The important purpose of soil and plant analyses is to identify limiting factors which can be corrected. Both types of limiting factors can be properly labeled. The more limiting factors that are corrected, the higher the yield will be, provided all those of the Liebig type have been corrected.

Interactions

Instead of laws of the minimum, we now can have a **Law of the Maximum**. The Law of the Maximum cannot operate if there are any Liebig-type limiting factors present. It has two major characteristics. First, the effect of a given input is progressively magnified as other limiting factors are corrected. The final result is greater than the sum of the effects of the individual inputs because of the way in which they interact. The interaction multiplies the effects of each. Second, yields can be highest or maximum only if there are no remaining limiting factors; the fewer limiting factors that remain, the higher will be the yield. How closely this can be approached, of course, depends

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upon economics. Fortunately, when dealing with Mitscherlich-type factors, those most economical to use can be chosen first.

Examples

Some examples of how the Law of the Maximum operates are shown.

An application of potassium (K) resulted in an orange yield increase of 81 lb per tree; when applied simultaneously with phosphorus (P), the increase attributable to K was 115 lb per tree; when applied with both P and nitrogen (N), the increase attributable to K was 202 lb per tree (University of California data). The same amount of K was applied in each case. Potassium was almost two and one-half times as valuable when applied with N and P as when applied alone.

Yield response of sugarcane due to K increased progressively from 4.4 tons/A to 5.7 tons/A when another limiting factor was corrected, to 6.6 with a third, to 9.8 with a fourth, to 12.7 with a fifth, to 14.0 with a sixth, and to 16.8 with a seventh (Pakistan Sugar Company data). The yield increase due to the K was multiplied 3.8 times as additional limiting factors were corrected. The value of the other inputs also increased with more K.

Further explanation as to how the various inputs interacted in this sugarcane experiment is indicated by the relative response to each of the seven management inputs into the system. With the control equated to 1.00, the values were 1.30 for a hot water seed treatment to control a fungal disease, 1.15 for a fungicide, 1.50 for urea management, 1.3 for a herbicide, 1.30 for a K treatment, 1.10 for a micronutrient program, and 1.20 for banding of additional nutrients. The final yield was 1.30 x 1.15 x 1.50 x 1.30 x 1.30 x 1.10 x 1.20 = 5.00 or a five-fold yield increase. The response was according to multiplication, not addition, which would total only 185 percent. This effectively explains the Law of the Maximum.

In another example, P increased the yield of cabbage by 5.7 tons/A, and K increased it by 7.0 tons/A. Both together increased it by 16.5 tons/A (Cornell University data). The result is greater than the sum of the parts, which is an important characteristic of the Law of the Maximum. The value of an input increases as other limiting factors are corrected. In this case, the increase for K alone was 5.7 tons/A and 10.8 tons/A when used with P.

These examples give new insights to maximum economic yield (MEY). A grower will obtain much more for each input dollar when as many limiting factors as possible are corrected simultaneously, especially those which are inexpensive to correct. The process has been called best management practices (BMPs), but could be called High-Precision Practices.

To maintain an intensively managed production system, it is essential that all limiting factors are identified, and the degree of limitation that each is responsible for be known. This is possible with a combination of laboratory diagnosis, field investigation, integration of available research, and crop experience data.

Some arithmetic with the variables in the sugarcane experiment gives degree of adequacy (we call it Multiple Action Yield Fraction) as 0.77 for seed treatment, 0.87 for fungicide treatment, 0.67 for urea treatment, 0.77 for the weed effect, 0.77 for the K treatment, 0.91 for the micronutrients, and 0.83 for the other nutrients. All these values multiplied together gives 0.20 or 20 percent. The yield for the control was 15 tons/A, approximately 20 percent of the highest yield which was 73 tons/A.

