KANSAS STATE UNIVERSITY

Kansas Fertilizer Research 2012

Report of Progress 1085

K·STATE Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

Kansas Fertilizer Research 2012

Contents

Kansas Fertilizer Research 2012

Introduction

The 2012 edition of the Kansas Fertilizer Research Report of Progress is a compilation of data collected by researchers across Kansas. Information was contributed by faculty and staff from the Department of Agronomy, Kansas agronomy experiment fields, and agricultural research and research-extension centers.

We greatly appreciate the cooperation of many K-State Research and Extension agents, farmers, fertilizer dealers, fertilizer equipment manufacturers, agricultural chemical manufacturers, and representatives of various firms who contributed time, effort, land, machinery, materials, and laboratory analyses. Without their support, much of the research in this report would not have been possible.

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Precipitation Data

Month	Manhattan	SWREC Tribune	SEARC Parsons	ECK Exp. Field Ottawa
	in.			
2011				
August	2.80	3.40	4.16	2.70
September	1.37	0.95	2.79	1.76
October	2.66	2.53	0.70	0.34
November	4.26	0.63	4.96	4.68
December	3.43	1.41	2.83	2.97
Total 2011	33.05	22.93	36.74	33.25
Departure from normal	-1.75	+5.03	-6.23	-7.05
2012				
January	0.02	0.05	0.00	0.05
February	2.12	0.30	3.04	2.42
March	2.71	0.86	6.23	4.33
April	2.11	2.21	9.24	1.77
May	1.35	0.21	4.96	2.41
June	4.15	0.59	1.89	0.72
July	0.69	0.39	0.90	0.50
August	4.31	0.65	4.26	0.95
September	2.83	0.98	5.09	5.41

SWREC = Southwest Research-Extension Center; SEARC = Southeast Agricultural Research Center;
ECK = East Central Kansas

Precipitation Data

Month	NCK Exp. Field Belleville	KRV Exp. Field	SCK Exp. Field Hutchinson	ARC–Hays
	---------- in. ----------			
2011				
August	5.54	2.42	3.22	3.41
September	0.87	2.43	0.74	0.48
October	0.55	0.34	1.56	1.35
November	1.37	2.90	3.62	0.74
December	1.50	2.83	2.81	2.09
Total 2011	30.97	27.56	2.16	16.77
Departure from normal	+.37	-8.08	-8.06	-6.20
2012				
January	0.13	0.04	0.14	0.00
February	2.70	2.50	3.43	0.60
March	1.24	2.82	2.64	0.67
April	4.96	2.17	1.31	1.35
May	0.27	1.77	1.69	2.82
June	5.31	2.98	3.76	1.60
July	3.19	0.71	1.78	0.58
August	2.82	4.53	4.21	0.40
September	1.69	0.82	1.86	2.75

NCK = North Central Kansas; KRV = Kansas River Valley; SCK = South Central Kansas; ARC = Agricultural Research Center.

Evaluation of Macro- and Micronutrients for Double-Crop Soybean After Wheat

A. Widmar and D.A. Ruiz Diaz

Summary

With double-crop soybean production, fertilizer is typically applied prior to planting wheat and is intended for both crops; when wheat nutrient removal is higher than expected, this may limit nutrient supply for the following soybean crop. The objective of this study was to evaluate the response of soybean grown after wheat to soil-applied and foliar fertilization, including changes in tissue nutrient concentration and response in grain yield. Four sites were established in 2011 and 2012. All sites for this study were rainfed on no-till fields planted immediately after wheat harvest. Macronutrients (nitrogen, phosphorus, and potassium [N, P, K]), micronutrients (iron, manganese, and zinc [Fe, Mn, Zn]), and sulfur (S) were band-applied at planting. Foliar micronutrients were applied at flowering (R1). Tissue samples were collected prior to foliar fertilizer application at R1. Preplant and post-harvest soil samples were collected and analyzed. The tissue and soil samples were analyzed for the nutrients applied with the fertilizer treatments. During the two years of this study, severe drought limited the potential yield response and possibly nutrient uptake, and this should be considered in data interpretation. Results across site-years indicated that tissue nutrient concentration for micronutrients was a poor indicator of potential yield response. Soybean seed yield showed small response to soil-applied S, Mn, and Zn, but when micronutrients were foliar-applied, seed yield decreased significantly, likely due to some leaf damage caused by foliar fertilizer application.

Introduction

Double-cropping soybean after wheat can be risky in much of Kansas due to the possibility of frost injury later in the season. Some years (such as 2011 and 2012), the lack of water becomes a severe issue for double-crop soybean grown after wheat that may leave very limited residual moisture in the soil; however, soybean can remain a productive and a profitable option most years. Double-cropping soybean after wheat carries several advantages that can make it a plausible option. A successful double-cropping system increases gross returns per acre relative to small production cost increases; spreads fixed costs such as land, taxes, and machinery over two crops; and reduces soil erosion because of continuous vegetative cover and enhanced use of land, labor, and equipment (Massey, 2010). According to a 2010 cost-return study in central and eastern Kansas, double-crop soybean can be very profitable. With average yields and grain prices in this region, return to annual costs can range from 11 to 150% (Dumler and Shoup, 2011). Coupled with limited inputs, this makes double-crop soybean a good option compared with letting the wheat field lie fallow during this period.

Several different application methods can be used to fertilize double-crop soybean, including broadcast, subsurface-band, or foliar application. Application timing is another factor that should be considered. The application typically is made preplant, preemergence, or even postemergence, depending on nutrients applied and soil test levels. Applying extra fertilizer when topdressing wheat to meet the fertilizer requirement for both the wheat and soybean is not uncommon (Minor and Wiebold, 1998); the wheat crop benefits from this application and will likely provide residual nutrients for the following soybean crop.

Another factor for fertility management of both crops is the potential mobility and loss potential of each nutrient in the soil, which can be particularly important for areas with high rainfall. When dealing with mobile nutrients such as N and S, direct application before soybean planting may be particularly important. Nutrients such as P, Mn, Fe, and Zn with limited mobility may benefit from band application near the roots for soybean (Minor and Wiebold, 1998).

Procedures

Field experiments were conducted at four locations throughout central and eastern Kansas in 2011–2012. Sites were located at Belleville (North Central KS), Coffeyville (Southeast KS), Ottawa (East Central KS), and Rossville. Soil types were Crete silt loam in Belleville, Bates silt loam in Coffeyville, Wilson silt loam in Ottawa, and Eudora Silt loam in Rossville (Table 1). Soybean was planted in 76-cm rows for Belleville, Ottawa, and Rossville. Coffeyville was drilled in 19-cm rows. Fertilizer was surface band–applied at planting in all locations. Nutrients applied included: N as urea (20 lb/a), P as monoammonium phosphate (MAP) (20 lb/a P_2O_5), K as potassium chloride (20 lb/a K_2O), S as elemental sulfur (20 lb/a S), Fe as iron sulfate (10 lb/a), and Zn as zinc sulfate (10 lb/a Zn).

Foliar micronutrients Fe, Mn, and Zn were applied at a rate of 0.2 lb/a at R1 growth stage. They were applied as HEDTA chelated Fe and EDTA Mn and Zn. Soil samples were collected before planting and after harvest to evaluate the change in soil test values at 0- to 15-cm depth. The uppermost fully developed trifoliate (without petiole) was collected at R1 and analyzed for N, P, K, S, Fe, Mn, and Zn.

The experimental design was a randomized compete block design with 7 treatments. Treatments followed an omission plot approach, with one nutrient (or set of nutrients) omitted from the mix for each treatment (Table 2). Statistical analysis was completed in SAS using the GLIMMIX procedure (SAS Institute Inc., Cary, NC). Site and block within site were considered as random factors in the model. Statistical significance was set at $P = 0.10$.

Results and Discussion

Soils at the study sites were all silt loam with near-optimum pH and nutrient levels, as indicated by soil test (Table 1). Potassium levels were very low at the Coffeyville location, suggesting a possible response to macronutrient application including K. Soil test for micronutrients (Zn, Fe, and Mn) are not calibrated for Kansas, but current guidelines indicate that soil test Zn would be in the optimum range (>1 ppm) for all sites and fertilizer Zn application would not be recommended.

Increase in tissue nutrient concentration with the application of macro and micronutrients were inconsistent (Table 3), with significant increases for tissue K across sites. Increase in leaf K concentration may be due to the low soil test K found at some sites in the study. Plant uptake from the band-applied fertilizer also may have been limited and therefore not evident by tissue analysis, or conditions during the growing season with limited rainfall may influence these results. Soybean seed yield showed small but significant yield increase to the application of S as well as Zn and Mn (Figure 1). This result may suggest that changes in tissue nutrient concentration were not a good indicator of potential yield response (Table 2 and Figure 1), but it is also possible that average yield increases are primarily contributed by sulfur from the Fe, Mn, and Zn sulfate fertilizer sources and additional analysis is required. Foliar application of the combination of micronutrients (Fe, Mn, and Zn) generated a decrease in seed yield (Figure 1). This was likely the result of visual leaf damage observed after foliar fertilizer application. Alternative foliar fertilizer sources may be required. Many studies have shown the benefit of foliar fertilizers, particularly for micronutrient management; however, similar to our results, some studies have shown different levels of leaf damage, suggesting that foliar application of some fertilizer sources may not be appropriate and sources as well as application rates should be considered to attain the intended beneficial effect of foliar fertilizer application.

Rainfall was significantly below yearly totals in all locations, and expected yield was well below the county averages for all locations. Preliminary results from this study showed that band-applied fertilizer application increased yield. Soil-applied fertilizers S, Mn, and Zn showed slight but significant yield responses across all locations. Similar yield tendencies were found for Fe, but they were not statistically significant. Foliar fertilizer significantly decreased yield across locations. This may have been caused by leaf damage from foliar fertilizer application. Although it was not statically significant, there was a numeric decrease in tissue Mn and Zn concentrations, but this did not affect yield.

References

Massey, R. 2010. Land economics: market and leasing trends. University of Missouri Extension.

Dumler, T.J., and D. Shoup. 2011. Double-crop soybean cost-return budget in central and eastern Kansas. Farm Management Guide, K-State Research and Extension, MF2537.

Minor, H.C., and W. Wiebold. 1998. Wheat-soybean double-crop management in Missouri, University of Missouri Extension, G4953.

Table 1. Soil information and average soil test results for 3 locations

Site	Soil series	CEC[1]	pH	OM	P[2]	K	Zn	Fe	Mn
		(meq/100g)		%	----------	----------	ppm	----------	----------
Belleville	Crete silt loam	19.23	5.29	2.2	42	630	1.7	112.8	83.4
Coffeyville	Bates silt loam	17.52	6.41	1.6	24	74	1.8	44.9	35.3
Ottawa	Wilson silt loam	23.10	6.86	2.2	13	125	1.4	30.6	35.2

[1] Cation exchange capacity.

