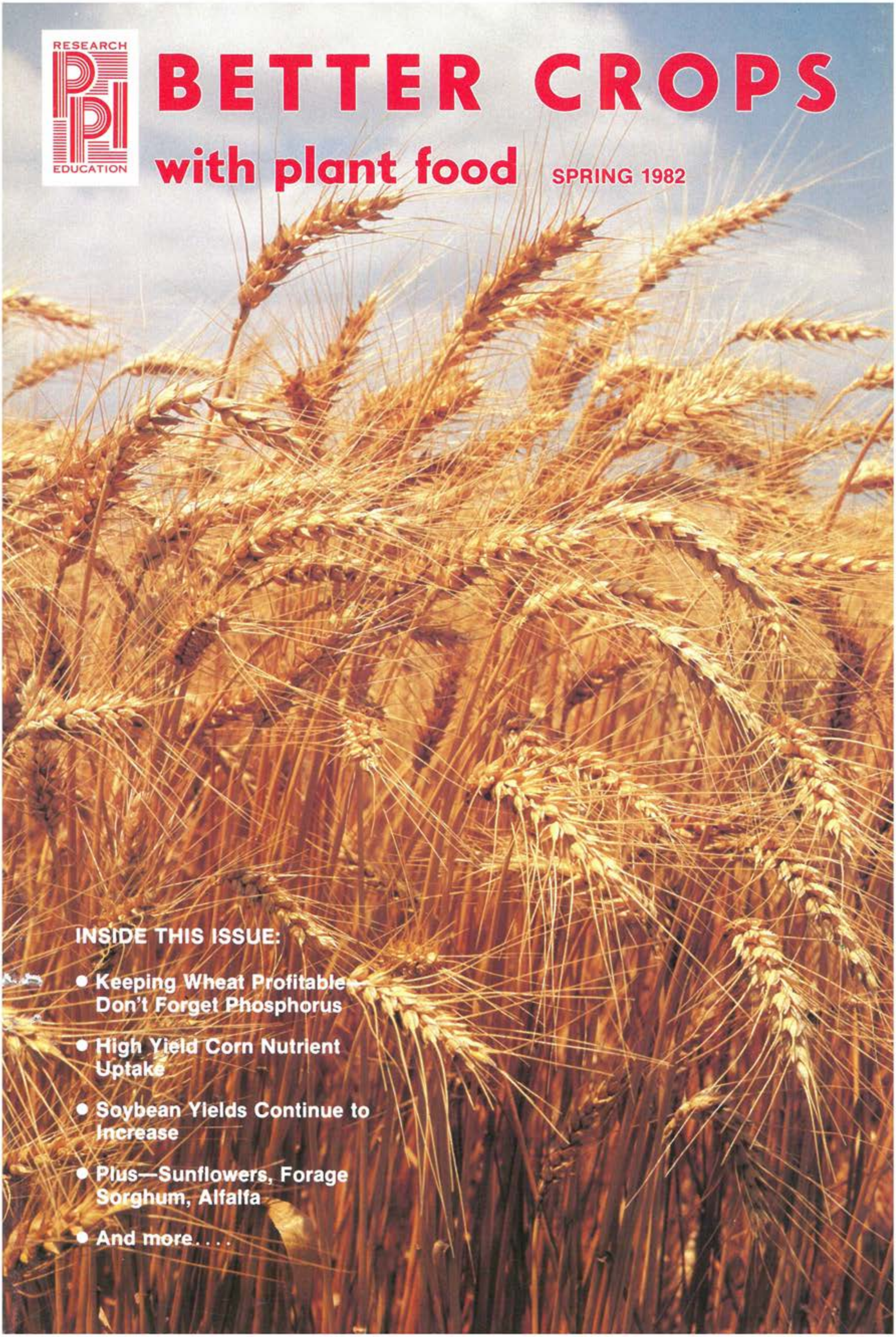
RESEARCH PPI EDUCATION

BETTER CROPS with plant food

SPRING 1982



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BETTER CROPS with plant food

Editors: Bill Agerton, Don Armstrong, and Santford Martin

Assistant Editor: Selma Bushman

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Efficient Use of Phosphorus On Winter Wheat

By G.A. Peterson, D. H. Sander, P.H. Grabouski and M.L. Hooker

ROW OR BAND APPLICATION has long been recognized as a means to improve phosphate use efficiency. As early as 1930, F.L. Duley demonstrated wheat grain yield advantages of 6 to 15 bu/A for row application compared to broadcast-preplant in Kansas.

A commonly used rule of thumb says: "Double the row-applied rate of phosphate if broadcasting". This is supposedly based on research around the world.

After reviewing the basis for this recommendation in Nebraska, we began to look at the research cited by other agronomists. We found very little evidence to support the recommendation.

Here's the key question: Is it really necessary to double the row-applied rates when broadcasting phosphates?

Increasing crop production costs make this decision more relevant than ever before. To seek an answer, we designed experiments to determine if there is a consistent relationship between row and broadcast P rates for winter wheat.

Southwestern Nebraska studies

Six fallow fields were chosen in southwestern Nebraska over a two-year period, three in each year. All fields were Keith silt loams and were deficient for wheat production. **Table 1** shows soil chemical characteristics. A phosphorus (P) test less than 25 ppm is deficient for winter wheat.

Both N and P variables were studied to assure a comparison of P application methods under optimum N conditions. The N rates ranged from 0 to 120 lb/A in 30 lb/A increments. The P rates ranged from 0 to 92 lb/A P_2O_5

Table 1. Chemical characteristics of the surface soil at experimental sites.

Site	pH	Organic matter	Bray & Kurtz #1 extractable P	NO_3-N (6 ft.)
		%	ppm	lb/A
1	7.7	1.08	14	26
2	7.4	1.40	8	23
3	6.9	1.27	19	13
4	7.3	2.02	19	52
5	7.1	2.02	17	27
6	7.7	1.51	10	24

Table 2. Wheat grain yield responses to P fertilization rate and method of application at the optimum N rate for that location.

P_2O_5 lb/A	1 Broad	1 Row	2 Broad	2 Row	3 Broad	3 Row	4 Broad	4 Row	5 Broad	5 Row	6 Broad	6 Row
	bu/A											
0	54		36		44		46		60		42	
23	56	56	36	42	45	48	51	52	66	67	44	46
46	58	61	42	46	45	47	48	47	62	63	44	50
69	62	64	43	44	47	49	50	49	70	70	48	54
92	62	65	41	46	48	50	51	58	67	65	52	54

in 23 lb/A increments.

Broadcast P treatments were applied 2 to 4 weeks prior to wheat seeding as 0-46-0 (triple superphosphate) and incorporated by cooperators' field operations.

The normal tillage depth used by wheat producers in the wheat-fallow system is 4 to 5 inches, but actual depth of P incorporation is uncertain. Row P applications placed the 0-46-0 directly with the seed. All N was applied as spring topdressings prior to or at the breaking of winter dormancy. At maturity, grain and straw were harvested from each plot.

Positive P responses

Table 2 shows that positive grain yield responses to P application occurred at all sites, just as the soil test had predicted. However, the effectiveness ratio of broadcast and row applied P rates was not the expected 2:1 relationship.

Note the responses at sites 2 and 5. At site 2, broadcast P never did achieve yields equivalent to row applied P, while at site 5 there was an equivalent response to the two methods. Other sites were intermediate between these extremes.

Table 3 summarizes the relationship between broadcast and row application methods for the set of experiments. Ratios of broadcast to row rates to achieve equal yield response ranged from 1.0 to 3.0—not a consistent relationship.

Table 3. Broadcast and row P rates to maximize grain yield response; ratio to obtain an equal grain yield response, as related to soil test level.

Soil Test	Site No.	Broadcast Rate to Maximize Yield Response	Rate of Row Applied to Give An Equal Yield Response	Ratio of Broadcast To Row
ppm P		P_2O_5 lb/A		
8	2	76	25	3.0
10	6	92	57	1.6
14	1	92	61	1.5
17	5	—	—	1.0*
19	3	—	—	1.0*
19	4	55	45	1.2

*No significant difference between methods and so ratio equal 1.0

Figure 1

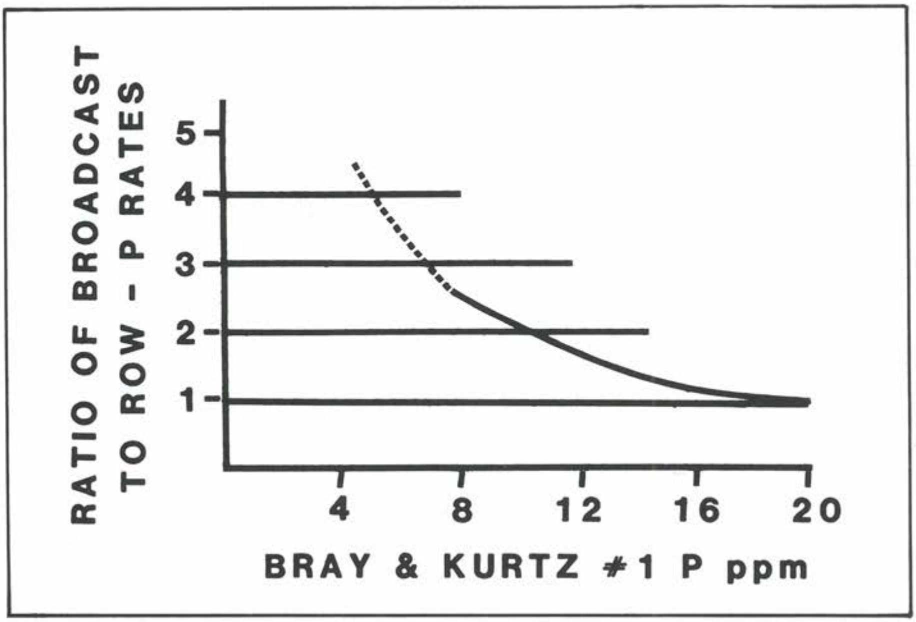

Figure 1 shows a predictable and consistent relationship with soil test level. Low soil tests exhibited an effectiveness ratio of about 3:1, while medium soil tests resulted in a ratio of 1:1. This indicates that recomendations should change with soil test level.

Possible to predict placement efficiency

Many researchers have demonstrated large benefits from banding fertilizer on soils low in available P and/or with high P fixation capacities. So it's not surprising that row applications were often more efficient than broadcast treatments.

However, the possibility of accurately predicting the relative effectiveness is very interesting.

Recommendations could be altered as soil tests dictate to include total nutrients needed and also the amount in relation to application method.

Accurate prediction of effectiveness is more significant because soils testing low or very low probably can't be efficiently fertilized with broadcast methods.

On the other hand, producers with medium soil P test levels don't need to double P rates for broadcast application. And broadcast application can be used economically and efficiently to avoid P application at planting if soil test P levels are medium. ■

Dr. Peterson and Dr. Sander are Professors of Agronomy at the University of Nebraska; Dr. Grabouski is Extension Specialist at the North Platte Experiment Station in Nebraska; Dr. Hooker is Assistant Prof. of Agronomy at the Garden City Branch Experiment Station, Kansas State University.

High-Yield Corn Nutrient Uptake

By Roy Flannery

AS CORN YIELDS INCREASE, so do the nutrient demands of the crop. Recent maximum yield corn studies begin to show just what these needs may be.

In our maximum yield corn study one of the most striking visual observations at tassel-stage was an obvious nitrogen (N) deficiency symptom where 250 lb/A of N had been applied as manure and fertilizer nitrogen. The yields on these plots were a respectable 218 bu/A. However, with an additional 250 lb/A of N balanced with extra P and K, yields were 312 bu/A.

In such an intensive management system, where many of the other controllable growth factors are near an optimum, nutrient requirements are great. The return for the extra fertilizer under the conditions of this experiment was $155.55 per acre, shown in **Table 1.**

Table 1. Yield and return from two fertilizer rates.