These calculations indicate how potent the effects of high precision can be and how devastating slight departures from the exact needs for crop production can be. For example, if 100 percent were the yield attainable and all factors except one were optimal, the final yield would be whatever that one factor represented whether it be 50 percent, 80 percent, or 90 percent. Two such factors each at 90 percent of limitation would give 81 percent of the yield attainable (0.90 x 0.90 = 0.81). For five such factors the yield would be 59 percent, and for 10 it would be only 35 percent. This is just about where the U.S.

stands in most of its crop production. The maximum corn yield that has been obtained is 370 bu/A; 35 percent of that is 130 bu/A, which is near national average. A farmer may do everything to 90 percent of perfection and yet get only 35 percent of the possible yield.

Improvement requires the pinpoint precision that laboratory diagnosis, computerized programming for decision making and expert consulting can provide. It may be little more costly to get 95 percent of perfection. But for 10 factors, the 35 percent yield would increase to 60 percent of that attainable, which for corn could be 220 bu/A. Some farmers do make it. The principles involved use the Law of the Maximum.

In reaching high yields with high precision, it is emphasized that excesses of input are avoided. Only that needed is used; environmental problems are avoided. Excess inputs may contribute to decreased yields anyway.

Careful planning is essential for farmers to obtain sufficient precision of inputs to approach the record yields, such as 370 bu/A of corn, or 6.5 tons/A (216 bu/A) of wheat, or 118 bu/A of soybeans. The effects of inputs and their interactions can be mathematically programmed. How closely record yields can be approached will depend upon skillful use of the Law of the Maximum together with use of economic and environmental principles and realities. ■

Phosphorus Nutrition in Idaho Potatoes

By Terry A. Tindall, Dale T. Westermann and Jeffrey C. Stark

Research in Idaho emphasizes the importance of phosphorus (P) placement and timing for maximum efficiency in potato production. Soil and petiole testing provides reliable guidelines for determining rates of P fertilization.

PHOSPHORUS is an essential nutrient required by all plants. Potato plant roots readily absorb P in the form of phosphate ions from the soil (water) solution. The absorbed P moves upward and downward in the plant. Phosphorus-deficient potato plants transfer P from older tissues to actively growing, younger tissues.

Symptoms of P deficiency include darker green, stunted, spindly leaves with younger leaflets that turn upward or curl. With prolonged deficiency, plants are small and have reduced leaf area.

Maximum potato yield occurs when sufficient P is available during early vegetative development and the entire period of tuber growth. Total plant P uptake increases rapidly during tuber initiation, levels off to a constant rate during tuber bulking and ceases with plant maturation. Tuber P uptake during maturation occurs primarily through the transfer of P reserves from the vine and roots.

Phosphorus Availability in Soil

The amount of P in the soil solution that is readily available for plant uptake is very small compared with the total amount of P in the soil. The calcium (Ca) in Idaho soils combines quickly with P fertilizer, causing reduced P availability to plants and very restricted P mobility in soil. Therefore, P fertilizer use efficiency is quite low compared with that of nitrogen (N) and potassium (K).

Preplant P Fertilizer

The accepted soil extraction method for measuring P availability in Idaho soils is sodium bicarbonate ($NaHCO_3$). Potatoes produced in soil containing little free lime . . . less than 5 percent calcium carbonate equivalent (CCE) . . . and soil test P less than 15 parts per million (ppm) respond to P fertilizer with improved yield and quality (**Table 1**).

Table 1. Recommended preplant P fertilizer application rates based on soil test P concentration and soil free lime content.

Soil test P, ppm (0 to 12 inch sample depth)	Free lime content		
	Less than 5%	10%	15% or more
	---------	lb P_2O_5/A	----------
0	240	354	466
5	160	280	400
10	80	200	320
15	0	120	240
20	0	40	160
25	0	0	80
30	0	0	0

Potatoes growing in soil containing high amounts of free lime (15 percent or more) respond to P fertilizer application when soil test P is less than 30 ppm. In most soils, the P fertilizer application rates shown in **Table 1** should provide adequate P from early plant growth through maturation. About 15 lb P_2O_5/A will raise the soil test P level by 1 ppm.

