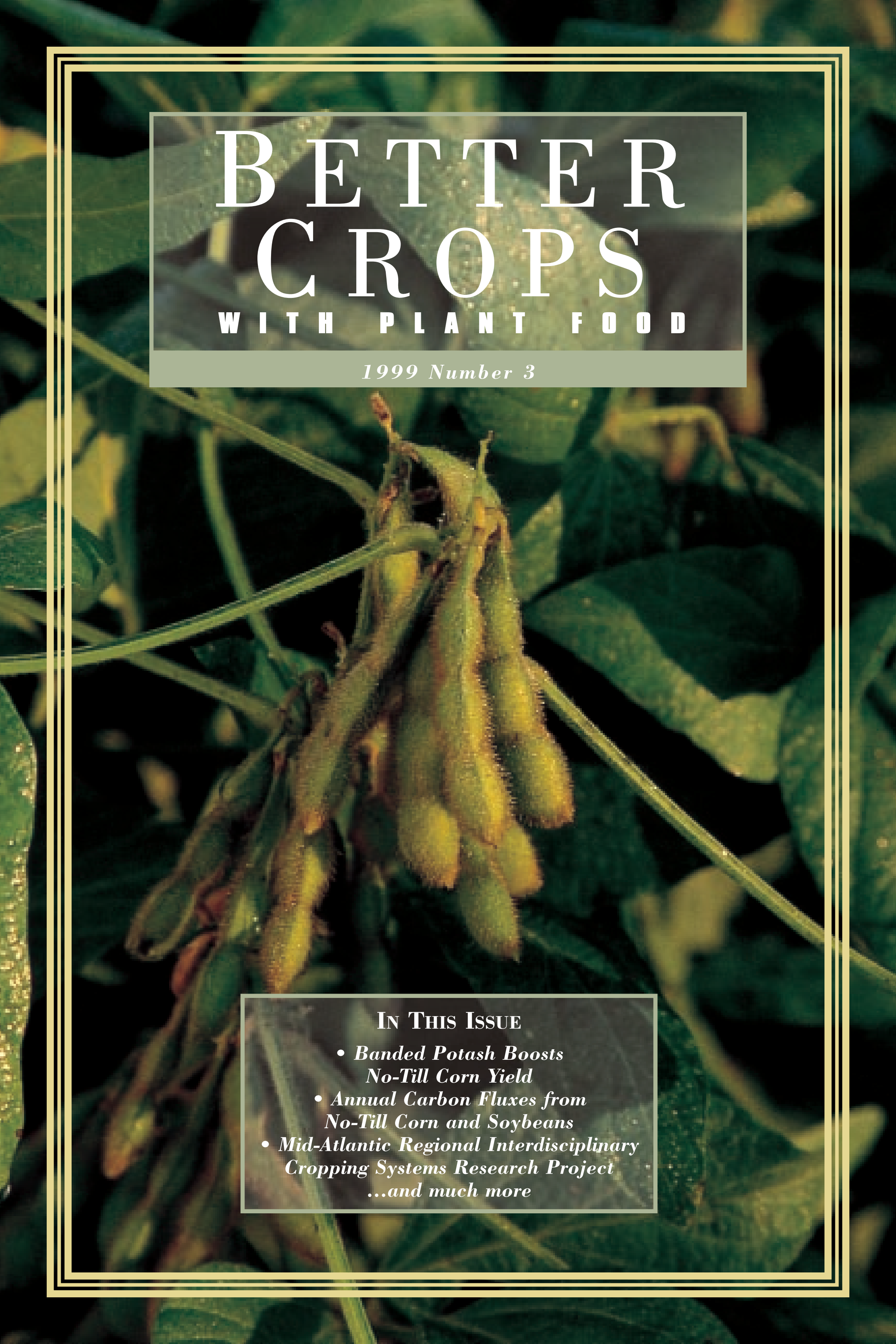

BETTER CROPS
WITH PLANT FOOD

1999 Number 3

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BETTER CROPS
WITH PLANT FOOD
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VIRGINIA

Mid-Atlantic Regional Interdisciplinary Cropping Systems Research Project

By R. Khosla, M.M. Alley, and W.K. Griffith

This project is a regional effort with a main study location in Virginia and cooperative studies at different locations throughout the region (Virginia, North Carolina, Maryland, and Pennsylvania). The main study location (Camden Farm, Port Royal, Caroline County, Virginia) integrates all current best management practices for each crop in rotation and incorporates new practices based on cooperative research results (**Figure 1**).

The primary objective of the multi-state project in the Mid-Atlantic region is to evaluate three different (one conventional and two alternative) cropping systems under rainfed conditions.

The main study site has four different soil types, ranging from coarse textured Bojac to heavy textured Wickham soil (**Figure 2**). The detailed cropping systems treatments and the timeline of the project are presented in **Table 1**. The specific cropping system treatments are as follows:

1) Standard rotation of three crops in 2 years: no-till corn, conventional-till wheat, no-till double-crop soybeans.
2) New rotation of four crops in 3 years, all no-tillage: no-till corn, no-till full season soybeans, no-till wheat, no-till double-crop soybeans.
3) New rotation of four crops in 2 years, all no-tillage: no-till wheat, no-till double-crop soybeans, no-till barley, no-till double-crop corn.

All phases of each rotation are present each year in order to obtain data for each crop in rotation under varying climatic conditions encountered each year. Thus, there are seven strips in each of three replications. Individual strips are 2,000 ft. long by 60 ft. wide. All management practices at the main study site are performed with commercial farm equipment and site-specific management tools, including use of the global positioning system (GPS), a geographic information system (SGIS™) and a yield monitor (GreenStar™).

Figure 1. Field layout of cropping systems project at main study site. Each experimental strip is 60 ft. x 2,000 ft.

Grid soil sampling (60 ft. x 300 ft. grid, from 0 to 18 in. soil depth) for variable rate fertilizer application phosphorus (P) and potassium (K) is done prior to planting corn and soybeans. Variable rate fertilizer application maps are prepared from the soil test results using SGIS™ software. Similar application maps are prepared for side-dressing corn. Nitrogen (N) fertilizer for side-dressing corn is

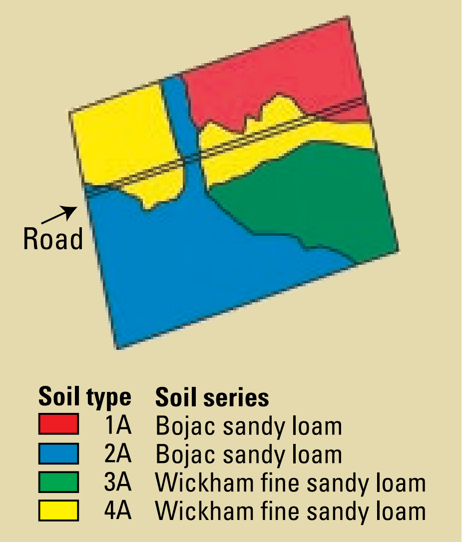

Figure 2. Soil type map of main study site.

varied by soil type (based on yield potential of each soil type), and fertilizer applications are made with a RoGator™ equipped with the Falcon Control System™.

Weather data at the main study site are recorded continuously using a Campbell Scientific weather station MetData1™. Volumetric soil water content to a 4-ft. depth is measured weekly on major soils in all 21 strips for all the crops in the cropping system. The weather and soil moisture data sets are combined to estimate water balance of each crop in the various cropping systems.

First-year results confirm the extreme importance of rainfall, rainfall patterns, and the water-holding capacity of the drought-prone soil types in the study. The 1998 growing season had sufficient rainfall early, but was relatively dry in July through mid-September. Full-season, no-till corn and soybean yields and water use efficiency for two contrasting soil types are shown in **Table 2**. Corn yields averaged 104 bu/A on a Bojac 2A soil and 193 bu/A on Wickham 3A. Yields increased as water-holding capacity increased. Corn extracted only 2.39 inches of soil water through the 4 ft.-depth on the Bojac during July and August of 1998. Approximately 50 percent of this water came from the 2 to 4 ft. depth. On the Wickham, corn extracted a total of 5.1 in. of soil water with about 60 percent from the 2 to 4 ft. depth. Similar yield and water use efficiency results were obtained with full-season soybeans with yields of 14 versus 42 bu/A on the Bojac and Wickham soils. The pounds of grain per acre-inch of water were 61 and 153, respectively.

TABLE 1. Complete cropping systems design with time scale.

Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7
Fall '97	**Spring '98**	**Fall '97**	**Spring '98**	**Spring '98**	**Fall '97**	**Fall '97**
Wheat-CT	NT Corn	NT Wheat	NT Corn	NT FS Beans	NT Wheat	NT Barley
Summer '98	**Fall '98**	**Summer '98**	**Spring '99**	**Fall '99**	**Summer '98**	**Summer '98**
NT DC Beans	Wheat-CT	NT DC Beans	NT FS Beans	NT Wheat	NT DC Beans	NT DC Corn
Spring '98	**Summer '99**	**Spring '99**	**Fall '99**	**Summer '99**	**Fall '98**	**Fall '98**
NT Corn	NT DC Beans	NT Corn	NT Wheat	NT DC Beans	NT Barley	NT Wheat
		Spring 2000	**Summer 2000**	**Spring 2000**	**Summer '99**	**Summer '99**
		NT FS Beans	NT DC Beans	NT Corn	NT DC Corn	NT DC Beans
		Fall 2000	**Spring 2001**	**Spring 2001**		
		NT Wheat	NT Corn	NT FS Beans		
Fall '99	**Spring 2000**				**Fall '99**	**Fall '99**
Wheat-CT	NT Corn				NT Wheat	NT Barley
Summer 2000	**Fall 2000**				**Summer 2000**	**Summer 2000**
NT DC Beans	Wheat-CT				NT DC Beans	NT DC Corn
Spring 2001	**Summer 2001**				**Fall 2000**	**Fall 2000**
NT Corn	NT DC Beans				NT Barley	NT Wheat
					Summer 2001	**Summer 2001**
					NT DC Corn	NT DC Beans

TABLE 2. Effect of soil type on water use efficiency and corn grain yield (Main Study, 1998).

	Yield, bu/A		Total water use, inches		Water use efficiency, lb/A-inch	
Soil type	Corn	Soybean	Corn	Soybean	Corn	Soybean
Bojac 2A	104	14	15.88	13.74	367	61
Wickham 3A	193	42	18.33	16.46	590	153

Cooperative Studies

Dr. David Holshouser is the principal investigator on the cooperative study entitled "Cultural Practices to Improve Yield Potential of Early Season Soybean Production Systems", which is located at the Virginia Tech Agriculture Research & Extension Center, Suffolk. His work is evaluating row spacing, plant population, and variety selection to achieve optimum yields of the soybean component in the various cropping systems under investigation in the main study. Dr. Holshouser is also looking at measurements of leaf area index (LAI) and/or light interception (LI) of a soybean canopy. They are good predictors of the proper row spacing and plant population that are needed for different soil types, cropping systems, and climatic conditions. In another cooperating study, Dr. Holshouser is determining the influence of late-season N and boron (B) applications to soybeans.

Dr. Gail Wilkerson of the Crop Science Department at North Carolina State University is the principal investigator on a cooperative study entitled "Precision Weed Management Using Variable Rate Application Technology." She and her students are developing software and field scouting programs to generate variable rate herbicide application maps for preemergence, pre-plant incorporated, and postemergence herbicide applications.

Dr. Bill Kenworthy and Mr. Ron Mulford are principal investigators with the cooperative study at the University of Maryland Lower Eastern Shore Research & Education Center, Poplar Hill Facility, Quantico. They are engaged in determining the most efficient and cost effective row width for corn and soybeans in a rotation of no-till and minimum tillage single crop soybean and corn grown on potentially droughty soils.

In addition, Dr. Greg Roth with the Pennsylvania State University is evaluating starter fertilizers, hybrid selection, and plant populations for obtaining maximum economic yields on rainfed soils in Pennsylvania. This work will develop a package of management practices for low water-holding capacity soils.

The ultimate success of the research will be when an improved production practice or crop management technique has been developed and the research team has approved its adoption for use in the main study. For example, the development of a measurement for soybeans shows promise as a good predictor of the proper plant population needed for different soil types. This might provide the geo-referenced information needed to effectively use variable rate seeding techniques. Another objective is to develop scouting techniques and software programs that will allow the use of variable rate herbicide applications. The team anticipates that both these research achievements may be tested in the main study beginning in the year 2000. BC

Dr. Khosla is an Assistant Professor and Extension Specialist of Precision Agriculture at Colorado State University, Ft. Collins. Dr. Alley is W.G. Wysor Professor of Agronomy at Virginia Tech. Dr. Griffith is Consultant, Agronomic Management Systems, Great Falls, Virginia.