Fertilizer Rate N	P_2O_5	K_2O	Yield	Cost of extra fertilizer & harvest	Net return for extra
	lb/A		bu/A	$/A	$/A
250	125	125	218	—	—
500	300	300	312	149.95	155.55

N = 20¢/lb; P_2O_5 = 28¢/lb; K_2O = 13¢/lb; Harvest cost extra = 30¢/bu; Corn price = $3.25/bu

Soil Tests

The experiment was conducted on a well drained Freehold sandy loam. The topsoil contained 70% sand, 23% silt, 7% clay, 1.31% organic matter and had a cation exchange capacity of 7.18 meq/100 gm. Before liming and fertilizing, the soil had a pH of 5.8 and tested very high in P and K and medium in Ca and Mg. See **Table 2.**

Micronutrients

One-half the plots received broadcast micronutrients: 1.5 lb/A boron, 5 lb/A copper, 25 lb/A manganese, and 10 lb/A zinc. **Table 3** shows that without micronutrient additions the grain yield increased 59 bu/A with higher N, P, and K rates. With the higher rates **and** micronutrients, corn yields increased by 94 bu/A.

Interaction of nutrients and the importance of balance are shown by the fact that no response to micronutrients was obtained at the lower fertilizer rate. But a 30 bu/A response occurred at the higher fertility level.

Dr. Flannery is a soil scientist at Rutgers University. In 1980 he harvested record corn research yields of 312 bu/A. This article details nutrient uptake information from the study.

Table 2. Soil test data

	pH*	P	K	Ca	Mg
			lb/A		
Topsoil	5.8	114	327	885	117
Subsoil	6.1	12	275	1,113	200

*Limed with 900 lb/A CaO plus 600 lb/A MgO after sampling and before planting

Table 3. Effect of micronutrients on corn yield

Fertilizer rate			Grain yield	
N	P_2O_5	K_2O	−Micro	+Micro
	lb/A		bu/A	
250	125	125	223	218
500	300	300	282	312

Nutrient Composition

Ear leaf samples taken at early tassel were analyzed for elemental concentration for the two fertility levels under the highest management treatment, in **Table 4.** Except for N at the lower fertility level, all nutrients were well above concentration levels now considered adequate for good yields. **However, remember that critical values accepted today may or may not be adequate for the yields now being achieved in maximum yield research.**

Table 4. Nutrient concentration of ear leaf at tassel

Element	Low fertility level 250-125-125 lb/A	High fertility level 500-300-300 lb/A	Suggested critical level
N %	2.56	3.18	2.75
P %	0.29	0.40	0.25
K %	2.13	2.28	1.75
Ca %	0.53	0.51	0.25
Mg %	0.15	0.17	0.13
S %	0.20	0.20	0.15
Mn ppm	33	43	20
Zn ppm	25	39	15
Cu ppm	9	11	3
B ppm	13	14	4

The response to micronutrients suggests higher critical levels may be needed for high yields since the levels were all more than double the present suggested critical levels.

Tissue samples were also taken at harvest from the ear and stover for N, P, and K. The results are shown for the two fertility levels in **Table 5.**

Table 5. Macronutrient composition of corn ear and stover samples from maximum yield plots.

Fertilizer rate	Plant part	N	P	K
lb/A			%	
250-125-125	ear	1.17	0.25	0.37
	stover	0.46	0.12	1.93
500-300-300	ear	1.48	0.36	0.42
	stover	0.97	0.13	2.22

For the high fertility level and the 312 bu/A yield these figures translate into a total uptake of 366 lb/A nitrogen, 177 lb/A P_2O_5, and 426 lb/A K_2O. ■

Keeping Wheat Profitable —Don't Forget Phosphorus

By Larry S. Murphy

CONTINUAL RISING COSTS seem like a never ending spiral to wheat growers. Higher yields are the best way to keep some profit in front of the race.

Breeders in Nebraska, Kansas, Colorado and Oklahoma are bringing on new varieties to keep stride with the challenge. For example, new semi-dwarfs have more and more yield potential. Too often, though, yields are limited by variety selection, seeding rate, seed quality, tillage practices, moisture conservation, fertilizer and other management practices.

Nitrogen—First Limiting Nutrient

Since the introduction of Turkey Red, Great Plains hard red winter wheat producers have depended heavily on nutrients released from the decomposition of soil organic matter. With time, less nutrients are released because organic matter declines to a relatively constant level as land is tilled.

Nitrogen (N) application for wheat is not new to the Great Plains. And fertilizer needs will increase as time goes on. In 1981, western Kansas, eastern Colorado, eastern Wyoming and western Nebraska experienced large areas of nitrogen-deficient, yellow wheat due to too little N released during the fallow period.

Phosphorus—the Second Limiting Element

With increasing use of N fallow winter wheat, eco-fallow wheat and continuous cropped areas, growers should note the second-most limiting element in the area—phosphorus.

Severely eroded areas, soils with low organic matter content and soils that contain large amounts of free calcium carbonate or lime are most likely to be phosphorus deficient in the Great Plains. Soil testing can predict deficiencies.

What Does Research Show?

Let's look at specific examples of how P application works to improve yields and keep wheat profitable.

University of Nebraska agronomists Gary Peterson, Don Sander and Charles Fenster reported in 1980 that phosphorus-deficient soils frequently yielded 8 to 12 bu/A less wheat than those fertilized according to soils lab recommendations.

Table 1 shows studies from southwest Nebraska. Soils in three of these four locations were very deficient in phosphorus; the fourth location was slightly above the deficient level.

Phosphorus tends to increase tillering, improve winterhardiness by

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Dr. Murphy is Great Plains regional director of the Potash & Phosphate Institute.

Table 1. Southwest Nebraska wheat responses to phosphorus: Grain yield, bu/A. 1980 NB

P_2O_5 lb/A	Furnas County Broadcast	Furnas County Band	Frontier County Broadcast	Frontier County Band	Hitchcock County Broadcast	Hitchcock County Band	Frontier County Broadcast	Frontier County Band
0	29		48		58		58	
16	29	39	47	58	63	65	58	66
35	30	36	52	51	58	57	60	64
51	30	43	51	60	64	70	60	69
68	25	41	52	60	60	57	62	65
86	32	37	57	62	64	64	61	64
P soil test: (ppm)								
0-4 inches	10		3		11		28	
4-8 inches	4		10		5		9	
Classified	low		low		low		medium-low	

development of better root systems and generally advance the maturity of plants.

Calculations show that higher yields are accompanied by **lower production costs per bushel and higher net profits per acre.**

Table 2 shows just how the values work out. Clearly, higher yields with adequate phosphorus turned a money losing situation into a profitable one. Of course, higher prices would increase profits even more. But \$40-\$60/A profits are better than \$35/A losses.

Table 2. Higher wheat yields mean lower production costs per bushel, higher profits. 1980 NB

	Furnas County				Frontier County				Hitchcock County			
P_2O_5 band with seed	Yield bu/A	Prod. cost \$/A	Prod. cost \$/bu	Net return \$/A	Yield bu/A	Prod. cost \$/A	Prod. cost \$/bu	Net return \$/A	Yield bu/A	Prod. cost \$/A	Prod. cost \$/bu	Net return \$/A
0	29	135	4.66	–28	48	135	2.81	43	58	135	2.33	80
16	39	142	3.65	2	58	142	2.45	73	65	141	2.16	100
35	36	147	4.08	–14	51	146	2.86	43	57	145	2.54	66
51	43	153	3.57	6	60	153	2.55	69	70	153	2.18	106
68	41	158	3.84	–6	60	158	2.63	64	57	154	2.70	57
86	37	161	4.36	–24	62	161	2.63	66	64	161	2.51	76

Wheat \$3.70/bu; P_2O_5 28¢/lb; 30¢/bu for extra yield harvested. Low P soil. Calculated at 60 lb/A of N, 15¢/lb.

Kansas data tell the same story in **Table 3.** Profits took the same turn when yields went up. Correcting the P deficiency with added phosphorus accounted for only a small portion of the total costs per acre. Too often we forget that it's necessary to spend money to make money. Cutting per acre costs can be false

Table 3. Wheat responses to phosphorus: lower production costs per bushel, higher profits. 1975-80 KS

	Ellsworth County				Cherokee County				Dickinson County			
P_2O_5 lb/A	Yield bu/A	Prod. cost \$/A	Prod. cost \$/bu	Net Return \$/A	Yield bu/A	Prod. cost \$/A	Prod. cost \$/bu	Net Return \$/A	Yield bu/A	Prod. cost \$/A	Prod. cost \$/bu	Net Return \$/A
0	27	129	4.78	–29	37	129	3.49	8	35	129	3.69	0
20	39	137	3.51	7	—	—	—	—	44	137	3.12	26
30	—	—	—	—	43	139	3.24	20	49	142	2.89	39
40	44	145	3.30	18	—	—	—	—	57	147	2.58	64
50	—	—	—	—	—	—	—	—	57	150	2.62	61
60	45	151	3.36	16	46	148	3.23	22	—	—	—	—
Soil test P (ppm):												
0-6 inches	5				12				3			
Classified	low				low				low			

Wheat \$3.70/bu: P_2O_5 28¢/lb; 30¢/bu for extra harvested yield. Calculated at 75 lb/A of N, 15¢/lb.

economy. It is the per bushel costs that we need to watch.

At the Southeast Kansas Branch Experiment Station, researcher Ray Lamond developed some impressive response data from the popular new semi-dwarf variety, Newton. Soils in the area of the study are very deficient in phosphorus. But when supplied with adequate phosphorus, wheat yields increase.

Note in **Table 4** that yields increased from a meager 6 bu/A to a healthy 52 bu/A when the highest rate of P was applied.

Table 4. Newton semi-dwarf variety evaluation for phosphorus needs. 1980 KS

Nutrient rates N lb/A	P_2O_5 lb/A	Yield bu/A	Protein %	Prod. Costs $/A	Prod. Costs $/bu	Net Return $/A
75	0	6	14.2	129	21.50	−107
75	30	38	12.0	147	3.87	−6
75	60	48	10.1	158	3.30	20
75	90	52	9.6	168	3.23	24

Soil test P: 2 ppm, low (0-6 inches)
Wheat $3.70/bu; P_2O_5 28¢/lb; N 15¢/lb; 30¢/bu for extra yield harvested.

Most P responses tend to flatten out after about 30-50 lb/A of P_2O_5 equivalent. But yields with Newton were still increasing at 90 lb/A of P_2O_5. **This points out the need for more information on just how to manage these new varieties.**

Many people have seen dramatic plant response with nitrogen. But it's not frequently seen with phosphorus. Take another look at grain protein in **Table 4**. Levels went down as yield went up, suggesting that nitrogen may have been limiting yields.

Colorado State University data from Dwayne Westfall shows that N response is very high when correlated with soil nitrate-nitrogen tests. Recent studies demonstrate a need for additional phosphorus.

In dryland studies, researchers noted increased growth when pre-plant phosphorus was added along with N. Colorado State University has a significant phosphorus research program on both dryland winter wheat and irrigated spring wheat.

What to Use

Phosphorus fertilization began long ago with the use of rock phosphate. Now, processed fertilizers with much higher water solubility are available. There is a wide range of solid and liquid forms, all with about the same agronomic performance.

Choice of a phosphorus source among the processed materials depends mostly on availability, dealer service and applied price.

How to Apply Phosphorus

The Nebraska agronomists compared broadcast, pre-plant applications with seed applications of phosphorus. See **Table 1**.

The researchers demonstrated that the efficiency ratio varies with soil test phosphorus levels. The ratio ranges from a 3:1 advantage for seed-placed or banded phosphorus at low soil test levels to a 1:1 ratio with no advantage at higher levels.

In other words, it takes three times as much broadcast phosphorus to do the same job on soils testing low in phosphorus. But as the test goes higher, the methods of application become equal.

Table 5. Phosphorus application methods affect wheat responses to fertilization and profitability.

P_2O_5	P Broadcast		P Knifed		P Band with seed	
			Kansas			
lb/A	Yield	Net Return	Yield	Net Return	Yield	Net Return
	bu/A	$/A	bu/A	$/A	bu/A	$/A
0	35	0	35	0	35	0
20	44	26	53	56	45	29
30	49	39	60	77	61	80
40	57	64	70	108	57	64
			Nebraska			
0	30	-25	30	-25	30	-25
20	—	—	—	—	—	—
30	33	-23	49	31	44	14
40	—	—	—	—	—	—

All soil P tests low. Wheat $3.70/bu; P_2O_5 28¢/lb; N 15¢/lb; 30¢/bu for extra yield harvested. No differentiation for costs of various methods of application of P. Net returns calculated from farm management data both states.

