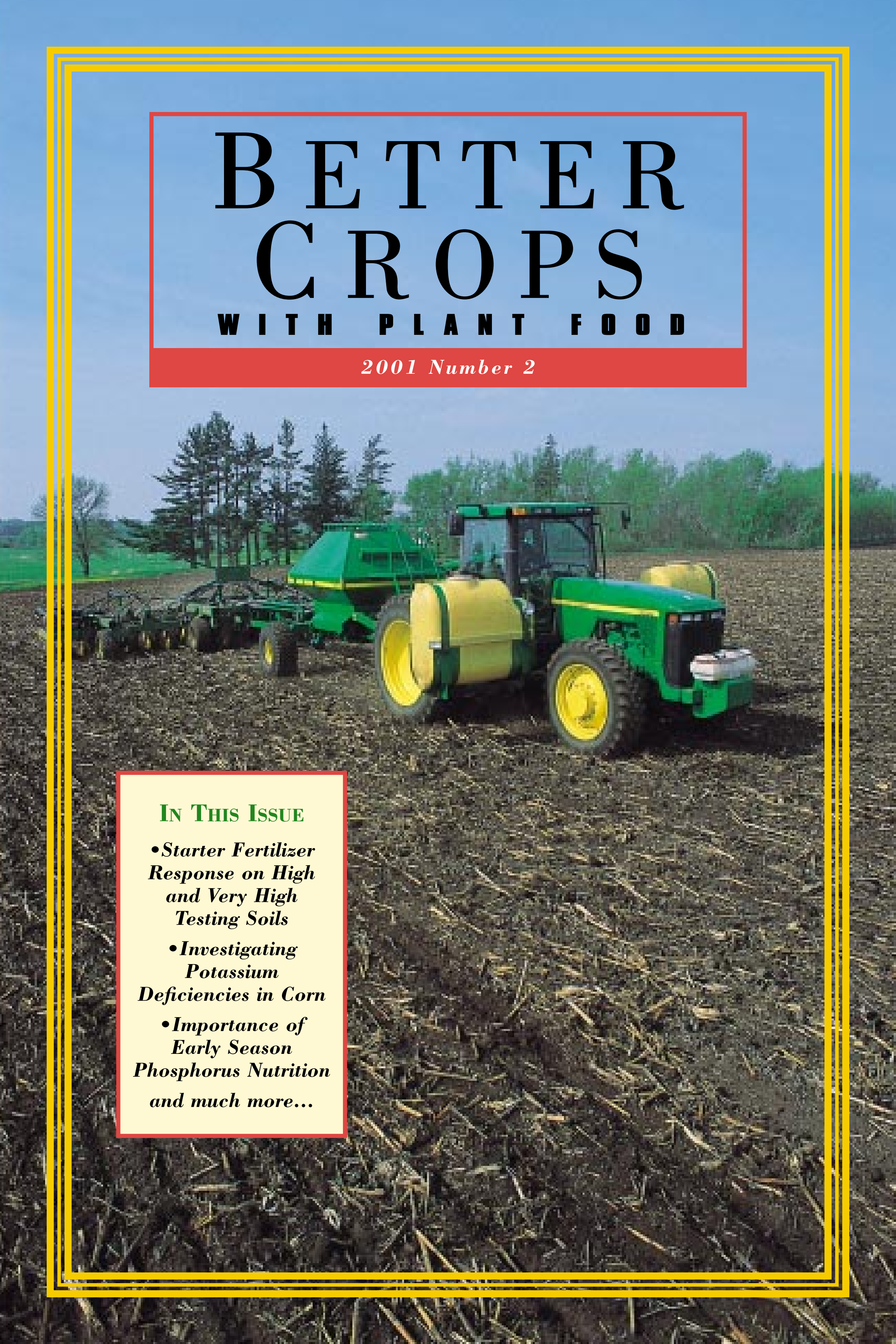
BETTER CROPS
WITH PLANT FOOD

2001 Number 2



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BETTER CROPS
WITH PLANT FOOD

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WISCONSIN

Starter Fertilizer Response on High and Very High Testing Soils

By L.G. Bundy and T.W. Andraski

Fertility research often emphasizes that the probability of crop response to added nutrients is minimal at high to very high soil test phosphorus (P) and potassium (K) levels. Such relationships have been established primarily by examining broadcast applications of nutrients. However, starter fertilizers present a different scenario. The placement of nutrients close to the plant makes them positionally available for uptake early in the plant's development. Probably for this reason, responses to starter fertilizer have been observed across a wide range of soil tests, including high to very high levels.

> Research shows that responses to starter fertilizer are possible where application at late planting dates of long-season hybrids appears to hasten maturity and increase yield potential.

This study investigated corn responses to starter fertilizer through replicated on-farm trials conducted at 100 locations in Wisconsin from 1995 through 1997. Ninety-three percent of the soils were in the very high soil test P category, and 73 percent were in the very high soil test K category. A 2x2 placement (2 in. below and 2 in. to the side of the seed) of starter fertilizer was compared to no starter. The average starter rate was 15-26-32 lb nitrogen (N)-P_2O_5-K_2O/A. A few of the sites had additional nutrients...sulfur (S), zinc (Zn), and magnesium (Mg), but yield response differences compared to NPK alone were not apparent. Cooperating farmers paid an average of $14.05/A for starter fertilizer, with costs ranging from $8.17 to $30.00/A.

The effects of starter fertilizer on grain yield, grain moisture, and early-season plant height averaged across sites for individual years and the three-year period are shown in **Table 1**. Starter fertilizer significantly increased yield by an average of about 4 bu/A in each of the three years. Yield response ranged from -10 to +42 bu/A. Using starter fertilizer resulted in significantly lower grain moisture contents (0.1 to 0.3 percent) in two of the three years, indicating

TABLE 1. Effect of starter fertilizer on average corn grain yield, grain moisture, and early-season plant height (approximately eight weeks after planting) from 100 on-farm trials, 1995-1997.

Measurement	Year	Number of observations	Starter fertilizer Without	Starter fertilizer With
Yield, bu/A	1995	44	127	131**
	1996	31	137	142**
	1997	25	144	147**
	Mean	100	134	138**
Moisture, %	1995	44	22.2	22.1
	1996	31	26.1	25.9†
	1997	25	27.6	27.3†
	Mean	100	24.8	24.6**
Height, in.	1995	44	48.3	50.5**
	1996	25	50.2	52.4**
	1997	20	55.9	57.4*
	Mean	89	50.6	52.6**

**, *, † Indicates significant at the 0.01, 0.05, and 0.10 probability levels, respectively.

accelerated plant growth or development resulting in earlier crop maturity. Early season plant height measurements taken about eight weeks after planting showed a significant effect of starter fertilizer in all years. Average plant heights were about 2 in. greater where starter fertilizer was applied.

Positive economic responses were considered to be those greater than or equal to 4.5 bu/A. This evaluation assumed corn at $2.50/bu and $10/A for starter fertilizer. The percentage of sites which had a positive economic response was 32 percent in 1995, 45 percent in 1996, and 48 percent in 1997. Grain moisture averaged 24.7 percent for sites with a positive economic response and 24.5 percent for those without. Average early-season plant height was similar between the two economic response categories. These results suggest that taller plants associated with the addition of starter fertilizer during the early part of the growing season did not necessarily translate into profitable yield responses.

Several variables were analyzed to determine if they contributed to the starter responses observed. They were soil pH, manure history, P rate in starter fertilizer, soil organic matter, surface residue, subsoil fertility group, soil texture, corn production zone, previous crop, soil test P, N rate in starter fertilizer, tillage, row spacing, K_2O rate in starter fertilizer, year, soil yield potential, planting date, soil test K, and relative corn maturity. Only the effects of soil test K level and corn hybrid relative maturity significantly affected the percentage of responsive sites. An initial analysis determined that relative maturity considered alone did not have a strong relationship to starter response ($r^2 = 0.05$). However, when planting date was also included, the two factors accounted for more of the yield variability. The inclusion of planting date was based on previous research showing this to be an important factor. The effects of planting date (PD) and relative maturity (RM) were combined by adding the planting date in Julian days to the relative maturity, creating a PDRM value. The PDRM value was better correlated to yield response (**Figure 1**). This relationship shows that the probability of a profitable response increases for longer season hybrids planted later (greater PDRM values). Response probabilities were also separated by soil test K level (**Figure 2**). Lower soil test K levels [below 140 parts per million (ppm)] resulted in higher overall probabilities of profitable responses.