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VIRGINIA

Soil-Specific Nitrogen Management on Mid-Atlantic Coastal Plain Soils

By R. Khosla and M.M. Alley

Application of nutrients such as N on farmlands is essential for profitable and sustainable crop production. Establishing nutrient rates for improving crop yield and profit, while minimizing environment risk, is challenging. The technology to assist in managing the inherent variability in fertility levels in farm fields has not been available until the recent development of variable-rate computer controllers that can be linked to the global positioning system (GPS). The potential exists to optimize nutrients with variable rate application according to the productivity potential and inherent fertility status of each soil type that exists in each individual field.

> Fields with highly variable soil types are typical of the mid-Atlantic Coastal Plain. Based on this pilot study, soil-specific nitrogen (N) application has the potential to optimize N application rates for corn production on variable soil types.

One of the impediments in variable rate fertilizer application is intensive grid soil sampling. It involves skilled labor, time and money in procuring and analyzing substantial numbers of soil samples from individual fields. Techniques of soil sampling and their comparison have been discussed by soil scientists for years. Regardless of the technique, grid soil sampling on small grids (i.e. 1 acre or less) is time consuming and cost intensive. There is a need for an alternative mechanism for making variable rate fertilizer applications that does not involve extensive soil sampling, especially for nutrients such as N that are highly mobile in the soil system.

In the mid-Atlantic Coastal Plain, corn grain yield response to N depends to a large extent on soil textural class and water holding capacity. In general, the coarser the soil, the lower the water holding capacity and the lower the yield potential. It was hypothesized that applying different (variable) rates of N fertilizer based on the soil types that exist in any given field may help to optimize the N fertilization program.

Depending on the field size, we have

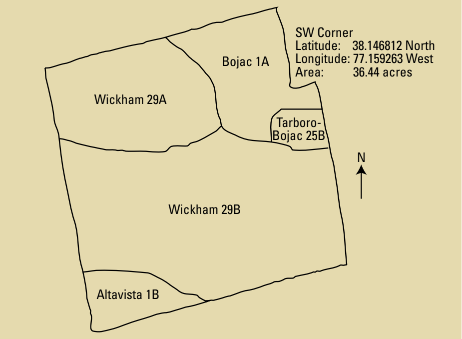

Figure 1. Geo-referenced soil map for a 36-acre test field, based on soil survey order II.

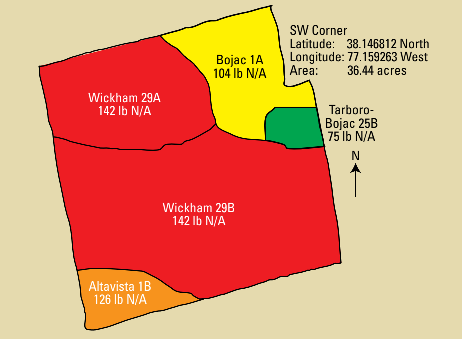

Figure 2. Soil-specific variable rate N application for side-dress corn on a 36-acre test field.

observed between two and 12 different soil types within a field, indicating the amount of soil variability that growers need to manage. Conventionally, farmers have been applying uniform rates of N fertilizer on the fields, usually based on the most productive area of the field.

The potential for soil-specific N applications to optimize N fertilization and increase field-average yields and profits was tested in a pilot study in Virginia in 1998. A 36-acre farm field planted to no-till corn that has five different soil types was chosen as a test field. The field boundary was mapped and a detailed soil map (1:12,000) for that location was obtained from the National Resources Conservation Service (NRCS) office in Virginia. The soils map was digitized, geo-rectified, and underlain with the real-time field boundary for delineating soil type boundaries as polygons (**Figure 1**).

Each polygon in the map representing different soil types was coded alpha-numerically using MAPINFO™ software. The rate of N to be applied in each polygon was determined in consultation with the farmer based on the yield goal for each soil type. A variable rate application map was prepared using the SGIS™ suite of software (**Figure 2**). No soil sampling was performed in the field. Variable-rate N fertilizer was applied on the 36 acres using a model 854 RoGator™ equipped with the Falcon™ control system (Ag-Chem Equipment Inc.). Grain yields were determined with a GreenStar™ yield monitor system on a John Deere 9610 combine.

Table 1 presents the soil types, corresponding land area, total N applied on each soil type, yield goal, actual grain yields, and the N use-efficiency for each soil type. The soil types in the 36-acre field (**Figure 1**) ranged from the Tarboro-Bojac, which is primarily sand with no argillic horizon, to Wickham soil that is highly productive with loamy surface horizon to clay and clay loam in the sub-surface. The grain yield goal varied from 100 bu/A to over 175 bu/A on Tarboro-Bojac and Wickham soil, respectively (**Table 1**). The range of N fertilizer application for side-dressing varied from 75 lb N/A to 142 lb N/A, in addition to 50 lb N/A applied as starter banded at planting (**Table 1**). The total variable rate N application on the test field was 4,463 lb. Current practice for the field would have utilized 5,173 lb N (142 lb N/A rate) for the side-dress application based on the N recommendation for the most productive soil in the field. The variable rate side-dress application utilized in the field reduced N loading by a total of 711 lb (19.5 lb N/A), but increased the N applied to the more productive soils. The grain yield varied from 49 bu/A to 185 bu/A on Tarboro-Bojac and Wickham soil, respectively (**Table 1**). The average grain yield for the test field was 172 bu/A. The overall N use efficiency for the whole test field was very high. The variable rate N application produced a ratio of 1:1...pounds of N applied per bushel grain produced. If the current practice had been utilized to obtain the 172 bu/A yield, the ratio of N to yield (bu/A) would have been 1.12 (**Table 1**). Nitrogen use efficiency was increased with the variable rate application.

Dr. Khosla is an Assistant Professor and Extension Specialist of Precision Agriculture at Colorado State University, Ft. Collins. Dr. Alley is W.G. Wysor Professor of Agronomy at Virginia Tech.

TABLE 1. Soil type, land area, rates of N fertilization at planting and side-dressing, total N applied, grain yield, yield goal, and apparent N use efficiency for corresponding soil types in the 36-acre test field, 1998.

Soil type	Area, acres	Starter-band N	Side-dress N	Total N	Grain yield	Yield goal	Apparent N use efficiency
			lb N/A			bu/A	lb N/bu of grain
Tarboro-Bojac 25B	0.9	50	75	125	49	100	2.55
Bojac 1A	5.8	50	104	154	146	140	1.05
Altavista 1B	4.6	50	126	176	176	160	1.00
Wickham 29A & 29B	24.7	50	142	185	185	175	1.04
Total acres	**36.0**						

ONTARIO

Banded Potash Boosts No-Till Corn Yield

By Tony Vyn, Ken Janovicek, and Tom Bruulsema

Ontario corn producers are increasingly interested in using less tillage, both to conserve soil and to reduce costs. Their main rotation crops, soybeans and winter wheat, grow well without tillage. They find no-till corn more difficult to manage, but are adopting a variety of minimum tillage systems involving less disturbance and mixing of soil.

In no-till soils, immobile nutrients such as potassium (K) may accumulate at the surface and be less available to corn plants. Three years of field research on predominantly medium testing soils confirm that K needs are indeed higher with less tillage and that K placement can be critical.

With less tillage, immobile nutrients such as K become stratified. In 1996 we conducted a survey of 54 Ontario fields in continuous no-till for at least 5 years (and an average of 9 years). Exchangeable K levels in the top 2 inches were generally at least double those in the 4- to 8-inch layer. No-till soils warm more slowly in the spring, and the root system may expand more slowly in no-till soils because of higher bulk density.

The purpose of this research was to determine whether corn grown in these long-term no-till situations would have different requirements for K rate and placement. We chose three sites where corn was being planted into a soybean-wheat-corn rotation under no-till for at least 7 years.

For no-till corn, K makes a difference. Dr. Tony Vyn inspects the plots in Paris, Ontario, during June of 1998.

At the Kirkton and Belmont sites, where fall tillage was appropriate, we applied both fall and spring K treatments. The fall application was broadcast. The spring-applied starter, placed in a band 2 inches beside and 2 inches below the seed (2x2), contained 45 lb K_2O/A for the high rate (54 lb/A in 1996), and none for the low rate (9 lb/A in 1996). The corn hybrid was Pioneer 3752.

At the Kirkton site, on a silt loam soil, corn responded to both fall and spring applied K. This was expected, as soil test K levels in the top 6 inches ranged from 65 to 90 parts per million (ppm), which fall into the responsive range. However, responses to starter K were twice as large for no-till corn than for corn grown after fall moldboard plowing (**Figure 1**). The extra response suggests that no-till corn had a greater need for added K.

At the Belmont site, on a silty clay loam

TABLE 1. Annual differences in corn yield response to applied K at the Paris site.

	Response, bu/A	
Corn hybrid	**1997**	**1998**
DeKalb 385B	19	21
NK 3030	20	14
NK Max 357	22	1
Pioneer 3820	23	16
Pioneer 3893	5	11

soil with higher soil test K, responses were generally small and insignificant in 1997 and 1998. However, starter K increased no-till corn yields from 208 to 216 bu/A in 1998.

At the Paris site, one trial addressed differences among hybrids in responsiveness. Five additional hybrids were compared on a lighter-textured loamy soil that ranged from 50 to 60 ppm in exchangeable K. We applied K in the spring at 110 lb/A of K_2O by three different methods: broadcast, combination broadcast/band, and deep band (6 inches).

Application methods made no difference. In both 1997 and 1998, hybrids varied in their response to applied K, but not consistently (**Table 1**). Hybrid-specific K requirements are difficult to predict.

In a second trial at the Paris site, we compared K application methods in three tillage systems. In the first, corn was no-till planted. In the second, corn was planted into spring-tilled zones 10 inches wide by 6 inches deep. In the third, soil was mulch-tilled with two to three passes of a cultivator just prior to planting. For each, we applied K by the same three methods as for the hybrid trial.

In no-till, corn yields increased with both broadcast or combination broadcast/band K (**Figure 2**). It appears that no-till corn made good use of K applied on the surface, perhaps because the wheat stubble helped maintain soil moisture near the surface. In zone-till, the deep placed K was most effective. Perhaps zone tillage encouraged the roots to go downward, resulting in greater use of deep-placed K. Corn planted after mulch-tillage did not respond to K application by any method.

In both the Kirkton and Paris trials, overall response to K was stronger with no-till than with tillage. No-till corn producers should pay close attention to K in their starter fertilizer, particularly when their overall soil test levels are in the medium range or less.

This research was not designed to identify an optimum rate. Nevertheless it is clear that effective no-till corn starters should contain some K, and likely more than 9 lb K_2O/A.

The effective rates in this work approach the maximum safe rates for a 2x2 band, when K is accompanied by a reasonable rate of N. Some no-till producers are exploring placement in more than one band, placing small amounts close to the seed and banding the remainder at a greater distance. The foregoing considerations support that approach, particularly when higher K rates are required.

Dr. Vyn is Cropping Systems Agronomist, Agronomy Department, Purdue University, West Lafayette, IN (formerly at Guelph). Mr. Janovicek is a research assistant at the University of Guelph, Ontario. Dr. Bruulsema is Eastern Canada and Northeast U.S. Director, PPI, Guelph, Ontario, Canada.

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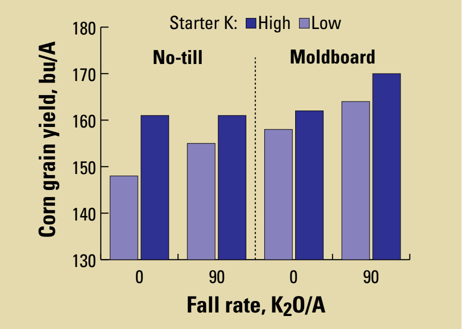

Figure 1. Corn grain yield response to K applied in the fall or as a spring starter at the Kirkton site. Average of 3 years, 1996-1998.