(continued on next page)

Dr. Tindall is Extension Soils Specialist and Dr. Stark is Research Agronomist, University of Idaho, Twin Falls and Aberdeen, respectively; Dr. Westermann is Research Soil Scientist, USDA-ARS, Kimberly, ID.

PHOSPHORUS is a key nutrient in potato production. This field is exhibiting a strong P response (left) that means higher yields and better quality.

Fertilizer Placement

Phosphorus availability is influenced by fertilizer placement and timing. Field research trials in southcentral Idaho compared banding and broadcasting preplant P fertilizer. Greatest petiole P concentrations occurred when P fertilizer was broadcast and tilled into the seedbed (**Figure 1**).

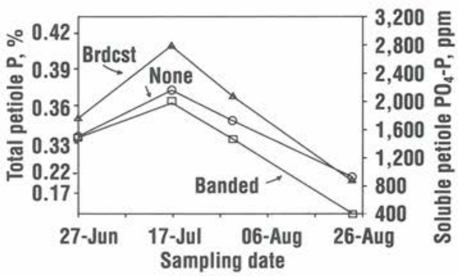

Figure 1. Potato petiole P concentration as influenced by placement.

Likewise, broadcasting P then incorporating it into the soil resulted in greater yields (**Table 2**). This is probably because broadcasting provides a greater opportunity for roots to come in contact with P fertilizer and to absorb it. Do not place P fertilizer below the active root zone of potatoes.

Place starter fertilizer materials above the seed piece at planting (directly in front of the hilling disks). Rates should not exceed 100 lb/A of fertilizer material.

Table 2. Influence of P fertilizer placement on total yield of potatoes.

	Phosphorus fertilizer rate, lb P_2O_5/A			
Placement	0	68	272	682
method	-------------	Yield, cwt/A	-------------	
None	364	–	–	–
Banded	–	389	441	–
Plowed	–	464	473	489
Disked	–	415	490	–

Available soil P = low

Mid-Season P Application

Mid-season P fertilizer application to potentially P deficient, healthy potato crops can significantly improve potato yield and quality (**Table 3**). However, fertilizing potato crops infested with root pathogens will probably have little effect on yield and quality.

Petiole P concentration is a good indicator of plant P status. Maintain P concentration above 0.22 percent total P (1,000 ppm soluble P) in the fourth petiole from the growing tip from tuber bulking until the beginning of maturation or until 20 days before vine kill (**Figure 2**). Petiole P concentrations higher than 0.22 percent provide enough P for maximum vegetative and tuber growth.

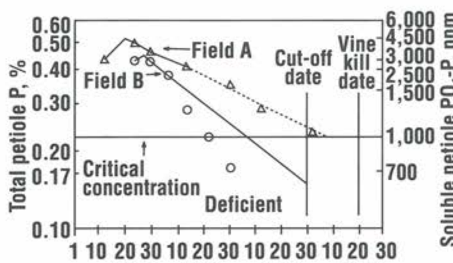

Figure 2. Evaluating mid-seasonal plant P adequacy from petiole P concentrations.

The need for a mid-season fertilizer application can be determined using a technique for predicting future P concentrations in petioles. Take petiole samples shortly after the petiole P concentration

Table 3. Influence of preplant and mid-season P fertilization on potato tuber yield and size distribution.

P_2O_5 rate, lb/A		Tuber yield, cwt/A				
Preplant	Mid-season[1]	Total	U.S. No. 1	>10 oz.	U.S. No. 2	U.S. No. 1 and 2 >10 oz.
0	0	467	298	92	130	150
136	0	460	383	130	30	143
136	45	485	405	142	47	165
136	91	520	434	195	45	217
136	182	494	406	185	53	208

[1]Applied as 10-34-0 or 12-62-0 on July 25; Available soil P = medium

PHOSPHORUS-DEFICIENT potato plants are stunted and are sometimes darker green than adjacent nondeficient plants. As severity of deficiency increases, leaves roll upward, exposing the gray-green lower leaf surface and giving the field a more "normal" green color.

has peaked and every 10 days afterward. As a general rule, collect the first petiole sample when the tubers are about 1 inch in diameter. Three or four sample dates will improve the accuracy of the prediction.