Dual Application

Kansas State University has studied dual application of phosphorus with large amounts of nitrogen pre-plant. The method usually involves placing the N and P in narrow bands in the soil at depths ranging from 3 to 6 inches.

The knifed, dual applications of N and P have performed about like seed-placed phosphorus—frequently better—occasionally slightly less effective.

The knifed, dual applications were outstanding when compared to broadcast pre-plant application.

Table 5 indicates yield differences that were recorded in Kansas and Nebraska studies. It also shows how profits can be affected.

Apparently, the dual application method enhances P availability by: (1) placing the phosphorus deeper in the soil where moisture is not limiting; (2) keeping the phosphorus in a high concentration of ammonium-nitrogen which may interfere with normal phosphorus soil reactions; and (3) improving phosphorus uptake by increasing the soil acidity in the immediate vicinity of the root.

Seed-placed phosphorus may enjoy some of the same advantages. But the amount of nitrogen placed with the phosphorus in seed application is much lower.

Nebraska, Montana, North Dakota, Washington, Oklahoma, and Alberta investigations have produced similar results with the dual NP applications.

There's another advantage—fertilization can be carried out during a tillage operation, cutting field time and fuel consumption. A disadvantage may be the use of higher priced phosphorus materials.

Is Phosphorus Limiting Your Yields?

Phosphorus response for winter wheat in the Great Plains is unlikely unless you have already taken care of N needs.

Check with your fertilizer dealer, extension agent or ag consultant. They will gladly point out how to collect soil samples and handle them for the best reporting.

Don't let phosphorus deficiencies reduce or eliminate your profits. Higher yields through better management will be the key to greater profitability. ■

Forage Sorghum Response to P and K Application

By R.B. Reneau, Jr.
and G.D. Jones

FORAGE sorghum has become an important silage crop. And it's well known that phosphorus (P) and potassium (K) are required for maximum yields.

But forage sorghum response to various combinations of P and K under field conditions hasn't been adequately documented.

A recent experiment on the Piedmont Research Station at Orange, Virginia determined the effect of K on four levels of P. The 1978-80 study measured yields and mineral content in tissue.

The K application rates were 0 and 200 lb/A; P rates were 0, 26, 52, and 104 lb/A. The soil was a Davidson clay loam.

Figure 1 shows that silage yields increased significantly with the lowest rate of P (26 lb/A) when no K was applied. Yields leveled off with increased P application.

With 200 lb/A of K, silage yields continued to increase with higher P rates. Yields leveled off at the highest P rate.

With or without K, the yield was closely related to P application. The data indicate the need for a combination of P and K to realize maximum yields.

Weather also influenced yields. In dry years, K application helped to realize the full benefit of increased P. In years with favorable moisture conditions, K application didn't increase yields significantly.

The separation between the two curves in **Figure 1** would be larger in dry years and smaller in years with good moisture conditions.

FORAGE SORGHUM YIELDS--RANGE OF P RATES, WITH & WITHOUT K

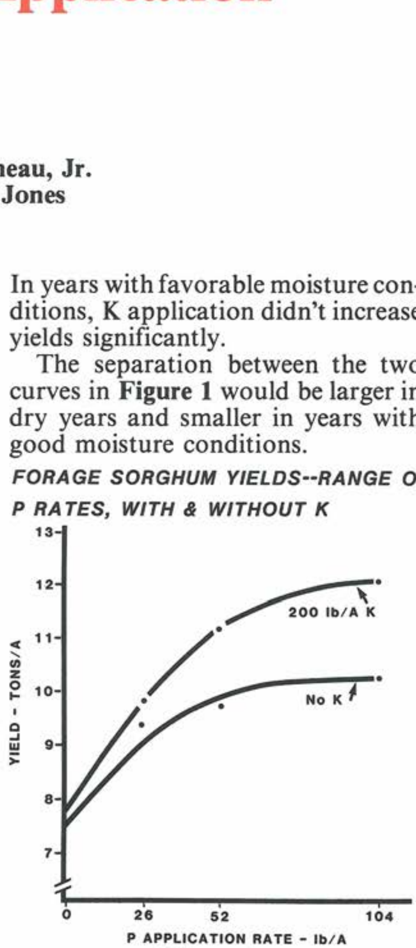


Figure 1

This indicates need for a higher concentration of diffusible K during dry years, to help offset effects of reduced moisture.

There's another possible explanation for lack of response to K during years with favorable moisture: subsoil K might be more available for uptake by forage sorghum.

Dr. Reneau and Dr. Jones are Agronomists at Virginia Polytechnic Institute and State University, Blacksburg, VA.

MAGNESIUM CONCENTRATION IN FORAGE SORGHUM --RANGE OF P RATES

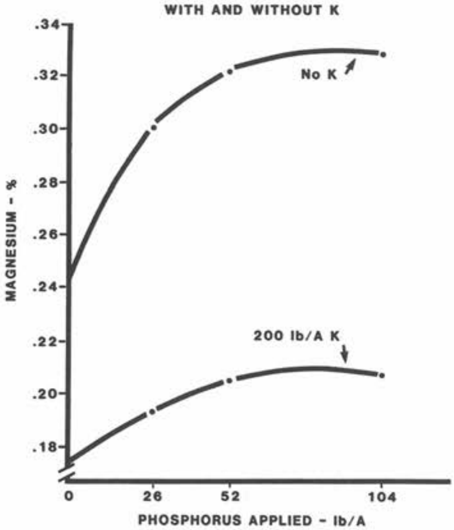


Figure 2

Calcium and Magnesium Uptake

Both P and K influence plant uptake of calcium (Ca) and magnesium (Mg). When excess K is present in solution, K competes with Ca and Mg for uptake. This antagonistic effect has been demonstrated many times for monocot crops (such as corn and forage sorghum). The effect is shown by the difference between the two curves in **Figure 2.**

Increases in Mg uptake with P application, such as those for each curve in **Figure 2,** have been reported by only a few researchers.

The relationship between P and K and Mg uptake should be examined more closely. Most cations are assimilated in a competitive uptake process. So increased application of P or K would not be expected to encourage Ca and Mg uptake.

Figure 3 shows a linear relationship between yield and Mg concentration in tissue. This relationship was apparent for both the 0 and 200 lb/A rates of K, at all rates of P.

There was an increase in Mg concentration with increased P. About 99% of the variation in yield could be attributed to Mg concentration in tissue.

Use of Ca as an additional variable did not improve the relationship shown in **Figure 3.**

The P concentrations in tissue did not vary significantly with P application above the 26 lb/A level. So the data indicate that increased yields for any K rate resulted from increased Mg uptake effected by P application.

The decreased Mg concentrations in relation to yield where 200 lb/A of K was applied appears related to competition of Mg and K for uptake. And higher yields where K was applied could also have diluted the concentration of Mg in tissue.

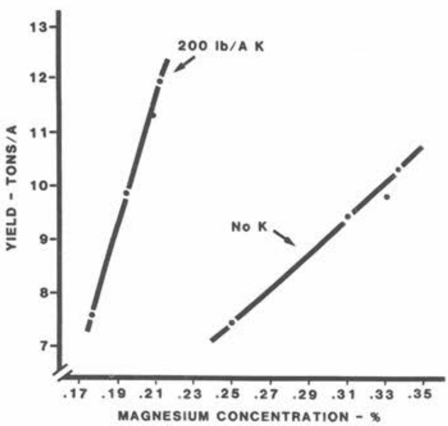
Earlier research with soybeans grown in the same area showed that the primary response was to K application.

Corn grown in the area from 1964 to 1966 produced only 33.5 bu/A where P was applied without K. When P was applied with K, yields averaged 112 bu/A—this indicates a large response to K application.

These results with corn and soybeans are opposite the data reported here for forage sorghum. This indicates a need for research to determine the differential response of P and K for these crops. ■

Figure 3

RELATIONSHIP OF FORAGE SORGHUM YIELDS & Mg CONCENTRATION IN TISSUE



Potash Pays

Fertilizing Sunflowers on Sandy Lands

By C. A. Simkins and
C. J. Overdahl
University of Minnesota

LARGE PORTIONS of the sunflower production area of Minnesota include coarse textured soils, commonly called "sandy lands". In some seasons, sunflowers are planted on more than a half-million acres of these soils.

Irrigation aids crop production on some of the sandy lands along the Red River Basin and in central and north central Minnesota.

But with proper fertilizer practices, sunflowers can produce economical yields without irrigation. Potash and nitrogen application may be keys to increased sunflower profits on sandy lands.

These soils vary from area to area. There are three important differences: (1) parent material on which they were formed; (2) drainage patterns; (3) quantity of organic matter in the surface plow layer.

Low K and N

But the soils generally have two things in common. They are low in potassium — often less than 100 lb/A exchangeable K. And they are low in available nitrogen—usually less than 30 lb/A of nitrate N in the depth of 0-24 inches.

Differences in parent material may also cause these soils to be low in phosphorus (P). This makes a soil test very important.

SUNFLOWER RESPONSE TO N AND K ON SANDY LANDS. In Minnesota studies, sunflower seed and oil yields have been dramatically increased by N and K_2O.

In 1979, irrigation trials near Becker in east central Minnesota showed yield increases of nearly 100%. **Tables 1 and 2** tell the story for both N and K.

Table 1. K increases profit in sunflowers.

K_2O	Yield seed	Oil yield	Increased value of oil
lb/A	lb/A	lb/A	$/A
0	1277	527	—
60	1965	870	79.15
120	2017	914	83.55
180	2082	932	81.45
240	2172	971	84.60
300	2033	916	84.25

K_2O — 11¢/lb Oil 25¢/lb Soil K level 60-90 lb/A, sandy loam

*Irrigated — 180 lb/A N applied MN

Table 2. N increases profits in sunflowers.

N	Yield seed	Oil	Increased value of oil
lb/A	lb/A	lb/A	$/A
0	1013	454	—
60	1746	777	71.75
90	1824	801	73.25
120	1866	812	71.50
150	1940	830	71.50
180	1940	823	65.25

Nitrogen — 15¢/lb Oil 25¢/lb

*Irrigated — 120 lb/A K_2O on entire field
N soil test level > 20 lb NO_3 N-2 ft. MN

Table 3. N and K fertilizer effects on percent oil in sunflowers.

N	Oil	K_2O	Oil
lb/A	%	lb/A	%
0	44.8	0	41.2
60	44.6	60	44.2
90	45.2	120	44.3
120	43.4	180	44.8
150	42.8	240	44.7
180	42.4	300	45.1
			MN

N, P & K BOOST SEED AND OIL YIELDS OF SUNFLOWERS

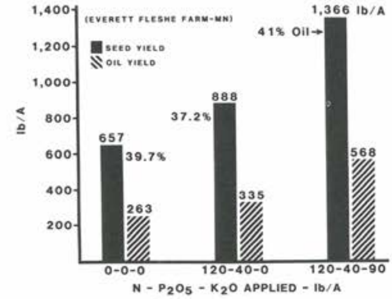


Figure 1

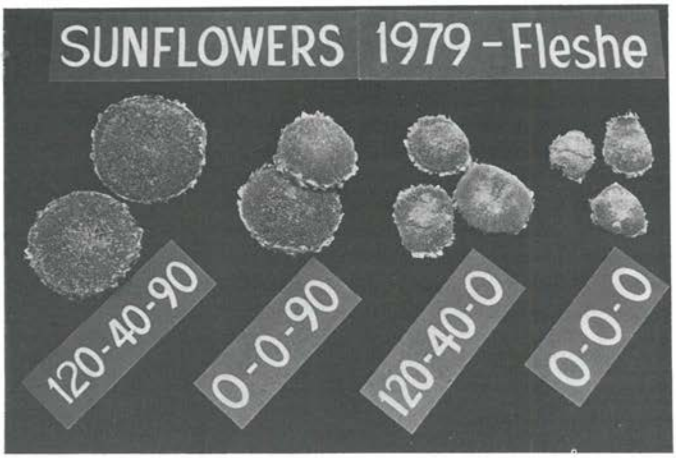
Table 3 shows how N and K fertilizer affected the percentage of oil in sunflowers. The percentage of oil in the harvested seed increased with increasing K rates. The percentage of oil generally declined with increasing N rates. But the increasing nitrogen rate did not decrease the total pounds of oil produced per acre.

Figure 1 shows the results of trials on the Everett Fleshe farm in Pennington County, northeast Minnesota.