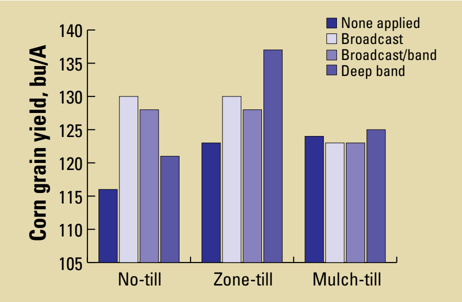

Figure 2. Corn yield response to K application method in three spring tillage systems at the Paris site. Average of 2 years, 1997-1998.

CALIFORNIA

Potassium Fertilization and Diagnostic Criteria for Pistachio Trees

By David Q. Zeng, Patrick H. Brown, and Brent A. Holtz

Although fertilizers in general have played an important role in California pistachio production, K fertilization has been largely ignored. Limited use of K could be partially attributed to: a) a scarce knowledge of K requirement and lack of documented K effects on improving nut yield and quality in pistachio; and b) the out-of-date view that California soils are not K-deficient and can supply adequate quantity of K for pistachio production. Consequently, K deficiency has occurred and affected the productivity of pistachio trees in many orchards. If K fertilizers are not adequately applied to replenish the soil K pools, K deficiency is expected to increase in severity and extent.

Potassium (K) fertilization of pistachio trees in the Central Valley of California substantially increased both nut yield and quality during a three-year study. Results indicated that the presently suggested leaf K critical level of 1.0 percent should be increased to 1.7 percent or higher.

This study was designed to determine the effects of K fertilizer, applied at the rates of 0, 120, 240, and 360 lb K_2O/A on leaf K concentration, nut yield, and quality of pistachio. Three field experiments were conducted from 1996 to 1998 on mature 'Kerman' pistachio trees in three commercial orchards located in Madera, Yolo, and Orland, CA. Available soil K in the surface 0 to 6 inches of soil was 82, 97, and 125 parts per million (ppm), respectively. Potassium was applied annually as potassium sulfate (K_2SO_4) via a specially designed fertigation system.

In pistachio, K deficiency is characterized by smaller, upward curling leaves with scorched leaf margin. The symptoms appear first on older leaves and those adjacent to the maturing fruits.

Potassium Fertilization Increases Leaf K

Pistachio trees exhibit highly dynamic seasonal K fluctuations (**Figure 1**). During spring flush from April to May, K demand is relatively low, and K uptake from the soil is minimal. Leaf K concentration during spring flush is usually below 1.0 percent. As fruit development proceeds, leaf K concentration increases dramatically, with the most significant increase occurring from July to September, the peak nut-fill period when the K demand and accumulation in the maturing nuts are maximal. Leaf K concentration declines rapidly after harvest in September, suggesting the translocation of leaf K to perennial tree organs to build the tree K storage pool.

Potassium fertilization improved K nutrition in the pistachio trees, with leaf K concentration being significantly higher in the K-treated trees than in the control trees not treated with K. However, the difference in leaf K concentration was not significant among the three K application rates, i.e., 120, 240, and 360 lb K_2O/A, except in the

Madera orchard where leaf K concentration was significantly higher in trees receiving 360 lb K_2O/A compared to those receiving 120 lb K_2O/A (data not shown).

Potassium Fertilization Increases Nut Yield

Average nut yield in control plots not receiving K fertilizers was 1,223, 1,934, and 1,963 lb/A in the Yolo, Madera, and Orland orchards, respectively (**Figure 2**). In contrast, when K was applied at the rate of 120 to 240 lb K_2O/A, the trees yielded 1,567 to 1,823 lb/A in the Yolo orchard, 2,806 to 3,179 lb/A in the Madera orchard, and 2,619 to 3,126 lb/A in the Orland orchard. With a further increase of annual K fertilization to 360 lb K_2O/A, the average nut yield was 1,695, 2,802, and 2,659 lb/A in the Yolo, Madera, and Orland orchards, respectively, which is a decrease of nut yield compared to 240 lb K_2O/A. This yield decrease was significant (at $P \leq 0.05$) in the Madera and Orland orchards, but not in the Yolo orchard. Reduced nut yield at high rates of K fertilization may be associated with reduced leaf calcium (Ca) and magnesium (Mg) concentrations, both of which were below the optimal ranges, suggesting potential antagonisms among K, Ca, and Mg (data not shown).

Fertilization Increases Nut Quality

The percentage of split, blank, and stained nuts and 100-nut weight are the major quality criteria used to grade pistachio nuts. It is desirable to produce a high percentage of split nuts and a high 100-nut weight, but low percentages of blank and stained nuts. **Figure 3** shows that the K-treated trees produced a significantly higher percentage of split nuts, higher 100-nut weight, and a significantly lower percentage of blank and stained nuts than in the control trees not receiving K. This clearly demonstrates improved nut quality due to K fertilization. However, there were no significant differences in these quality parameters among the treatments receiving K fertilization. Increased percentage of split nuts and nut weight are indicative of enhanced nut filling, probably due to enhanced photosynthesis and photoassimilate transport to the developing nuts when K fertilizer is applied. Nut staining is caused by fungal diseases, i.e., *Botroyspheria* and *Alternaria*, as pistachio trees are highly susceptible to fungal infections in orchards with high humidity. Reduced nut staining in the K-treated trees

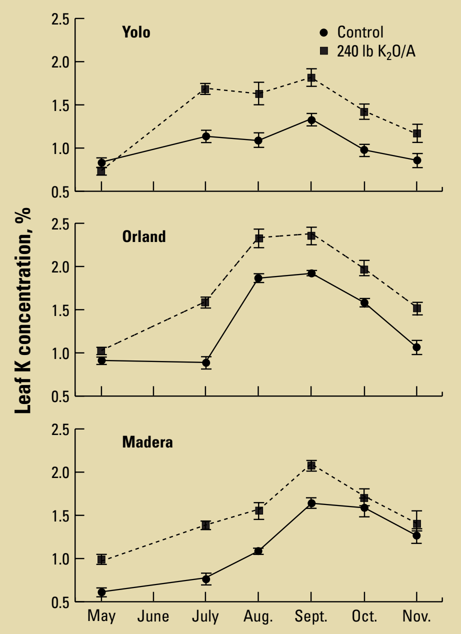

Figure 1. Seasonal variation in leaf K concentration in pistachio in 1998 in three orchards. Each value is the mean ± standard error of 5 replicates.

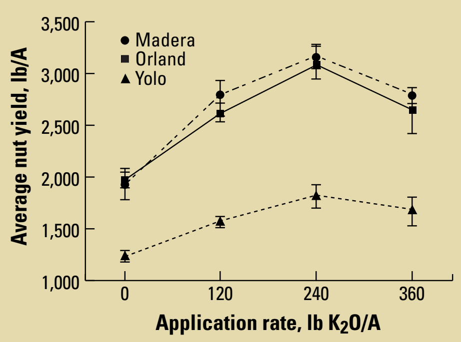

Figure 2. Yield of in-shell nut (average of 3 years) as affected by K applied at various rates in pistachio. Each value is the mean ± standard error of 5 replicates.

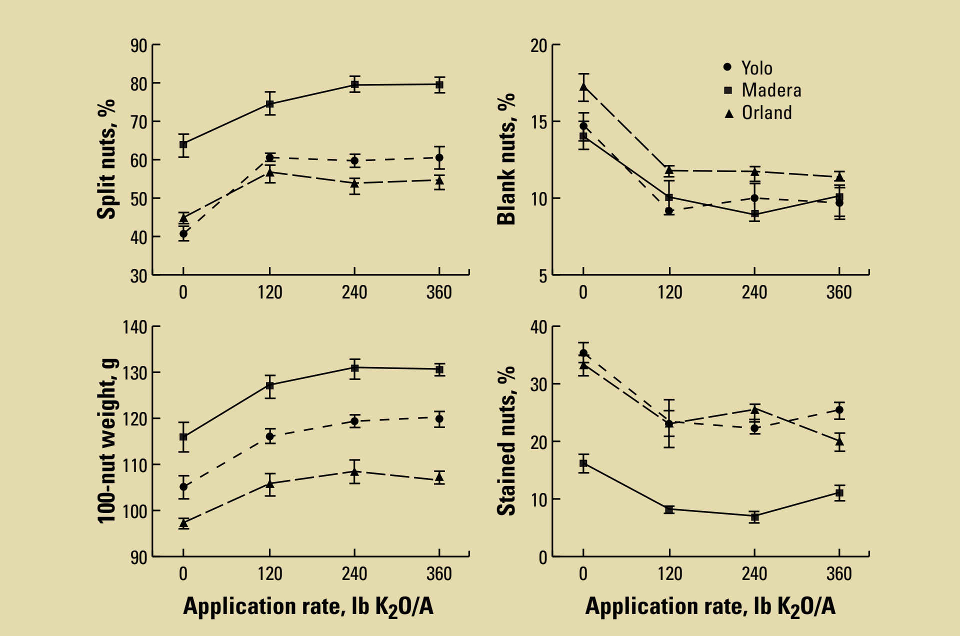

Figure 3. Potassium application improves pistachio nut quality. Each value is the average of 5 replicates ± standard error.

indicates that K may help build resistance of pistachio trees to diseases.

The Diagnostic Criteria for K Nutrition

In this study, the marketable, in-shell nut yield and leaf K concentration during the nut-fill period were averaged over three years for each orchard to perform a regression analysis at $P \leq 0.05$. The maximum nut yield ($Y_{100\%}$), 95 percent of the maximum yield ($Y_{95\%}$), and their corresponding leaf K concentrations ($K_{100\%}$ and $K_{95\%}$) were calculated. Researchers often use $Y_{95\%}$ as the reference point to diagnose nutrient status (sufficient vs. deficient) and refer to it as the critical leaf value. There was a significant, positive correlation between nut yield and leaf K concentration during nut fill in pistachio. Maximum nut yield ($Y_{100\%}$) was 1,844, 3,228, and 2,769 lb/A, with corresponding leaf concentration ($K_{100\%}$) being 2.03, 1.96, and 2.29 percent in the Yolo, Madera, and Orland orchards, respectively. The $K_{95\%}$ at $Y_{95\%}$ was 1.67, 1.69, and 2.02 percent in these three orchards, respectively. These results indicate that the presently suggested critical leaf K value of 1.0 percent, which was developed based on the expression of visual deficiency symptoms in the leaf, is too low to predict the K fertilization requirements for optimal pistachio production and that new K diagnostic criteria associated with optimal yield levels should be adopted.

Conclusions

Potassium fertilization increased leaf K concentration, nut yield, and quality in pistachio. The critical leaf K value for 95 percent maximum yield is 1.67 to 2.02 percent. It is recommended that K fertilizers be applied at the rate of 120 to 240 lb K_2O/A in California pistachio production. BC

Dr. Zeng is a former graduate research assistant and Dr. Brown is Associate Professor, Department of Pomology, University of California, Davis. Dr. Holtz is Pomology Farm Adviser, Madera County, CA.

Acknowledgements *– The authors appreciate the research grants from the California Pistachio Commission and the Potash & Phosphate Institute.*

ILLINOIS

Annual Carbon Fluxes from No-Till Corn and Soybeans

By S.E. Hollinger and T.P. Meyers

Continuous carbon dioxide (CO_2) and water flux monitoring from an 80-acre no-till field near Champaign, Illinois, was begun in August 1996. The field was in soybeans in 1996 and 1998 and corn in 1997. The objective of the continuous monitoring is to understand the annual water and C cycle for a typical Midwest no-till agriculture ecosystem.

High yield agriculture makes sense from the perspective of efficiently using natural resources to produce needed food and fiber. This research explores another benefit of high yield no-till agriculture – carbon (C) sequestration.

These measurements represent the only long term, continuous monitoring of CO_2 on a no-till corn and soybean ecosystem and provide valuable information regarding the role agriculture may play in sequestering CO_2. From an agricultural standpoint, a better understanding of the C cycle and of canopy CO_2 and water fluxes during the growing season will improve our knowledge of how weather impacts crop growth and yield under different management practices.

The role of agriculture in sequestering CO_2 is an important issue in the climate change debate and the subject of ongoing research. It is important to note that in the strictest sense, sequestering of CO_2 by agricultural ecosystems refers to organic C in the soil. The measurements reported here use a broader definition which includes soil organic C and C contained by the residue left on the surface. The C in the surface residue represents short-term C fixation but serves as a pool for the longer term CO_2 sequestering in the soil organic matter.