An example of predicting the need for additional P is presented in **Figure 2**. Early-season petiole samples for two fields are plotted on a semi-logarithmic basis. A line is drawn through the data points to the cut-off date (20 days before vine kill). If the line remains above this critical P concentration of 0.22 percent, then no additional P fertilizer will be needed during the growing season. In the example, Field A has sufficient P for the entire growing season. Field B does not and will require a mid-season P fertilizer application.

If additional P is needed, P fertilizer may be injected through the irrigation system. An injection rate of 40 lb/A P_2O_5 in early to mid-July will often satisfy mid-season petiole P deficiencies. Application should coincide with the presence of fine roots near the surface of the potato hills to ensure maximum P uptake. Be sure that the fertilizer and irrigation water are compatible to avoid plugging the nozzle with precipitates.

Summary

- Preplant P fertilizers should be broadcast and disked into the upper 4 to 6 inches of soil or plowed under. Banding or sidedressing preplant P fertilizer during marking, planting or hilling generally results in lower plant uptake and tuber yield. If P is adequate according to the soil test, placement probably has little effect.

- Starter fertilizer containing P should be placed above the seed piece.

- The availability of P in most solid granular and liquid P fertilizer materials is similar when the materials are applied at equivalent rates.

- Monitor petiole P concentrations at regular intervals throughout the early and mid-tuber bulking stages of potato development. Mid-season P fertilizer needs can be determined by plotting early season petiole P concentrations on semi-logarithmic graph paper and using the plot to predict late season P concentrations. ■

Phosphorus Reserves High in Coastal Plain Tobacco Soils

By M. Ray Tucker

Available phosphorus (P) in North Carolina Coastal Plain tobacco soils has increased to high levels from continued application of high P fertilizer grades. The fertilizer industry can provide tobacco grades lower in P content and these should be used by growers when soil tests reflect high P availability.

NORTH CAROLINA is the leading state in production of flue-cured tobacco. Demand for tobacco increased dramatically following the Civil War and has grown to the extent that it is now the leading cash crop in the state. North Carolina currently produces around 265,000 acres of flue-cured tobacco, grossing more than $1 billion annually. Gross income ranges from $3,000 to $4,000/A, depending on yields and current market value.

Building Soil P

Recognizing the high market value of tobacco and relatively low fertilizer input costs, growers have traditionally applied high rates of P, above actual crop requirements, as insurance for high yields. In many cases P has been applied when current soil tests indicated none was needed.

Tradition has also played a major role in buildup of soil test P because growers have continued to use grades of P fertilizers such as 3-9-9, 4-8-12, and 6-12-18 even though lower P tobacco grades are available. Plant food utilization data show flue-cured tobacco yielding 3,000 lb/A removes only 25 lb of P_2O_5. The long-term application of P in excess of crop removal has resulted in significant buildup of P reserves in most tobacco soils.

Soil test summary data from 1988-1992 for the 10 leading Coastal Plain tobacco counties representing about 50 percent of the total flue-cured acreage show the current level of P in tobacco soils (**Figure 1**).

Changes

Starting several years ago, extensive educational efforts were undertaken by the North Carolina Department of Agriculture (NCDA) and North Carolina State University (NCSU) agricultural advisors. Through these efforts, progress has been made in shifting away from the tobacco fertilizer grades high in P (**Table 1**). This educational effort has been enhanced through the cooperation of the fertilizer industry in making tobacco grades such as 6-6-18 and 8-0-24 available for growers. Since 1979, the rate of P applied for tobacco has declined 56 percent (**Table 2**).

Table 1. Changes in P-containing fertilizer grades from leading North Carolina Coastal Plain tobacco counties.