[2] Zn, Fe, and Mn analyzed with the DTPA extraction; P, Mehlich-3, colorimetric. K, Ammonium-acetate.

Table 2. Treatment numbers and nutrient(s) omitted from each treatment following an omission plot approach

Treatment number	Nutrient(s) omitted
1	None
2	N, P, K
3	S
4	Fe
5	Mn
6	Zn
7	Foliar Fe, Mn, Zn

Table 3. Increase in tissue nutrient concentration with addition of fertilizer treatments

Nutrient	Increase in concentration	Significance
	ppm	*P > F*
N	0.20	0.122
P	0.02	0.119
K	0.33	0.004
S	0.01	0.154
Fe	5.66	0.393
Mn	-0.81	0.893
Zn	-1.41	0.154

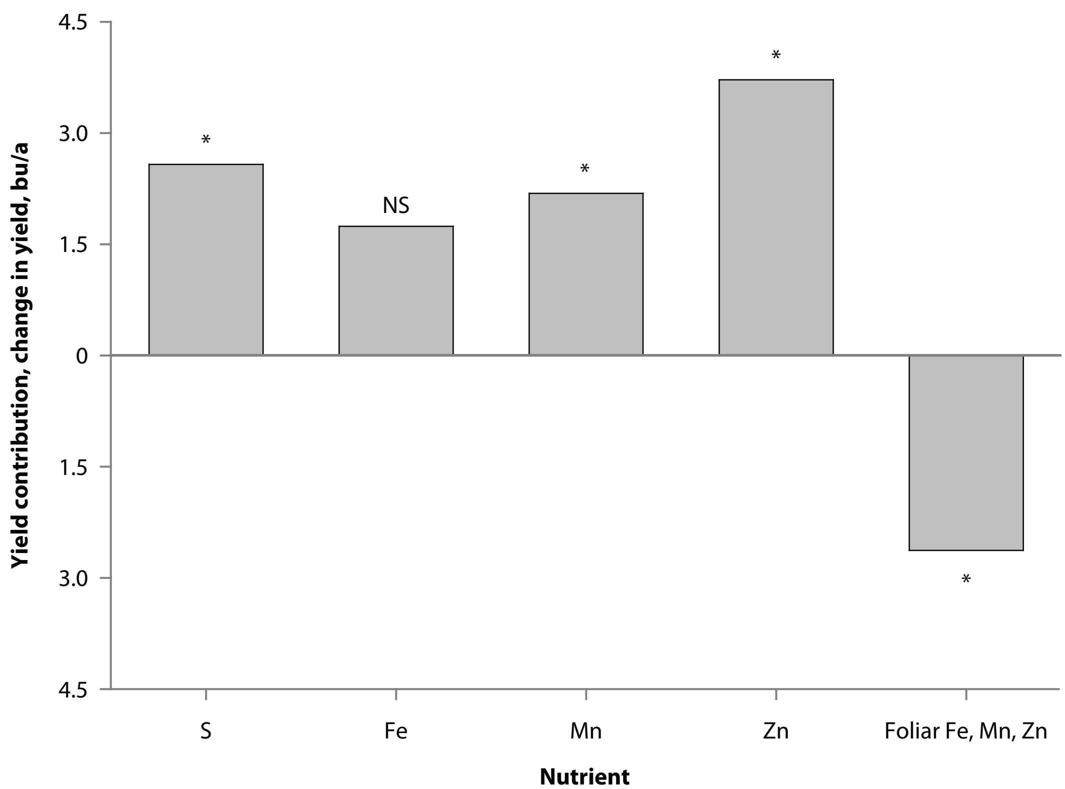

Figure 1. Yield response contributed by each of the nutrient(s). Yield values are expressed as the difference between Treatment 1 and the other treatments (Table 1.) Asterisk indicates statistically significant differences from zero.

Corn Hybrids with Contrasting Root Systems: Response to Soil and Fertilizer Phosphorus

E.W. King and D.A. Ruiz Diaz

Summary

Because of corn genetic improvements for water-limited scenarios, root system architecture and growth are being considered because they may affect overall nutrient uptake, particularly for immobile nutrients. The objective of this study was to evaluate plant response and phosphorus (P) uptake with contrasting, generally shallow, and generally deep-rooted corn hybrids. Over two years were a total of seven sites, two in 2011 and five in 2012. Four sites were rainfed and three were irrigated. Throughout the study, two hybrids were assessed with starter and broadcast P application methods. The experiment design was a factorial and in a randomized complete block with two starter, two broadcast, and two hybrid combinations for a total of 8 treatments. Early growth biomass was evaluated at the V6 growth stage, including whole-plant tissue P concentrations. Ear leaf tissues were also collected at the VT-R1 growth stage and analyzed for P concentration. Finally, grain yield was assessed at the end of each growing season. Preliminary results show significant differences in grain yield response between hybrids; differences were also significant with broadcast P fertilizer application. Generally, these two hybrids show different responses, and further analysis will evaluate their P use efficiency.

Introduction

Corn response to starter fertilizer application can vary by hybrid. These differences may be related to different genetics factors including growth habits and differences in root systems. Corn genetic improvements for water-limited conditions have led to consideration of root system architecture and growth, which may affect overall nutrient uptake, particularly for immobile nutrients. A hybrid having a high rate of root growth, root biomass, and uptake of N and P can be expected to show little response to starter fertilizer; therefore, a positive response to starter fertilizer may be expected of a hybrid with a slow rate of root growth and/or low nutrient uptake rate (Rhoads and Wright, 1998).

Considering that hybrids may differ in rooting characteristics, previous studies in Kansas evaluated the response of several corn hybrids to starter fertilizer application. Gordon et al. (1994) evaluated the effects of starter fertilizer on six corn hybrids with maturities ranging from 2,530 to 2,850 growing degree units (GDU) grown under no-tillage, dryland conditions. Results showed significant differences in amounts of N and P uptake at the V6 growth stage, and differences in N and P concentrations among hybrids were found in ear leaf tissue at VT. Gordeon and Fjell suggested that differences in rooting system among corn hybrids can show a significant interaction with nutrient uptake from fertilizer and soil P, but the study evaluated specific commercial hybrids available at that time that were not categorized based on root system architecture; therefore, results cannot be applied to general categories based on root system architecture. The objective of this study was to evaluate plant response and P uptake for hybrids with contrasting root systems, including generally shallow and generally deep-rooted corn hybrids.

Procedures

A total of seven sites were established in two years (2011 and 2012), including three irrigated sites and four sites under rainfed conditions. Throughout the study, two hybrids were assessed with starter and broadcast P application methods. The experiment design was a factorial in a randomized complete block, with two starter, two broadcast, and two hybrid combinations for a total of 8 treatments combinations. Fertilizer treatments included (1) starter fertilizer at 20 lb/a P_2O_5 dribble-placed and (2) broadcast fertilizer applied at 100 lb/a P_2O_5 before planting in the spring. The factorial design also includes combinations of the starter and broadcast treatment. Composite soil samples were collected from the 0- to 15-cm depth from each block. Samples were analyzed for soil test P by the Mehlich-3 extraction method. Plant nutrient status was evaluated by tissue analysis for total P early in the season (V6) and at tassel (VT). Early growth biomass was measured at V6 stage. Grain yield was measured at the end of the season. Statistical analysis was completed using the GLIMMIX procedure in SAS (SAS Institute, Inc., Cary, NC). Sites and blocks within sites were considered as random factors in the analysis. Significance was established at $P \leq 0.05$.

Results and Discussion

Soil test P varied by location from low to high (Table 1), and plant response to P fertilizer application (starter and broadcast) was observed for some parameters, including grain yield for broadcast P application (Table 2). Plant early growth was different among hybrids and significantly affected by fertilizer application (Figure 1). Plant P uptake was generally higher for the shallow-rooted hybrid, especially with fertilizer P application (Figure 2). Results also show significant differences in grain yield between hybrids and statistical difference in grain yield with the addition of broadcast P fertilizer; however, no statistical differences in grain yield were found with starter P fertilizer, although average grain yield across sites show a slight increase in grain yield (Figure 3).

Preliminary results indicate that the two hybrids with contrasting rooting systems respond differently to fertilizer P application, which suggests that groups of hybrids with similar root systems may express similar response to P fertilizer application and soil P use. Further analysis is evaluating differences in P use efficiency and possible implications of hybrid selection for P management under different management systems (irrigated and rainfed) as well as tillage systems.

References

Gordon, W.B., D.A. Whitney, and D.L. Fjell. 1998. Starter fertilizer interactions with corn and grain sorghum hybrids. Better Crops with Plant Food 82(2):16–19.

Rhoads F., and D. Wright. 1998. Starter fertilizer: nitrogen, phosphorus, corn hybrid response, and root mass. Better Crops with Plant Food 82(2):20–24.

Table 1. Preliminary soil test results. Samples collected from each block at the 0–15-cm depth

	Site						
Soil test	Belleville rainfed 2011	Topeka rainfed 2011	Belleville rainfed 2012	Hutchinson irrigated 2012	Hutchinson rainfed 2012	Rossville irrigated 2012	Scandia irrigated 2012
	ppm						
Phosphorus	42	23	53	23	59	15	15
Potassium	339	220	458	277	242	189	615

Table 2. Partial analysis of variance (ANOVA) across site years

	Fixed effect						
Response variable	Hybrid (H)	Starter (S)	H × S	Broadcast (B)	H × B	S × B	H × S × B
	p > F						
Early growth	0.019	<0.001	0.538	<0.001	0.975	0.362	0.729
Phosphorus uptake	0.105	<0.001	0.794	<0.001	0.445	0.065	0.395
Ear leaf phosophorus concentration	0.487	0.527	0.682	0.976	0.361	0.978	0.269
Grain yield	<0.001	0.413	0.169	0.001	0.297	0.158	0.472