Measurements of atmospheric CO_2 and water vapor concentrations are obtained using an open-path infrared gas analyzer. The CO_2 and water vapor fluxes are computed from these measurements and wind data obtained from a 3-dimensional sonic anemometer. By convention, a negative CO_2 flux means the atmosphere is losing CO_2 while the ecosystem is gaining CO_2. Conversely, a positive CO_2 flux means the atmosphere is gaining CO_2 and the ecosystem is losing CO_2. Other continuous measurements taken at the site include air temperature, relative humidity, soil temperature, soil moisture, precipitation, barometric pressure, incoming global radiation, net radiation, incoming photosynthetically active radiation (PAR), and outgoing PAR. The flux station and weather instruments are located approximately 300 yards from the west, 300 yards from the south, and 100 yards from the north edges of the field. During the 1998 growing season, the leaf area index of the canopy

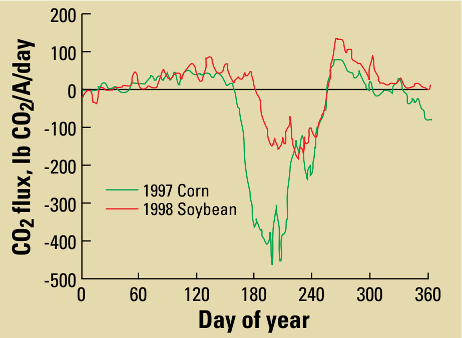

Figure 1. Carbon dioxide flux from a no-till corn (1997) and soybean (1998) field. A negative CO_2 flux indicates a gain of CO_2 by the ecosystem.

was measured weekly, and plants were destructively sampled to monitor above-ground plant biomass. Plant growth analysis will be continued in future years to study the effects of short-term weather events on crop growth and yields.

Data from two full growing seasons, one with corn (1997) and the other with soybean (1998), allow a preliminary comparison of the CO_2 cycles over a no-till ecosystem (**Figure 1**). Two major differences were observed between the two crops and the two years. The corn crop in 1997 reached a state of net fixation of CO_2 by the ecosystem (fluxes going negative) by June 8 (day 159). In 1998, when soybeans were in the field, net fixation of CO_2 did not occur until July 2 (day 183). The maximum ecosystem fixation rates were also different. Corn had a maximum fixation rate of 570 lb/A/day and soybeans 240 lb/A/day. The maximum soybean fixation rate was 42 percent of the maximum corn fixation rate. The maximum rate of ecosystem CO_2 loss, when crops were not growing, was greater for soybean (178 lb/A/day) than for corn (106 lb/A/day). The maximum CO_2 fixation rates observed are only slightly greater than the maximums computed in the mid-1960s for corn and soybeans. Average daily CO_2 fixation rates were also close to those reported in the literature.

In 1997 there was a net fixation of 9.2 tons/A of CO_2 from the time the crop was planted on April 18 until the crop was harvested on October 19. Of this C, approximately 3.1 tons/A were removed through the harvest of the grain. This represents a grain yield of 143 bu/A. A net of 6.1 tons/A was left on the land. The C left in the ecosystem represents the crop residue on the surface and old roots in the soil. The soybean ecosystem had a net CO_2 fixation of 2.3 tons/A from planting (June 1) to harvest (October 10) in 1998. The CO_2 removed in the grain was approximately 1.2 tons/A which represents a yield of 46.5 bu/A. Estimates of the CO_2 removed with the grain are arrived at by assuming that CO_2 comprises 92 percent of the corn and soybean grain. After the grain was removed from the field at harvest, an estimated 1.1 tons/A were left in the field in the form of surface residue and old roots.

The amount of C fixed by corn in 1997 might have been greater if a 20-day dry period had not occurred in late July (**Figure 2**). The decrease in the rate of CO_2 fixation from July 29 (day 210) to August 23 (day 235) was due to drought stress and cloudiness. Even though the canopy did not appear stressed, there was a reduction in the CO_2 fixation efficiency that began approximately 6 days after the last rain.

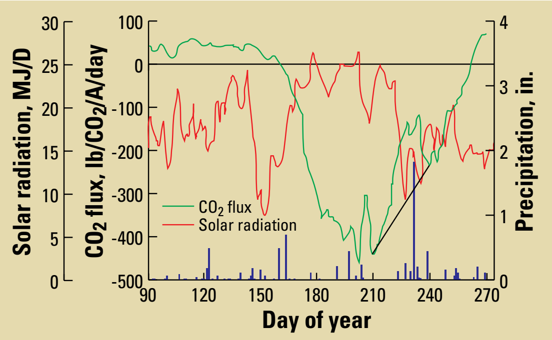

Figure 2. Carbon dioxide flux response of a no-till corn canopy in 1997 to solar radiation and rainfall. A negative CO_2 flux indicates a gain of CO_2 by the ecosystem.

TABLE 1. Seasonal net CO_2 exchange from a no-till field with corn in 1997 and soybeans in 1998.

Crop	Period	Net CO_2 exchange, tons	Evapotranspiration, in.	Precipitation, in.	Grain CO_2, tons
Soybean	Oct 20 1996 - Apr 18 1997	-1.56	5.05	6.42	–
Corn	Apr 18 1997 - Oct 19 1997	9.20	14.45	9.01	-3.13
Corn	Oct 20 1997 - Jun 1 1998	-1.58	8.33	10.67	–
Soybean	Jun 2 1998 - Oct 19 1998	2.22	14.46	7.59	-1.16
Soybean	Oct 20 1998 - Mar 31 1999	-1.15	3.95	5.06	–
Total	**Oct 20 1996 - Mar 31 1999**	**7.13**	**46.24**	**38.75**	**-4.29**

A negative CO_2 value indicates a C loss by the ecosystem.

Carbon dioxide fixation efficiency can be defined as the pounds of CO_2 fixed per acre per day divided by the solar radiation in megajoules (MJ) per day. In this case, CO_2 fixation efficiency was reduced by 40 percent. After the stress was reversed on day 220, CO_2 fixation rate never recovered to the pre-stress condition. Total CO_2 fixation was reduced by an estimated 0.25 tons/A. Because the crop was in the grain fill period, the yield loss during this period was approximately 8.8 bu/A, assuming that all the CO_2 fixed would have been stored in the grain and removed at harvest. The total yield loss due to the reduced CO_2 fixation efficiency was 5.7 bu/A, approximately 3 bu/A during the period from day 210 to day 220 and the rest from day 221 to day 235. An additional 3.1 bu/A was lost due to reduced solar radiation associated with the cloudiness during the rainy period from day 221 to day 235.

From October 20, 1996 to the end of March 1999, there was a net CO_2 gain of 2.84 tons/A. The average annual CO_2 gain for the ecosystem in a no-till corn and soybean rotation was 2.20 tons A/year. This compares to an estimated annual net fixation by a hardwood forest of 4.5 to 7.3 tons/A/year.

There was a net CO_2 gain of 4.49 tons/A to the ecosystem (**Table 1**) when the field was planted to corn in April 1997 and before the soybeans were planted in June 1998 and a net CO_2 loss of 0.09 tons/A from the field between the time soybeans were planted on June 1, 1998 and the end of March 1999. These totals also account for the CO_2 removed from the fields in grain. The difference between the two years was due mainly to the differences in the crop photosynthetic capacity and the residue left on the surface. Weather can also account for some of the differences. However, the weather effects in these data are masked by the large crop differences. To fully separate the effects of weather from the crop effects, simultaneous measurements need to be taken in corn and soybean fields. The soybean ecosystem experienced a greater loss of CO_2 due to the decomposition of the corn residue during the spring and summer and a large loss of CO_2 during the fall after the soybean crop was harvested. This large CO_2 loss (**Figure 1**) occurred after the soil and soybean residue were soaked by rain while soil temperatures were still above 50° F. The greater loss of CO_2 from the ecosystem in the spring of 1998 could also be attributed to the higher soil temperatures (**Figure 3**). The spring of 1997 was relatively cool and dry, while the spring of 1998 was warmer and wetter. The microbial activity necessary to decompose the surface residue is greater when conditions are wet and warm. Thus, the surface residue decomposes more rapidly.

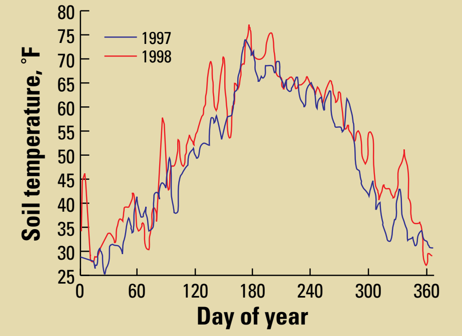

Figure 3. Annual soil temperature cycle at 3 inches during 1997 and 1998.

These CO_2 measurements show the potential for considerable short-term CO_2 sequestering by a no-till ecosystem in the Midwest. Additional monitoring of corn and soybeans over a no-till system during the same year is needed to determine the true contribution of no-till agriculture to CO_2 sequestering and the differences between the two crops. Earlier research showed that soil organic matter is decreased with conventional tillage practices. The degree to which this is true can also be investigated using the same instruments employed in this study. BC

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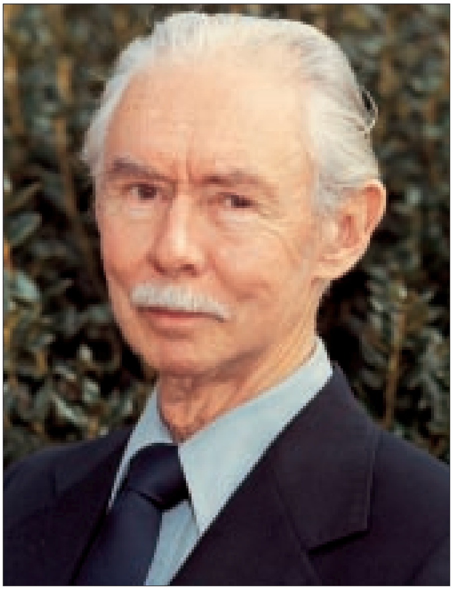
Acknowledgments *– The authors thank Mr. John Reifsteck for the use of the field from which these measurements were taken.*

In Memoriam: Dr. J. Fielding Reed December 15, 1912 - June 8, 1999

Dr. J. Fielding Reed, President Emeritus, Potash & Phosphate Institute, died on June 8, 1999 in St. Mary's Hospital in Athens, Georgia. He was 86 years old at the time of his death.



Dr. Reed was born December 15, 1912 in Baton Rouge, Louisiana. He attended Louisiana State University (LSU), where he received a B.S. degree in chemical engineering in 1933, an M.S. degree in biochemistry in 1934, and Ph.D. degree in biochemistry in 1937. During 1939-40, Dr. Reed held a Rockefeller Foundation postdoctorate fellowship at Cornell University, where he also earned a Ph.D. degree in soil science. After returning to LSU, he served as Assistant Agronomist and Professor of Soils until 1942.

As Agronomist with the North Carolina Department of Agriculture and North Carolina State University (NCSU), he helped to pioneer soil testing as it related to soil fertility studies. His early methods of taking soil samples, standardizing and calibrating tests, and using assembly line methods to process large numbers of soil tests were innovative. His research in the field of soil chemistry included studies of the importance of colloid considerations and the effect of soil cation exchange properties on nutrient uptake and composition of plants. Dr. Reed served as Director of the Soil Testing Division of the North Carolina Department of Agriculture and was also Professor of Agronomy at NCSU.

In 1949, Dr. Reed joined the staff of the American Potash Institute...now known as the Potash & Phosphate Institute (PPI)...as Director, Southern Territory. In January of 1963, he was named Executive Vice President. He was later elected President of the Institute, serving from January of 1964 until April of 1975.

During his 25-plus years with the Institute, Dr. Reed traveled hundreds of thousands of miles across North America, Europe, Scandinavia, India, Taiwan, Korea, Japan, Australia, and Latin America, representing the Institute and its programs.

Under Dr. Reed's leadership, the headquarters location of the Institute was moved from Washington, D.C., to Atlanta, Georgia. Agronomic research and education programs of the organization flourished. During his presidency, Institute scientists cooperated with official agriculture on hundreds of research projects and field demonstrations. They helped create and distribute more than 10 million pieces of agronomic literature and visual aids. They spoke by invitation to an estimated million specialists and farmers at field days, university seminars, and other professional meetings. And, North American farmers nearly doubled their use of potash.