Year	3-9-9	4-18-12	6-12-18	6-6-18
	----------	P_2O_5, million lb		----------
1979	13.53	3.85	5.31	0.37
1980	10.61	3.29	5.14	1.07
1981	8.99	2.27	3.20	1.78
1982	8.33	1.83	1.96	2.23
1983	6.37	1.52	1.17	2.82
1984	6.87	1.41	0.93	3.34
1985	4.41	1.01	0.57	3.31
1986	2.93	0.53	0.26	3.24
1987	3.21	0.53	0.23	3.24
1988	3.53	0.35	0.22	4.23
1989	3.35	0.38	0.17	4.29
1990	3.15	0.52	0.32	5.24
1991	2.61	0.35	0.20	4.52
% Change	−81	−91	−96	+1,122

Data compiled from NCDA Fertilizer Tonnage Reports.

Dr. Tucker is Chief Agronomist, Soil Testing Lab, Agronomic Division, North Carolina Dept. of Agriculture (NCDA), Raleigh, NC.

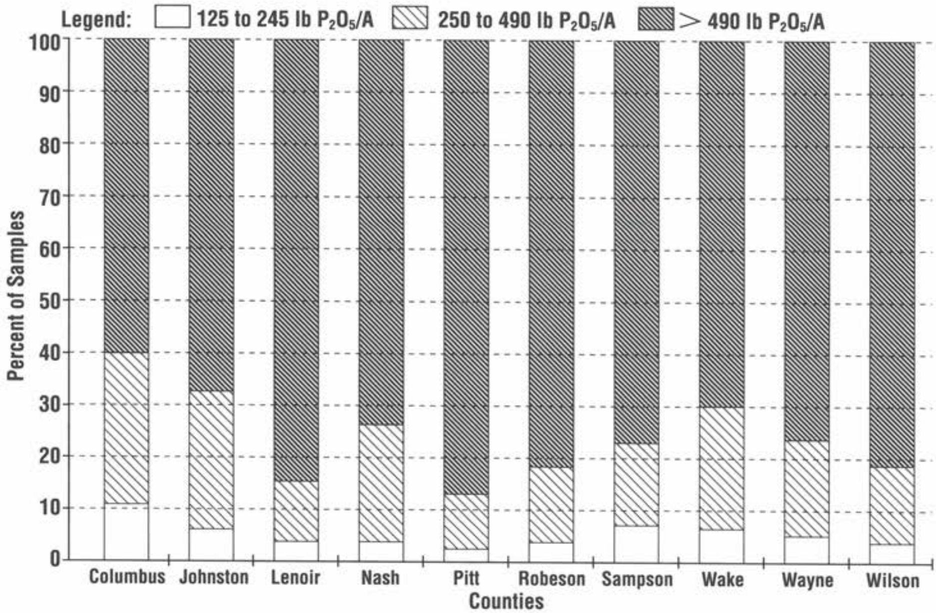

Figure 1. Soil test P summary from leading Coastal Plain tobacco counties in North Carolina. Data from NCDA Agronomic Division's annual soil test summaries.

The data in **Figure 1**, plus extensive research and on-farm tests, indicate that further P reductions could be made without any impact upon tobacco yield or quality. It is an appropriate time for everyone associated with tobacco production to encourage accurate fertilizer applications that follow soil test recommendations. It is a pro-active approach to environmental concerns and the most profitable one for the grower.

Table 2. Reduction in phosphorus application on North Carolina flue-cured tobacco.

Year	P_2O_5, Million lb	P_2O_5, lb/A
1979	24.44	185
1980	22.27	147
1981	19.91	132
1982	15.75	123
1983	12.40	119
1984	13.60	129
1985	10.23	102
1986	7.64	90
1987	7.85	86
1988	8.34	84
1989	8.19	77
1990	9.22	82

Data compiled from NCDA Fertilizer Tonnage Reports; NCDA Agricultural Statistics, Raleigh, NC.