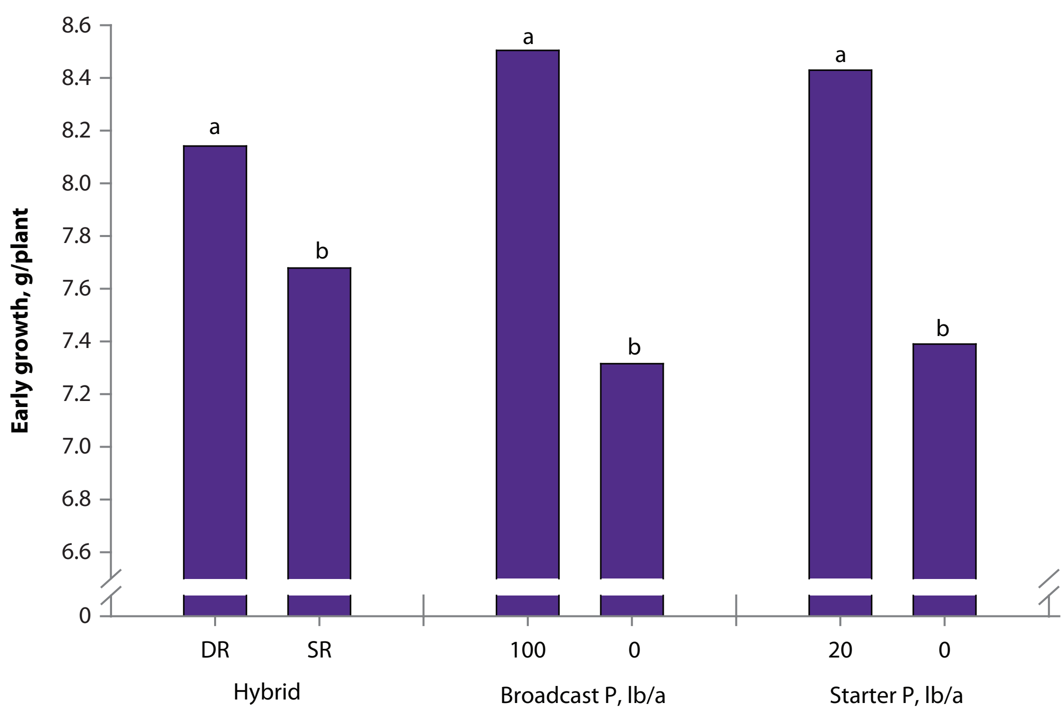

Figure 1. Early growth at the V5–V6 growth stage. DR = deep-rooted hybrid, SR = shallow-rooted hybrid. Results were summarized across all sites throughout the 2011–2012 growing seasons.
Different letters indicate statistically significant differences at $P \leq 0.05$.

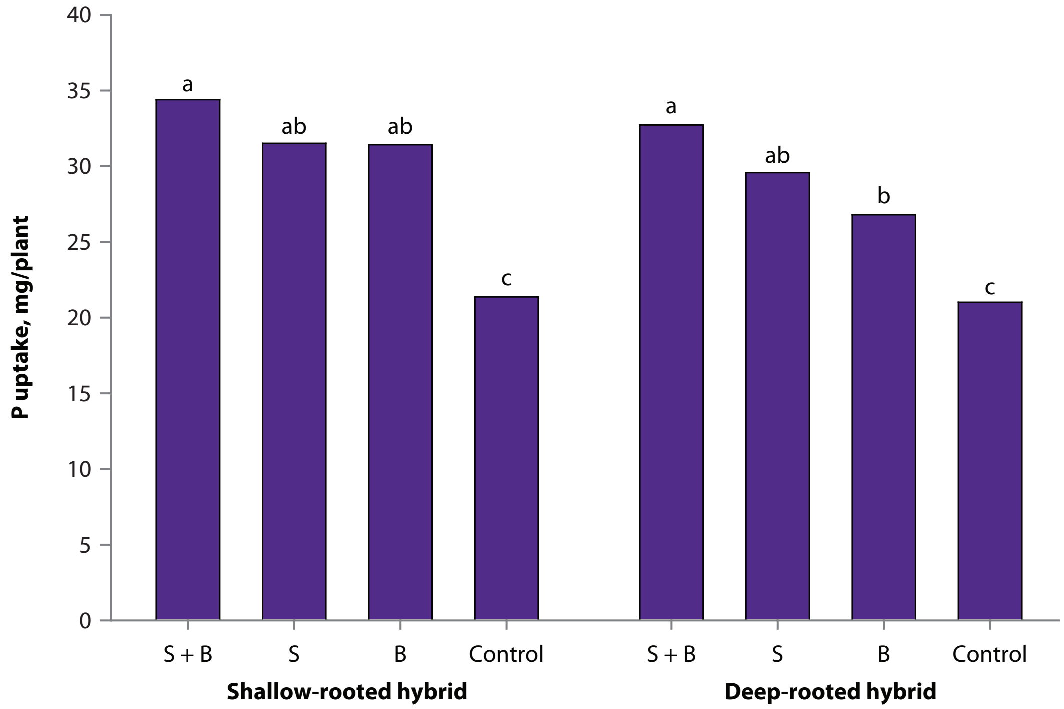

Figure 2. Phosphorus uptake. S = starter, B = broadcast. Results were summarized across the two sites from the 2011 growing season.
Different letters indicate statistically significant differences at $P \leq 0.05$.

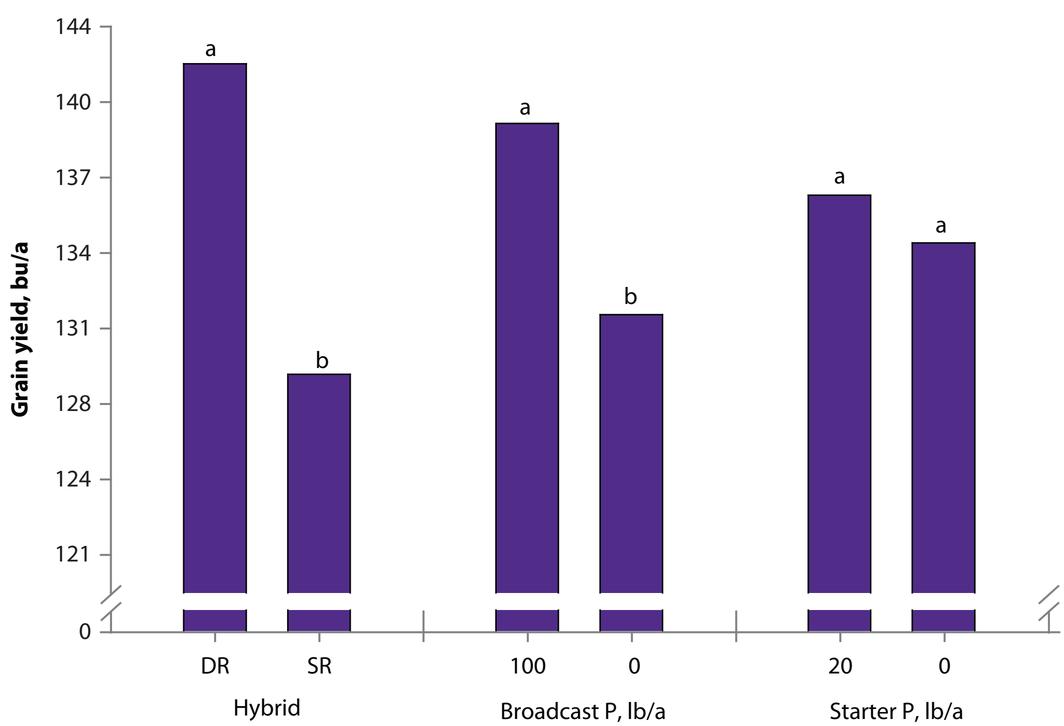

Figure 3. Grain yield. DR = deep-rooted hybrid, SR = shallow-rooted hybrid. Results were summarized across five sites from the 2011–2012 growing seasons.
Different letters indicate statistically significant differences at $P \leq 0.05$.

Corn and Soybean Response to Starters After Broadcast Fertilizer Application

I. Arns and D.A. Ruiz Diaz

Summary

Corn response to fertilization and placement methods has always been a subject of interest and extensive research, but studies on soybean response to placement have been limited in Kansas. The objective of this study was to evaluate the effects of starter and broadcast fertilizer application on corn and soybean in a typical corn-soybean rotation in Kansas. Grain and seed yield, early growth, and nutrient concentration and uptake were evaluated over 8 site-year trials in Kansas for both corn and soybean in 2011 and 2012. Treatments were unfertilized control, nitrogen-phosphorus-potassium (NPK) dribble starter, broadcast monoammonium polyphosphate (MAP) or diammonium phosphate (DAP), and the combination of starter and broadcast. Soil samples and plant tissues were collected and analyzed for N, P, and K concentration. Corn early growth was measured at V6 to V7 growth stages. After corn and soybean reached physiological maturity, grain yield was determined. None of the individual sites showed a significant effect of starter and broadcast treatments or an interaction between the two placement methods on corn or soybean grain yield. Corn early growth, P concentration, and uptake of young corn plants increased significantly across site-years. Broadcast increased corn plant K concentration and uptake, whereas starter increased K uptake only. Phosphorus concentration on soybean leaves was increased by broadcast application, but K concentration was decreased by starter or broadcast alone.

Introduction

Fertilizer placement and application method can substantially affect yield response and producer profitability. Starter fertilizer is a common practice in the United States to enhance crop yield potential. Some studies have reviewed (Bundy et al., 2005; Randall and Hoeft, 1988) the effects of placement and fertilization of P and K on different crops and have shown that starter fertilizer often increases corn grain yield compared with a control treatment with no fertilization, and such a response can be explained by soils with P and/or K deficiency. Ketcheson (1968), however, found that soils with high nutrient levels do not always supply enough nutrients to the plant during the early part of growing season given that certain conditions can limit nutrient availability. Low-temperature soils for example, can reduce root growth (Ching and Barber, 1979; Havlin, 2005) and nutrient uptake by plants (Mackay and Barber, 1985). Starter fertilizer can help avoid these effects and can positively influence early growth and grain yield by increasing the nutrient concentration and availability in the root zone when cool temperatures slow root growth and nutrient diffusion (Borkert and Barber, 1985). Overall, yield increases due to starter application are most frequently found on low-testing soils, poorly drained soils, late-planted crops, long-maturity hybrid groups, and conservation tillage systems (Bundy and Andraski, 2001; Randall and Hoeft, 1988). Fertilizer application as starter, broadcast, and the combination of both has been evaluated extensively for the past few years on corn in many states, but studies on soybean response to placement are limited in Kansas. Therefore, the objective of this study was to evaluate the effect of starter and broadcast fertilizer applications on corn and soybean in a typical corn-soybean rotation in Kansas.

Procedures

Eight site-year trials were conducted with corn and soybean in two locations in northeast Kansas during 2011 and 2012. Fields with corn-soybean rotation histories were selected to represent the common crop pattern in the region of study. The experiments were established at two Kansas State University research farms. Table 1 summarizes site information. Odd sites were managed under no-tillage approximately 6 years. Sites 2, 6, and 8 were chisel-plowed in the fall and turbo-tilled in the spring just before planting. Site 4 was V-ripped (subsoiled) in the winter and field-cultivated in the spring. The experimental design consisted of a factorial arrangement in a complete randomized design with 4 treatments and 4 replications. Treatments were (1) unfertilized control; (2) NPK dribble starter; (3) NPK dribble starter in combination with broadcast fertilizer (P and K), and (4) broadcast NPK before planting. Starter was a mixture of commercial formula 3-18-18 and 28% urea-ammonium nitrate (UAN), making a total application of 15 lb/a of N and 21 lb/a of each P_2O_5 and K_2O. Broadcast fertilizer was a combination of MAP (11-52-0) and KCl (0-0-62) for a total application rate of 100 lb/a for both P_2O_5 and K_2O. The broadcast application rates were those commonly used by producers before corn in a corn-soybean rotation and were intended for both crops in the rotation.