Table 2 summarizes the probability of obtaining a positive economic return from starter fertilizer for several corn hybrid RM ratings at various planting dates on soils with very high soil test P and K levels. For example, the probability of a positive economic return from starter for a 90-day corn hybrid would be 10 percent if planted on April 25

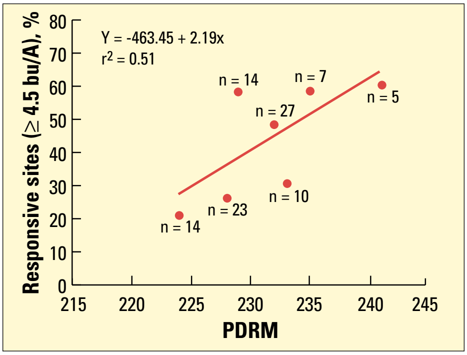

Figure 1. Relationship between planting date in Julian days (PD) plus corn relative maturity (RM) and the percentage of sites with a profitable yield response to starter fertilizer, 1995-97 (n = number of observations in each PDRM grouping).

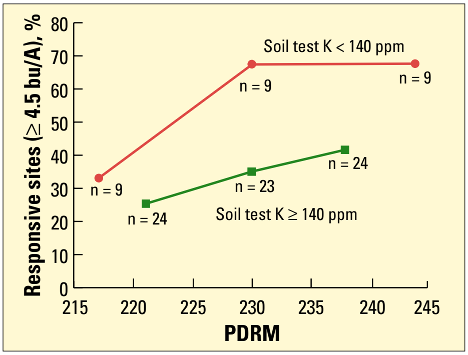

Figure 2. Effect of soil test K level on the relationship between PDRM and the percentage of sites with a profitable yield response to starter fertilizer, 1995-97 (n = number of observations in each PDRM grouping).

Information Agriculture Conference Set for August 7-9, 2001

The popular Information Agriculture Conference series continues with InfoAg 2001 scheduled for August 7, 8 and 9. Organized by PPI/PPIC/FAR, InfoAg 2001 will take place at the Adam's Mark Hotel – Airport, Indianapolis, Indiana.

Dr. Harold F. Reetz, Jr., PPI Midwest Director, is serving as conference planning coordinator. With over 70 hours of presentations and workshops, the program will include updates on machinery, data analysis techniques, yield mapping, remote sensing, variable-rate application, site-specific nutrient management, communications options, simulation tools, and more. As with previous Information Agriculture Conferences, an exhibit area will feature some of the latest in site-specific systems, data management, and communications technology. There will also be a return of the special CyberDealer sessions targeting the business aspects of incorporating site-specific management systems into services of retail supply and consulting businesses.

Individual registration fee for InfoAg 2001 is $350.00 until July 15 and $450 thereafter.

More information and details are available by phone at (605) 692-6280 or fax (605) 697-7149, or the website at **www.ppi-far.org/infoag**.

TABLE 2. Probability of obtaining a positive economic return from starter fertilizer to corn for several corn relative maturity ratings at various planting dates on soils with very high P and K levels.

Relative maturity	**4/25**	**5/1**	**5/5**	**5/10**	**5/15**	**5/20**	**5/25**	**5/30**
				Planting date probability, %				
90	10	15	20	25	30	35	40	45
95	15	20	25	30	35	40	45	50
100	20	25	30	35	40	45	50	55
105	25	30	35	40	45	50	55	60
110	30	35	40	45	50	55	60	65

and increase to 45 percent if planted on May 30. For a longer-season hybrid, such as 110-day corn, the probability of a positive economic return would be 30 percent if planted on April 25 and increase to 65 percent if planted on May 30.

Corn response to starter fertilizer has traditionally been associated with cool, wet growing conditions. This research indicates that planting date and relative maturity are also important factors. While soil test K appeared important for determining probability of response, soil test P was not. This study demonstrates that responses are possible, and in some cases highly probable, where starter applied at late planting dates of long-season hybrids appears to hasten maturity and result in greater yield potential, even on very high testing soils.

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KANSAS

In-season Fertilization for High Yield Soybean Production

By R.E. Lamond and T.L. Wesley

Kansas research showed that soybean yields were increased by late-season nitrogen (N) fertilization at six of eight sites. Differences between N rates were minimal, and N sources performed similarly. In nearly all cases, 20 lb N/A was sufficient to achieve the positive responses noted. The two nonresponsive sites had yields below 50 bu/A. Results suggest that soybeans with high yield potential (greater than 55 bu/A) may not be able to supply enough N during peak demand via atmospheric N (N_2) fixation.

The soybean is a nutrient dense, high protein seed. Consequently, nutrient requirements of a soybean crop are rather high. One bushel of soybeans contains more than 3.5 lb of N, 0.9 lb of P_2O_5, and 1.3 lb of K_2O in the grain alone. Symbiotic N_2 fixation supplies N for soybeans. In most cases, preplant or planting-time N applications are not recommended. Their effects on soybean grain yield have been measured in many studies with inconsistent results.

What are the reasons for the inconsistencies? Many factors are likely involved. The fact that successful N_2 fixation in soybeans is dependent on bacteria which can be affected by many factors such as soil pH, moisture, temperature, fertility, organic matter, and soil nitrate-N (NO_3-N) levels complicates the situation. Whenever symbiotic N_2 fixation is slowed or stops, fertilizer N may become more important. Additionally, well nodulated soybean roots don't necessarily guarantee efficient N_2 fixation. Any one or all of the soil parameters mentioned can play a role in whether or not soybeans will respond to N fertilizer application.

Most states do not generally recommend preplant or planting time N fertilizer for soybean production. Some states do recommend some fertilizer N where soybeans have never been grown before or on ground coming out of the Conservation Reserve Program (CRP). This is in addition to a recommendation for thorough seed inoculation.

Late-Season Supplemental N Fertilization

Past research has shown the period of peak N demand in soybean production is during pod fill or growth stages R1 to R6. The N demand at this time is great, and fixed N alone may not be enough to meet it. Both soil N and fixed N may be necessary for maximum soybean yield, particularly under high-yield environments.

Producers of irrigated soybeans are now routinely achieving yields in excess of 60 bu/A. A 70 bu/A soybean crop requires nearly 250 lb N/A to be translocated into the developing seeds during pod-fill. Late-season supplemental N may increase yields in these instances. In addition, future soybean marketing strategies may include protein and oil concentrations. Late-season supplemental N also has potential to affect these seed quality considerations. We initiated work in Kansas in 1994 to evaluate the effects of late-season N fertilization on the yield and protein and oil contents of irrigated soybean with high yield potential.

This research was conducted in 1994 and 1995 at four irrigated sites. Several N rates and sources were evaluated at each location as shown in the following details.

Locations: Johnson County (JO94, JO95), Shawnee County (SN94, SN95), Reno County (RN94, RN95), Stafford County (SF94, SF95)

N Rates: 0, 20, 40 lb N/A applied at R3 growth stage (first pods $^1/_4$ to $^1/_2$ in. long)

N Sources: urea ammonium nitrate solution (UAN), urea, urea + NBPT, ammonium nitrate (NH_4NO_3)

TABLE 1. Location and cultural practice for research sites.

Location	Site	Row spacing, in.	Variety	Seeding rate, seeds/A
Johnson County	J094	30	Asgrow A4138	160,000
Brunker Farm	J095	30	Asgrow A4138	160,000
Shawnee County	SN94	36	Asgrow A3935	180,000
Parr Farm	SN95	36	Asgrow A3935	180,000
Reno County	RN94	7.5	Asgrow A3935	200,000
Seck Farm	RN95	7.5	Asgrow A3834	200,000
Stafford County	SF94	30	Resnick	125,000
Sandyland Field	SF95	30	KS3494	125,000

TABLE 2. Selected soil characteristics of research sites.