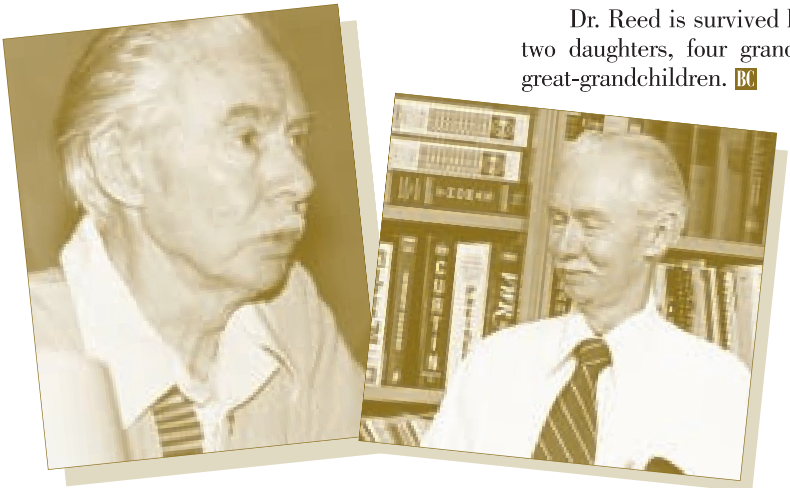
Internationally known as a man of keen intelligence and wit, Dr. Reed was recognized with awards and honors too numerous to mention. He was elected Fellow of ASA, SSSA and CSSA and was the recipient of the Agronomic Service Award from ASA. He served as President, Southern Section, ASA, and as

Vice President of the American Association for Advancement of Science (AAAS). He was elected Fellow, American Institute of Chemists. He was also the only industry leader ever elected President of the Southern Association of Agricultural Scientists.

Following his retirement as President of the Institute, Dr. Reed moved to Athens, Georgia, and taught at the University of Georgia, emphasizing the "diagnostic approach" to crop nutrient management. His association with the university continued for many years. He always enjoyed the association with students and took pride in the achievements of many he advised.

Dr. Reed was also active with the Georgia Plant Food Educational Society (GPFES), serving as President and as Executive Secretary-Treasurer. Three agronomy scholarships offered by GPFES are named in his honor, two at the Athens campus and one at Abraham Baldwin College, Tifton. Fellowships awarded by PPI each year to deserving graduate students are also identified as the "J. Fielding Reed PPI Fellowships." In 1998, the J. Fielding Reed endowed scholarship was established, sponsored by the Agronomic Science Foundation and supported by PPI, the Foundation for Agronomic Research, and others.

Dr. Reed is survived by his wife, Olivia, two daughters, four grandchildren, and six great-grandchildren.



BRITISH COLUMBIA

Timing of Nutrient Applications in Apple Orchards Using Fertigation

By Denise Neilsen and Gerry H. Neilsen

During a growing season, fruit trees use nutrients taken up by the roots and nutrients remobilized from previous years of uptake to support the growth of new tissues. The timing of uptake likely determines whether or not a nutrient is partitioned to the fruit. In studies conducted at the Pacific Agri-Food Research Centre in Summerland, the effect of timing of B and K applications on tree nutrition and fruit nutrient concentration has been assessed. Fertigation (applying nutrients through an irrigation system), is a method of nutrient supply which offers great flexibility in timing of applications.

Surveys of British Columbia (B.C.) apple orchards receiving drip irrigation have shown that certain nutrients may rapidly become depleted in coarse textured soils. Boron (B) and potassium (K) are two of the nutrients most susceptible to depletion, and B and K deficiencies have been identified in high density apple plantings in B.C. However, both nutrients have been reported to cause a reduction in storage quality if found in high concentration within the fruit.

In sandy soils with low organic matter content, B availability is closely related to B concentration in the soil solution. Soil solution B can be increased through fertigation and availability controlled quite precisely during the year (**Figure 1**). This is reflected in both leaf and fruit B concentrations (**Figure 2**). In 1996, trees received 0.012 oz. B/tree/year which resulted in high leaf B concentrations which were well above the critical level for deficiency...20 parts per million (ppm), but below the critical level for toxicity (60 ppm). Fruit B concentration was also high. In 1997 and 1998, a lower amount of B was applied either in spring or fall or not at all (as illustrated in **Figure 1** for 1998). Both leaf and fruit B levels were lower in response to the lower B rate. Leaf B levels fell below the critical value for deficiency the second year after B applications were ended, indicating a rapid decline in the tree and soil B storage pools. Fall application of B kept leaf B concentration above the deficiency level and also resulted in low fruit B levels. Thus, fall applications maintained tree B status without endangering fruit quality.

A similar experiment with timing of K applications had very different results. Potassium was applied at the rate of 1.06 oz. K/tree, either in spring-early summer, early-mid summer, or not at all. Because late applications of nitrogen (N) may have detrimental effects on tree winter hardiness, early K plots received K as potassium nitrate (KNO_3) and late K plots received K as potassium chloride (KCl). Nitrogen was supplied at the rate of 1.41 oz. N/tree/year either as ammoni-

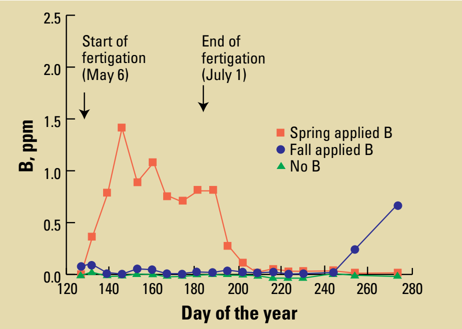


Figure 1. Soil solution B concentration in response to timing of application.

um nitrate (NH_4NO_3)...control and late K plots...or as KNO_3 plus NH_4NO_3 (early K plots).

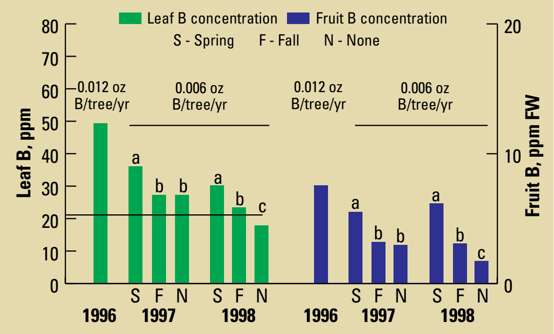


Figure 2. Leaf and fruit B content in Jonagold/M.9 apple trees in response to timing of B application.

Monitoring of soil solution K concentrations revealed an unexpected response to K applications (**Figure 3**). Plots receiving late K had very high K concentrations early in the growing season, prior to K application. It is surmised that as these plots were receiving half of their N in the ammonium form, there was considerable exchange of the added ammonium (NH_4) for K, which had been adsorbed by the soil the previous year.

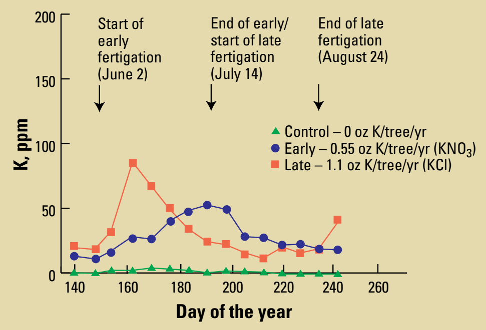


Figure 3. Soil solution K concentration in response to timing of K application in 1997.

In the early application treatments, soil solution K concentrations rose steadily after fertigation commenced in early June and were highest at the end of the fertigation period, suggesting a gradual saturation of soil cation exchange sites. Plots receiving no K had consistently lower soil solution K concentrations than plots fertigated with either KCl or KNO_3.

Potassium concentrations in leaves reflected the soil solution data (**Figure 4**). Timing of K supply had no effect on leaf K concentration, but trees receiving no K had consistently lower leaf K concentrations from 1996 to 1998. These findings suggest that precise timing of K applications to meet plant requirements may be particularly difficult if NH_4 based fertilizers are used to supply N. No trees had leaf K concentrations below the 1.2 ppm critical value for K deficiency. Except in 1997, when both application of K and timing of applications affected fruit K nutrition, there were no significant effects of K applications on fruit K concentrations (**Figure 4**). (Note: FW is abbreviation for fresh weight.)

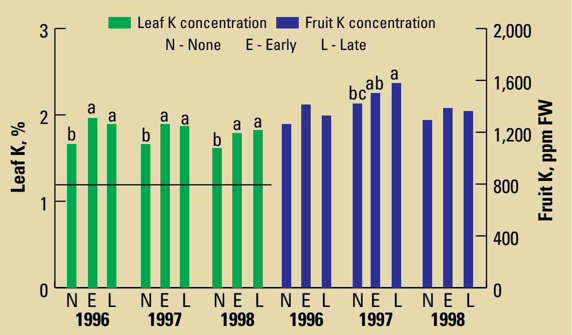


Figure 4. Leaf and fruit K content in Jonagold/M.9 apple trees in response to timing of K application.

The success of timing of nutrient applications to meet plant requirements for growth, while controlling fruit nutrient concentrations in order to maintain fruit quality, may depend on the mobility of the nutrient in the soil. Mobile nutrients such as B are easier to manage than nutrients such as K which are adsorbed by soil. Adsorbed K may be replaced by other fertilizer nutrients such as NH_4 and thus become more available during times when it is not being applied than in times when it is being applied. BC

The authors are research scientists with Agriculture and Agri-Food Canada, Pacific Agriculture Research Centre, Summerland, B.C.

PART 1

Phosphorus and Potassium Economics in Crop Production: Costs

By T.S. Murrell and R. D. Munson

Low crop prices have led many farmers to re-examine their soil fertility programs. Many are trying to cut costs and still maintain their production levels. Phosphorus (P) and potassium (K) are integral and well-proven parts of a profitable nutrient management program. Management decisions about P and K must be based on sound agronomic principles to assure profitability. Amounts of P and K producing maximum economic yields also minimize losses in tough times. This is the first of a three-part series that will provide a review of the economics of P and K fertilization to assist farmers, dealers, consultants, and other agribusiness professionals in their management of these nutrients.

Economic evaluations of P and K fertilization are usually performed through partial budgeting. Partial budgeting considers only the cost and revenue items associated with a particular management practice.

Soil sampling costs include laboratory analyses and labor for sample collection. **Fertilizer product expenses** are the costs per pound of nutrients and the amount needed. **Fertilizer application costs** are those associated with product application, such as custom spreading. With yield increases from fertilization, added costs are incurred for **handling (auger, tractor or truck, and labor) and hauling** to the farmstead and/or market. In addition, increased yields may translate to increased **drying costs and increased storage expenses.** Storage expenses will be determined from the farmer's decision whether or not to store grain and if so, for how long. The cost for each of these items will vary by location and depend on whether farmers do the work themselves or use commercial services. It is important for farmers who do the work themselves to include their own expenses, such as equipment, labor, fuel, and other costs.

Calculating Expenses Associated with P and K Fertilization

Calculating expenses requires the identification of inputs that have value beyond the current year. Such practices should have their costs spread over time (amortization). For instance, soil sampling for immobile nutrients such as P and K is usually conducted once every 2 to 4 years. Information gathered from sampling often affects fertilizer management decisions for two or more years. In corn and soybean rotations, the recommended rates of P and K for corn and soybeans are often applied only one year in the rotation. However, the fertilizer application has value for at least two years, depending on the rate used. A simple approach to amortizing such investments is to divide the total costs by the number of years between reinvestments as shown in the examples in **Table 1**.

Amortizing expenses accounts for the value that P and K fertilization may have beyond the year of application if rates are great enough. In some cases, farmers can spread payments for some of these investments over time. Farmers must have sufficient capital to pay expenses up front that cannot be paid on an annual schedule. This is the usual case for fertilizer product costs. Concerns over

TABLE 1. Example calculations of annual expenses associated with fertilization.