These trials showed the value of K on sunflowers grown on sandy soils without irrigation.

Applying 90 lb/A of K_2O boosted oil yields 233 lb over the NP treatment. The potassium use returned approximately $58 for an investment of $10 in fertilizer.

The photo below illustrates the increased size of sunflower heads, especially when K was included in the fertilizer. Fertilization also increased the size of sunflower seeds. ■



In Some Areas

Wheat Grain Protein Content Can Predict Nitrogen Need

By R. Jay Goos, Dwayne Westfall, and Albert Ludwick

MOST OF THE WINTER WHEAT in the west-central Great Plains is grown in a wheat-fallow rotation. In the past, nitrogen (N) mineralized from soil organic matter provided enough N to meet the crop needs.

Decades of cropping, fallowing, and erosion have left the majority of the surface soils at or below 1.5% in organic matter content. Organic matter depletion, coupled with increased yield potentials due to better varieties and moisture conservation, have led to increased incidence of N deficiencies in eastern Colorado, western Nebraska and western Kansas.

Still, the concept persists that winter wheat grown after fallow does not require fertilizer.

Soil testing for available nitrogen (nitrate) can predict nitrogen needs. Problems exist with soil testing in eastern Colorado, however. There is little strip-cropping and the land is usually farmed in large, variable fields. It takes a significant effort to collect enough soil samples from these large fields to adequately characterize them for accurate recommendations. Currently, few wheat farmers in eastern Colorado test their dryland fields.

While soil testing is being promoted, the concept of grain protein content also emphasizes the problem of declining N fertility to Colorado growers.

It's generally agreed that wheat protein content is directly related to N available in the soil. We studied the feasibility of using protein content to diagnose the N fertility of growers' fields on a "rule of thumb" basis. Although most wheat growers in eastern Colorado have never used soil testing, they often know the protein content of wheat from their fields.

Data for this study are from 29 nitrogen-rate experiments conducted during the 1977-1980 growing seasons.

Results and Interpretation

In 1978 our data in **Figure 1** indicated that grain protein contents less than 12% were usually associated with insufficient nitrogen nutrition for maximum wheat yield. Data from the other three years of this study agreed with this general observation.

Data from all four years are summarized in **Figure 2.** Protein contents of 12% or higher were associated with sufficient N nutrition for maximum grain yields. Most of the overlap between the sufficient N and deficient N observations occur between 11-12% protein. **Below 11% protein, N deficiency limited yields in most observations. Table 1 presents a summary of data analysis.**

Dr. Goos is a soil scientist at North Dakota State University; Dr. Westfall is an agronomist at Colorado State University; Dr. Ludwick is Potash & Phosphate Institute western regional director at Davis, CA

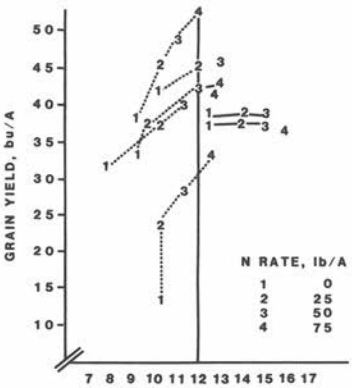


Figure 1

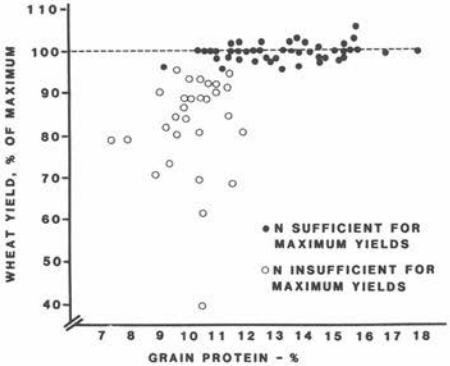


Figure 2

This simple approach requires four assumptions for guidelines to be applicable: 1) Nitrogen is the only element potentially deficient; 2) Nitrogen fertilization is accomplished early, well before floret intitiation; 3) Environmental conditions during grain filling are normal; 4) Weeds, diseases, lodging, and insects are not problems.

The guidelines in **Table 1** would not be appropriate for spring wheat or for winter wheat grown in other climatic regions. However, it should be possible for other researchers to use existing N response data for the interaction chi-square approach to develop post-harvest protein guidelines useful in their production areas.

Post-harvest wheat protein guidelines could have many uses:

1. Farmers not using N can learn from wheat protein information if their fields need a soil testing and fertilization program.
2. Farmers can better judge whether their N programs and application rates are generally adequate.
3. Areas approaching N deficiency can be identified so an educational effort can be launched.
4. Protein data are routinely obtained for the farmer to use in the marketing process.

Disadvantages include:

1. A post-harvest evaluation does no good for the crop just harvested.
2. Yield loss cannot be determined.
3. Future N rates cannot be predicted without N rate study data.

A post-harvest evaluation of a grower's N program provides mostly qualitative information on whether N applications for the past season were adequate. But, coupled with soil analysis for available N and knowledge of yield potential for the area, it can provide an accurate prediction for future N needs.

Post-harvest N evaluation of the grain could be a useful tool for increasing wheat yields and profitability in eastern Colorado and surrounding wheat producing areas. ■

Table 1. Guidelines for interpreting grain protein contents in eastern Colorado.

Protein content	Interpretation
Less than 11.1%	Probability greater than 95% that N deficiency limited yields.
11.1 — 12.0%	Transitional zone — difficult to determine if N was deficient based on protein alone.
Greater than 12%	Probability greater than 95% that factors other than N nutrition were limiting yield.

Weather and Technology Trend in Corn Yields

By Louis M. Thompson

AFTER A SPECTACULAR increase in the 1960's, there was considerable concern that corn yields were leveling off in the 1970's. This article shows that corn yields are still trending upward in relation to fertilizer use, and that weather was a significant factor in depressing yields in the mid-1970's.

Figure 1 compares the trend in nitrogen (N) fertilizer rates applied to corn in the five principal Cornbelt states from 1945 to 1980.

There was a sharp upturn in fertilizer use in the 1960's, which was associated with low cost of N in relation to corn prices and a decade of very favorable weather in the Cornbelt. The rate of fertilizer N applied to corn almost tripled in ten years.

The rate continued upward in the 1970's but at a slower rate. Price relationships and some unfavorable weather were largely responsible for the slowing of N fertilizer use.

Figure 2 shows the trend in corn yields in the five principal Cornbelt states from 1930 to 1980. The graph was developed from a crop/weather model published in 1969.

The dotted lines show the year-to-year variability in corn yields estimated by the U.S. Department of Agriculture. The solid lines show the year-to-year variability in yields calculated from weather data.

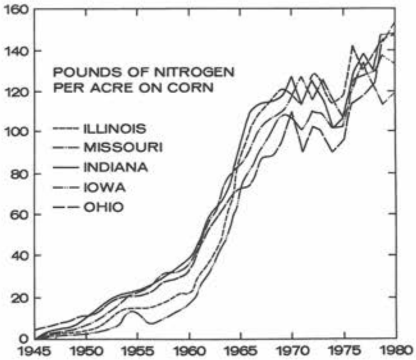


Figure 1

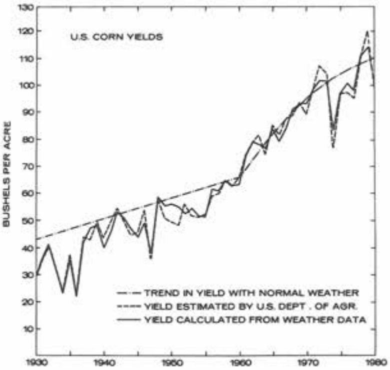


Figure 2

The model uses multiple curvilinear regression with time trends and six weather variables. The weather variables are: (1) precipitation from September through June; (2) July rainfall; (3) August rainfall; (4) June temperature; (5) July temperature; and (6) August temperature.

Each weather variable is treated as a parabolic relationship using a linear and squared term. There are two time trends: a linear trend from 1930 to 1960, and curvilinear trend from 1960 to 1980. The curvilinear trend was developed by using a linear and squared term for years—coded so that 1960 was year one and 1980 was year 21.

By assuming no departure from normal weather each year the regression equation can be used to calculate yield with "normal" weather. The term normal weather is used rather than "average" in this case.

Normal weather is good weather for corn. In ordinary regression analysis the regression line passes through the average, but in this case the line for normal weather indicates a favorable yield level.

Throughout the decade of the 1930's corn yields were depressed by lower than normal rainfall and above normal temperature. There were periods of unfavorable weather in the 1950's and 1970's associated with drought.

The 1940's were generally favorable, and the 1960's represented the best weather known in Cornbelt history. This decade of favorable weather stimulated rapid increase in fertilizer use.

Other Factors

While the yield trends are correlated with N fertilizer use, it should be recognized that there are many other factors associated with high yields. These factors include: other nutrients, better control of weeds, insects and diseases; better timing in planting and harvesting; better drainage and some irrigation; better seeding practices including higher population and better varieties in particular.

Researchers have shown that improved varieties have contributed about 50 bu/A toward higher yields.

Climate Change

Finally, there has been an improvement in climate for corn in the Corn Belt since 1930. This change is associated with a cooling trend. The trend has also been associated with increased summer rainfall.

By holding technology constant in the regression equation and substituting weather data from 1890 to 1980 one can calculate the corn yield for any year from 1890 to 1980, assuming a given level of technology. The results of such an analysis indicates that corn yields are about 10 bu/A higher as result of climate change from 1930 to 1980.

As for future corn yields, one must recognize that a new breakthrough in technology might occur. But even with trends in present technological developments, one might expect yields to improve about one bushel per acre per year with normal weather during the next decade. ■

Dr. Thompson is Associate Dean of Agriculture, Iowa State University, Ames, Iowa.

Soybean Yields Continue to Increase

By W. M. Walker, E. R. Swanson, and S. G. Carmer

IN MANY PARTS OF THE WORLD the soybean is recognized as a valuable vegetable protein addition to the human diet and a protein supplement in animal feeds.

Thus, there's reason for concern if soybean yields have reached a yield plateau in major production areas. Since Illinois and U.S. soybean yields are major components of annual world production, an evaluation of trends in production should help estimate future supplies. Limited acreage available for crop production places considerable emphasis on production per unit area.

Illinois average soybean yields have been recorded since 1919 and U.S. yields since 1924.

In a study of yield trends with linear piecewise regression analysis, we used average soybean yields as the dependent variable and time (years) as the independent variable. Over 90% of the variation in soybean yields in each data set was explained by the regression models.

Figure 1 illustrates the trends in soybean yields for the U.S., Illinois, and Allerton Trust Farms. Both Illinois and U.S. soybean yields increased an average of about 0.5 bu/A/yr until 1941. This was a period when soybeans developed into a major grain crop. Both researchers and producers were learning techniques of soybean production.

From 1941 to 1956 the annual rate of increase in soybean yield was slightly less than 0.25 bu/A for both Illinois and the U.S. During this period corn yields were increasing at a rate of over one bu/A/yr. Corn may have competed for the interest of both producer and researcher. Also, there was not a large competitive grain market for soybeans such as we have at present, so marketing interest was probably much less.

From 1956 to 1979 the annual increase in soybean yields in Illinois was 0.47 bu/A; for the U.S. it was about 0.35 bu/A. During this period a large and competitive national and world-wide market has developed for soybeans and soybean products.

Both researcher and producer interest in soybeans has increased with a subsequent increase in total acreage and yield per acre.

In general, soybeans have responded well to a combination of management practices such as row width, fertility, variety selection and weed control. An individual producer may improve yields through improved management practices. Similarly, researchers have determined that one or more combinations of practices will improve yields under given conditions.

Results of this analysis of the trend in soybean yields indicate that annual average yields are continuing to increase in both Illinois and the U.S.