Broadcast fertilizer was spread 1 to 4 weeks before planting at all sites. At sites 2, 4, 6, and 8, broadcast fertilizer was incorporated before planting and non-incorporated at the no-till sites (1, 3, 5, and 7). Nitrogen fertilizer was applied in spring 1 month prior to planting by injecting anhydrous ammonium at an N rate of 150 lb/a for sites 2 and 4. At sites 1 and 3, 160 lb/a N was applied as side-dress urea at V5 corn growth stage. Trials located in Shawnee County were irrigated with center pivot sprinkler irrigation systems, and irrigation was applied as needed during the growing season. All other sites were dryland.

Composite soil samples were collected from a 0–6-in. depth from each small plot before planting and fertilizer application. Plant population was measured in a 25-ft section of two central rows of each plot for both crops. Site means ranged from 24,546 to 32,600 plants/a for corn and 69,000 to 147,400 plants/a for soybean. The aboveground parts of 10 corn plants were collected from each site at V6 to V7 growth stage to evaluate early growth, nutrient content, and uptake. Corn ear leaves were collected at silking (R1) and analyzed for N, P, and K concentration. Soybean leaf samples consisting of the most recently developed, fully expanded trifoliolate leaf (petiole excluded) were collected between early bloom (R1) and full bloom (R2) stages and analyzed for N, P, and K concentration. Nutrient uptake was calculated from concentrations and oven-dried weights. After corn and soybean reached physiological maturity, grain yield was determined by harvesting the center two rows of each plot. Grain yield was adjusted to a moisture content of 15% for corn and 13% for soybean.

Statistical analysis was completed using the generalized linear mixed model (GLIMMIX) procedure of SAS (SAS Institute, Inc., Cary, NC, 2006) assuming fixed treatment effects and random block and site effects. For all analysis of variance (ANOVA) procedures, least significant difference (LSD) was used to compare treatment means by site, across years within each county, and across site-years only when the interaction between treatments or the treatment means were statistically significant at $P \le 0.10$. When county was analyzed across years, sites included in the statistical analysis always were located in separate fields. When significant, plant population was used as covariate in the analysis.

Results and Discussion

Corn

None of the individual sites or analysis across site-years showed significant effects of starter and broadcast treatments or an interaction between the two placement methods (Table 2). Nevertheless, when yield data were analyzed across years within location, the response was significant ($P < 0.10$) due to starter in Riley County (Figure 1).

Corn early growth increased ($P < 0.10$) at three sites with fertilization: sites 1, 2, and 4 (Table 3). Although the broadcast P-K rate was almost 10 times greater than starter rate, biomass results shows statistically similar responses between starter and broadcast applied alone at all sites or across (site) years analysis. This result indicates no advantage of one placement over the other when it comes to corn early growth response. Across years in Riley County (sites 1 and 3), the combination of starter and broadcast was higher than other treatments, although it was not statistically different. A significant response in biomass was observed across years in Shawnee County under conventional tillage conditions (sites 2 and 4). In this case, there was an interaction between the two placement methods. Starter after broadcast application showed the highest biomass value being statistically different than the other treatments. Analysis across years, within location, demonstrated that placement methods under no-till and conventional-tillage systems can stimulate early growth differently. Analyzing across site-years, either starter or broadcast, increased biomass over the control; nevertheless, we observed an additional effect when they were applied in combination, showing an increase in early growth over the starter or broadcast applied alone.

Fertilization influenced ($P \le 0.10$) P concentration of young corn plants at three sites (1, 2, and 4), of which all had a significant interaction between starter and broadcast (Table 3). Across years in Riley County, fertilization had no significant effect in early plant P concentration. At Shawnee County, on the other hand, there was an interaction between starter and broadcast treatments. Starter alone decreased P concentration over the control, which can be explained by fertilization effects on early growth and known nutrient dilution effects (Plenet and Lemaire, 1999). Only the combination of starter and broadcast increased P concentration over the control, which might be the result of the interaction between both that compensated for the dilution effect through higher P uptake. Analysis across site-years showed the same response as across years in Shawnee County. Early P uptake increased at three sites. Fertilization showed a significant effect in P uptake across years in Riley County. In this case, there was an interaction between placements in which only the combination of starter and broadcast increased P uptake over the control. Across years in Shawnee County, starter and broadcast alone increased P uptake over the control. When P uptake was analyzed across site-years, the same outcome occurred.

Fertilization never decreased early plant K concentration. There was no interaction between starter and broadcast when analyzing early plant K concentration and K uptake (data not shown); thus, only the main effects of starter and broadcast are compared in these cases (Table 4). Broadcast increased K concentration at all sites and across site years, and starter did only at sites 1 and 4 and across years in Riley County. Starter had no effect on K concentration across site-years. The difference between starter and broadcast was significant across years and across site-years at site 2 in Shawnee County, where broadcast increased K concentration more than starter. Starter and broadcast alone enhanced K uptake at sites 1, 2, and 4 and across years at both counties and across site-years (Table 4).

Soybean

Soybean grain yield was not significantly affected by fertilization at any site or across site-years (Tables 5 and 6). At sites 5, 6, and 8, soil test P was classified as low or below the critical level of 20 ppm according to Kansas State University soil test report (Leikam et al., 2003). On this basis, yield response was expected as soil test P was at the crop responsive range for yield; however, because no yield response was found, soybean seems not to be limited by soils with P in the low range or between 12 and 18 ppm as was found at these three sites. At site 7, where the combination of starter and broadcast or broadcast alone increased yield by 5.2 bu/a over the control, there was an increase trend for seed yield, but this difference was not statistically significant. Interaction effects on P concentration were not significant at any site or across site-year analysis (data not shown), so only the main effects were evaluated. Broadcast always increased P concentration over the control (Table 7), and starter enhanced P concentration only at Shawnee County across years.

Leaf K concentration showed no significant response to starter fertilizer at any site (data not shown). Broadcast decreased K concentration across years in Riley County (Table 7). In Shawnee County, starter was the only treatment that decreased K concentration over the control. A significant interaction occurred in this case, in which broadcast alone or in combination did not change K concentration compared with the control treatment. Across site-years, both starter and broadcast decreased K concentration. Again, an interaction occurred between placements, in which starter after broadcast application was not statistically different than any treatment.

Conclusion

Results of this study suggest that corn yield response to starter might occur under no-till and drought stress conditions. There was no yield increase across years in Shawnee County or across site-years; therefore, early growth and nutrient uptake response to starter and/or broadcast were not reliable indicators of grain yield response. Soybean seed yield was not affected by any fertilization treatment, even at sites with soil tests below the critical level for P. This result could be explained by the high concentration of P and K found on the soybean trifoliolate, meaning that these nutrients were not limiting soybean yield.

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Table 1. Site description, soil data, hybrids, varieties, and planting date for 2011 and 2012 trials

			Soil classification		Soil-test values					
Year	Site	County	Series[1]	Subgroup[2]	Phosphorus	Potassium	pH	Organic matter	Variety[3]/ hybrid[4]	Planting date
					---------- ppm ----------			%		
Corn										
2011	1	Riley	Eudora SL	F. Hapludolls	24	449	6.2	2.5	DK-6342	4/29
2011	2	Shawnee	Eudora SL	F. Hapludolls	17	228	6.8	1.6	DK-6449 VT3	4/28
2012	3	Riley	Eudora SL	F. Hapludolls	26	370	5.8	2.4	DK-C63-49	4/18
2012	4	Shawnee	Eudora L	F. Hapludolls	16	249	6.5	1.7	DK-6323	4/19
Soybean										
2011	5	Riley	Rossville SL	C. Hapludolls	12	306	6.7	2.2	KS 3406RR	5/11
2011	6	Shawnee	Eudora SL	F. Hapludolls	16	161	6.2	1.6	LG C3616RR	5/16
2012	7	Riley	Eudora SL	F. Hapludolls	24	458	6.3	2.8	KS 3406RR	5/10
2012	8	Shawnee	Eudora SL	F. Hapludolls	18	135	6.8	1.3	Asgrow 3282	5/14

[1] SL, silt loam; L, loam.
[2] F, fluventic; C, dumulic.
[3] LG, LG Seeds; KS, Kansas AES.
[4] Corn hybrid: DK, DeKalb.

Table 2. Corn yield and early growth as affected by starter and broadcast fertilizations by site, across years within locations, and across site-years

	Riley			Shawnee			
Treatment	2011	2012	Across years	2011	2012	Across years	Across site-years
	yield, bu/a						
Control	59	43	51b[1]	146	244	195	123
Starter (S)	63	50	56a	143	241	192	124
Broadcast (B)	61	43	52b	152	238	194	123
S × B	57	44	50b	142	251	195	122
	plant dry weight, g/plant						
Control	8.4b	8.2	8.3	6.5b	3.3c	4.9c	6.6c
Starter (S)	8.1b	7.8	8.3	10.4a	6.1b	8.4b	8.3b
Broadcast (B)	8.3b	8.6	8.4	10.1a	5.3b	7.3b	8.1b
S × B	9.5a	8.7	9.3	11.3a	8.8a	9.9a	9.5a

[1] Numbers followed by different letters within each column represent statistically significant differences at the $P \leq 0.10$.

Table 3. Placement effects on early plant phosphorus (P) concentration and uptake in corn (V6 to V7 growth stage)

		Treatments							
				Broadcast				Broadcast	
Site location	Year	Control	Starter	No starter	Starter	Control	Starter	No starter	Starter
		plant P concentration, g/kg				plant P uptake, mg/plant			
Riley County	2011	4.0ab[1]	3.9b	3.9b	4.2a	33.5b	33.6b	32.2b	39.5a
	2012	3.7	3.7	3.6	3.5	30.2	28.3	30.7	30.0
Across years		3.8	3.8	3.7	3.9	31.7b	31.2b	31.5b	35.8a
Shawnee County	2011	2.8c	2.7c	3.3b	3.7a	18.9d	27.9c	33.4b	41.5a
	2012	3.0a	2.5b	2.8a	3.0a	10.0c	15.0b	15.0b	26.0a
Across years		2.9b	2.5c	3.0b	3.4a	14.4c	21.4b	24.2b	33.9a
Across site-years		3.4b	3.2c	3.4b	3.6a	23.1c	26.2b	27.8b	34.7a

[1] Numbers followed by different letters between columns represent statistically significant differences at the $P \leq 0.10$ (LSD).