Example cost items	Example cost	Amortized?	Years amortized	Annual expense
Soil sampling				
Grid soil sampling (analysis and labor)	\$8.00/A	yes	4	\$2.00
Soil sample analysis only (P, K, and pH)	\$7.50/sample	yes	2	\$3.75/sample
Fertilizer product	\$0.25/lb P_2O_5	yes	2	\$0.125/lb P_2O_5
	\$0.12/lb K_2O	yes	2	\$0.06/lb K_2O
Fertilizer application				
Bulk fertilizer application (labor, power, and applicator provided)	\$4.50/A	yes	2	\$2.25/A
Variable rate fertilizer application (labor, power, and applicator provided)	\$10.00/A	yes	4	\$2.50/A
*Harvest expenses of additional yield**				
Grain hauling from field to farmstead storage	\$0.05/bu	no	—	\$0.05/bu
Grain hauling from storage to market, one way by truck, minimum charge	\$0.06/bu	no	—	\$0.06/bu
Grain handling (auger, tractor, and labor)	\$0.04/bu	no	—	\$0.04/bu
*Drying expenses of additional grain** (continuous flow dryer with fuel)	\$0.022/pt/bu	no	—	\$0.022/pt/bu
Storage expenses of additional grain (optional)*				
Monthly rental	\$0.02/bu	no	—	\$0.02/bu
Annual rental	\$0.11/bu	no	—	\$0.11/bu

*Data: Lazarus, W. 1997. Minnesota farm custom rate survey. University of Minnesota Extension Service Publication FS-3700-GO. University of Minnesota, St. Paul, MN.

cash flow may cause many to attempt to recover their P and K fertilization investments the first year, even though P and K have value beyond the year of application.

Long-term Benefits of P and K

Both P and K can increase yields for several years if rates are adequate. These nutrients undergo many complex reactions in soils and become part of a nutrient pool that is available over time. They are released from this pool as crops take them up from the soil solution. To show just how long P and K may be available, one needs to examine the long-term effects of a single fertilizer application. **Table 2** shows that a one-time application of 298 lb P_2O_5/A produced a 14-year total return of \$661.44. The application also raised soil test levels to 43 parts per million (ppm). Using \$0.23/lb P_2O_5, which was the April, 1975 price of 0-46-0 (National Agriculture Statistics Service), the fertilizer product cost was \$68.54/A. Adding to this a one-time \$4.50/A bulk fertilizer application fee and \$7.50/A for soil testing, plus a total of \$43.08/A of additional harvest expenses for the 14-year period, the total return was \$537.82/A, providing an average annual net return to the P application of \$38.42/yr. Averaged over the 14-year period, the annual application rate was 21 lb P_2O_5/A. When the same initial rate of P_2O_5 was applied, followed by annual applications of 23 lb P_2O_5/A for the 14-year period, the total and average annual net returns were \$562.16/A and \$40.15/A/yr. respectively. Annual applications of 23 lb P_2O_5/A without the large initial application produced total and average net returns of \$467.24/A and \$33.38/A/yr. Historic March or April P_2O_5 prices were used to calculate phosphate fertilizer expenses each year. Application costs of \$4.50 were assumed for each year for the 23 lb P_2O_5/A rate. Corn price during this 14-year period ranged from \$1.41 to \$3.12 per bushel, demonstrating that low crop prices have occurred before. The current price situation is not unique and will probably occur again. In this example, a single, large P_2O_5 application

TABLE 2. Residual effects on corn grain yield and returns from a one-time P application of 298 lb P_2O_5/A, applied in the spring of 1975.

Year	Corn grain yield[1] 0 lb P_2O_5/A	Corn grain yield[1] 298 lb P_2O_5/A	Corn grain yield increase from P	Average annual corn price[2], $/bu	Annual return from yield, $/A	Bray P-1 soil test 0 lb P_2O_5/A (17 ppm in fall, 1975)	Bray P-1 soil test 298 lb P_2O_5/A (43 ppm in fall, 1975)
	bu/A					ppm	
1976	138.0	138.9	0.9	2.05	1.85	14	33
1977	134.1	135.3	1.2	1.99	2.39	13	36
1978	150.9	157.2	6.3	2.17	13.67	11	29
1979	160.9	176.7	15.8	2.42	38.24	9	23
1980	157.9	169.9	12.0	3.00	36.00	9	25
1981	163.2	185.0	21.8	2.34	51.01	9	23
1982	145.7	179.0	33.3	2.69	89.58	8	18
1983	120.3	147.3	27.0	3.12	84.24	6	14
1984	111.2	151.8	40.6	2.51	101.91	7	13
1985	144.6	175.0	30.4	2.02	61.41	7	13
1986	116.5	157.5	41.0	1.41	57.81	7	15
1987	129.6	152.8	23.2	1.89	43.85	6	11
1988	60.2	74.6	14.4	2.45	35.28	7	9
1989	123.4	142.7	19.3	2.29	44.20	4	8
Mean	132.6	153.1	20.5	2.31	47.25		
Total			287.2		661.44		

[1] J.R. Webb, A.P. Mallarino, and A.M. Blackmer. 1992. Effects of residual and annually applied phosphorus on soil test values and yields of corn and soybean. J. Prod. Agric. 5(1):148-152.

[2] Iowa Agricultural Statistics Service data for average annual price received by Iowa farmers. Data available online at http://www.nass.usda.gov/ia/prices/crn60_up.txt

that raised the soil test to very high levels, followed by annual applications, resulted in greater long-term profitability than either a similar amount of P_2O_5 distributed annually over the 14-year period or the single large application by itself. This example demonstrates that P has long-term effects on yield, so limiting the amortization schedule of P and K to short times between applications may produce very conservative estimates of actual benefits produced, depending on the rate applied. Both P and K are capable of providing benefits well beyond such periods.

The long-term benefits of P and K are complex, and general principles for determining long-term value are being investigated. Much of the complexity is due in part to the site-specific reactions of P and K. The amortization process outlined above is an attempt to recognize the value of P and K beyond the year of application. These estimates may be used as a first approximation until better amortization schedules are developed.

Knowing the appropriate costs involved with P and K fertilization is critical to making well-informed decisions about nutrient management in times of low crop prices.

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PART 2

Phosphorus and Potassium Economics in Crop Production: Net Returns

By T.S. Murrell and R.D. Munson

Soil test calibration curves are used to find soil test levels that are optimum for the production of a given crop. They link a specific soil test, long-term expected yield, and probability of yield response. Soil test calibration curves like the one in **Figure 1** show the relationship between the relative yield of a given crop, or percent of the yield goal attainable, and soil test levels. These curves are created by analyzing yield response data from P or K rate studies conducted at many different sites and initial soil test levels. Usually, P or K applications are broadcast. Relative yields for a given location and year are calculated by dividing the average yield of the plots where no P or K fertilizer was applied by the average yield of the plots receiving fertilizer at adequate or greater rates. Therefore, one rate study at a given site in a given year (site-year) produces one point on the soil test calibration curve.

Determining net returns (profit) generated by phosphorus (P) and potassium (K) use comes from experimental data. The increase in yield will largely determine the profitability of P and K fertilization. Realistically, it is not possible to collect P and K response data on every farm. Consequently, actual responses to P and K use at a particular site are usually unknown. However, guidance in the rates of P and K to use can be determined from long-term university experiments on many soils in a given state over many years. These data provide a first approximation of realistic amounts to apply and the responses a farmer may expect.

Figure 1 demonstrates the principle common to almost all calibration curves: Lower soil test levels are associated with lower yields and a higher probability of crop response to P or K inputs. An important feature of the soil test calibration curve is the *critical level*. The critical level is the soil test below which yield response to applied P or K is more probable. Above the critical level, soil test levels are not expected to limit yields, and little crop response from broadcast P or K is expected.

Yield response to P and K broadcast applications at various soil test levels can be roughly estimated from soil test calibration data. The underlying assumptions of such estimates are 1) factors other than P or K do not prevent a crop from reaching the yield goal, 2) university recommended rates are optimum for a site, 3) crop response at a particular site will reflect a response estimated from many sites and years, and 4) yields, after fertilization, will approach 100 percent relative yield. Using **Figure 1** as an example, that means that P applied at recommended rates to a soil testing 2 parts per million (ppm) Olsen P is capable, over the long-term, of increasing winter wheat yields by 35 percent. If this percentage increase is multiplied by the yield goal, it can be converted to a bushel estimate. For instance, if the yield goal is 75 bu/A, estimated increase in yield from following university recommendations for broadcast applications is 0.35 x 75 bu/A, or approximately 26 bu/A.

Examples of calibration data from several states and crops are reproduced in **Tables 1** and **2**. They should be interpreted with the

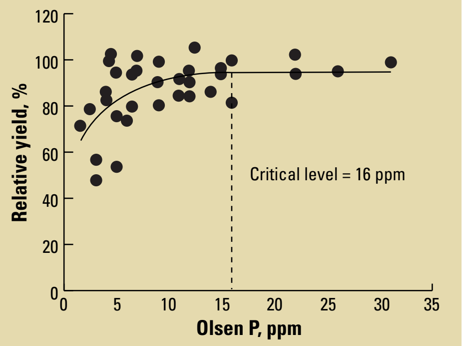

Figure 1. South Dakota soil test calibration data for winter wheat. Data from 34 site-years, 1986-1996 (R. Gelderman, J. Gerwing, C. Stymiest, and S. Haley, SDSU).

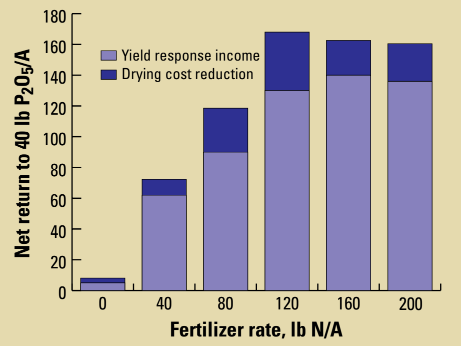

Figure 2. Phosphorus hastens maturity and lowers drying costs, adding to the return to P fertilization (K. Dhuyvetter and A. Schlegel, KSU).

assumptions outlined above. Where they exist, long-term, local data should be used to refine response estimates based on these data.

The amount of P and K required to raise soil test levels by 1 ppm (termed buffer capacity) depends on local conditions and management practices. (A review of this complex topic by D.F. Leikam is available in the 1992 Proceedings, North Central Extension – Industry Soil Fertility Conference.) Some university-Extension publications provide average values that may be used as general estimates. For instance, the University of Illinois *Agronomy Handbook* suggests that 18 lb P_2O_5/A and 8 lb K_2O/A be used as application rates needed to raise P and K soil test levels by 1 ppm. The magnitudes of crop responses to P and K in any single year can be quite variable. There are many factors that interact with P and K to influence crop growth and development. It is beyond the scope of this paper to discuss these. However, one must be aware that factors such as levels of other nutrients, diseases, insects, moisture level, etc. will influence how crops respond to P and K in a particular year.

Usually, the data comprising soil test calibration curves come from studies that focus on the influence of either P or K on yields. All other nutrients are applied at rates believed non-limiting for crop production. Results from such a study are shown in **Table 3**. These data represent a part of the larger P rate study conducted on winter wheat in South Dakota shown in **Figure 1**. It is interesting to note the differences in yield responses between two sites with similar soil test levels. The Watertown site showed dramatic wheat yield increases to P, while the Ideal site showed no response. The non-responsiveness of the Ideal site was attributed to dry weather and miner-

TABLE 1. Phosphorus calibration examples (Bray P-1, except where noted).

Soil test level, ppm	Average relative yield, % Corn Iowa	Corn or Soybean Illinois	Spring wheat N. Great Plains[1]	Winter wheat Kansas
2.5	66.5	42.0	61.2	35.0
5.0	77.3	54.8	78.0	56.4
7.5	86.7	69.3	85.9	73.6
10.0	91.3	81.3	90.4	82.1
12.5	94.1	90.2	93.3	87.9
15.0	95.9	94.7	95.4	92.3
17.5	97.1	97.3	97.0	95.0
20.0	98.0	98.0	98.2	97.1
22.5	98.7	98.6	99.1	98.2
25.0	99.3	99.1	99.9	99.3
27.5	99.6	99.5	100.0	100.0
30.0	99.8	99.8		
32.5	99.9	100.0		
35.0	100.0			

[1] Olsen P

Data: Potash & Phosphate Institute, PKMAN: A tool for personalizing P and K management. Version 1.0.

alization of P from the previous alfalfa crop. The Watertown site was fallow the previous year. These data show that responses to P and K are not always predictable for a given year. Response at any given site and year from broadcast applications can be either greater or less than these long-term averages, depending on local conditions and how many yield-limiting factors are present. Long-term studies do show that soil test levels are an important indicator for determining the long-term probability and profitability of a yield response to fertilizer additions. Keeping in mind the limitations and assumptions outlined above, producers lacking local P and K response data can use the data in **Tables 1** and **2** to begin quantifying possible risks and benefits of P and K fertilization.