Summary

Soil test summary data show Coastal Plain tobacco soils with high P reserves. These reserves are being addressed by the fertilizer industry with fertilizer grades such as 6-6-18 or 8-0-24. A continued effort should be made to promote such fertilizer grades for tobacco grown on soils with high P reserves. Fertilizer dealers or agricultural advisors can recommend the appropriate fertilization program for meeting nutrient needs beyond P. ■

Sulfur: The Missing Link for Warm Season Grasses

By J.L. Sanders, J.M. Phillips, J.E. Rechcigl and M.M. Eichhorn

Sulfur (S) deficiency can limit effectiveness of other nutrients and yields of warm season grasses. This article points out some guidelines for nutrient management.

EVERY FARMER who has ever pulled his truck out of a mudhole with another vehicle knows his chain is only as good as its weakest link. Sulfur, a sometimes overlooked nutrient, may be the weak link in many fertility programs for warm season grasses.

Why Has Sulfur Become the Weak Link?

Today S is becoming more of a limiting nutrient in forage production than in the past. The reasons for this increasing need include:

- increased crop yields which require more S
- increased use of high analysis fertilizers containing little or no S
- the Clean Air Act which has reduced the amount of atmospheric S fallout in rainfall
- reduced S reserves from organic matter losses due to mineralization and erosion.

Sulfur's Link in the Plant

Sulfur deficiencies are now reported across the United States and Canada in areas where they were unheard of before. Although S is a secondary plant nutrient, it is often referred to as the fourth major nutrient, along with nitrogen (N), phosphorus (P) and potassium (K).

In the plant, S is required for:

- amino acids
- proteins
- photosynthesis
- winter hardiness.

Sulfur deficiencies are often confused with N deficiencies. Symptoms of S deficiency appear as:

- stunted plant growth
- general yellowing of leaves.

SULFUR POINTER: Remember, in less severe S deficiencies, visual symptoms may not be apparent, but both yield and quality of forages will be affected.

Sulfur concentrations in grasses should range between 0.2 and 0.5 percent. The S status of forages is best diagnosed by plant analysis.

Sulfur's Link in the Soil

Sulfur is supplied to the plant from the soil by organic matter and minerals, but it is often present in insufficient quantities and available at inopportune times for the needs of high-yielding grasses. Most S in the soil is tied up in organic matter and cannot be used by the plant until it is converted to the sulfate (SO_4) form by soil bacteria.

SULFUR POINTER: Sulfate is mobile in the soil and can be leached out of the root zone in some soils under heavy rainfall conditions. As a soil begins to dry out, sulfate may move toward the soil surface as water is evaporated. Because of mobility of S, a soil test may not give dependable information as to the soil's S supplying ability. Plant tissue analysis gives a better view of S needs.

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Sulfur's Link with Warm Season Grasses

Coastal Bermudagrass

Coastal bermudagrass is widely grown for pasture and hay throughout the southern U.S. **Table 1** shows that as yields increase, requirements for nutrients, including S, also increase dramatically.

Table 1. Total nutrient uptake of Coastal bermudagrass.

Hay yield, tons/A	N	P_2O_5	K_2O	Mg	S
	----------------		lb/A		----------------
6	258	60	288	18	30
8	368	96	400	26	44
10	460	120	500	32	55

SULFUR POINTER: Remember, these are the amounts of each nutrient taken up by the plant. Since the plant operates at only about 20 to 70 percent overall uptake efficiency (depending on nutrient), more nutrients than listed here must be available from the soil and fertilizer.

A 5-year experiment in Louisiana showed that S fertilization can significantly affect forage and digestible dry matter yield of Coastal bermudagrass (**Table 2**).

Table 2. Sulfur increased forage and digestible dry matter yields of Coastal bermudagrass.

Sulfur rate, lb/A	Yield, lb/A
Forage Yield	
0	12,590
24	13,091
48	13,504
72	13,862
96	14,580
Digestible Dry Matter	
0	7,095
24	7,330
48	7,580
72	7,728
96	8,123

Nitrogen rate = 400 lb/A

An important question is whether to split S applications. Data from a 3-year trial in Louisiana (**Table 3**) show that a single application of ammonium sulfate in the early spring was equal to or better than other methods of application. Weather conditions, plant growth and intensive grass management in some years may point to a need for split applications.