Allerton Trust Farms

The Allerton Trust Farms in Piatt County, Illinois, are managed by the University of Illinois Department of Agricultural Economics. Allerton

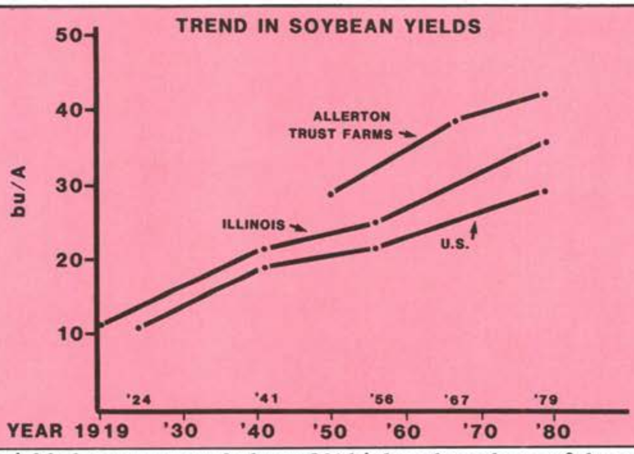


Figure 1

soybean yields have averaged about 9% higher than those of the surrounding county. These data were analyzed to determine the trend in yield from a "well managed" farm.

Figure 1 includes the trend in Allerton soybean yields from 1950 to 1979. From 1950 to 1967 yields increased about 0.56 bu/A/yr; from 1967 to 1979 they increased about 0.28 bu/A/yr. During the early period, yields increased more rapidly than either state or U.S. yields, but the rate of increase in yields has declined during the most recent period.

Presumably the most timely agronomic and economic research is more readily available for use by the Department of Agricultural Economics than would be the case for the average producer in Illinois or the U.S.

If so, then the decline in rate of annual increase in soybean yields at the Allerton Trust Farms or any other "well managed" system should be of great concern to research administrators, soybean researchers, and others concerned with national and world food supplies.

If the rate of increase in yield has declined or is declining on "well managed" farms, then undoubtedly such will be the case for state and national yields in the future unless the trend toward a decline is reversed.

Slower Increases

Our analyses do not show that a plateau or "leveling off" of Illinois or U.S. soybean yields has occurred. However, trend analysis of soybean yields from the Allerton Trust Farm indicates that the **annual rate of increase** in yield per acre has decreased. If the results at Allerton portend the Illinois or national future, then the rate of increase in yield can be expected to decline in the future.

It has been suggested that current producers of crops are rapidly consuming available technology. Thus, further improvements in soybean production technology will be needed to maintain or increase production per unit area.

New technology is largely developed through research. Unfortunately, the cost of conducting research is increasing. It is tempting to budget-cutters to decrease rather than increase research budgets.

Administrators in both the public and private sectors of society must realize that discovery of new technology involves both time and money. Restoration of a depleted research organization may be more costly than maintenance would have been. Adequate salaries and operating budgets are necessary for development of necessary soybean production technology so that annual yield increases can be maintained or enhanced. ■

Dr. Walker is Prof. of Biometry and Soil Fertility; Dr. Swanson is Prof. of Agricultural Economics; Dr. Carmer is Prof. of Biometry; all are located at the University of Illinois.

Sulfur for Corn on Sandy Soils

By George W. Rehm

IN 1952, corn growing on sandy soil in Pierce County, Nebraska developed a yellow color. It was caused by sulfur (S) deficiency and corrected by application of Epsom salt ($MgSO_4H_2O$).

That early discovery of the need for sulfur fertilizer has stimulated continued studies of the use of S for corn production in Nebraska.

Initial studies generally showed small yield responses. Often, the differences in growth brought about by use of S fertilizers disappeared as the season progressed.

Sulfur for irrigated corn

Development of automated sprinkler irrigation systems prompted a shift of S studies for corn from dryland to irrigated production. From 1973 through 1975, the use of S fertilizers for production of irrigated corn was examined at several sandy sites in northeastern and northcentral Nebraska. Results from six locations are summarized in **Table 1.**

Table 1. Irrigated corn responses to S on sandy soils, NB, 1973-1975

Rate of Sulfur	1973		1974		1975	
	Pierce	Holt	Pierce	Holt	Pierce	Holt
lb/A	bu/A					
0	163	165	143	98	112	186
10	—	—	163	110	130	187
15	184	154	—	—	—	—
20	—	—	170	110	132	187
30	182	157	167	101	133	190
40	—	—	—	—	133	186
45	182	155	—	—	—	—

Yields for each rate of applied sulfur are averaged over the sources of sulfur used. There were no source by rate interactions.

Soluble sources equal

Several soluble fertilizer materials were broadcast to supply the rates of S used in the studies. The data indicated that the source of S had very little effect on yield. The yields presented in **Table 1** are averages of all sources used.

Not all sites alike

Before 1973, it was assumed that S would be needed for corn production on all sandy soils in Nebraska. The application of S, however, had no effect on yields at the sandy sites in Holt County in 1973, 1974, and 1975. Yet, yields

Dr. Rehm is with the University of Nebraska, Northeast Experiment Station, Concord, NB.

Table 2. Organic matter and SO_4-S content of the soils at the experimental sites in Pierce and Holt Counties, NB.

Year	County	Organic matter content	$SO_4^=$-S
		%	ppm
1973	Pierce	.89	4.7
	Holt	1.40	5.6
1974	Pierce	.97	3.8
	Holt	3.77	12.1
1975	Pierce	.85	2.7
	Holt	2.15	7.9

Table 3. Irrigated corn responses to starter sulfur, NB

Sulfur Applied	Year 1978	1979
lb/A	bu/A	
0	160	154
6	171	174
12	173	179
18	174	180

responded positively to fertilizer S at the sandy sites in Pierce County during the same three years.

Why the difference?

Analysis of the soil samples showed some variation in the amount of $SO_4^=$-S in the soil, **Table 2.** But these values do not provide a very good explanation for the difference in response. Although the soils at all sites were sandy, there were major differences in the **organic matter** content of the surface soil.

About 90-95% of the total amount of S in soils is present in the organic matter. So it is reasonable to assume that the S released from the breakdown of the organic matter combined with the S supplied in the irrigation water was sufficient to meet the S requirements of the irrigated corn at the Holt County sites. With low levels of organic matter, the corn in Pierce County responded to the application of fertilizer S.

It's also important to note that relatively low rates of fertilizer S were needed to achieve the highest corn yields at these sites. These rates were much lower than the rates of nitrogen (N) and phosphorus (P) needed to achieve maximum yields on the same soils. Possibly still higher yields could have required higher S rates but data are scarce.

Sulfur in a starter fertilizer

The studies from 1973 through 1975 involved broadcast application of S. To gain more information, later studies were designed to focus on the use of S in a starter fertilizer. Potentially responsive sites low in S and organic matter were selected for this study.

There were substantial responses to the use of S in a starter fertilizer in both 1978 and 1979, shown in **Table 3.** Again, S source had no effect on yield. So the yields listed in **Table 3** are averaged over all sources used.

The response to S reached a maximum at the 12 lb/A rate of sulfur applied in a starter. Although a deficiency of S can create a substantial yield reduction, these data show that S applied close to the seed can be very effective.

A direct soil test for sulfur?

Recommendations for S use for corn in the Great Plains would be simpler if all sandy soils responded uniformly to the application of S. Field data, however, show that this is not the case.

Can we rely on a soil test for S in the same way that we use soil tests as a basis for making fertilizer recommendations for nitrogen, phosphate, potash, and zinc? Although widely accepted soil test procedures exist for other nutrients,

Table 4. Sulfur recommendations for corn on sandy soils, NB

Content	Organic matter content (% in top 8 inches) Less than 1.0%	Greater than 1.0%
ppm		
0 to 5	15 lb/A S in a starter + 25 lb/A S broadcast	15 lb/A S in a starter or 25 lb/A S broadcast
6 to 8	15 lb/A S in a starter or 25 lb/A S broadcast	None
Greater than 8	None	None

this is not the case with S. No single procedure has been accepted as being completely suitable for predicting the S fertilizer requirements of crops.

Two chemical procedures are combined for making S recommendations for corn on sandy soils in Nebraska. Sulfate-S is extracted with a calcium phosphate solution. This value is combined with the soil organic matter content in making S recommendations, **Table 4.**

It is also important to know the S content of irrigation water. Sulfate-S in water is a readily available S source for plants. If the S content of the water is 6 ppm or greater, no broadcast S is recommended and S applied in a starter fertilizer should be adequate for maximum yields.

Admittedly, this method of arriving at S recommendations for corn is not perfect. The data, however, suggest that this method is superior to generalized statements that broadcast, preplant S fertilizer will be needed for corn on all sandy soils.

Supplemental S in the irrigation water may be needed on low organic matter soils where $SO_4^=$-S values in the water are less than 6 ppm. Growers should remember that S deficiencies may be magnified by cold, wet conditions prior to and following seeding—especially on coarse textured, low organic matter soil. ■

New Folder

Soil Testing for High Yield Agriculture

FARMERS should use every helpful tool available during these days of economic stress. Soil testing offers a useful means of monitoring soil fertility status. It can help with fertilizer needs when used along with other diagnostic aids and experience.

Some questions have been raised recently about the reliability of soil tests and their interpretation.

A new folder from the Potash & Phosphate Institute looks at some points that should be recognized if soil tests are to be used wisely in modern high yield farming.

For more information, contact:

Potash & Phosphate Institute

2801 Buford Hwy., N.E., Suite 401

Atlanta, GA 30329

PHONE: (404) 634-4274

Long Term Study

Corn Yields with Fertilizer Rates from Zero to High

By W. L. Parks and Lawson Safley

WHAT CROP YIELDS could be expected if no fertilizers were available over a long period of time? What yield levels do soil test recommendations produce? And what happens when high amounts of N, P, K, minor elements, and manure are applied?

Twenty years of data from a long-term corn fertilization experiment at the Highland Rim Experiment Station in Tennessee help answer these questions. The study compared four treatments on Dickson soil.

The June and July rainfall has been closely related to corn yield. During eight of the years, the June-July rainfall was 2 inches or more above normal. Corn yield was the highest during most of these eight years.

Corn yield was lowest in 1966, 1980, and 1975. June-July rainfall was lowest in 1964, with 1975 and 1966 next to lowest. In 1980, August rainfall was only 1.65 inches.

Figure 1 shows corn yield trends with these treatments: no-fertilizer; soil test fertilization; high fertilizer and minor elements; and with high fertilizer, minor elements and manure.

In the no fertilizer treatment, the plant population was 12,000 plants per acre in 42-inch rows.

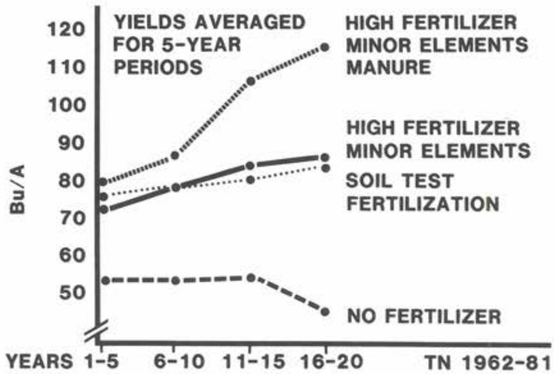
In the soil test fertilization treatment, the plant population was 18,000 plants per acre in 42-inch rows.

In the high fertilization treatments, the plant population was 18,000 plants per acre in 30-inch rows.

THE NO-FERTILIZER plots yielded an average of 51.8 bu/A from 1962

CORN YIELDS AS RELATED TO FERTILIZER

Figure 1



Dr. Parks is Professor, Department of Plant and Soil Science, University of Tennessee. Lawson Safley is superintendent, Highland Rim Experiment Station.

through 1981—20 years of continuous corn.

The yields ranged from a high of 65.2 bu/A in 1971 to a low of 32.5 bu/A in 1980. The yield was below 50 bu/A in nine of the years.

THE SOIL TEST FERTILIZATION plots averaged 78.8 bu/A over the same period.

The yields ranged from a high of 120.9 bu/A in 1981 to a low of 32 bu/A in 1980. The yields were above 100 bu/A for five years and below 50 bu/A in only three of the years.

This treatment received 120 lb/A of N each year. No phosphate or potash was applied during the first three years of the experiment.

In 1965, 1966, 1968, and 1972 the fertilizer application included 30 lb/A of P_2O_5 and 30 lb/A of K_2O. In all other years, 50 lb/A of P_2O_5 and 50 lb/A of K_2O were applied.

THE HIGH FERTILIZATION treatment produced a higher average yield—79.5 bu/A over the 20 year period.

Yields ranged from a high of 129.3 bu/A in 1976 to a low of 23.3 bu/A in 1980. Yields were over 100 bu/A during seven years and below 50 bu/A for 5 years.