Economics of Banded P and K Placement

Increasing yields with P and K can occur even on soils testing high and very high in these nutrients. The previous discussion demonstrated the importance of soil test levels on estimating crop response to broadcast P and K applications. However, it is well known that P and K, applied in starters or banded in other ways, can produce benefits even at high to very high soil test levels. Data in **Table 4** demonstrate the economic benefits of starter K on corn yield. In this example, an investment in 20 lb K_2O applied as starter increased net returns at low costs per added bushel. Banded placement of P and K provides higher concentrations of these nutrients near roots, increasing their availability. Increased availability is especially important when conditions inhibit root proliferation and/or crop development. Examples of such conditions are a cool, wet spring or a late planting of corn hybrids with longer relative maturities.

Banded fertilizer applications are especially important in reduced-tillage systems. Placement of P and/or K below the soil surface can boost yields on soils that have higher concentrations of P or K occurring near the soil surface. Data from Minnesota show the economic advantage to using banded K in a ridge-till system (**Table 5**). In this example, the highest net returns resulted from the 20 and 40 lb K_2O/A rates. Profitable responses occurred even with higher costs associated with band applications. Yield increases resulted from placing K deep in the ridge where nutrient depletion had been greatest. These are examples illustrating that there is more to economic decisions about P and K fertilization than simply soil test levels. The entire cropping system must be evaluated to determine the best strategy for managing P and K in a profitable manner.

TABLE 2. Potassium calibration examples (ammonium acetate).

Soil test level, ppm	Average relative yield, % Corn Missouri	Corn Illinois	Soybean Illinois
60	62.0	52.5	59.5
70	69.8	66.0	66.0
80	76.3	74.5	73.5
90	82.0	82.0	79.6
100	86.8	87.2	85.2
110	91.0	91.9	90.2
120	96.0	95.0	94.6
130	97.0	97.1	97.1
140	98.3	98.4	98.4
150	99.6	99.3	99.3
160	100.0	99.9	99.9
170		100.0	100.0

Data: Potash & Phosphate Institute, PKMAN: A tool for personalizing P and K management. Version 1.0.

TABLE 3. Winter wheat yields resulting from P treatments, 1995. Phosphate applied with the seed as 0-46-0.

Rate of P_2O_5, lb/A	Site: Ideal, 4.5 ppm Olsen P (bu/A)	Watertown, 5.0 ppm Olsen P (bu/A)
0	33	39
25	32	49
50	34	45
75	31	56
100	32	73
Significant response?	No	Yes

Data: R. Gelderman, J. Gerwing, C. Stymiest, and S. Haley (SDSU).

Value-Added Income Associated with Fertilizer Use

Benefits of P and K fertilization go beyond yield increases. These nutrients often improve crop quality which can lead to premiums being paid. Some of the benefits of P and K are summarized below.

Benefits of P:

- Increased nodulation and greater nitrogen (N) fixation
- Better water use efficiency
- Improved disease resistance
- Higher crop quality
- Earlier maturity
- Increased root growth: can lead to improved yield under moisture stress

Benefits of K:

- Increased nodulation and development
- Increased ability to withstand drought stress
- Improved disease resistance
- Higher crop quality
- Increased grain development
- Increased kernel plumpness
- Reduced lodging
- Improved winter-hardiness
- Better N use efficiency

The contribution of crop quality to gross revenue is usually not straightforward. It is often difficult to know the true value of increased root growth or improved disease resistance. For this reason, quality is often not considered in fertilizer economics. Occasionally, however, some studies are conducted that allow contributions of crop quality to be quantified. **Figure 2** demonstrates the economic impact of earlier maturity and therefore lower grain moisture after P fertilization. Fertilizer expenses used in this calculation were annual costs of sampling, application, handling, har-

TABLE 4. Corn yield and economic benefits of row K at various soil test K levels (Wisconsin).

K soil test, lb/A	Corn yield at two K rates: 0 lb K_2O/A	20 lb K_2O/A	Added yield	Added gross return[1]	Added cost[2]	Net return	Cost per added bushel, $/bu
	bu/A			$/A			
158	105	127	22	44.00	14.59	29.41	0.66
167	117	158	41	82.00	20.67	61.33	0.50
227	143	158	15	30.00	12.35	17.65	0.82
331	142	162	20	40.00	13.95	26.05	0.70

[1] Corn price set at $2.00/bu.

[2] Added costs include additional harvest costs ($0.32/bu), potash cost (0.14/lb K_2O), band application cost of $4.00/A, and soil sampling costs of $0.75/A. (See discussion for **Table 1** in Part 3 of this series.)

TABLE 5. Deep banded K boosts yields and profitability on a soil testing 157 ppm K in a ridge-till system (Minnesota).

Deep banded K_2O/ rate, lbs/A	Corn grain yield, bu/A	Yield increase, bu/A	Added gross return	Added cost	Net return	Cost per added bushel, $/bu
			$/A			
0	153	—	—	—	—	—
20	162	9	18.00	10.43	7.57	1.16
40	162	9	18.00	13.23	4.77	1.47
60	159	6	12.00	15.07	-3.07	2.51
80	165	12	24.00	19.79	4.21	1.65

[1] Corn price set at $2.00/bu.

[2] Added costs include additional harvest costs ($0.32/bu), potash cost (0.14/lb K_2O), band application cost of $4.00/A, and soil sampling costs of $0.75/A. (See discussion for **Table 1** in Part 3 of this series.) Base cost without K: $300/A; corn sale price: $2.25/bu; band applications: $4.00/A.

vest, and drying costs listed in **Part 1, Table 1** (see page 21). A low corn price of $2.00/bu was assumed. Phosphate cost was not amortized.

In times of low crop prices, farmers need to understand what benefits are possible from P and K fertilization. Local data, collected over many sites and years, provide a good basis for estimating crop response to these nutrients. However, where such research does not exist, the approaches presented in this paper for estimating response provide a first approximation of yield increases that may occur. It is also important to realize that there is more to managing P and K than just soil test levels. Banded P and K applications can be profitable even on soils that test high in these nutrients. Proper P and K management strategies require knowledge about the benefits of these nutrients under management practices unique to each farmer.

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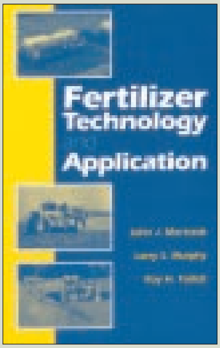
New Book Available...
Fertilizer Technology and Application

A new book titled *Fertilizer Technology and Application* offers easily accessible information on the production and application of commonly used fertilizers, lime and gypsum. The intended audience of the book includes agronomists, fertilizer dealers, crop consultants, researchers and teachers of soil fertility and fertilizers, and others around the world.



The 200-page book is authored by J.J. Mortvedt, L.S. Murphy, and R.H. Follett. The price is $34.95 plus $6.00 for shipping and handling. Copies can be purchased from Meister Publishing Company, 37733 Euclid Ave., Willoughby, OH 44094; phone (440) 942-2000 and fax (440) 942-0662.

Information Agriculture Conference Rates High Marks from Participants

InfoAg99 drew more than 600 participants August 9, 10 and 11 to the campus of Purdue University, West Lafayette, Indiana. Program tracks featured data analysis, site-specific management guidelines, communications technology in agriculture, a nutrient management planning workshop, and business aspects of precision agriculture. Updates on technology such as the global positioning system, geographic information systems, remote sensing, variable rate application, and other site-specific topics were featured. New tools in nutrient management planning were introduced at InfoAg99, recognizing the importance of livestock manure considerations in crop production. A new publication series called Site-Specific Management Guidelines was also part of the proceedings.

The conference was organized by PPI/PPIC, Foundation for Agronomic Research (FAR), and Purdue, in cooperation with other sponsors and supporters. For more about the Information Agriculture Conference, call (605) 692-6280, fax (605) 697-7149, or check the website at www.ppi-far.org/infoag99.

PART 3

Phosphorus and Potassium Economics in Crop Production: Putting the Pieces Together

By T.S. Murrell and R.D. Munson

Fertilizer used properly can result in yield increases that help spread fixed and variable costs over more bushels, lowering cost per bushel. Lower expenses per bushel mean that the farm is operating more efficiently, a characteristic seen on more profitable farms. Calculating costs per bushel requires not only fertilizer costs, but also the entire set of overhead and direct costs associated with a farm and a particular crop.

In the event the farmer has not accounted for all of his or her expenses, local farm management associations may have summary data of farmers belonging to a local association.

To calculate costs per bushel, one simply divides total production costs by the bushels produced. As an example, consider corn response to K fertilization in **Table 1**. In this example, the costs considered were soil sample analyses, fertilizer, application, and harvest costs. Soil samples, taken every 2 years, representing 5 acres, and analyzed for P, K, and pH, were assumed to cost \$0.75/A/year for chemical analysis. Potassium fertilizer price was set at \$0.14/lb K_2O, and application costs were \$2.25/A/year. Corn price was \$2.00/bu; harvest costs included \$0.15/bu for handling and hauling and \$0.17/bu drying costs, assuming corn was harvested at 23 percent (pt) moisture and dried to 15.5 percent at \$0.022/pt/bu [(23 pt - 15.5 pt) (\$0.022/pt/bu) = \$0.17/bu].

These data demonstrate that crop responses to appropriate application rates of K can lower unit costs of production and increase net profit per acre. In this example, the total cost per bushel dropped from \$2.05 to \$1.84. Higher investments led to greater returns and a more efficient production system. The same concepts apply to appropriate P fertilization. Local crop response data, where they exist, provide estimates for the profitability of P or K additions. Where local data do not exist, generalized responses, such as those discussed in **Part 2** of this series, may provide first approximations needed to calculate expected returns. It should also be noted that the returns and lower unit costs were based on response data from a single crop in a rotation. Residual effects of P or K applications on future crops were not considered. These data, then, probably underestimate the true value of P and K fertilization, depending on the rates used.

When times are tough, farmers try to lower their fixed and variable costs. Fixed costs are relatively inflexible and often hard to reduce. They can be controlled somewhat by improving efficiency and by making decisions such as maintaining a functional piece of equipment rather than purchasing a new one. Many farmers may target variable costs, such as fertilizer, for cost reductions. However, before cutting down on phosphorus (P) and potassium (K) use, they should carefully evaluate their soils and fertility program. Nitrogen (N), P and K account for a high percentage of crop yields and are critical to successful farming operations. Those who fine-tune their system for maximum economic yields maximize their profits in good times and minimize their losses in bad times.

Prices and Recommended Rates

Optimum fertilizer rate is determined by the farmer's preference of marginal net return. Marginal net return is the added dollar value returned per last dollar invested. **Figure 1** shows marginal returns for long-term P response data. The optimum rate was determined from single year crop response as the P rate yielding $1.00 returned per $1.00 invested. Applying more P than optimum would result in less than $1.00 return per $1.00 invested, cutting into profits. Such curves do not normally consider multiple-year effects of a single application.

An analysis of economic optimum rates, which maximize profit or minimize loss, is based on current market prices. Changing market conditions will lead to changes in optimum fertilizer rates. Two important economic factors that vary from year to year are crop price and fertilizer material cost. Curves similar to that in **Figure 1** were constructed for corn prices ranging from $2.00 to $4.00/bu and for P_2O_5 prices ranging from $0.15 to $0.35/lb. **Table 2** shows the influence of these two variables on the optimum P rate calculated from the previous examples. This table demonstrates that optimum P rates for the example in **Figure 1** can vary from 28 to 51 lb P_2O_5/A, considering P_2O_5 prices from $0.15 to $0.35/lb and corn prices from $2.00 to $4.00/bu. Fluctuations in P fertilizer price affect optimum rates less at higher corn prices. Fluctuations in crop price affect optimum rates less at lower P fertilizer prices. If modest swings in P fertilizer cost or corn price are expected in a given year, the optimum P rate chosen for a particular crop year does not change greatly. For instance, if the corn price increases from $2.00 to $2.50 and P costs are

TABLE 1. Potassium fertilization increases corn yields and return per acre by lowering the unit cost of production (Ohio).