Site	pH	Bray-1 P	K	Organic matter, 0-6 in.	Profile N 0-6 in.	6-24 in.
		ppm[1]		%	ppm	
J094	6.9	41	125	0.7	4.1	–
J095	6.8	44	165	0.8	3.0	5.5
SN94	7.3	65	305	2.8	6.7	–
SN95	7.7	67	240	3.1	7.9	6.3
RN94	6.8	50	210	1.2	2.7	–
RN95	6.8	48	190	1.7	3.0	2.2
SF94	6.9	31	140	0.9	3.1	–
SF95	6.7	52	130	1.3	7.8	4.5

[1] ppm = parts per million

All sites were in a corn/soybean rotation and were managed for optimum production. **Tables 1** and **2** summarize cultural practices and soil test information, respectively, for the study locations. An important component of any high yield system is adequate fertility of phosphorus (P), potassium (K), and other nutrients. Cooperators in this study had built high to very high soil P and K levels through a history of balanced fertilization.

Late-season supplemental N application increased irrigated soybean grain yield at six of the eight locations (**Table 3**). Nitrogen sources performed similarly, except the 40 lb N/A rate of UAN which resulted in reduced yield. The high rate of UAN caused severe leaf burn at most locations. The UAN was applied through flat fan nozzles with a backpack sprayer in 40 gallons per acre (GPA) total volume. Leaf burn would not be a problem with UAN applied through an irrigation system. Visual inspection of soybean root systems indicated prolific, healthy-looking nodules at all study locations.

Soybean protein concentrations were increased at four of eight locations, and oil concentrations were increased at three of seven sites by the application of N at R3 growth stage.

The 11 percent (7 bu/A) overall yield increase with late-season N fertilization makes this practice economically viable for producers of high-yielding irrigated soybeans.

(continued on page 11)

Kansas studies showed positive responses to late-season N application for irrigated soybeans with high yield potential.

INDIANA

Evaluating Spatial Variability of Soil Parameters for Input Management

By Sylvie Brouder, Brenda Hofmann, and Harold F. Reetz, Jr.

Agronomic recommendations are usually designed to provide good results under average conditions over a relatively large geographic area. Nutrient recommendations, for example, are commonly targeted for an average soil and management system and are applied for general soil types across a whole state, or even across multiple states. Variety recommendations are usually made for average conditions over a large area and multiple years. Pesticide recommendations likewise are usually the same for large areas.

> Crop production is affected by factors that vary both in space (spatial variability) and time (temporal variability). Site-specific crop and soil management systems apply agronomic science to manage production practices and inputs to address spatial and temporal variability on the farm.

Site-specific management, on the other hand, should focus on the unique characteristics of the field, the soil types, and the management system. It is through managing specifically for those unique characteristics that the value of site-specific systems can be realized. In changing one component, we affect the optimums for others. In understanding those interactions and how to manage them we find the real value of site-specific management. Responding to those interactions, paying attention to details of the system, is the key to profitable implementation of site-specific management. Successful action begins with field assessment that focuses on the spatial and temporal differences in manageable production components instead of on the production uniformities.

When studying and managing several varying factors, as is usually the situation in crop and soil management, it is important to look not only at which factors vary, but also at whether their variability is independent or linked to another factor. If the variabilities of certain factors are linked, then their measurement and management may be more efficiently handled by using one as a predictor, or surrogate, for the variability in the other. If there is no relationship between the variances of two factors, then they should be assessed separately and may require independent management.

Studies at the Purdue University Davis

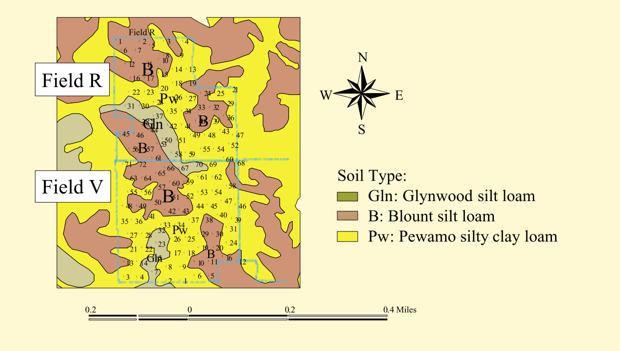

Figure 1. Two adjacent 35-acre fields are being intensively sampled to characterize soil and plant variability. Numbered points mark locations of soil samples collected on a 0.5-acre grid intensity.

Research Center in east central Indiana are focusing on analysis of the spatial structure of soil nutrient availability and its relationship to plant nutrient status, nutrient export, and on the spatial and temporal stability of yield and yield variability.

In order to study spatial variation in soil test values a stratified, systematic, unaligned pattern imposed on a 0.5-acre grid was used to select the point sample locations, and multiple core composites were collected (**Figure 1**). Several approaches are being used to analyze these data. Common interpolation techniques such as kriging are being used to characterize the sampling intensity needed to adequately describe expected soil test values at unsampled locations. Moving window analysis, a very simple statistical technique, is being used to explore whether manageable soil properties such as phosphorus (P), potassium (K), and pH vary spatially in such a way as to permit their joint management.

For this analysis, fields were divided into 32 overlapping five-acre local neighborhoods, each containing nine to 13 soil-sampling points (**Figure 2**). The analysis in the variability of ***means*** of the sampling points as you move across the landscape identifies the spatial variability of the individual factors. The analysis of variability in the ***standard deviations***, on the other hand, helps determine whether these variations are related or are independent.

Conclusions from the preliminary analysis of the soils data underscore the need to be able to integrate information from other data layers such as crop performance into smarter sampling strategies. Specifically:

1. Descriptive univariate statistics indicate substantial within-field variability in input needs that would be overlooked in a whole field approach to management. For example, the mean soil pH across the field is 6.5, requiring no lime additions. However, point soil test values range from 5.0 to 7.9.
2. Results of kriging and cross validation show that the 0.5-acre sampling grid may be too sparse to adequately characterize the structure of spatial variability of selected soil parameters. **Table 1** gives the results the semivariance analysis used to find the best models to describe the spatial structure of selected soil properties. Our results show that, while models can be fit to our data, the models' abilities to predict the soil test values at untested locations within the field are not very good. For example, sample locations for P must be closer together than 130 ft. (range = 130 ft.) in order to be dependent (to be able to predict something about the soil test value at one location simply by knowing the soil test value at the neighboring location). The model cross validation shows how well we can predict the soil test value at any sample point from all the other sample points. A model that predicts the right value at every single location would have a regression coefficient (slope) of 1.0, an r^2 of 1.0 and a Y-intercept of 0. Y intercepts greater than 0 and regression coefficients less than 1 indicate that the model tends to over predict lower soil test values and under predict higher ones.
3. The spatial analysis of the five-acre moving window means and standard deviations for various parameters shows that P and K

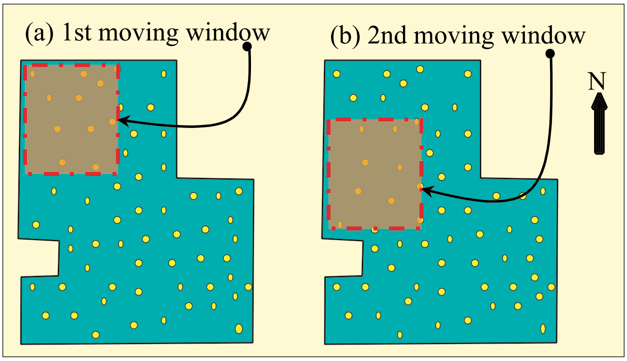

Figure 2. Overlapping moving windows were used to calculate moving average statistics (means and standard deviations) for five-acre regions of the field. Each moving window contained 9 to 13 soil sample grid points (yellow dots).

TABLE 1. Semivariance analysis of selected soil properties.