This treatment received 300 lb/A of N, 100 lb/A of P_2O_5, and 300 lb/A of K_2O, plus 50 lb/A of a mixture of minor elements.

THE HIGH FERTILIZATION plus manure averaged 97.6 bu/A over the years. This means that the yearly application of 10 tons manure per acre was worth more than 18 bu/A of corn.

This effect was undoubtedly due to improved physical condition of the soil—primarily increased aeration, infiltration, permeability, and water holding capacity.

Yields ranged from a high of 177.3 bu/A in 1976 to a low of 25.7 bu/A in 1966. Yields were over 100 bu/A half the time and below 50 bu/A in only three years.

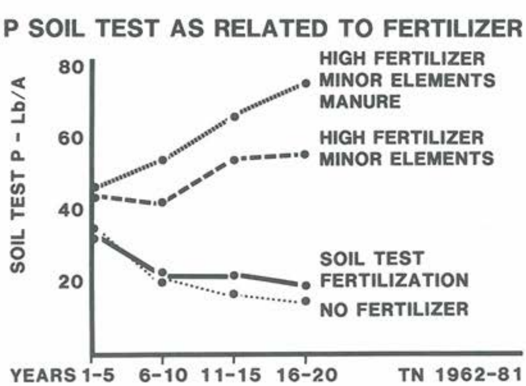
The soil test fertilization increased yields over no fertilizer by 72.7 bu/A in 1981, 63.1 bu/A in 1979, 47.1 bu/A in 1963, 46.5 bu/A in 1973, 40.9 bu/A in 1976, and 37.9 bu/A in 1970.

The two treatments yielded essentially the same in 1969, 1975, and 1980. In 1966, the no-fertilizer treatment yielded slightly more than the soil test fertilization treatment.

The yield difference between soil test fertilization and heavy fertilization plus minor elements ranged from minus 15.5 bu/A in 1969 to plus 27.9 bu/A in 1976.

The high fertilization plus manure produced the highest yields every year but two. In 1967 soil test fertilization produced 3.8 bu/A more and in 1980 the

Figure 2



unfertilized corn produced 1.2 bu/A more than the high fertilization plus manure.

The greatest yield increases were 48 bu/A in 1976, 43.5 bu/A in 1979, 24.5 bu/A in1974, 22.8 bu/A in 1981, 20.2 bu/A in 1972, and 20 bu/A in 1969.

SOIL TESTS. Figures 2 and 3 illustrate the trend in P and K soil test as related to fertilizer during the 20 years.

The test results for 1962 and 1963 were from composite samples taken over the entire experimental area. The area had been cropped previously and the soil test levels of P, K, and pH were high.

All plots were treated with 3 tons/A of lime in the spring of 1965. Application was repeated on the high fertilizer plots in the spring of 1970, 1974, and 1979.

During the first 15 years, the no-fertilizer and soil test fertilization treatments received 3 tons/A of lime while the two high fertilizer treatments received 12 tons/A.

The pH values indicate that the high fertilization rates reduced the soil pH to critical levels in about 3 to 4 years after a heavy lime application. The pH of the unfertilized treatment has remained near neutral. And the pH of the soil test treatments has dropped about 0.5 units since the 1965 lime application.

SOIL PHOSPHORUS LEVELS tested extremely high when the experiment started (26 lb/A is considered high).

In the unfertilized treatment, the P soil test values declined steadily over the years. And by 1975 the P test had reached a low level (15 lb/A or below).

In the soil test fertilization treatment, the soil phosphorus values were very high at the start. But soil P declined to medium (16 to 25 lb/A) by 1965. It remained in the medium range but has declined slowly through the years.

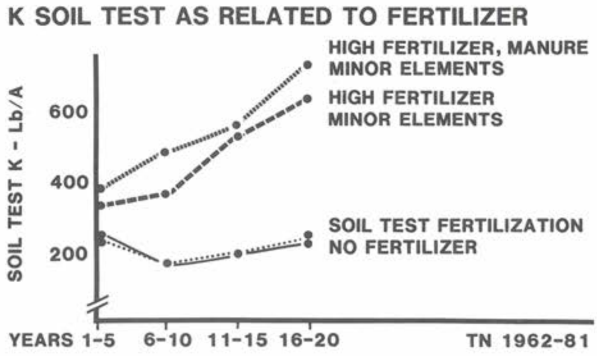
In the two high fertilization treatments, the soil P values were very high at the start and remained in the high and very high range throughout the experiment.

SOIL POTASSIUM LEVELS tested high (200 lb/A is considered high) at the start and remained in the medium and high levels throughout the 20 years in the no-fertilizer and soil test fertilization treatments.

In the two high fertilizer treatments, the soil K levels tested very high throughout the experiment and has gradually increased throughout the years. The treatment receiving manure tested about 600 lb/A of available K in 1976—or 150 lb/A higher K than the high fertilizer treatment not receiving manure.

These results indicate that corn yields ranging from about 45 to 50 bu/A might be expected with "no-fertilizer farming," if soil has been limed and has a high level of available P and K. ■

Figure 3



Have Corn Yields Reached a Plateau?

By W. M. Walker, E. R. Swanson, and S. G. Carmer

FOOD PRODUCTION and potential food deficits are receiving increased attention from world and national leaders. Food exports to help pay for oil imports have made crop production in the U.S. an important consideration in foreign policy.

Some prognosticators suggest that crop responses to various inputs have "leveled off" or that crop yields have reached a plateau. Others suggest that sufficient technology is available to not only maintain but further improve yields.

Corn Production

An analysis of corn production history in Illinois and the U.S. may help us determine "where we are" in terms of yield potential for the 1980's.

Total yield can be increased through expanded acreage or increased yield per acre. But there is limited area available that is suitable for expansion in grain production, so total corn production will change through improvements in technology or changing the ratio of corn acreage to acreage of other crops.

Record Yields

In 1979 record corn yields per acre were harvested in Illinois and the U.S. However, in 1980 moisture deficits along with high seasonal temperatures led to a decrease in corn yield per acre in Illinois and several other states.

In 1981 yields increased again to record levels. What are reasonable expectations for the 1980's?

State and national average corn yields per acre have been recorded since 1866. A statistical analysis of these data helps in predicting future yields.

The statistical methods used have been characterized by various terms such as "lineau splines" or "linear piecewise regression analysis." More technically oriented readers can review its development in the literature. This report presents results obtained with the technique in a study of trends in corn yields.

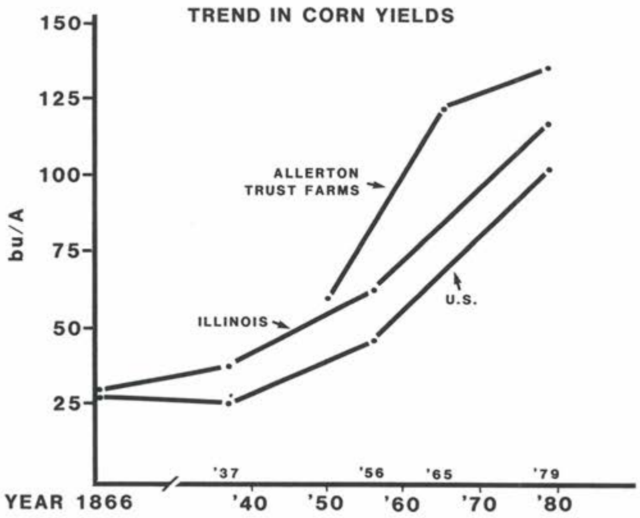
Figure 1 illustrates the trend in corn yields for the U.S., Illinois, and Allerton Trust Farms. From 1866 until 1937 corn yields increased about 0.12 bu/A/yr in Illinois but were relatively stable for the U.S.

For both the U.S. and Illinois the rate of increase in corn yield per acre began a dramatic change about 1937. From 1937 to 1956 per acre corn yields increased about 1.3 bu/yr in Illinois and about 1.09 bu/yr for the U.S.

From 1866 to 1937, corn yields increased about 8.5 bu/A in Illinois. But from 1937 to 1956 the change in average yield in Illinois was about 25 bu/A.

Dr. Walker is Prof. Of Biometry and Soil Fertility; Dr. Swanson is Prof. of Agricultural Economics; Dr. Carmer is Prof. of Biometry; all are located at the University of Illinois.

Figure 1



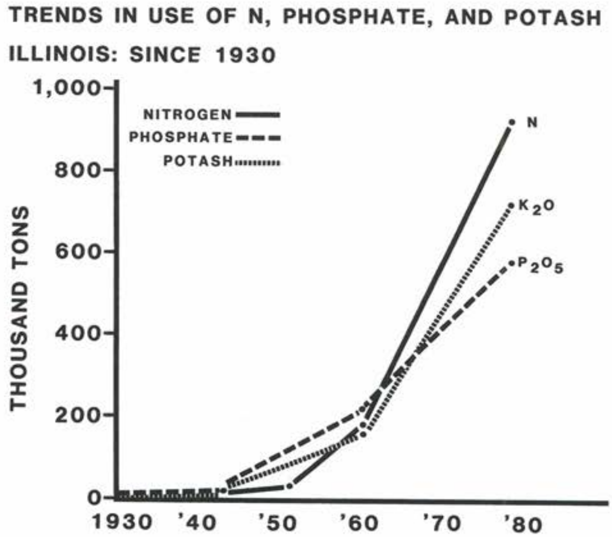
In a period of 19 years corn yields increased about threefold when compared with the previous 71 years.

From 1956 to 1979 annual increases in corn yields have been even more striking. Yields have increased nearly 2.5 bu/A/yr in the U.S. during this period—a 56 bu/A increase in 23 years! Few experts would have predicted such a possibility in 1956.

There are many reasons for the dramatic changes in corn production since 1937:

- About 25% of Illinois' corn acreage was planted to hybrids in 1937, up from 10% the previous year. But 1943 corn acreage planted to hybrids had increased to 96%.
- From 1930 to 1943 use of the major plant nutrients, nitrogen, phosphorus, and potassium, was relatively stable and at a rather low level in Illinois. From 1943 until the late 1950's and early 1960's the amount of fertilizer used in corn production increased at a rapid rate each year, as shown in **Figure 2.**

Figure 2



The rate of increased fertilizer use has been even greater in the 1960's and 1970's. A large part of fertilizer used in Illinois is for the 11 to 12 million acres of corn.

These two major management practices—hybrid selection and fertilizer use—undoubtedly have had a great influence on increases in corn yield in both the U.S. and Illinois.

As illustrated in **Figure 1,** the largest annual increases in corn yield have been obtained since 1956. Part of these annual yield increases also must be attributed to use of adequate quantities of major plant nutrients and to corn hybrids with improved resistance to lodging and other favorable charcteristics.

Research has also shown that, in the Midwest, higher plant populations and earlier planting contribute to significant yield increases. Larger farm equipment makes it more feasible for producers to aim for earlier planting dates. For example, the percentage of Illinois corn planted by May 10 almost doubled between the early 50's and early 70's.

Trends

Corn yields averaged 93 bu/A in Illinois and 91 bu/A in the U.S. in 1980. As shown in **Figure 1** the predicted yield for 1979 was less than the yield that was harvested. For 1980 the predicted yield was greater than that actually harvested.

Such deviations about a trend line have occurred in the past and are to be expected in the future. Results of our analysis support the conclusion of others: corn yields have not yet plateaued.

Allerton Trust Farms

The Allerton Trust Farms in Piatt County in central Illinois are managed by the University of Illinois Department of Agricultural Economics. A recent publication indicated that corn yields on this farm have been 13% higher than in the surrounding county.

Presumably, crop management would be at a higher level than that of the average Illinois or U.S. farm. Therefore, an analysis of corn yields from the Allerton Farms should provide an evaluation of trends in yield under a relatively high level of management.

Figure 1 illustrates results from analysis of Allerton Farm corn yields. During the first period from 1950 to 1965, annual increases in yield were about 4.3 bu/A. However, during the period from 1965 to 1979 average increases in yield have been slightly less than one bu/A.

Even though average yields at Allerton are higher than in the surrounding county, the rate of increase is of major concern. A slowing of the rate of increase in yield from a well managed farm suggests that large annual increases in production from all farms may not continue.