K_2O rate, lb/A	Corn grain yield, bu/A	Additional yield, bu/A	Added gross revenue, $/A	Additional costs from yield response to K, $/A	Added costs from K fertilization, $/A	Net return, $/A	Added net return, $/A	Total cost per bushel, $/bu
0	146	—	—	—	—	-8.00	—	2.05
50	167	21	42.00	6.72	10.00	17.28	25.28	1.90
100	174	7	14.00	2.24	7.00	22.04	4.76	1.87
200	187	13	26.00	4.16	14.00	29.88	7.84	1.84

Base cost without K: $300/A; soil test K: 126 to 209 lb/A; corn price: $2.00/bu.

TABLE 2. Effects of crop prices and fertilizer expenses on recommended P rates for corn, based on an Iowa State University 14-year P rate study.

P_2O_5 price, $/lb	Recommended P_2O_5 rate, lb/A @ corn prices, $/bu					Difference from $2.00/bu corn prices, lb P_2O_5
	2.00	2.50	3.00	3.50	4.00	
0.15	44	47	49	50	51	7
0.20	40	44	47	48	49	9
0.25	36	41	44	46	48	12
0.30	32	38	42	44	46	14
0.35	28	35	40	42	44	16
Differences from $0.20/lb fertilizer costs (lb P_2O_5/A):	16	12	9	8	7	

Data: J.R. Webb, A.P. Mallarino, and A.M. Blackmer, ISU.

$0.20/lb P_2O_5, the optimum rate changes by only 4 lb P_2O_5/A, which is beyond the precision of most application equipment.

Managing Risk

There are three basic types of risk that producers face in their fertilization program: 1) risk that a fertilizer application will not be profitable, 2) risk that soil test levels within a field are yield-limiting, and 3) risk that soil test levels are not high enough to cushion errors or financially-trying times (reduced flexibility). **Figure 2** shows how these risks are related to soil test levels. At lower soil test levels, there is a higher probability that a fertilizer application will be profitable in the year of application, but increased risk that soil test levels are yield-limiting or do not allow much room for error. Soil fertility held very near medium, based on general small plot soil test calibration research, requires that soil testing and sampling be performed well and that the sampled field have fairly uniform soil test levels. Uniformity of soil test levels can be tested by more intensive sampling.

Farmers should be aware that there are several examples where more intensive sampling has identified field areas testing much lower and much higher than the field average. Soil test levels close to the medium range require annual fertilizer additions, or at least additions large enough to cover the nutrient needs of the crops produced between applications. Building soil test levels to the high side of medium or to high allows more room for error and reduces the risk that soil tests might be yield limiting. In addition, producers who have built their soil tests to high or very high levels may be able to skip an annual P or K application, but use row applications where appropriate. However, building soil tests to levels higher than medium increases the risk that annual yield returns will not cover fertilizer expenses. Each producer must realize the risks associated with the various soil test levels and make decisions based on the risks he or she is willing to accept.

Managing Soil Test Levels

Without soil testing, no reasonable estimate of yield responses to fertilizer can be

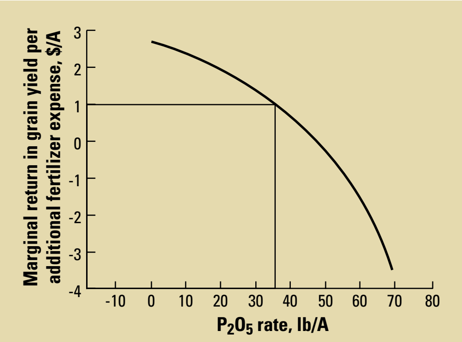


Figure 1. Marginal returns to phosphate fertilizer expenses for $2.00/bu corn, $0.25/lb P_2O_5, and added handling, harvest, and drying costs. Data source: J.R. Webb, A.P. Mallarino, and A.M. Blackmer, ISU.

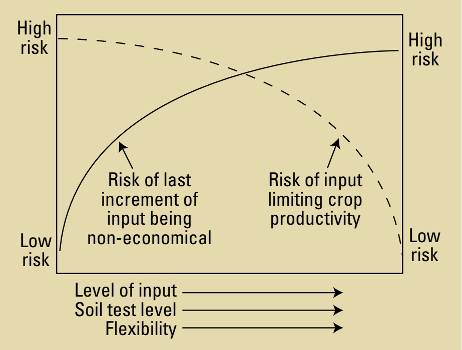


Figure 2. Risk incurred at various soil test levels (D. Leikam, personal communication).

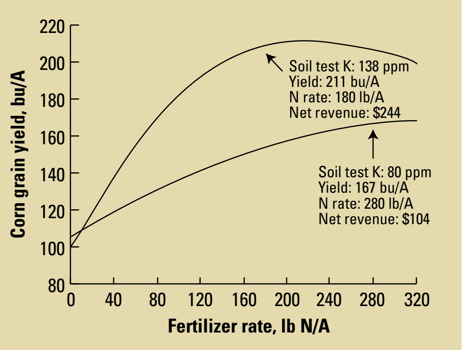


Figure 3. Higher soil test K levels increase N use efficiency and net returns to N fertilization (Data: Ohio; prices set at $2.50/bu corn, $0.20/lb N).

TABLE 3. Average P and K crop removal numbers for corn, soybeans and wheat.

Crop	P removal, lb P_2O_5/bu	K removal, lb K_2O/bu
Corn	0.38	0.28
Soybeans	0.80	1.40
Wheat	0.50	0.26

made unless check strips are left and harvested separately. The previous discussion has demonstrated that soil testing is important for managing risk. Soil testing is a very inexpensive management practice on which important decisions can be made. Similar small investments producing valuable information are field scouting and plant analysis. Time spent on management decisions, such as analysis and problem assessment, is a characteristic of more profitable producers.

It is important to remember that nutrients are removed from a field when harvested portions of the crop are removed. Some average removal rates for corn, soybeans and wheat are listed in **Table 3**. Crop removals will reduce the quantity of P and K in the soil. This will be reflected in reduced soil test P and K values. The effects of crop removal are shown in **Part 1**, **Table 2** of this series. Since no annual P was applied after the first year, soil test levels decreased with time. It is also interesting to note that soil tests declined more rapidly for the soil with a higher initial soil test level. This is a relationship that is commonly observed in long-term studies. For this reason, farmers with soil test levels high enough to skip an application of P or K should closely monitor changes in soil tests to ensure they have not dropped to yield-limiting levels.

Nutrient Interactions

Information presented so far has concentrated upon the effects of a single nutrient. However, nutrients often interact to provide benefits beyond those possible for one nutrient. An example of this is shown in **Figure 3**.

This 1999 Midwest corn showed symptoms of K deficiency. In a recent summary of soil test levels, 44 percent of North American samples tested medium or below in K, with several Corn Belt states exceeding 60 percent.

Optimum N rate at the higher soil test K level of 139 parts per million (ppm) produced approximately 44 bu/A more grain with 100 lb/A less N than did the optimum N rate at the lowest soil test K level. This resulted in an additional $140/A net return to N fertilization, or about $2.37 for each ppm of increased soil test K. Higher levels of K led to lower N requirements to produce higher yields and profits. Knowledge of interactions is important when trying to assess the effects of one nutrient application. Yield-limiting levels of one nutrient reduce yield and quality effects of another nutrient. For this reason, balanced nutrition is necessary to ensure optimum crop growth and yield.

Both P and K are important parts of a profitable farming operation. They provide many benefits in addition to yield. In times of low crop prices, they can increase efficiency and improve profits. Knowledgeable decisions related to the management of these nutrients can be of great assistance to farmers as they find ways to improve their farming operations. BC

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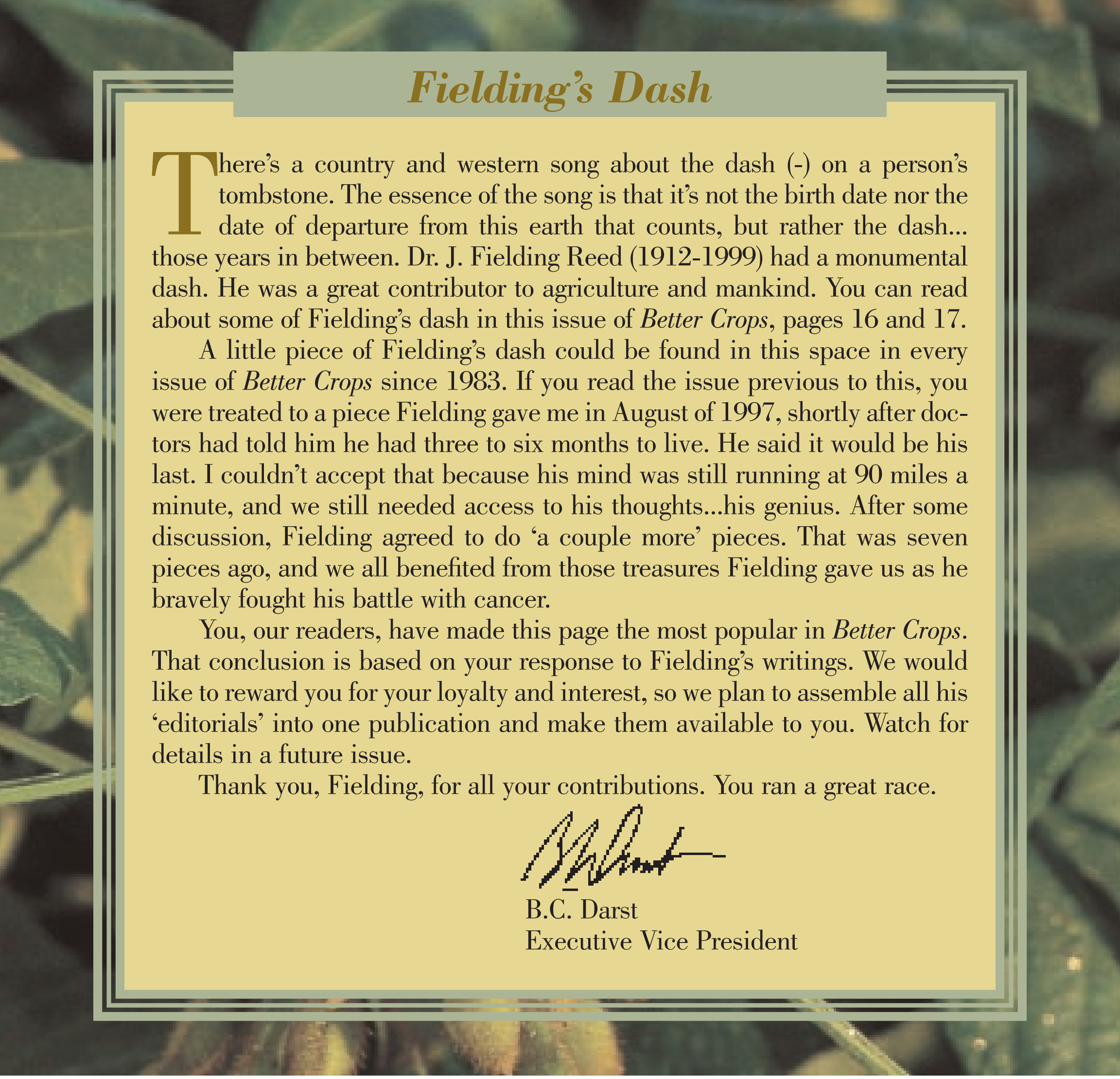

Fielding's Dash

There's a country and western song about the dash (-) on a person's tombstone. The essence of the song is that it's not the birth date nor the date of departure from this earth that counts, but rather the dash... those years in between. Dr. J. Fielding Reed (1912-1999) had a monumental dash. He was a great contributor to agriculture and mankind. You can read about some of Fielding's dash in this issue of *Better Crops*, pages 16 and 17.

A little piece of Fielding's dash could be found in this space in every issue of *Better Crops* since 1983. If you read the issue previous to this, you were treated to a piece Fielding gave me in August of 1997, shortly after doctors had told him he had three to six months to live. He said it would be his last. I couldn't accept that because his mind was still running at 90 miles a minute, and we still needed access to his thoughts...his genius. After some discussion, Fielding agreed to do 'a couple more' pieces. That was seven pieces ago, and we all benefited from those treasures Fielding gave us as he bravely fought his battle with cancer.

You, our readers, have made this page the most popular in *Better Crops*. That conclusion is based on your response to Fielding's writings. We would like to reward you for your loyalty and interest, so we plan to assemble all his 'editorials' into one publication and make them available to you. Watch for details in a future issue.

Thank you, Fielding, for all your contributions. You ran a great race.

B.C. Darst
Executive Vice President

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