		Isotropic model				Cross validation of model			
Parameter	**Model**	**Range A_0, ft.**	**Effective range, ft.**	**Proportion $C/C_0 + C$[1]**	**r^2**	**Regression coeff. (S.E.)**	**r^2**	**Y intercept**	**S.E. of production**
Bray P-1, ppm[2]	Exponential	130	394	0.94	0.88	0.82 (0.19)	0.13	10.3	18.0
K, ppm	Spherical	269	269	0.999	0.78	0.67 (0.60)	0.10	47.5	29.3
OM, %	Exponential	194	577	0.999	0.95	0.79 (0.12)	0.25	0.77	0.69
pH	Spherical	148	148	1.0	0.45	0.78 (0.20)	0.10	1.4	0.55

[1] C_0, nugget; C, sill; [2] ppm = parts per million.

change together in space, and that regions of high variability in soil test P are also highly variable in soil test K (**Tables 2** and **3**). Regions of greatest and least variability in organic matter (OM), cation exchange capacity (CEC), calcium (Ca), and magnesium (Mg) were different from the regions of extreme P and K variability. Therefore, in this field, there is the potential to monitor and manage P and K together, but their spatial variability does not match that of OM, CEC, Ca or Mg. Thus, P and K should be considered independent of those parameters. A smart sampling strategy that minimizes the total number of soil samples collected while still successfully characterizing zones of uniformity in P and K availability and fertilizer need would not necessarily be optimal for the identification of the spatial variability in OM, a soil property that may be required for the development of optimal variable rate (VR) nitrogen (N) recommendations.

The relationships among different soil test parameters, like those determined in this study, will likely vary geographically due to differences in soil physical properties, management history, climate, and other factors. The spatial variability of common soil test factors measured in this study shows that current sampling patterns do not provide sufficient information to accurately draw soil test variability maps. Because sampling densities needed to provide such accuracy are impractical and cost-prohibitive, other tools are needed to refine soil-sampling procedures for accurate representation and management decisions on VR nutrient application. More intense data sets are needed from remote sensing, soil electrical conductivity, yield monitors, and other more data-intense, lower-cost measurements of within-field variability. These measurements can help define management zones, which can be combined with less-dense soil samples to provide a more accurate prediction of spatial variability of soil nutrient levels.

To date, much of the effort in site-specific management has been focused on P and K

TABLE 2. Spearman Rank correlation (p-value) for selected soil properties. Comparisons are between area means of "moving windows."

	OM	**Bray P-1**	**K**	**Mg**	**Ca**	**pH**
Bray P-1	0.41(*)					
K	0.39(*)	0.90(***)				
Mg	0.46(*)	0.02(n.s.)	-0.03(n.s.)			
Ca	0.62(***)	0.17(n.s.)	0.29(n.s.)	0.77(***)		
pH	0.81(***)	0.05(n.s.)	-0.02(n.s.)	0.71(***)	0.55(**)	
CEC	0.81(***)	0.29(n.s.)	0.41(*)	0.60(***)	0.90(***)	0.25(n.s.)

*, **, *** = significant at the 0.05, 0.01, and 0.001 levels, respectively.

TABLE 3. Spearman Rank correlation (p-value) for the standard deviations of selected soil properties. Comparisons are between standard deviation of area means of "moving windows."

	StdD-OM	StdD-Bray P1	StdD-K	StdD-Mg	StdD-Ca	StdD-pH
StdD-Bray P-1	0.13(n.s.)					
StdD-K	-0.08(n.s.)	0.51(**)				
StdD-Mg	0.34(n.s.)	-0.07(n.s.)	0.05(n.s.)			
StdD-Ca	0.44(*)	0.12(n.s.)	0.35(n.s.)	0.71(***)		
StdD-pH	-0.11(n.s.)	0.55(**)	0.40(*)	0.10(n.s.)	0.11(n.s.)	
StdD-CEC	0.66(***)	0.04(n.s.)	0.22(n.s.)	0.66(***)	0.86(***)	-0.10(n.s.)

*, **, *** = significant at the 0.05, 0.01, and 0.001 levels, respectively.

management and on liming, because variability in those components was measurable and technology for VR application was available.

The most cost-effective approach for inputs such as P, K and lime is still to build them to a level where they are not limiting. But with site-specific systems, that level can be determined for each management zone (or grid cell) within each field, based on the characteristics and productive potential of that individual zone. If the field has been well-managed under conventional systems, shifting to site-specific management will likely reduce the fertilizer application for parts of the field and increase it for others, but will usually increase the total fertilizer application and should generate an increase in yield potential.

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This project is part of a 15-state multi-disciplinary, site-specific soybean-corn systems research and education program, coordinated by the Foundation for Agronomic Research (FAR), with initial funding from the United Soybean Board and supplemental funding from numerous industry, university, and government sources.

In-season Fertilization...(continued from page 7)

TABLE 3. Effect of late-season N rate and source on irrigated soybean yield.

N rate, lb/A	N source	Grain yield, bu/A JO94	JO95	SN94	SN95	RN94	RN95	SF94	SF95	Avg.
0	–	64	58	72	57	56	58	35	43	55
20	UAN	70	62	76	62	75	66	39	47	62
40	UAN	65	56	73	60	59	73	37	41	58
20	AN	64	66	78	64	61	71	38	47	61
40	AN	69	66	76	69	61	66	35	44	61
20	Urea	67	63	76	65	69	76	37	48	63
40	Urea	70	69	74	68	67	68	43	51	64
20	Urea + NBPT	64	63	79	65	82	72	41	46	64
40	Urea + NBPT	70	70	83	70	67	67	42	48	65
LSD(0.10)		5	5	7	4	11	9	NS	NS	6

Assuming soybean prices of $5.00/bu and $0.30/lb N, these results would show a return of $35.00 per acre for a $6.00 per acre investment in 20 lb N.

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SOUTH DAKOTA

Investigating Potassium Deficiencies in Corn

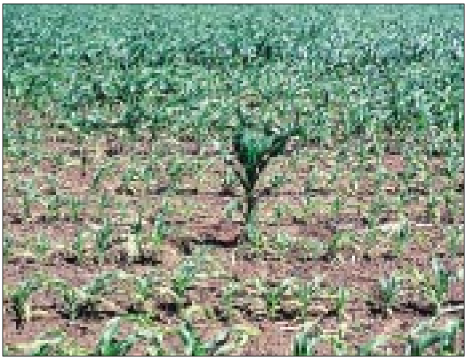
By James Gerwing, Ron Gelderman, and Anthony Bly

Potassium deficiencies have been occurring more frequently in South Dakota in the past few years. The occurrence of deficiency symptoms can vary widely. For instance, soils formed from glacial till may test lower in K and exhibit deficiencies on only side slopes or eroded areas. (See photo at left below.) Non-eroded areas are usually adequate in available K. On coarse-textured soils, such as those formed in glacial outwash, large areas or whole fields may be affected (photo at right below).

Several conditions can cause K deficiency. Compacted soil conditions restrict root growth and hinder a plant's ability to take up nutrients and water. Soils that are too loose make it more difficult for K to move through the soil to replenish the K taken up near the root. Excessively wet or dry soil conditions adversely affect plant growth and uptake of K, as do inadequate supplies of other essential nutrients such as nitrogen (N) and phosphorus (P). Certain tillage systems, such as no-till, may also make K positionally unavailable during part of the growing season under drier conditions.

The far western Corn Belt has traditionally used little potassium (K) fertilizer because the dominant soils of the region are derived from parent materials high in plant available K. However, long-term cropping has depleted indigenous K reserves in some areas to the point where K deficiencies are becoming more common.

In South Dakota, many producers have not been overly concerned about their K soil fertility. The drier climate has historically kept K in good supply. However, decades of cropping without replacement of the K removed by harvested plant portions have depleted soil supplies to yield-limiting



Small-scale variability in K deficiency symptoms, representative of that seen in eroded areas. The large plant (center) was pulled from 15 rows back for relative size comparison.

Larger areas showing K deficiency on soils formed from glacial outwash.

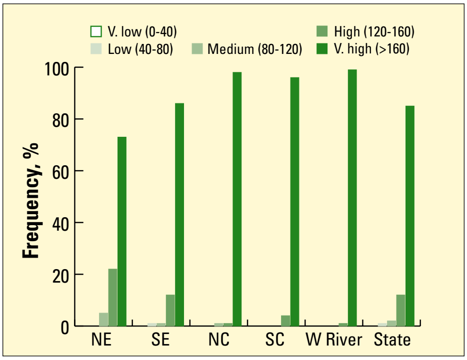


Figure 1. Potassium soil test summary for samples submitted to the South Dakota State University Soil Testing Laboratory, 1998-1999.