Table 3. Effects of ammonium sulfate application frequency on Coastal bermudagrass yields (3-year average).

S application frequency	Total S applied	Avg. yield	Avg. response to S
	-----------	lb/A	------------
0	0	13,173	0
April 1	120	15,013	1,840
April 1 and after 2nd harvest	120	14,913	1,740
April 1, after 1st, 2nd and 3rd harvest	120	13,750	577

Bahiagrass

Florida research has indicated that bahiagrass should respond to S fertilization when plant tissue is below 0.2 percent S. A 3-year study showed that S fertilization had a significant influence on both bahiagrass yield and quality. Ammonium sulfate produced significantly higher yields and protein contents than ammonium nitrate at the same N rates (**Figures 1 and 2**). It was noted that S not only increased bahiagrass yields but also increased plant numbers.

(continued on next page)

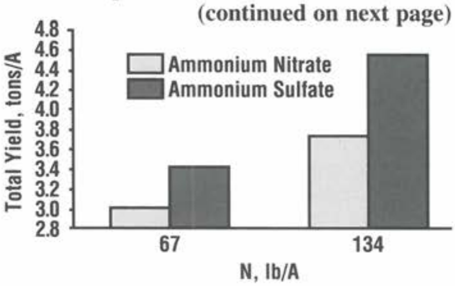

Figure 1. Effect of ammonium nitrate and ammonium sulfate rates on bahiagrass yields.

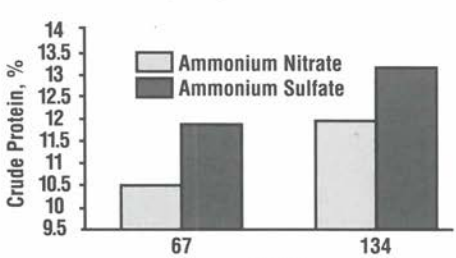

Figure 2. Effect of ammonium nitrate and ammonium sulfate on percent crude protein content of bahiagrass.

Ammonium sulfate also had a significant effect on digestibility and S concentration in bahiagrass (data not shown). Bahiagrass fertilized with N alone (ammonium nitrate) was deficient in S at both N levels.

Sulfur's Link to Animal Nutrition

Sulfur is an essential nutrient not only for forages, but also for the animals that consume those forages. Researchers report that forage growth may be near maximum rates, but S content may be inadequate for ruminant animal nutrition. In the southeastern U.S., high rates of N fertilization have caused depression of the S concentration in Coastal bermudagrass and increased the N to S ratio. This appears to contribute to low animal performance.

SULFUR POINTER: Many researchers recommend a N:S ratio of 10:1 to 15:1 for optimum animal nutrition. It should be noted, however, that in a deficiency situation (with both low N and S), an "adequate" ratio can be misleading. Both nutrients could be limiting animal production, even though an "adequate" ratio has been maintained.

Nitrate poisoning in animals is a result of the accumulation of abnormally high nitrate content in forages consumed by ruminant animals. Plants with severe S deficiency may accumulate higher concentrations of nitrate than S-fertilized plants, resulting in greater likelihood of nitrate poisoning.

Copper (Cu) is an essential nutrient for animals. Researchers in Arkansas and Louisiana have studied the effects of increased S rates on Cu concentrations in Coastal bermudagrass. As S fertilization was increased up to 96 lb S/A, forage yields increased. However, there was no significant effect on Cu concentrations in the plant tissue (**Table 4**) . . . no depression of Cu concentrations occurred.

Table 4. Effects of S on yields, S and Cu concentrations of Coastal bermudagrass.