Table 4. Potassium (K) concentration and uptake at V6 to V7 corn growth stage as affected by starter and broadcast application

		Treatment							
	Year	Starter		Broadcast		Starter		Broadcast	
Site location		No	Yes	No	Yes	No	Yes	No	Yes
		---------- plant K conc., g/kg ----------				------ plant K uptake, mg/plant ------			
Riley County	2011	52.0b[1]	54.2a	51.9b	54.3a	433b	492a	440b	484a
	2012	52.0	53.2	51.2b	53.9a	436	440	468	408
Across years		52.0b	53.8a	51.5b	54.3a	434b	475a	428b	481a
Shawnee County	2011	47.8	46.1	44.2b	49.7a	406b	504a	376b	533a
	2012	48.8b	51.8a	48.7b	52.0a	215b	390a	233b	371a
Across years		48.3	48.5	46.1b	50.7a	310b	444a	306b	449a
Across site-years		50.1	51.1	48.8b	52.5a	372b	456a	366b	463a

[1] Different letters represent significant differences (LSD, $P \leq 0.10$) when there was a significant treatment main effect within each treatment.

Table 5. Soybean yield as affected by starter and broadcast fertilizations by site, across years within locations, and across site-years

	Riley			Shawnee			
Treatment	2011	2012	Across years	2011	2012	Across years	Across site-years
	-- yield, bu/a --						
Control	31[1]	30	27	49	73	61	44
Starter (S)	32	34	33	51	73	62	48
Broadcast (B)	33	35	34	50	74	62	48
S × B	30	35	33	50	73	62	48

[1] Treatment means were not statistically significant different at $P \leq 0.10$.

Table 6. Phosphorus (P) and potassium (K) concentration at R2–R3 growth stage on soybean trifoliolate as affected by broadcast application

	Treatment				
		Broadcast			
Location	Year	No	Yes	No	Yes
		----- P conc., g/kg -----		----- K conc., g/kg -----	
	2011	3.6b[1]	3.9a	24.7b	23.6a
Riley County	2012	4.0b	4.3a	20.9	20.5
Across years		3.8b	4.1a	22.0b	22.8a
	2011	3.9b	4.2b	23.0	23.2
Shawnee County	2012	4.1b	4.4a	16.3b	17.3a
Across years		4.0b	4.3a	19.7	19.7
Across site-years		3.9b	4.2a	21.2	21.1

[1] Statistical significance of the treatment main effect at $P \leq 0.10$.

Table 7. Fertilization affects K concentration in trifoliolate soybean at R2 stage

Site	Year	C[1]	S	B	S × B
		K concentration, g/kg			
Riley County	2011	25.3	24.0	23.6	23.6
	2012	20.9	21.0	19.9	21.1
Across years		23.1a	22.5ab	21.8b	22.2b
Shawnee County	2011	23.7a[2]	22.3b	22.9ab	23.5a
	2012	16.4	16.2	16.9	17.7
Across years		20.0a	19.3b	19.2ab	20.6a
Across site-years		21.6a	20.9b	20.8b	21.4ab

[1]C, control; S, starter; B, broadcast.

[2] Numbers followed by different letters between each column represent statistically significant differences at $P \leq 0.10$.

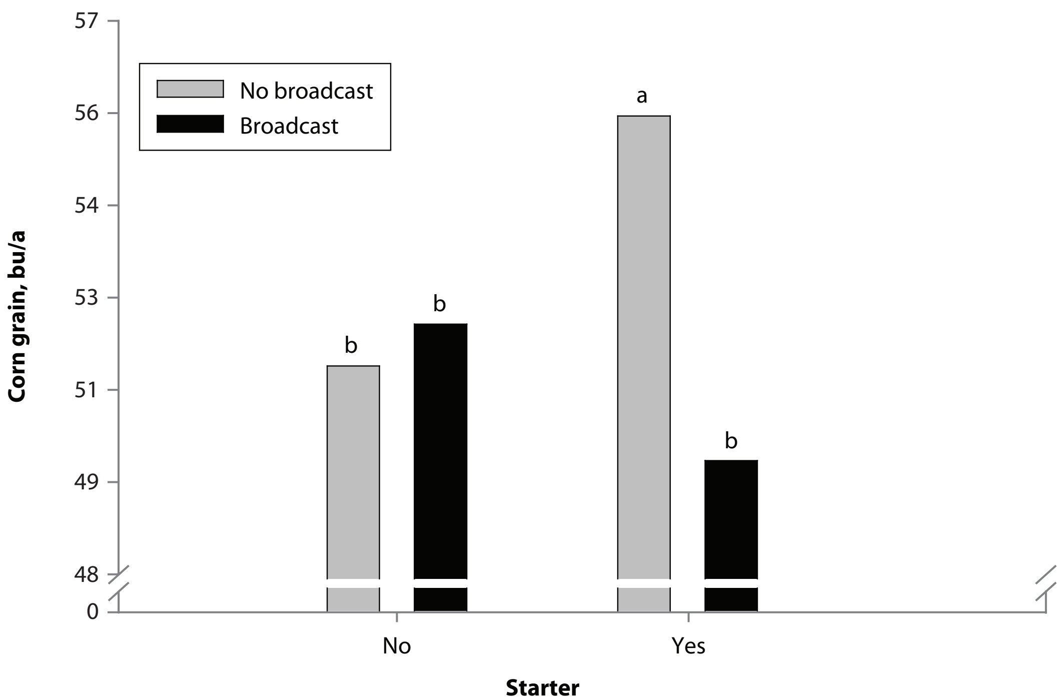

Figure 1. Fertilization effects on corn yield across years in Riley County.
Letters represent differences treatments when the main treatment effect was significant at $P \leq 0.10$.

Evaluation of Soybean Response to Direct and Residual Fertilization

I. Arns and D.A. Ruiz Diaz

Summary

Fertilizer application is traditionally done before corn (*Zea mays*) and intended for both corn and soybean (*Glycine max* (L.) Merr.); however, studies evaluating the need for direct soybean fertilization and response to residual fertilizer are limited. The objectives of this study were to (1) evaluate the effect of residual and direct fertilization on soybean after corn under a corn-soybean rotation system and (2) study the effect of fertilizer phosphorus (P) and potassium (K) application on soil test P (STP) and soil test K (STK) changes over time. Soybean trials were conducted in 2012 at two locations in Kansas. In 2011, a study was established to evaluate the effect of P and K fertilization on corn. The following year, soybean was planted on the same plots to evaluate the effect of residual and direct fertilization on soybean. Soil samples were collected in 2011 and 2012. Soybean leaf was analyzed for P and K, and yield was determined after physiological maturity. Application of P and K fertilizer generated significant increases in STP and STK after one year of application. The rate of P and K fertilizer required to increase 1 ppm/year of the respective nutrients was from 5.7–10.4 lb/a for P_2O_5 and from 1.1–2.7 lb/a for K_2O, respectively. These values are lower than current guidelines, suggesting that some farmers in Kansas may be overapplying P and K fertilizer. Direct fertilization increased soybean yield, whereas residual fertilizer did not; therefore, maintenance rates may be effective not only to sustain STP and STK levels but also to improve soybean yield.

Introduction

Phosphorus and potassium are essential nutrients for soybean production, but excess application of these nutrients and soil degradation can cause several environmental issues. Developing a long-term P and K fertilization management strategy is essential to adjust application rates and maintain soil test P (STP) and soil test K (STK) at levels that guarantee optimal crop profitability and prevent water pollution. Some studies indicate that to maintain STP and STK, the required rates of P and K are dependent on the initial soil test level, and that greater rates of fertilizer P and K are needed to maintain levels when initial soil test values are higher (Dodd and Mallarino, 2005; McCallister et al., 1987; McCollum, 1991; Webb et al., 1992). The amount of fertilizer needed to maintain certain soil test levels and crop yields also depends on several factors, such as soil type and mineralogy, subsoil available nutrient content, and nutrient removal through harvested products (McCallister et al., 1987).

Critical levels for STP and STK are the target soil test levels for optimum crop yield. Below these levels, crop yield may be restricted by nutrient availability in the soil. Kansas State University has estimated a critical level of 20 mg/kg by Mehlich-3 (Frank et al., 1998) and 130 mg/kg K by ammonium acetate (Warncke and Brown, 1998) methods (Leikam et al., 2003). Moreover, in the latter study, the amount of P and K required to increase STP and STK by 1 mg/kg is 18 lb/a P_2O_5 per year and 9 lb/a K_2O per year. According to Rehm et al. (1984), soil test values for P on loamy fine sand soils was increased by 1 mg/kg P for each 19 lb/a of P applied. Dodd and Mallarino (2005) found on fine loamy soils that the amount of P needed to increase STP by 1 mg/kg P was from 35 to 57 lb/a P_2O_5 per year. Similarly, Randall et al. (1997) found on clay loam soils under corn-soybean rotation that the amount of P necessary to increase 1 mg/kg of P was from 41 to 53 lb/a P_2O_5, and to increase 1 mg/kg of K, approximately 23 lb/a K_2O per year was needed. Soils with high clay content or fine-textured soils exhibit higher buffer capacity and adsorption than coarse-textured soils, then higher adsorbed P and K; therefore, more fertilizer P and K will be needed in clay soils than in sandy soils (Havlin et al., 2005).

Dodd and Mallarino (2005) showed in a long-term study that corn and soybean respond 50 to 70% of the time to annual P fertilization when soil test levels were equal to or less than 20 mg/kg and show no response under higher soil test P. Similarly, Mallarino and Barcos (2009) found that yield responses to P broadcast fertilization applied before corn and soybean normally occurred when soils were equal or lower than 22 mg/kg.

Most producers in Kansas do not apply direct fertilizer P or K to soybean; instead, they generally rely on residual effects of corn fertilization from the previous year. Soybean is normally the second crop and is typically less responsive to fertilizer in the year of application than corn (deMooy et al., 1973). According to deMooy et al., soybean is perhaps more efficient in recovering residual fertilizer from the soil than other crops. According to Randall et al. (2001), under low STP levels, substantial soybean yield increase may occur from residual P application from corn, either with broadcast or band-applied. Buah et al. (2000), on the other hand, found that soybean responded to P fertilization in the year of application more frequently than to residual P fertilizer application, especially under low STP. According to this study, application of smaller annual P applications may be more effective than larger semiannual applications for increasing soybean yields. In contrast, deMooy et al. (1973) found no statistical differences in soybean yield increases between direct and residual response to P and K under soils with STP and STK in medium and high ranges.