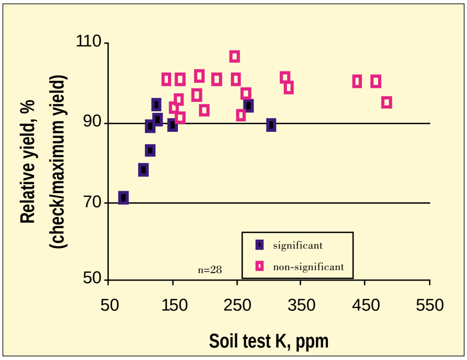


Figure 2. Corn grain yield response to added K as influenced by soil test K, South Dakota, 1996-2000.

levels in some areas. A recent survey of samples analyzed by the South Dakota State University (SDSU) Soil Testing Laboratory (**Figure 1**) reveals that 85 percent still test very high in K. However, primarily in the eastern part of the state, approximately 10 percent of the samples tested may be at levels that are yield limiting. In east central and northeast South Dakota, there are many cases where whole field samples test high or very high for soil test K but have areas that test low or medium. These areas can have severe K deficiency for corn and sometimes soybeans.

TABLE 1. Influence of broadcast potash (as potassium chloride, KCl) on corn grain yield in five site-years.

	Site-year yields, bu/A				
K_2O rate, lb/A	**1999 A**	**2000 A**	**2000 B**	**2000 C**	**2000 D**
0	99	134	127	100	81
60	112	148	122	119	86
120	124	149	137	117	83
240	122	156	134	115	80
Prob > F[1]	0.01	0.05	0.30	0.05	0.68
Soil test K, ppm[2]	106 (M)	127 (H)	152 (H)	114 (M)	141 (H)

[1] Values of 0.05 or less are commonly considered to indicate a significant treatment effect.

[2] Soil test categories: M = medium, H = high.

Current educational efforts at SDSU include meetings and field days to educate farmers, county Extension personnel, and agribusiness professionals on the causes, effects, and detection of K deficiency. Many in the state have never encountered it before. Our current research is focused on defining critical soil test K levels through correlation with yields and calibrating the rates needed to correct deficiencies for various nutrient placement methods.

An example of the data being collected for soil test correlation is shown in **Table 1**. This particular study investigates the effects of incremental broadcast K rates on corn grain yield. Of the five site-years studied in 1999-2000, the three testing below 140 parts per million (ppm) all showed significant yield increases from applied K. For these sites, average responses ranged from 10 to 25 bu/A. Considering all responsive and non-responsive sites studied so far, a preliminary assessment is that the critical range in soil test levels may be 140 to 150 ppm. The inclusion of future results could alter this range (**Figure 2**).

Dr. Gerwing, Dr. Gelderman, and Dr. Bly are with South Dakota State University; e-mail: Ronald_Gelderman@sdstate.edu.

SOUTHEAST

Potassium for Enhancement of Turfgrass Wear Tolerance

By L.E. Trenholm, R.N. Carrow, and R.R. Duncan

The influence of potassium (K) on wear tolerance of two warm-season turfgrass species was evaluated at the University of Georgia. Potassium tissue concentration was an important factor which enhanced wear tolerance of both species, primarily through maintenance of turgor pressure and shoot tissue moisture. Application of K significantly increased wear tolerance and visual quality of seashore paspalum growing on a clay soil. No response to K was seen in turf growing on a high sand-based green. Warm-season turfgrass managers should base their K fertility program on soil and tissue K levels to maintain adequate tissue K for enhancement of wear tolerance, especially in stress environments.

Potassium is an important component of a turfgrass fertility program. Although effects from K application may not be readily evidenced through increased turf shoot growth or darker green leaf color, K can reduce numerous stresses on turf. One of the primary ways that K reduces turf stress is through regulation of stomatal functioning, which enhances shoot water potential of the turfgrass plant. Maintenance of turgor potential by K can also help overcome stress effects of cold temperatures, salinity, drought, or wear injury from traffic.

A series of studies at the University of Georgia looked at turfgrass wear tolerance and how it may be influenced by fertility. In one study, three hybrid bermudagrass cultivars and seven ecotypes of seashore paspalum were evaluated. The grasses were established on an Appling sandy clay loam. Paspalum is currently undergoing testing for use on golf courses, athletic fields, lawns, and landscaped venues where a high quality, stress tolerant turf is required. This species is native to coastal and marshy environments worldwide, often growing in close proximity to extremely saline water.

Research results indicated that greater shoot density, shoot moisture, and shoot tissue K concentration improved wear tolerance in both species (**Table 1**). Potassium, which increased cell turgidity and reduced tissue succulence, provided shoot tissue with greater mechanical strength to withstand the pressure and abrasion resulting from wear injury. Another important mechanism of wear tolerance in paspalum was a reduction of total cell wall (TCW) content in leaf tissue. This allowed for greater flexibility of shoot tissue and resulted in less shoot tissue injury.

A second study, also conducted on a clay soil, looked at the effect of K silicate [21 percent silicon (Si)] on wear tolerance of two paspalum ecotypes. Turf quality, color, shoot density, and wear tolerance of both grasses were enhanced due to application of 0.36 lb K_2O/1,000 sq. ft. biweekly or application of K silicate, which supplied an equivalent amount of K_2O and 0.5 lb Si/1,000 sq. ft. (**Table 2**). Analysis of tissue nutrient levels showed that there was an inverse relationship between concentrations of K and Si, with preferential K uptake occurring at the expense of Si uptake. Preferential K uptake is most likely attributable to the evolution of this species in coastal venues, where efficient

K uptake may alleviate salinity stress. Although this inherent characteristic of efficient K uptake may initially provide paspalum with ample shoot K levels, it also may result in depletion of soil K over time. It is therefore important that turfgrass managers monitor soil and tissue K levels to ensure that adequate soil K is available for paspalum.

TABLE 1. Factors which increased wear tolerance of seashore paspalum and hybrid bermudagrass.

Factor	Seashore paspalum	Hybrid bermudagrass
High K shoot concentration[1]	Yes	Yes
Greater shoot density	Yes	Yes
Higher shoot moisture[1]	Yes	Yes
Reduced TCW content[1]	Yes	Yes

[1] Factors which are influenced by K fertility.

TABLE 2. Turf responses which were improved due to application of K or K + Si as K silicate.

Treatment, lb/1,000 sq. ft.	Turf quality	Turf color	Shoot density	Wear tolerance
0.36 K_2O	Yes	Yes	Yes	Yes
0.36 K_2O + 0.5 Si	Yes	Yes	Yes	Yes

TABLE 3. Effects of K and Si shoot tissue concentration on turf quality scores.

Shoot nutrient	Turf quality	Turf color	Shoot density	Si concentration
K	Increased	Increased	Increased	Decreased
Si	Decreased	Decreased	Decreased	*

*Due to the K and Si interaction, increasing rate of K silicate did not necessarily increase Si tissue concentration.

Further analysis of shoot tissue levels indicated that increasing K concentration imparted greater turf quality, turf color, and shoot density in both ecotypes, while Si concentration decreased these characteristics (**Table 3**). This implied that any enhancement of turf visual scores due to application of K silicate was likely a response to K and not to Si within the treatment.

Potassium additionally had an effect on cell wall components in the first trial of this study, conducted from May to July during active growth of paspalum. Total cell wall constituents at this time were significantly lower in plots receiving the highest rates of K silicate or K alone. Reduction of TCW content, which had previously been shown to increase wear tolerance of paspalum, may be another mechanism by which K improves wear tolerance in this species.

In a third study to evaluate the effects of nitrogen (N) and K on a high sand-based surface similar to a putting green, no responses to K in terms of turfgrass growth, quality, or wear tolerance were observed. Two greens-type paspalum ecotypes received K biweekly at rates of either 0.24 or 0.96 lb K_2O/1,000 sq. ft., for a total annual rate of 2.4 or 9.6 lb K_2O/1,000 sq. ft. Differences in K leaf tissue levels were observed on only one ecotype in two consecutive trials of this study. In the case where differences occurred, significantly greater K levels were found in tissue from plots which received the higher rate of K. In the other cases, K tissue levels ranged from 1.9 to 2.8 percent, regardless of amount of applied K, averaged over both ecotypes. The lack of difference in tissue levels may imply that a) paspalum is extremely efficient at uptake and utilization of K and therefore exhibits no response to the higher rate of K; b) root growth or morphology was not sufficient to take up the additional K; or c) the treatments were leached through the sand profile. As K uptake efficiency is largely determined by root growth or morphology, this could be a consideration in new turfgrass stands that have not yet fully developed their root systems. However, in this case, analysis of root depth indicated that roots of these grasses were adequately and uniformly developed. The most probable cause of lack of response exhibited would be extremely efficient uptake capacity.