Analysis of these data indicate that the **rate of increase in corn yields from the Allerton Trust Farms is less than the rate of increase in corn yields in Illinois or the U.S.**

It is probably true that corn yields at Allerton are not yet the agronomic maximum. But corn producers face similar kinds of economic and biological constraints as those at Allerton. In terms of corn for consumption or for export, economics as well as corn production technology affect the supply of corn. So both must be considered in future yield predictions.

Summary

Our analyses of the trends in corn yields for Illinois and the U.S. show no evidence that a plateau in corn yield has occurred. For the near future, current evidence suggests further increases in average yield per acre. Producers as a group have not exhausted the supply of corn production technology.

Corporate, national, and state budget-cutters may be tempted to dismantle research for a period of time. But they should be reminded that start-up costs will increase, just as annual research costs have been increasing.

In fact, some research is necessary just to maintain current yields since new pests that attack corn may evolve or be imported. Maintenance research is not very realistic from either practical or scientific viewpoints.

Evidence based on analysis of Allerton Trust Farm corn yields does suggest that the **rate of increase in corn yields** at high levels of management is decreasing.

Further improvement in corn yield per acre may occur through: 1) a major research accomplishment with an import similar to that of hybrid corn, 2) delineation and improvement of management practices such as a specific hybrid, fertilization and tillage practice for a specific soil environment, 3) more favorable economics such as a higher price for the product or lower cost of production, and 4) more extensive use of irrigation in corn producing regions.

High corn yields have been achieved through intensive research. To insure even higher yields, sufficient research must be conducted to continually replenish technology that is consumed by producers.

New ideas haven't "gone out of style" but, unfortunately, the cost of testing them in the laboratory and field has greatly increased.

Whether we can afford further sophisticated research to improve corn production depends upon the allocation of research funds by administrators and research funding by private and public sectors. Improved funding of research is necessary to develop new and improved corn production technology to maintain or increase present annual yield increases. ■

In Arizona

What Are Nutrient Needs of High Yield Alfalfa?

By Dale Smith and A. K. Dobrenz
University of Arizona

SOME ALFALFA HAY producers in the Colorado/Gila River Valley near Yuma, Arizona have matched experimental plot yields of 14 tons/A. Even higher yields appear possible.

But these high yields can be attained only with an adequate supply of soil nutrients and with proper irrigation-water management.

Alfalfa is a heavy feeder on potassium (K), phosphorus (P), magnesium (Mg), and other major and minor elements. For example, a 15 ton/A crop would remove 850 lb of K, 100 lb of Mg, and 90 lb of P. Yet specific critical limits for nutrients in alfalfa are not well defined for high yield levels. Higher concentrations may be needed to sustain top yields, forage quality and stands through the years.

Tissue Tests

Preliminary tissue tests in 1979 near Tucson and Mesa, Arizona indicated possible lack of sufficient Mg and P for maximum growth and yield in some alfalfa fields. Therefore, in spring 1980 the second crop of alfalfa was sampled at first flower in 49 fields throughout the main growing areas in Arizona.

Suggested minimum sufficiency levels in alfalfa herbage at first flower of the first or second harvests are: phosphorus, 0.30%; magnesium, 0.35%; and potassium, 2.80%. These values are for maximum growth and yield in Arizona. The tissue survey of 49 fields showed that 25% of the alfalfa fields contained a tissue-P level of over 0.30% (dry weight of the shoots) and that 49% contained a level of P between 0.25 to 0.29%.

However, 18% of the alfalfa fields contained only 0.20 to 0.24% P; 8% contained between 0.15 to 0.19% P. **Figure 1** shows the results.

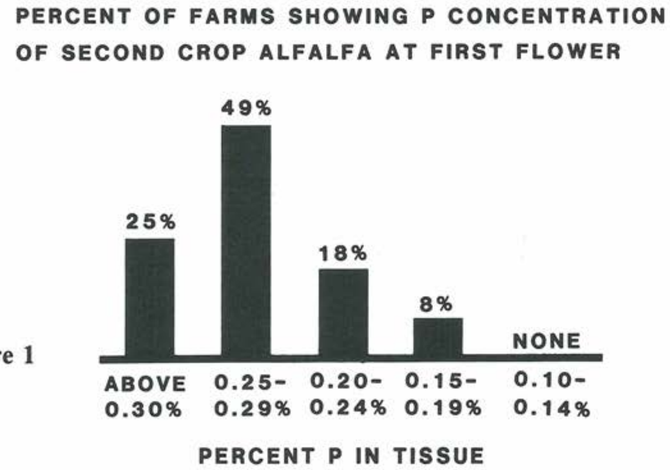


Figure 1

The tissue survey showed that 6% of the alfalfa fields contained more than 0.35% Mg (dry weight of the shoots), 22% contained between 0.30 to 0.34% Mg, and 31% of the fields contained between 0.25 and 0.29% Mg. See **Figure 2.** However, 27% of the alfalfa fields contained betwen 0.20 to 0.24% Mg and 14% contained between 0.10 to 0.19% Mg.

In Arizona, K fertilization usually has not resulted in increased alfalfa hay yields. The tissue survey showed that 21% of the alfalfa fields contained a tissue-K level of over 3.50% (dry weight of the shoots), 49% of the fields were

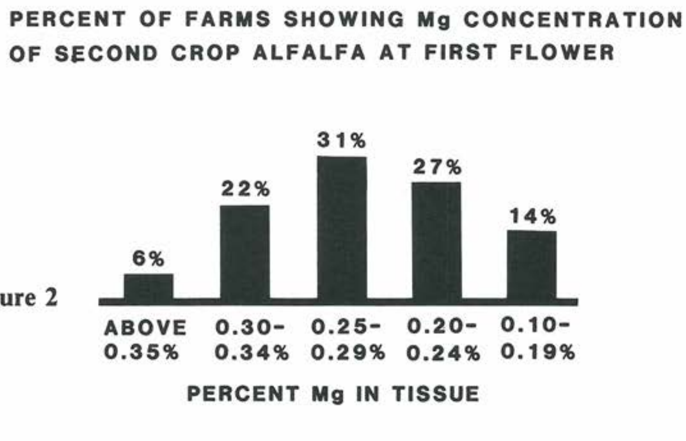


Figure 2

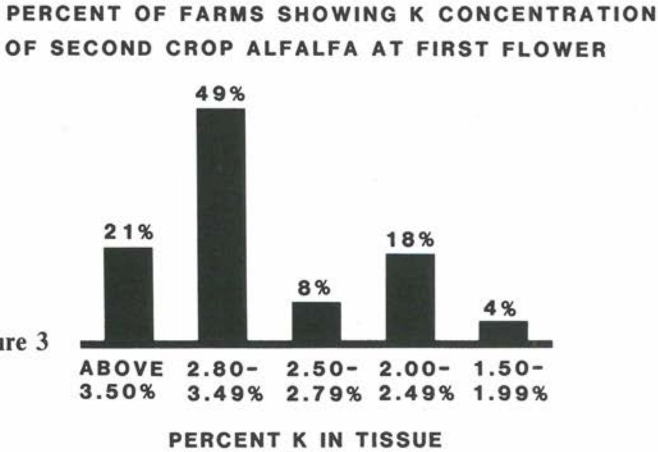


Figure 3

between 2.80 to 3.49% K; 8% were between 2.50 to 2.79% ; 18% were between 2.00 and 2.49% K, and 4% were between 1.50 to 1.99%. See **Figure 3.**

Fields in the lower categories of tissue P and K were scattered throughout the state.

However, the alfalfa in certain areas was much lower in Mg. Highest tissue-Mg levels were found in the Colorado-Gila River area of Yuma County, where ten fields average 0.32% Mg. On the other end of the scale, four fields in the Safford area (Graham County) averaged only 0.18% and four in the Avra Valley (Pima County) averaged only 0.14% Mg.

All of the alfalfa tissue samples appeared to contain satisfactory levels of Zn (only 6 fields were below 20 ppm), Mn (only 5 fields were below 25 ppm), S (only 2 fields were below 0.30%), Ca, Cu, Fe, and B. One field in Yuma County irrigated with pump water contains a high tissue-boron level of 110 ppm.

Soil Analyses

Soil analyses for 10 elements also were made on 34 of the 49 fields. There were no significant correlations between nutrient levels in the soil and those in the topgrowth. The soil was analyzed by Midwest procedures and may have incorrectly estimated the soil availability of P and certain other nutrients due to their high pH and calcium content. About 79% of the soils had a pH between 8.0 and 8.5, and the remainder were all over pH 7.0.

However, a soil test does not always indicate the relative amounts of the soil nutrients the plant can or does absorb from the soil. Various environmental factors can alter the ultimate absorption of nutrients by plants.

Greater use of tissue-analysis in Arizona would assure that the crop is obtaining sufficient amounts of nutrients for maximum growth and yield. Tissue-analysis of the entire nutrient profile (10 to 12 elements) offers a diagnostic tool to ascertain whether plants obtain sufficient amounts of the individual elements.

Summary

This survey provides insight into the nutritional status of alfalfa in its principal growing-areas of Arizona. Low tissue levels of Mg appear to be more widespread than those of P or K.

Alfalfa response to fertilization with these nutrients will receive more study in the field and the greenhouse. ■

Take-all

Fertilizers Suppress Wheat Disease

By Neil W. Christensen
and Ronald G. Taylor

Oregon State University

TAKE-ALL ROOT ROT is one of the major diseases limiting wheat yields under high rainfall and irrigated conditions in Oregon. Increased frequency of wheat in the crop rotation has also contributed to the increased incidence and severity of the disease.

The soil-borne fungal pathogen *Gaeumannomyces graminis* var. *tritici.* causes take-all in wheat. Disease attack results in rotten, blackened roots with infection extending to the crown and basal stem in severe cases.

Infected plants are stunted and mildly chlorotic. They have few tillers and they ripen prematurely. Heads of infected plants may be bleached (whiteheads) and contain few kernels. Effective fungicides and sources of genetic resistance are not available.

Several conditions and practices increase take-all severity: planting wheat following wheat or other crops which host the fungus; early planting, which favors early infection and establishment of the fungus; mild winters and cool springs; wet soils; slightly acid to alkaline soils; and uptake of nitrate-nitrogen (NO_3-N) by wheat plants.

Research conducted with T. L. Jackson, Department of Soil Science, and R. L. Powelson and M. E. Halsey, Department of Botany & Plant Pathology, shows that crop management and fertilization can suppress take-all.

These practices reduce severity of the disease: (1) delayed seeding; (2) banding ammonium-nitrogen (NH_4-N), phosphorus (P), and chloride (Cl) with the seed at planting; and (3) spring topdressing with NH_4-N and Cl containing fertilizers.

Figure 1 illustrates effects of liming and delayed seeding on grain yield of wheat grown on a Willamette silt loam soil at the North Willamette Experiment Station (NWES). Lime application in 1969 increased soil pH and reduced grain yield of the 1977-78 wheat crop infected with take-all root rot. Delayed seeding increased grain yield substantially at all soil pH levels.

In contrast to the effects of lime on

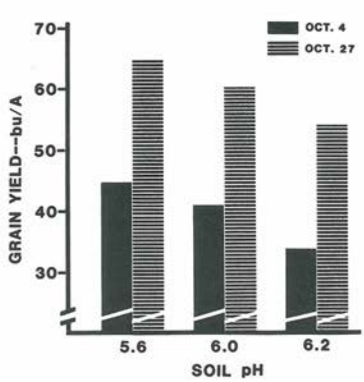


Figure 1

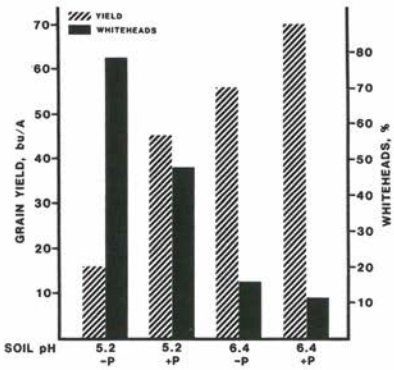


Figure 2

moderately acid soils, liming a severely acid Nonpariel clay loam soil reduced take-all severity and increased grain yield as illustrated in **Figure 2.**

Banding 60 lb/A of P_2O_5 with the seed at planting reduced the severity of take-all and increased grain yield on both limed and unlimed plots.