Although several studies have evaluated the effects of fertilization and placement on soybean and corn, limited information is available on the residual effects of previous crop fertilization on soybean; moreover, information on how STP and STK change over time given certain initial soil test level and soil type is limited. The objectives of this study were to (1) evaluate the effects of residual fertilization on soybean after corn under a corn-soybean rotation system, and (2) study the effects of fertilizer P and K application on STP and STK changes over time.

Procedures

This study was conducted in 2011 and 2012 at two locations in Kansas (Table 1). In 2011, a study was established to evaluate the effects of P and K fertilization on corn. Soybean was planted over corn residue plots in the following year to evaluate the effects of corn broadcast fertilization on soybean. Broadcast fertilizer in 2011 was a combination of monoammonium phosphate (MAP) [11-52-0 (N-P_2O_5-K_2O)] and potassium chloride (KCl) [0-0-62 (N-P_2O_5-K_2O)] for a total application rate of 100 lb/a P_2O_5 and 100 lb/a K_2O. The broadcast application rates are those commonly used by producers before corn in a corn-soybean rotation and are intended for both crops in the rotation (Leikan et al., 2003). Soybean treatments are described in Table 2. Broadcast application on soybean was a combination of MAP 11-52-00 (N-P_2O_5-K_2O) and KCl [00-00-62 (N-P_2O_5-K_2O)] for a total application rate of 40 lb/a P_2O_5 and 70 lb/a K_2O. The fertilizer application rates were determined by total nutrient removal for soybean estimated based on yield potential. Broadcast was applied 3–4 weeks before planting soybean and was incorporated at Topeka before planting and non-incorporated at Ashland. Topeka was irrigated as needed with center pivot sprinkler irrigation systems, whereas Ashland was non-irrigated. The experimental design consisted of a randomized complete block design with four treatments and four replications. Plots were 50 ft long with 4 rows, and row spacing was 30 in.

Soil samples were collected from each small plot before fertilizer application in 2011 prior to planting corn. In 2012, soil samples were collected only from one treatment plot that received both broadcast (100 lb/a P_2O_5 and 100 lb/a K_2O) and starter (20 lb/a P_2O_5 and 20 lb/a K_2O) applications in 2011. Sampling was completed before fertilizer was applied on soybean. Composite soil samples of 10–12 cores were collected from 0–6-in. depth in the row and between rows with a ratio of 1:3; i.e. every four cores, one core was taken in the row and three cores were taken between the rows. Samples were analyzed for P by the Mehlich-3 method (Frank et al., 1998) and for K with the ammonium acetate method (Warncke and Brown, 1998). Soil pH was measured using a 1:1 soil:water ratio (Watson and Brown, 1998), and soil organic matter (OM) was determined by the Walkley–Black method (Combs and Nathan, 1998).

Plant population was measured in a 25-ft section of two central rows of each plot. Soybean leaf samples were collected consisting of the most recently developed fully expanded trifoliate leaf (petiole excluded) between early bloom (R1) and full bloom (R2) stages (Pedersen, 2009). Plant samples were dried at 140°F (60°C) in a forced-air oven and ground to pass a 2-mm screen. Ground samples were digested using sulfuric acid and hydrogen peroxide in a Digesdahl Analysis System (Hach Co., 1991). Nitrogen and P were measured by colorimetry, and K was measured by flame photometry. After soybean reached physiological maturity, yield was determined by harvesting the center two rows of each plot. Harvest was completed with a small plot combine at both locations, and seed yield was adjusted to a moisture content of 130 g/kg. Statistical analysis was completed using the generalized linear mixed model (GLIMMIX) procedure of SAS (SAS Institute Inc., Cary, NC, 2006) assuming block and locations as random factors in the model. Statistical significance was determined at the $P \leq 0.10$ level. When significant, plant population was used as covariate in the analysis. Statistical analysis was completed by location and across locations.

Results

Soil test values

Fertilizer application significantly increased soil test P and K at both locations (Figure 1). The 120 lb/a P_2O_5 rate (100 lb/a P_2O_5 as broadcast and 20 lb/a P_2O_5 as starter) applied in Ashland in 2011 on corn increased the soil test P by 18 mg/kg P; i.e., from 24 to 42 mg/kg P in 1 year. Topeka received the same rate of P as Ashland, and STP increased 14 mg/kg P, from 14 to 28 mg/kg P; therefore, the rate of P fertilizer required to increase 1 mg/kg P per year was from 5.7 to 7.4 lb/a P_2O_5 in Ashland and from 7.2

to 10.4 lb/a P_2O_5 in Topeka (Figure 2). Rehm et al. (1984) found a similar rate of P (10 lb/a P) necessary to increase STP by 1 mg/kg per year; however, their work was conducted under sandier soils (loamy fine sand). STK increased in Ashland 89 ppm K, or from 450 to 539 ppm, and in Topeka by 53 ppm K, or 232 to 285 ppm K after 1 year of 120 lb/a K_2O application (Figure 1). The amount of K fertilizer needed to increase STK by ppm per year was from 1.1 to 1.9 lb/a K_2O in Ashland and from 1.9 to 2.7 lb/a K_2O in Topeka. Phosphorus and K removal by soybean seeds in 2012 was not considered, so the amount of fertilizer required to increase soil test P and K may be overestimated. Although the results shown are from only one year, the difference between the amounts of fertilizer needed to increase soils test levels are much lower than in Leikam et al. (2003), probably because our study was conducted only on silt loam soils.

Crop response

Fertilization significantly increased leaf P concentration in Ashland (Figure 3). Either residual, direct fertilization, or the combination of both was effective at increasing leaf P concentration. None of the fertilizer treatments affected leaf P concentration in Topeka. Results across locations showed a significant effect of fertilizer treatments, and at Ashland all of them were effective at increasing leaf P concentration (Figure 3). According to Buah et al. (2000), residual or direct P fertilization frequently increased leaf P concentration on soybean.

Soybean yield increased significantly with residual fertilizer in combination with direct broadcast application in Ashland (Figure 3). Residual fertilization or direct application alone did not affect yield compared with the control. In Topeka, there was a slight increase in yield when direct fertilization was applied, with a response similar to Ashland; however, fertilization was not significantly different than the control (Figure 3). According to Dodd and Mallarino (2005), soybean does not always respond to annual P fertilization when soil test level is equal or less than 20 mg/kg, which may explain the lack of yield response to fertilization in Topeka. Across both locations, residual treatment had no effect on yield. The combination of residual and direct fertilization and the direct application only significantly increased yield over the control and the residual treatment. The lack of response of the residual fertilization agrees with Buah et al. (2000), who found that smaller annual P applications may be more effective than larger semiannual application for increasing soybean yields.

Conclusions

Application of P and K fertilizer generated significant increases in soil test levels for the respective nutrients after 1 year of application. The rate of P and K fertilizer required to increase 1 mg/kg per year of the nutrients was from 5.7–10.4 lb/a P_2O_5 and from 1.1–2.7 lb/a K_2O. These values are lower than current guidelines, suggesting that producers may be overapplying P and K fertilizer.

Soybean yield was increased by residual fertilizer in combination with direct broadcast application in Ashland, where soil test level was above the critical level of 20 mg/kg. Residual fertilizer only was ineffective in increasing yields. In Topeka, soil test P was considered low, and there was an increase on yield over the control at this location. Across locations, direct fertilization alone and combined with residual fertilization significantly increased soybean yield by about 4 to 5 bu/a; therefore, maintenance rates may be effective not only to sustain STP and STK levels but also to improve soybean yield.

Overall, this study provided some information about soil test P and K and yield response to fertilization, but more research is needed involving more locations and soils types across Kansas to obtain more representative results.

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Table 1. Location description, soil classification, soil analysis, varieties, tillage, and planting date for soybean

Year	Location	County	Soil classification: Series[1]	Soil classification: Subgroup[2]	pH	OM	Variety[3]	Tillage system[4]	Planting date
						g/kg			
2011	1	Riley	Eudora SL	F. Hapludolls	6.2	25	KS 3406RR	NT	10/05/2012
2011	2	Shawnee	Eudora SL	F. Hapludolls	6.8	16	Asgrow 3282	CT	14/05/2012

[1] SL, silt loam.
[2] F, fluventic.
[3] KS, Kansas Agricultural Experiment Station.
[4] CT, conventional tillage. Location 2 was chisel-plowed in the spring and turbo-tilled in the fall; NT, no tillage.

Table 2. Description of soybean phosphorus (P) and potassium (K) broadcast rates applied in year 1 as residual fertilization from corn and the following year 2 as direct fertilization applied on soybean

Treatment	Year 1 (corn) P	Year 1 (corn) K	Year 2 (soybean) P	Year 2 (soybean) K
	----	---- lb/a ----	----	----
Control without fertilization	0	0	0	0
Residual broadcast	100	100	0	0
Direct broadcast	0	0	40	70
Residual + direct broadcast	100	100	40	70

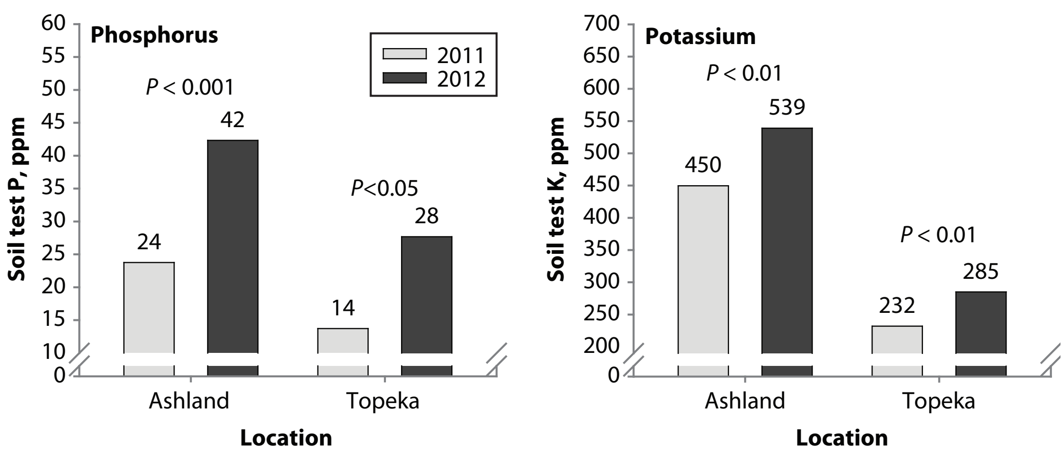

Figure 1. Soil test phosphorus (Mehlich-3) and potassium (ammonium acetate) levels as affected by fertilizer application of 120 lb/a P_2O_5 (20 lb/a P_2O_5 as starter and 100 lb/a P_2O_5 as broadcast) and 120 lb/a K_2O (20 lb/a K_2O as starter and 100 lb/a K_2O as broadcast) in 2012 after 1 year of fertilizer application on non-fertilized plots from 2011.