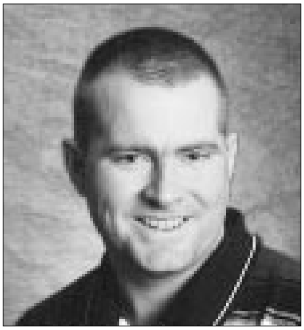
The implication of these studies for

(continued on page 17)

J. Fielding Reed PPI Fellowships Awarded to Three Graduate Students

Three outstanding graduate students have been announced as the 2001 winners of the "J. Fielding Reed PPI Fellowship" awards by the Potash & Phosphate Institute (PPI). Grants of $2,000 each are presented to the individuals. All are candidates for either the Master of Science (M.S.) or the Doctor of Philosophy (Ph.D.) degree in soil fertility and related fields. The three winners for the year 2001 are:

Angela Marie Ebeling,
University of Wisconsin-Madison



Sean Patrick Evans,
University of Nebraska-Lincoln

Nathan Ormond Nelson,
North Carolina State University, Raleigh

"Since the program began in 1980, 128 students have received the Fellowships. We are impressed each year with the quality of the applicants for this award, which recognizes and encourages an excellent group of graduate students in agronomic sciences," said Dr. David W. Dibb, President of PPI.

Funding for the Fellowships is provided through support of potash and phosphate producers who are member companies of PPI.

Scholastic record, leadership, and excellence in original research are among the important criteria evaluated for the Fellowships. Following is a brief summary of information for each of the 2001 recipients.

Angela Marie Ebeling was born in Bluffton, Ohio, where she grew up on a small dairy farm. She received her B.S. degree in chemistry from Wisconsin Lutheran College, Milwaukee, in 1999 and is currently studying for her M.S. degree in soil science at the University of Wisconsin-Madison. Among other awards and honors, Ms. Ebeling received the Rath Distinguished Merit Scholarship while an undergraduate and the Richard D. Powell Memorial Scholarship as a graduate student. The title of her thesis is 'Dairy Diet and Manure Phosphorus Effects on Plant Availability, Soil P, and P Losses in Runoff'. The objectives of her research are (1) to determine dairy diet P effects on the amounts and forms of P in manure as well as on P losses in runoff and P uptake to corn from land-applied manure and (2) to determine the P forms and plant availability in soils amended with organic P sources through greenhouse and incubation studies.

Sean Patrick Evans is a native of Murrayville, Illinois. He received his B.S. degree at Purdue University in 1996. He is now attending the University of Nebraska-Lincoln where he is working on an M.S. degree in weed science. Mr. Evans has been the recipient of numerous awards, including the NRCS Silver Merit Award for Service and the Henry Beachell Memorial Fellowship in Agronomy. The objectives of his research are to determine the critical period of weed control in corn as influenced by nitrogen (N) fertilizer rate, implement comparative growth analysis of corn grown under weedy versus weed-free conditions among various N levels, and calculate N use efficiency of corn as influenced by duration of weedy and weed-free periods, including the partitioning of N between weeds and corn.

Nathan Ormond Nelson was born in Logan, Utah. He received his B.S. degree at Kansas State University in 1998 and completed his M.S. degree at North Carolina State University in December of last year. He is currently studying for his Ph.D. degree at North Carolina State University. He has been honored with many awards and other recognition, including the J. Fielding Reed Scholarship and the Morris K. Udal Scholarship in Environmental Excellence. He is a member of Phi Kappa Phi. For his Ph.D. research program, Mr. Nelson will study phosphorus (P) leaching and subsurface P transport. His research project will involve monitoring, quantifying, and predicting P loss in subsurface drainage beneath agricultural waste application fields. He hopes that his research can assist in determining environmentally and economically sustainable methods of maintaining high levels of agricultural production.

The Fellowships are named in honor of Dr. J. Fielding Reed, who served as President of the Institute from 1964 to 1975. Dr. Reed passed away in 1999.

The Fellowship winners are selected by a committee of PPI scientists. Dr. A.E. Ludwick, PPI's Western U.S. Director, served as chairman of the selection committee for the 2001 Fellowships.

Potassium for Turfgrass...

(continued from page 15)

turfgrass breeding programs is to select for ecotypes with high inherent K tissue content in both paspalum and bermudagrass when screening for wear tolerance. This will enhance wear tolerance through maintenance of shoot turgor potential and, in paspalum, through reduction of TCW content.

For turfgrass managers, these results demonstrate that paspalum growing on clay soils similar to those in Georgia and the Piedmont region may exhibit increased turf quality, color, and density and reduced shoot tissue injury from traffic when tissue K levels are adequate. Although paspalum is very efficient at K uptake and utilization, it is important that soil and tissue levels continue to be monitored, or available soil K could become depleted due to the efficient uptake capacity of this species. Monitoring K tissue levels will assist turfgrass managers in scheduling K fertility programs and may result in application of less K than required by hybrid bermudagrass. On a sand-based soil, or where salinity may require extra leaching to remove salt build-up, K tissue tests can provide the most accurate information on K fertility needs of the turfgrass. Maintenance of adequate K tissue levels is important for enhancement of wear tolerance in both paspalum and hybrid bermudagrass.

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WESTERN CANADA/GREAT PLAINS

Importance of Early Season Phosphorus Nutrition

By C.A. Grant, D.N. Flaten, D.J. Tomasiewicz, and S.C. Sheppard

Phosphorus (P) fertilization is a major input on the Great Plains, as many soils lack sufficient P to optimize crop production. Effective nutrient management requires that nutrients be available in adequate amounts when needed by the plant. Ensuring that P is plant available early in the growing season is of particular importance.

Phosphorus is critical in the metabolism of plants, playing a role in cellular energy transfer, respiration, and photosynthesis. It is also a structural component of the nucleic acids of genes and chromosomes and of many coenzymes, phosphoproteins and phospholipids. Early season limitations in P availability can result in restrictions in crop growth, from which the plant will not recover, even when P supply is increased to adequate levels. An adequate supply of P is essential from the earliest stages of plant growth.

A growing plant may experience different stages in mineral nutrition, based on the balance among internal and external nutrient supplies and crop demand for nutrients. Initially, plants will live on their seed reserves, with external supply having little effect on plant growth. A second stage occurs when growth rate is determined by nutrient supply through a dynamic balance between internal plant factors and external (soil) supply. In a final stage, the relative growth rate may decline for reasons other than inadequate nutrition. At this point, the growth rate of deficient and sufficient plants may converge, since the factor most limiting to growth is not nutrient supply.

The length of time required for a P deficiency to show an effect on plant processes depends on the extent of P reserves in the plant. In tissues of most higher plants, the majority of the P is present as inorganic P. Concentrations of stored inorganic P tend to vary to a great extent with external P availability, while concentrations of metabolically active organic P tend to be more stable. Only a small amount of the P present in the plant is actively involved in metabolism. If P supply is adequate, most of the inorganic P pool is nonmetabolic and stored within the vacuole as orthophosphate. Under P stress, the inorganic reserves are depleted, while the metabolic levels remain essentially unaffected. Therefore, high concentrations of stored P from the seed, or from luxury uptake early in the season, form reserves of available P that can buffer against short-term fluctuations in P supply later in the plant's life cycle.

Effect of P Deficiency on Plant Development

Moderate P stress may not produce obvious deficiency symptoms. However, with a more severe deficiency, plants become dark green to purplish in color. Phosphorus deficiency can reduce both respiration and photosynthesis, but if respiration is reduced more than photosynthesis, carbohydrates will accumulate, leading to dark green leaves. A deficiency can also reduce protein and nucleic acid synthesis, leading to the accumulation of soluble nitrogen (N) compounds in the tissue. Ultimately, cell growth is delayed and potentially stopped. As a result, symptoms of P deficiency include decreased plant height, delayed leaf emergence, and reductions in tillering, secondary root development, dry matter yield, and seed production.