Aluminum and manganese toxicity and decreased P uptake often reduce root and plant vigor of wheat on severely acid soils. Limited development of new roots probably contributed to the increased severity of take-all at pH 5.2.

Our results suggest that liming severely acid soils benefits wheat plants more than it benefits the pathogen and that the reverse is true when moderately acid soils are limed.

The form of applied N and Cl also influences the severity of take-all root rot as illustrated in **Figure 3.** Rates of 30 lb/A of N banded with the seed plus 120 lb/A of N topdressed in March increased grain yield.

Plots receiving NO_3-N [$Ca(NO_3)_2$ treatment] had slightly lower yields and more severe take-all than did plots receiving NH_4-N [$(NH_4)_2SO_4$ treatment]. The application of Cl and NH_4Cl further reduced the percent root attack by take-all and increased grain yield.

Table 1 shows that both fall and spring Cl applications have increased yields of wheat crops infected with take-all root rot. These data also illustrate that chloride-containing salts other than NH_4Cl can be used to suppress the disease.

Chloride applied in either fall or spring as NH_4Cl, KCl, or NaCl increased wheat yields on a Willamette silt loam at the Keyt location.

At the NWES location, the highest yields were obtained with NH_4Cl plus KCl or NaCl banded at planting and followed in the spring with topdressed NH_4Cl.

On a Woodburn silt loam soil at the Hyslop location in 1979-80, fall applied $(NH_4)_2SO_4$ plus KCl was nearly as

Figure 3

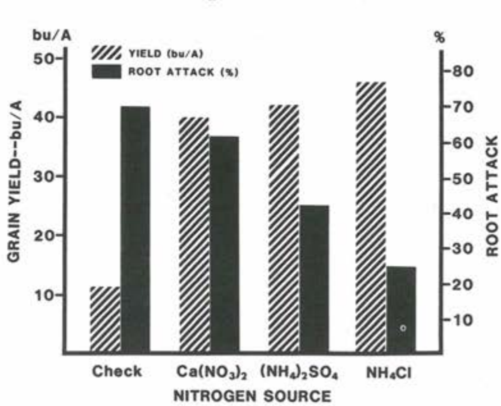


Table 1. Yield of winter wheat infected with take-all — as influenced by N and Cl sources

Fertilizer Treatment*		Grain Yield			
Fall	Spring	Keyt 1979-80	NWES 1977-78	Hyslop 1979-80	Hyslop 1980-81
		bu/A			
check		38	17	22	—
AS	AS	100	60	81	62
AC	AS	112	—	—	59
AS	AC	110	—	—	74
AC	AC	115	66	101	75
AS+KCl	AS	120	61	97	—
AS+NaCl	AS	110	70	—	—
AC+KCl	AC	113	74	100	—
AC+NaCl	AC	120	74	—	—
AS	AS+KCl	110	—	—	—
AS	AS+NaCl	108	—	—	—

*AS = ammonium sulfate; AC = ammonium chloride; KCl = potassium chloride; NaCl = sodium chloride.

effective in increasing grain yield as was NH_4Cl applied in both the fall and the spring.

In 1980-81, however, spring application of Cl was more effective in increasing grain yield at the Hyslop location than was fall Cl application. Cool, wet weather in 1980-81 contributed to severe outbreaks of stripe rust *(Puccinia striiformis)* and *Septoria* spp. leaf and head diseases which were held in check by spring Cl application.

Our research shows that growers can minimize losses due to take-all through cultural practices and fertilizer management. For best results, farmers should adopt a complete "package" of management practices where there's risk of take-all root rot. To combat take-all in western Oregon, here are our current recommendations:

1. Plant after October 20.
2. Plant last those fields with a high risk of take-all.
3. Band fertilizer with the seed at planting as follows:
   20 to 30 lb/A of NH_4-N; 40 to 50 lb/A of P_2O_5;
   35 to 40 lb/A of Cl; 10 lb/A of sulfur, or more if none was applied the previous spring or summer;
   30 to 40 lb/A of K_2O as KCl where soil tests indicate a need for K or Cl;
4. Topdress 75 to 125 lb/A of Cl with N applications in February or March.

Summary

Disease suppression from NH_4-N and Cl fertilization is not well understood. It may be related to stimulation of organisms antagonistic to the take-all fungus, a reduction in rhizosphere pH resulting from NH_4 uptake by the host, Cl suppression of nitrification, Cl suppression of NO_3 uptake by the plant through anion competition, and changes in the internal water status of plants due to Cl uptake. Research is continuing to unravel the mysteries of disease suppression through fertilization. ■

Soil and Fertilizer Phosphorus Determine Winter Barley Performance

By Wayne R. Knapp
Cornell University

PHOSPHORUS NUTRITION plays an important role in reaching higher yields with winter barley. Where winters are severe, P fertilization is critical for plant survival and spring growth vigor. These are the keys that determine final crop performance.

A series of experiments in New York state over the past several years studied winter barley response to P fertilization. The tests include 13 different barley cultivars on soils with P test levels ranging from low to very high.

At planting, superphosphate was band-applied one-inch below the seed at rates from 0 to 80 lb/A of P_2O_5. All trials had 100 lb/A of 0-0-60 and 30 lb/A of ammonium nitrate (NH_4NO_3) applied uniformly at planting. Another 150 lb/A of ammonium nitrate was broadcast in the spring. Seeding rate was 2 bu/A in early September.

Figure 1 shows the mean grain yield response of the 13 cultivars to phosphorus fertilization in each of the seven experiments. **Figure 2** shows the results for only the 1980 experiments. Soil test P values are from the Cornell

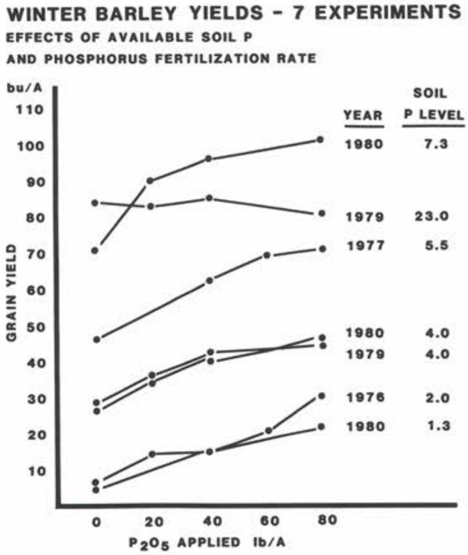


Figure 1

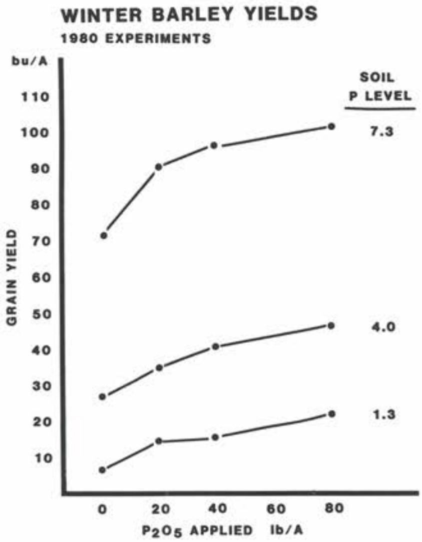


Figure 2

Soil Testing laboratory.

The scale for available P is 1-3, low; 4-9, medium; 10-20, high, and 20+, very high. To avoid complications from other soil factors, all the studies except the P=23 and P=1.3 sites were conducted on Honeoye-Lima silt loam soils at Cornell's agronomy research farm near Aurora, NY. The P=23 was a Genessee silt loam soil near Mt. Morris. The P=1.3 was an Erie silt loam near Ithaca. All sites had a pH of 7.1 to 7.3.

All trials except the P=23 site gave highly significant and sizeable yield increases with P fertilization. However, the response curves varied from site to site. These differences appeared to be related to the initial level of available P in the soil.

Soils testing low in P produced linear responses to P fertilization with no evidence of yields leveling off at the 80 lb/A P_2O_5 rate.

Medium level P soils produced curvilinear responses. As soil test P levels increased, the response curve to P fertilization tended to flatten at somewhat lower P fertilizer rates.

The experiment on a very high P soil showed no yield response to P fertilization. However, lodging was a serious problem in this entire experiment.

Initial Fertility

Figure 1 also shows that the initial P fertility level of the soils has a major role in determining potential winter barley yields. Proper P fertilization can greatly improve barley performance on low P soil. But a single P application can't compensate for the smaller amount of available soil P and bring barley yields up to those of a soil with more available P initially.

To examine this further, the three experiments in 1980 had soil samples taken 3 inches deep, directly from rows in late November. **Table 1** summarizes the results of analysis for available P.

Table 1. Effects of applied P fertilizer on soil test levels.

Applied P_2O_5	Initial Soil P Level		
	Low	Medium	Medium-High
lb/A		(soil test value)	
0	1.3	4.0	7.3
20	1.7	4.4	10.4
40	2.4	7.3	13.5
80	2.8	9.0	19.5

Applying P to the low test soil had only a small effect on increasing available P. The medium soil showed double the available P. The highest level P soil produced nearly a three-fold increase. Thus, soil responses were quite similar to those for the barley yields.

More P became available for the crop with P fertilization on all soils. But total available P was still lower with a low testing soil than for a higher one.

Yield Increase

What was the reason for the barley yield increase with increased P? Plant counts taken in November 1980 and again in April 1981 showed that P availability greatly affected winter survival.

Table 2 summarizes the percentage of plants surviving with the different soil and fertilizer P levels. Increasing the fertilizer P on the low level soil particularly increased plant survival. On the high test soil the increases were smaller, but still significant.

Table 2. Effect of P fertilization on winter survival of barley on soils differing in initial P availability.

Applied P_2O_5	Initial Soil P Level		
	Low	Medium	Medium-High
lb/A	(% plant survival)		
0	17	43	79
20	33	59	81
40	35	59	84
80	45	63	92

These survival differences help account for the yield differences. Even with the 80 lb/A fertilizer rate, barley on the low test soil had survival only equal to that of the medium soil with no P added. The same occurred with the medium compared to the high P soil.

Thus, yield potential was apparently limited by plant survival. However, once an adequate number of plants survived (such as with the high P soil) added phosphorus fertilizer appeared to increase yield primarily through increased plant vigor and tiller production.

Summary

These studies clearly show the importance of phosphorus fertility for winter barley production. In areas where winter survival is a concern, P fertilization is critical. But even when plant survival is not the major factor, barley gives a significant yield response to P application.

These tests also indicate that **initial level of available P in the soil plays a major role in determining barley yield.** Fertilizer application cannot completely compensate for yield loss resulting from a low level of phosphorus in the soil.

In 1980, seven wheat varieties grown on the three soils showed response similar to that found with barley at the three soil test P levels. ■

Amoco Joins in Support of Foundation for Agronomic Research

AMOCO FOUNDATION, INC. has awarded a three-year research grant totaling $60,000 to the Foundation for Agronomic Research (FAR).

"We are honored that Amoco Foundation is a supporter of FAR," said Les Schnake, manager of the Fertilizer & Pesticides Department, Amoco Oil Company, a subsidiary of Standard Oil Company (Indiana). Amoco Foundation is supported by Standard.

FAR is a tax-free organization which sponsors research in crop production systems emphasizing total management for maximum economic yields. The Foundation for Agronomic Research is affiliated with the Potash & Phosphate Institute (PPI), with headquarters at Atlanta, Georgia.

In announcing the funding, Mr. Schnake commended FAR and PPI for its staff of agronomic scientists who direct research and education programs.

Currently, FAR sponsors 36 different research projects in the U.S. and other countries. FAR was established in 1980 to encourage support for crop research from all segments of the fertilizer industry, as well as seed, pesticide, farm equipment, and other industries.

"We're encouraging the quest for maximum crop yields in research and maximum economic yields for the farmer," notes Dr. R. E. Wagner, president of FAR and PPI. "Teamwork from all disciplines will focus on the interactions and practices needed to break the barriers that limit production and profits."

Other contributors with concern for continued efforts in crop research have previously announced their support of FAR. They are: Agrico Chemical Company; Chemical Enterprises, Inc.; International Minerals & Chemical Corporation; Kalium Chemicals—PPG Industries, Inc.; Potash Corporation of Saskatchewan; The Sulphur Institute; Texasgulf Inc.; DeKalb AgResearch, Inc.; and Frit Industries, Inc.

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