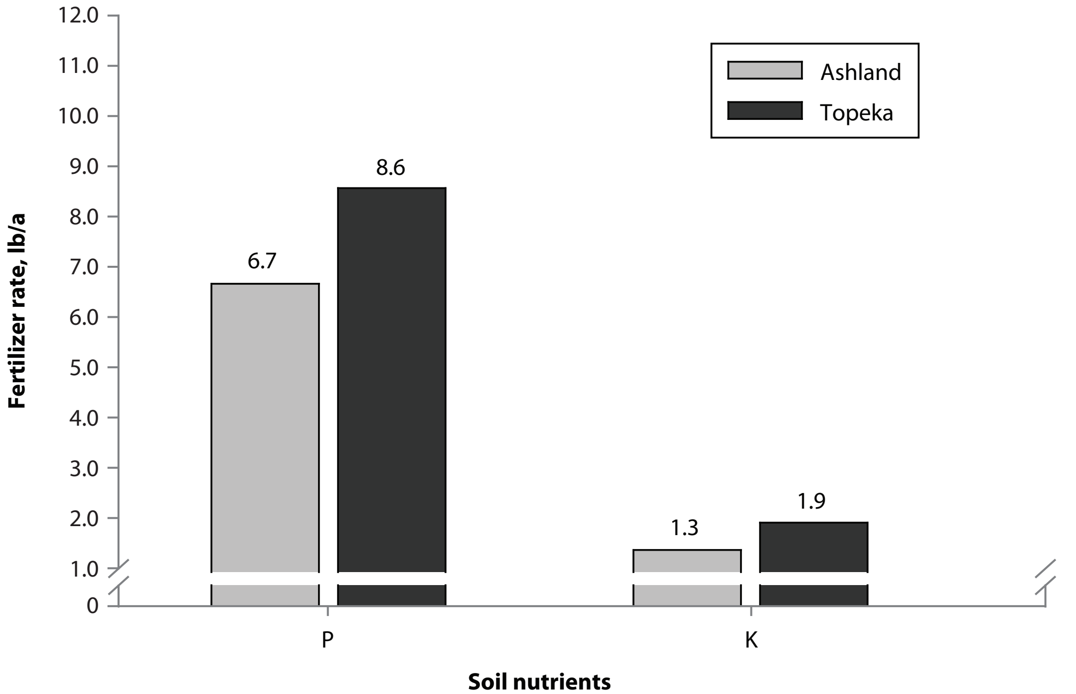

Figure 2. Rate of phosphorus (P) and potassium (K) fertilizer required to increase 1 mg/kg per year of P and K in Ashland and Topeka. Soils were first sampled before fertilization in March 2011 and were sampled again in March 2012, 1 year after fertilizer application.

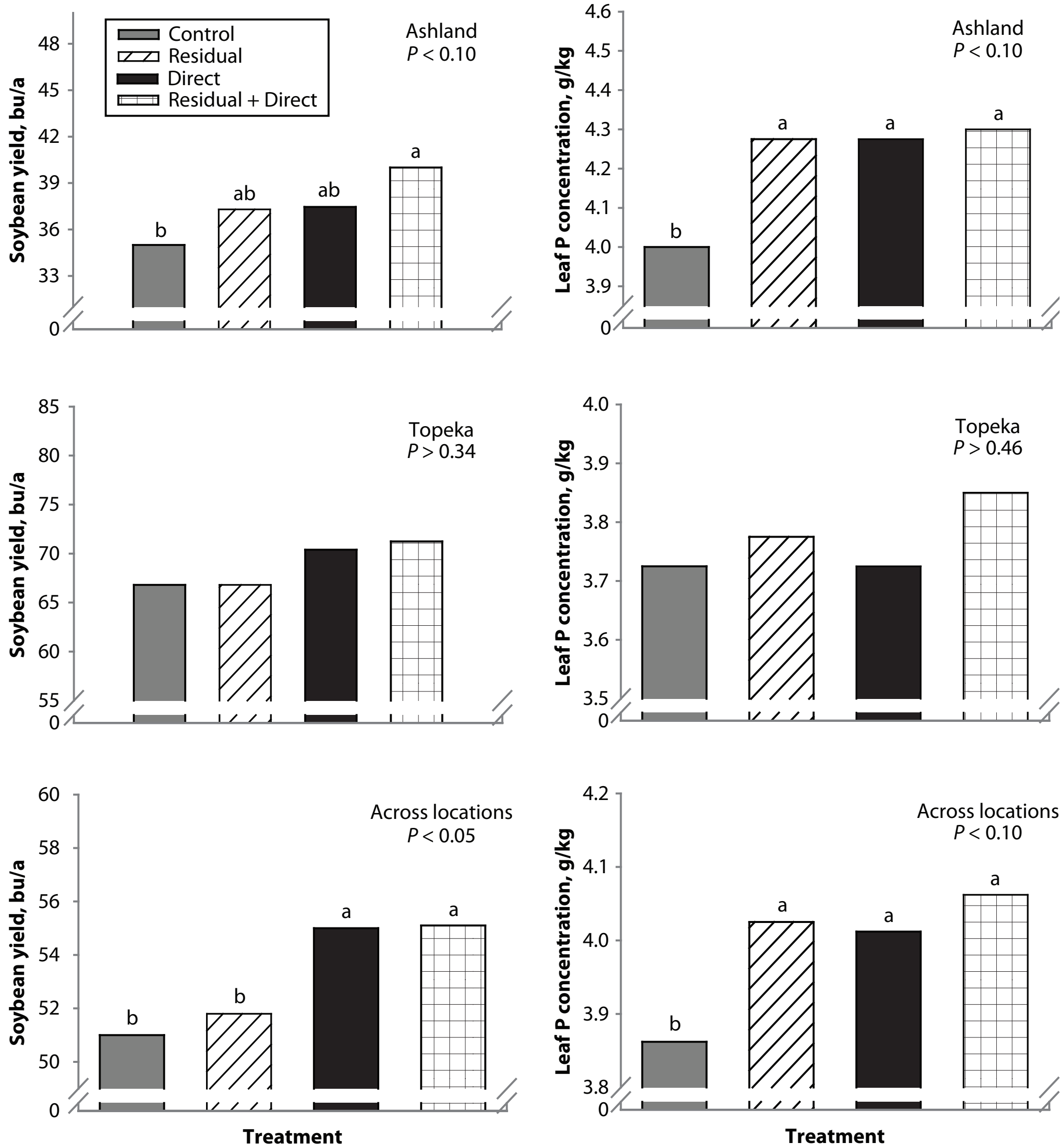

Figure 3. Direct and residual broadcast fertilization effects on soybean yield and leaf P concentration (R2 growth state) for each location and across locations in 2012. Direct fertilization consisted of 20 lb/a P_2O_5 and 70 lb/a K_2O and residual of 100 lb/a P_2O_5 and 100 lb/a K_2O. Soybean was planted over the corn residue plots trials from 2011. Ashland was no-till and non-irrigated, and Topeka was conventional tillage and irrigated. Different letters indicate statistically significant differences at $P < 0.10$.

Relationship Between Fall Soil Test Nitrate-Nitrogen Level and Spring Topdress N Response in Winter Wheat

A.R. Asebedo and D. B. Mengel

Summary

Testing for nitrate-N in the fall for making nitrogen (N) recommendations on winter wheat is a common practice; unfortunately, few farmers utilize this tool, and its value has been questioned in some areas due to overwinter N loss. The development of sensor technology has provided an alternative procedure that can deal with the issues of N loss and still provide insight into the availability of residual N to a crop. The objective of this report is to evaluate the relationship between wheat yield and fall soil nitrate-N and determine if it is still a viable practice to utilize in N management of wheat. Data were drawn from 16 different N management experiments in Kansas. Wheat yield was compared with fall nitrate-N levels and a strong relationship was established. Soil sampling in fall for nitrate-N can have a significant impact on N recommendations for winter wheat, thus improving N management, and is still strongly recommended.

Introduction

In the past several decades, interest in improving N management in winter wheat has increased. Recent efforts have been focused on improving nitrogen use efficiency (NUE) or increasing the percentage of applied fertilizer N taken up by a crop, which would result in increased profits per acre for producers while reducing N loss to the environment. Some products of these efforts have been the creation of N fertilizer products that reduce N loss, optical sensors that can evaluate wheat's N status, and changes in methods and timing of N applications. With so many new practices incorporated into N management systems, older practices are starting to be considered dated and discarded.

Taking fall soil N samples to estimate the amount of available N present in the soil before planting was a recommended practice for making an N recommendation for winter wheat for many years, but with the creation of new N management tools, the value of the information from fall soil N samples has come under severe scrutiny. Due to the mobility of nitrate-N in the soil, soil test values observed in the fall may be completely different than values observed in the spring. Because most producers wait until spring greenup to make their N application, does soil sampling in the fall for nitrate-N provide useful information for N management in wheat? The objective of this study was to evaluate the relationship between N fertilizer response by wheat and fall soil nitrate-N and determine if it is still a viable practice to utilize in N management of wheat.

Procedures

Data were drawn from 18 experiments conducted in 2006 through 2012 throughout Kansas in cooperation with producers and Kansas State University experiment stations (Table 1). Each location was rainfed and used crop rotations, tillage, cultural practices, and wheat varieties that were representative of the area. Each field study utilized small research plots, normally10 ft × 50 ft. Soil samples to a depth of 24 in. were taken by experimental block prior to planting and fertilization. Samples from 0 to 6 in. were analyzed for soil organic matter, Mehlich-3 phosphorus, potassium, pH, and zinc. Soil profile 0- to 24-in. samples were analyzed for nitrate-N, chloride, and sulfate. Fertilizer needs other than N were applied in the fall at or near seeding.

Flag leaf tissue samples were taken at Feekes 10.5 and were analyzed for N content. Grain yield was measured by harvesting an area of 5 ft × 47 ft within each plot at all locations. Yields were adjusted to 12.5% moisture, and grain was analyzed for N content and protein. Relative yield was calculated using the following equation (relative yield = site check plot yield / site high yield). Delta yield was calculated by using the following equation: delta yield = economic optimum yield – check yield. Regression analysis was conducted using PROC REG in SAS (SAS Institute Inc., Cary, NC).

Results

Analysis of yields taken from plots that received no N fertilizer shows a strong positive relationship with fall soil profile nitrate-N (Figure 1). Wheat yields increased rapidly as soil N levels increased.

By converting check plot yields to a relative yield, or percentage of the fertilized yield at each location (Figure 2), one can see not only the yield of the check plot, but also the N responsiveness of the site. This shows that at low soil nitrate levels, sites respond well to applied fertilizer, but that when fall soil profile nitrate-N levels are greater than 100 lb/a, relative yield is approaching 100%, and it is unlikely the site will respond to additional fertilizer N applied in the spring.