S Rate, lb/A	S Concen., %	Cu Concen., ppm[1]	Yield, lb/A
0	0.13	5	12,590
24	0.16	4	13,091
48	0.20	4	13,505
72	0.24	4	13,862
96	0.28	4	14,582

[1]parts per million

Sulfur's Weakest Links

Be on the lookout for conditions that can influence S needs, affect S concentrations in forages, forage production, forage quality . . . **and forage profits.**

- sandy soils
- low organic matter soils
- areas of high rainfall
- high yield management
- high quality/high protein crops
- areas with low atmospheric fallout of S (located away from urban areas)
- low S irrigation water.

Sulfur may be the missing link in your forage production program. ■

RESPONSE of Coastal bermudagrass to N and S was recorded in these Arkansas research plots.

BAHIAGRASS in plots at left and right both received 134 lb/A rate of N as ammonium nitrate. Note response in plot at right which also received S at a rate of 77 lb/A.

Environotes from TVA

By John E. Culp

SEVERAL ENVIRONMENTAL technologies are being introduced by TVA to agricultural retailers. Our work includes sponsoring model site demonstrations to develop and introduce secondary containment structures. Structures included are load-in, load-out, storage, mixing and rinsing. Demonstrations are active in 17 states.

TVA is also working with 35 retail dealers in 20 states on individual technology demonstrations. These demonstrations include site assessments to determine the impact of a retailer's facility on the environment.

TVA has worked with the industry to develop and introduce an environmental manual, videotapes and environmental checklist. These identify strategies and structures dealers can use to install safeguards at their sites.

Later this year, TVA will release a self-evaluation environmental package. It is being tested at this time. The package consists of a videotape, a comprehensive questionnaire, and a customized report generated by an expert system which analyzes a retailer's responses. The report will help dealers identify problems and corrective actions based on regulatory compliance and best management practices.

Remediation

TVA is field testing solar remediation technology. Scientists are also conducting research to develop a number of remediation technologies.

The field testing under way is on a low-cost passive solar evaporation unit. This technology is designed to reduce the volume of aqueous waste-containing pesticides. A demonstration unit costs about $4,000 and can evaporate 900 to 1,200 gallons of water annually based on Alabama climatic conditions. We have field tests under way on this technology at a metal plating company in Tennessee and at agricultural retailer sites in Idaho and Washington.

Researchers are also exploring this technology in TVA laboratories and experimental sites. The objective is to develop a simple and economical process to reduce the volume of, and where possible to destroy pesticides in, dilute aqueous waste streams. Research will continue on the solar evaporator technology. The field testing in Idaho and Washington will contribute to the further development of this technology.

TVA is also conducting photocatalytic oxidation studies to test the potential application of catalyzed solar-light driven photooxidation as a means for destroying pesticides in dilute waste water streams. Early experiments have shown promise in destroying atrazine, metolachlor and metribuzin under both solar and artificial UV light irradiation.

The objective of these technologies is to provide the agricultural retailer with low-cost remediation technology through solar evaporation and destruction capabilities. ■

SOLAR REACTORS for studying the TiO_2 catalyzed degradation of pesticides.

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Beware

There's Nothing Wrong With Making Mistakes, But Don't Respond With Encores

"It is time for a change" is the theme of the new Washington. We all agree, but farmers in particular had better watch that "change" carefully. There are 95 of "them" and 5 of you farmers. And the 95 think they are subsidizing you when actually you are subsidizing them.

We empathize with the homeless, the handicapped, the poor, the jobless, the aged and the spotted owl. But we can't afford to spend all of our money and efforts on the non-producer, while overlooking those who make the country great . . . the producers.

One area threatened is agricultural research and Extension. Too few realize their contributions to America in production agriculture. Everywhere, positions are being eliminated and budgets slashed. The public is unconcerned . . . unaware of the role that agricultural research and Extension play in full shelves and reasonable prices.

"Time for change" affects research and Extension in another way. The emphasis is shifting from production to community development, food safety and environmental issues. Great . . . but not at the expense of production.

Beware! Don't let "them" threaten your future and theirs by crippling these research and educational programs.

J. Fielding Reed

Better Crops WITH PLANT FOOD
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Suite 110, 655 Engineering Drive, Norcross GA 30092