Plants respond to P deficiency by adaptations that maximize the likelihood of producing some viable seed. Generally, P stress decreases the number of seeds produced more than seed size. For example, in cereal crops the reduction in seed number occurs through reduced numbers of fertile spikes and reduced numbers of kernels per spike (**Figure 1**). Reducing the number of seeds formed increases nutrient supply per seed and enhances the likelihood of producing viable seed for successful reproduction.

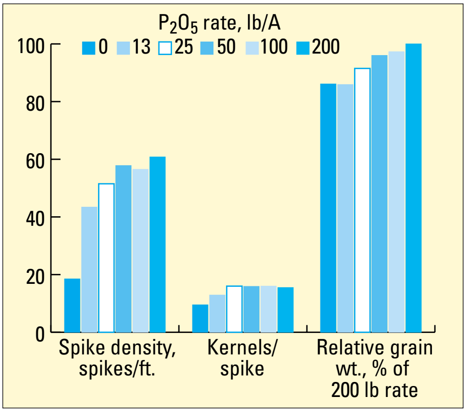

Figure 1. Effect of applied P rate on mean spike density, number of kernels per spike, and relative grain weight of barley (cv. Schooner). Measured at Parilla, Australia in 1986 (adapted from Hoppo et al., 1999).

Phosphorus Supply during Early Plant Growth Is Critical

A large number of studies in many plant species have shown that early season P supply is critical for optimum crop yield. Withholding P during early plant growth will limit crop production and cause a restriction in crop growth from which the plant may not recover. Phosphorus limitation later in the season has a much smaller impact on crop production than do limitations early in growth.

Research with spring wheat and intermediate wheatgrass found that maximum tiller production was obtained when P was supplied in the nutrient culture for the first four weeks of growth (**Table 1**).

If P was withheld for the initial four or more weeks, final tiller production was less than maximum. Secondary (tiller) root development followed the same pattern as tiller development. Available P is required early in plant growth for maximum root development. Final dry matter yields of spring wheat and intermediate wheatgrass were reduced to some extent when plants were exposed to a P-deficient medium during different portions of the first five weeks of growth (**Table 2**). Supplying P for the first three to four weeks of growth led to reduced dry matter yields. In addition, withholding P for the first two to three weeks led to lower dry matter yields. Although both crops absorbed only small quantities of P during the first two weeks of growth (15 percent of maximum for wheat and 5 percent for intermediate wheatgrass), this early accumulation of P was extremely important for maximum dry matter and grain yields at maturity.

TABLE 1. Average tiller and secondary root development of wheat as influenced by the absence of P during various intervals (adapted from Boatwright and Viets, 1966).

Weeks without P in a 10-week growth period	Tillers/6 plants at week 10	Secondary roots/6 plants at week 10
0-control	27.7	120.0
First 2 weeks	22.3	76.2
Last 2 weeks	23.0	123.6
First 4 weeks	10.3	21.6
Last 4 Weeks	24.0	106.2
First 6 weeks	9.4	19.8
Last 6 weeks	24.0	66.0

TABLE 2. Influence of P supply in nutrient medium on the dry matter accumulation of spring wheat and intermediate wheatgrass. Results presented as a percentage of the check (1 to 5 weeks). Adapted from Boatwright and Viets, 1966.

P supply period weeks of growth	Spring wheat	Intermediate wheat-grass
	...... Dry matter, % of check	
1-5	100	100
1-4	80	66
1-3	50	25
3-5	80	59
4-5	30	19

A number of reasons have been proposed as to why early season P is so critical for later plant growth and development. However, the most likely effect is that a process in the plant leads to an irreversible response that impairs later growth, even if the plant receives adequate nutrients later. The mechanism for growth impairment by early season P deficiency may relate to restrictions in carbon (C) nutrition of the plant. In field-grown corn, P deficiency slows the rate of leaf appearance and leaf size, particularly in the lower leaves. The effects of reduced leaf growth and solar radiation interception on C nutrition of the plant caused by P deficiency may reduce subsequent nodal root emergence, which would have an additional impact on P uptake capacity.

Yield response of corn to seed-placed P is related to the P concentration at the four- to five-leaf stage, or possibly earlier. It has been suggested that a mechanism relating seedling P nutrition to kernel number in corn might be due to the effects of P on early ear size. A P deficiency during ear formation, which occurs by the six- or seven-leaf stage, could decrease ear size, leading to fewer initiated kernels per ear. A similar mechanism may occur in other species, as evidenced by the reductions in seed number with P deficiency in a variety of crops.

Requirement for P Supply during Grain Fill/Flowering

Although P supply during early development has a dominant effect on crop yield potential, there may also be a requirement for an external supply of P later in crop growth. It has been suggested that spring wheat normally attains maximum uptake of P by heading, and P accumulation in the grain is largely due to redistribution from the leaf and stem tissue. However, in studies of hard red spring wheat under irrigation, only 45 percent of the total above-ground P had been accumulated by flowering. As the plant developed, P was removed from the leaves and stems and moved to the grain. At maturity, the distribution of P among the leaves, stems, heads, and grain was approximately 3, 8, 9, and 80 percent, respectively. Adequate P had been absorbed by winter wheat at the first node stage to ensure maximum P concentration levels in the mature grain, but a small supply of P was required through the ripening stage to allow carbohydrate translocation mechanisms to function for maximum mature grain yield. Phosphorus in the head of wheat may be supplied from post-anthesis soil uptake, as well as internal redistribution of nutrients accumulated during early growth.

Differences among Plants in P Uptake Strategies and Effectiveness

The importance of P for plant survival has supported the development of plant adaptations to improve the access of the crop to P supplies. Concentration of P in the soil solution is usually low since it is rapidly adsorbed onto soil surfaces as well as precipitated as calcium (Ca), magnesium (Mg), iron (Fe), and aluminum (Al) phosphates. Most P moves to the plant by diffusion rather than mass flow. As movement through the soil to the root is restricted, diffusion is generally considered to be the rate-limiting factor in P absorption by plants. It is estimated that, on average, P can only diffuse approximately 0.004 in., thus only P within 0.004 in. of a plant root is positionally available for absorption.

Uptake of P by the plant is proportional to the root density, so enlargement of the root surface area increases the ability of the plant to access and absorb P from the soil. Therefore, many plants respond to low soil P concentrations by enlarging the root system and developing highly branched roots with abundant root hairs to enhance their ability to explore new soil reserves of P and efficiently extract P from the soil when areas of high P are encountered. Many plants will form associations with mycorrhizal hyphae, which also increase the ability of the crop to access and absorb P.

It has been reported that the root:shoot ratio was increased with early season P deficiency. Growth reduction was generally greater in the shoot than in the root, allowing the plant to maintain root growth and encounter and extract P from the soil. Growth of tops and roots closely paralleled the distribution of P between the plant parts. Where P supply was low, the proportion of P held in plant roots was higher than where the P supply was moderate. At higher P status, there was also a relative increase in root P as compared to shoot P. This may imply P retention by the root to meet its requirements at low concentration, P export to the shoot at sufficient concentrations, and P retention by the root at high concentration to avoid P toxicity in the shoot.

While increased rooting is an important factor in improved P access under conditions of a limited P supply, there are other plant responses to restricted P supply that can increase the accumulation of P in the plant. Some plants release phosphatases into the growth medium to break down organic phosphates, increasing the supply of available P. Plants such as canola can acidify the rhizosphere through secretion of organic acids to increase P availability. Some plants may also respond to P deficiency by increasing their ability to accumulate the P that they contact. In corn, a decrease in P level in the plant appears to signal the roots to absorb P more rapidly. Plants which have experienced P stress show a great increase in rate of P uptake when they come in contact with P as compared to plants that have not experienced P stress. The higher rate of uptake leads to higher P concentration in the tissue in the initially P-stressed plants as compared to those with an adequate P supply.

Early-season response of spring wheat to seed-placed P is shown at right in the photo, compared to wheat with no P at left.

Phosphorus-deficient plants may lose the ability to regulate P uptake, leading to unrestricted uptake of P when P supply in the nutrient solution is re-established. It has been suggested that normal plants have a regulatory mechanism that limits excessive P uptake or accumulation, with the mechanism being ineffective in P-deficient plants. Therefore, P-deficient plants may accumulate toxic amounts of P on exposure to levels of solution P that, when continuously available, are non-toxic. A high ratio of organic to inorganic P in the plant seems to signal a transport system to increase the influx rate. The restoration of an external inorganic P supply appears to be regulated by inorganic P concentration in the plant, which could help to protect plants against P toxicity.

Soil Temperature and P Supply

When considering P supply early in the growing season, soil temperature is of particular importance, as annual crops on the Great Plains are frequently planted in cold soil. Therefore, temperature may influence the ability of the plant to access P during the early stages of crop growth, with slower diffusion of P in soil and lower soil P solubility. This may be of particular relevance where cold soil temperatures at seeding may enhance the need for P application near the seed row.

The simplest effect of soil temperature is on P solubility, with less P being soluble at lower temperatures. However, the effect of temperature is not necessarily the same among different soils. In research on soils where root growth was least affected by low temperature, plant uptake of P was most affected by temperature. Clearly, solubility of soil P was affected, regardless of the effect on root growth.

Temperature also has an influence on the rate of reaction of fertilizer P with soil. Fertilizer P reacts and transforms rapidly when first applied to soil, but continues to transform for months afterward. The transformation is generally to less-soluble forms, with lower temperatures slowing the process. Obviously, this effect of temperature can be important in early season and is opposite to the effect on the solubility of native soil P. The result is that with cold soil, native soil P will be less available to the plant, and fertilizer P will remain more available. This increases the relative value of fertilizer P for cold soils.

Banding of fertilizer P is a common practice because the plant uses P in the band more effectively than broadcast P. Temperature can affect plant use of banded P by influencing root proliferation in the fertilizer band compared to adjacent unfertilized soil. In one study, at warm soil temperatures, wheat showed little root proliferation in the band, but at 50°F, root mass was up to 3.6-fold greater in the P band than in the adjacent soil volume. However, at soil temperatures above 68°F, banded P became more toxic and decreased growth. As a result, plants were able to exploit the differences between the availability of soil and fertilizer P brought about by cold soil temperatures.

Phosphorus Concentration in Seed

Enhanced P concentration in the seed may be used to improve early season P supply and increase subsequent plant growth. Many plants can subsist on the P contained in the seed for about two weeks. Under greenhouse conditions, wheat grown from seed of the same size but with increasing P concentrations (0.14 to 0.37 percent), produced higher dry matter yields up to 35 days after seeding. In the field, the increases in wheat dry matter yield persisted until 67 days after seeding. Similarly, with wheat seeds that varied in P concentration by 40 percent, higher P concentration seedlings emerged more rapidly than low P seedlings. The high P seedlings had greater early growth, higher leaf numbers, and higher leaf area. Increasing P status of the seed increased root length, but the effect of P was greater on shoot than root growth. Increasing seed weight had similar effects to increasing seed P concentration, with the effects of seed weight and P status on leaf area appearing to be additive.

TABLE 3. Cumulative uptake of fertilizer and soil P by wheat at various stages of growth with a comparison of two P fertilizers[1] (Mitchell, 1957).

	4 weeks		7 weeks (heading)		9 weeks (soft dough)		13 weeks (mature)		Grain
Fertilizer	Total	Fertilizer	Total	Fertilizer	Total	Fertilizer	Total	Fertilizer	yield,
source	P, mg								g/pot
Monoammonium phosphate[2]	27.0	12.5	177.0	75.5	195	77.0	281	101.0	78.0
Dicalcium phosphate plus Ca nitrate	19.7	1.9	126.0	15.1	182	19.0	241	22.0	63.3
Unfertilized	18.8	—	95.0	—	146	—	188	—	49.0

[1] Data from field trials at Birch Hills, SK, 1948. Figures are averages of four replicates of a 6 ft. row.

[2] Application rate for fertilizers was 23 lb P_2O_5/A.

Fertilizer Management

If P supplied from the soil and seed reserves is inadequate to support optimum crop yield, fertilizer applications can supply P to the plant. Phosphorus supply during the first two to six weeks of growth tends to have a large impact on final crop yield in most crops; therefore, it is important that P fertilizer applications are managed in a way that ensures early season access to the fertilizer by the growing crop.

Relative uptake of P from soil and fertilizer sources will differ with crop type and growth stage. Research showed that rate of uptake of soil P increased in the four- to six-week period of wheat growth and that as the root area expanded, an increasing proportion of the P in the plant was derived from the soil, rather than from fertilizer application (**Table 3**). The total amount of P and the amount of fertilizer P taken up by wheat plants increased with increasing rates of P fertilization, with the percentage of the total P coming from the fertilizer increasing with increasing fertilizer rate. Therefore, the amount of soil P used decreased with increasing rates of applied P.

Phosphorus is relatively immobile in the soil and so remains near the site of fertilizer placement. It will react with Ca and Mg present in high pH soils to form sparingly soluble Ca and Mg phosphate compounds. These compounds are less available to the plant than fertilizer P and become increasingly less available over time. In acid soils, similar reactions occur with Fe and Al oxides. Band placement of P reduces contact with the soil and should result in less fixation than broadcast application. In P-deficient soils with a high P fixation capacity, the best means of supplying P for early crop growth is generally by banding the fertilizer near to or with the seed (i.e. use of starter P). In soils where the soil P levels are not extremely low (e.g. soils with a history of P fertilization), P fertilizer may be effectively applied in a deep-band, dual-banded with the N.

While precision placement of P is one strategy to optimize early season uptake of P, an alternate approach may be to develop and maintain high concentrations of P in the soil. In Manitoba, a single broadcast application of 400 or 800 lb P_2O_5/A increased crop yields and maintained soil P at levels above those where a response to application of additional P would be expected, even after eight years of cropping. Continued assessment of the availability of P to crops early in the season on soils with high residual P levels, whether from previous fertilization or manure applications, is required in order to determine the likelihood of a response to applications of additional fertilizer P.

Summary

Crops require an adequate P supply during the early stages of growth to optimize crop yield. It is important to recognize P deficiency and to manage cropping systems to ensure adequate levels of available P are provided to the young, developing crop. This requires recognition of the potential effects of management practices on soil physical and biological characteristics that can influence the early season availability of P to crops. Band placement of P fertilizer in or near the seed row and maintenance of soil levels of P through long-term fertilizer management are among the practices that should be adopted to optimize P nutrition.

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Interested in more detail on this topic? A review paper from which this article was developed has been published in the Canadian Journal of Plant Science. Copies of the journal manuscript reprint are also available from Dr. Adrian Johnston, PPI/PPIC Western Canada Director, located at Saskatoon, SK Canada; e-mail: ajohnston@ppi-ppic.org.

THE LAND

Throughout history, men and women have given their lives in defense of 'the land.' An early example, set forth in the Bible in First Kings, chapter 21, is that of a landowner who was killed rather than surrender the small piece of property he owned next to the King's palace.

Also according to the Bible, God made the first ever land grant to Adam, in Genesis, chapter 2. He emphasized the importance of stewardship, in the 25th chapter of Leviticus, when he commanded the nation of Israel to leave the land idle every seventh year, not removing vegetation, so the land could replenish itself. (The command was not heeded, and both Israel and the land suffered the consequences.)

The above references demonstrate the oneness of man and the land, a relationship as old as history itself and which continues to endure. The fragile interdependence of the land's need for stewardship and man's requirements for the fruits of the land has never been more visible than it is today.

Dr. Norman Borlaug, Nobel Peace Prize laureate, once described a 'highway' of cereal grains, circling the equator. Imagine it as being more than eight feet thick and 65 feet wide. The highway represents the amount of production needed to feed the world's population for a single year. Just to keep up with human food demands, it must be 'rebuilt' every 12 months and an additional 650 miles added. Those numbers are startling, but consider the fact that arable land available for agricultural production will only amount to about a half-acre per person within the next 25 years.

Can agriculture provide sufficient food for the world's growing population with the shrinking per-capita land base? It can, but only if science continues to develop new technologies which allow us to grow more crops per unit of land...and only if we maintain our commitment to stewardship.

My late brother, Hack, was a farmer and dairyman. He believed in the Bible, and he loved the land. He provided me with the biblical references cited above and also shared his thoughts about **'the land'**, and I quote, "May I say that the relationship (between mankind and the land) is too evident to scoff at, and I believe farmers today try harder than anyone to preserve this heritage and put something back."

Hack was right on both counts.

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