Figure 3 shows the amount of N fertilizer required to produce an additional bushel of wheat, or delta yield, as the responsiveness of the site changes. At highly responsive sites, sites with high delta yield and low soil test N, the amount of fertilizer N required to produce an additional bushel of wheat is low, 2 lb/a of fertilizer N or less. But at high soil test–low response sites, the amount of N required to produce a bushel of additional yield increases dramatically. A number of additional conditions such as drought, disease, and poor root growth can influence this relationship.

Although soil sampling for N adds cost and takes time, the information is clearly beneficial for predicting the responsiveness of a field to N fertilizer. High nitrate-N levels in the fall are a good indicator of a large amount of carryover N from previous crops and that adjustments to future N recommendations would be prudent.

Unfortunately, very few people use profile N sampling as a basis for making fertilizer recommendations for any crop. When soil sampling for N is not done, the K-State fertilizer recommendation formula defaults to a standard value of 30 lb/a available N. In this particular dataset, the average profile N level was 43 lb/a N (Table 1). Most recommendation systems default to a standardized set of N recommendations based on yield goal and/or the cost of N. Without sampling for N or using some alternative method of measuring the soil's ability to supply N to a crop, such as crop sensing, the recommendations made for N will be inaccurate, resulting in a reduction in yield or profit per acre and increased environmental impact. Due to the drought of the past two years, there have been many situations where large amounts of N have been present in the soil at planting of wheat or summer crops such as corn or grain sorghum. Failure to account for that valuable resource can result in excess vegetation, increased plant disease, inefficient use of soil water, and reduced yield.

Although new practices have been developed to improve N management in winter wheat, soil sampling in the fall for nitrate-N remains an important practice to manage N efficiently and can result in considerable savings for producers.

Table 1. Experimental data for all reported locations

Year	Location	Soil NO_3	Check plot yield	Economically optimal yield	Response to N
		lb/a	-------------------- bu/a --------------------		
2006	Manhattan	52	44	75	32
2007	Manhattan	46	45	45	0
2007	Tribune	127	64	64	0
2008	Partridge	57	47	73	26
2009	North Farm	48	49	83	34
2010	Johnson	73	69	71	2
2010	North Farm	34	32	53	21
2011	Randolph	49	34	42	8
2011	Rossville	54	44	66	22
2012	Manhattan	52	37	53	16
2012	Ottawa	23	19	48	29
2012	Rossville	24	11	31	20
2012	Manhattan	51	34	54	20
2012	Rossville	26	13	27	14
2012	Ottawa	21	33	63	30
2012	Sterling	11	9	24	15
2012	Gypsum	13	11	42	31
2012	Manhattan	22	21	36	15

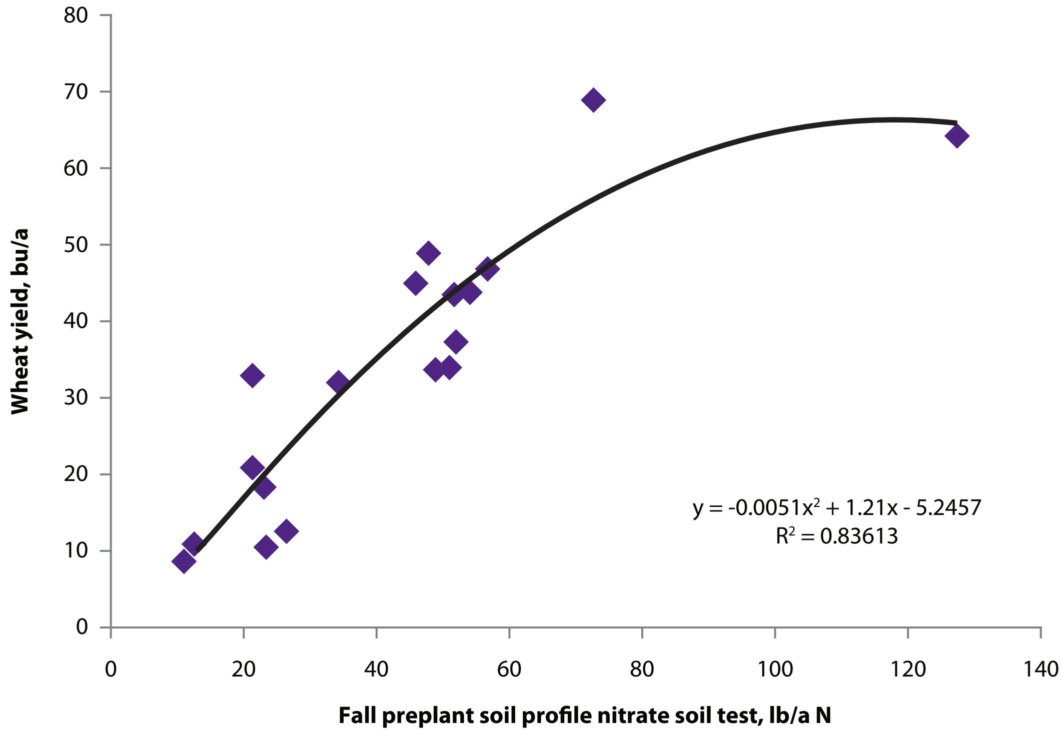

Figure 1. Relationship between fall soil nitrate content and wheat yield, with no fertilizer nitrogen (N) applied.

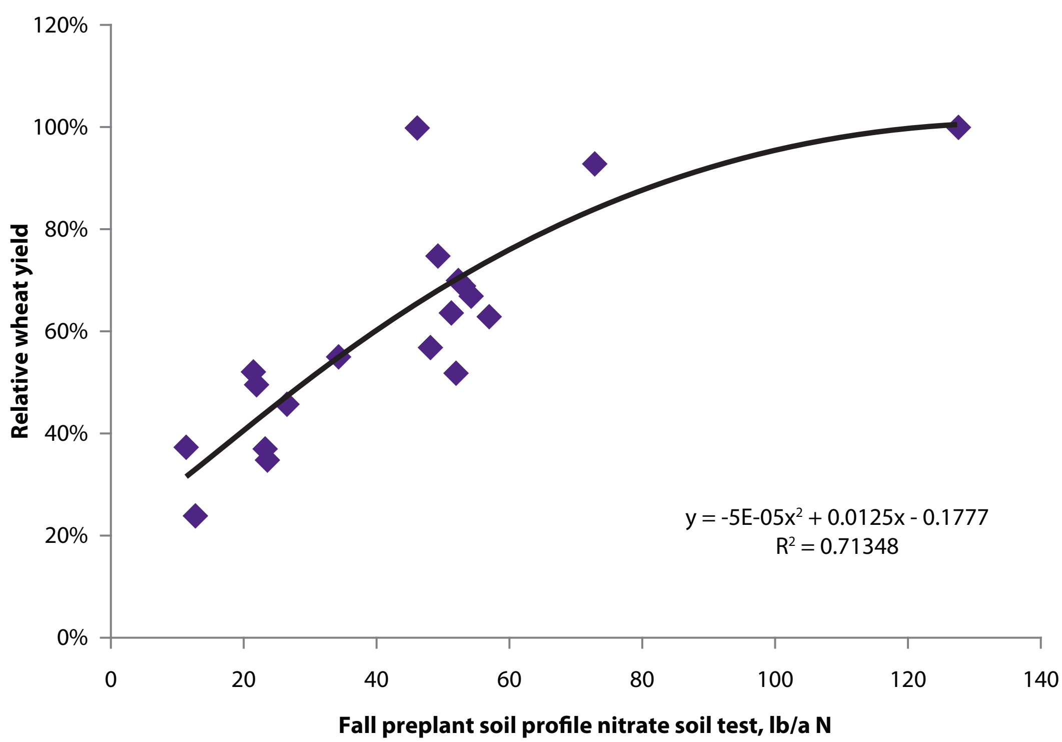

Figure 2. Relationship between fall soil nitrate content and relative yield with no fertilizer nitrogen (N) applied.

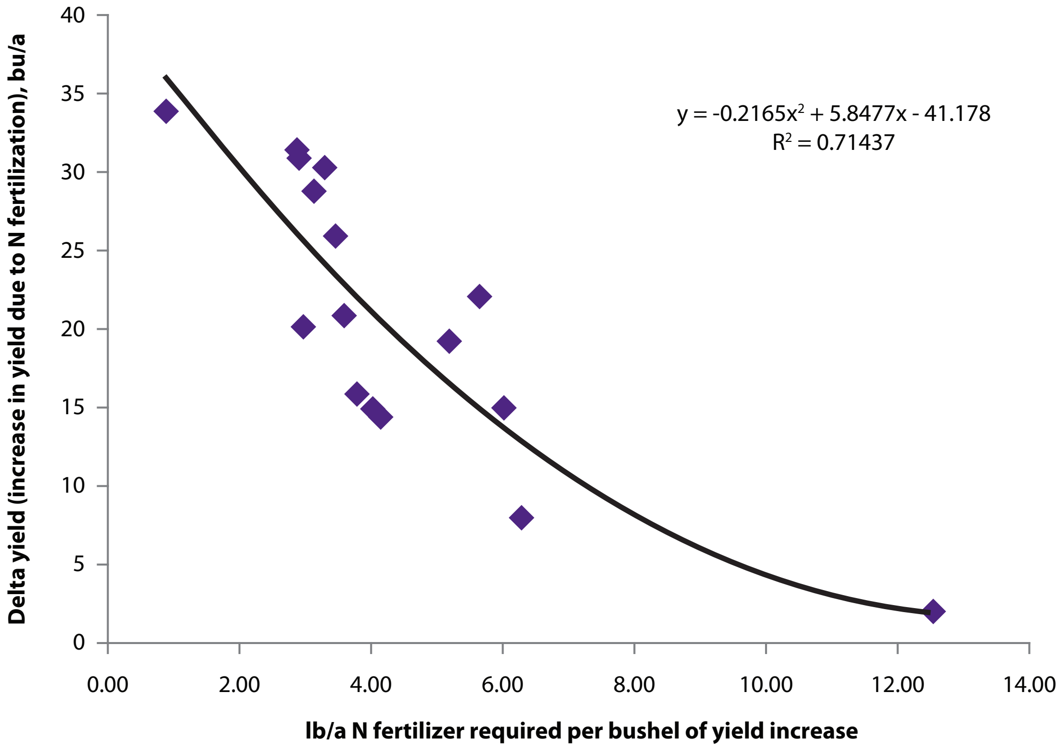

Figure 3. Pounds of applied fertilizer nitrogen (N) required per bushel of yield increase over non-fertilized check plot yield.

The Use of Nitrification Inhibitors with Anhydrous Ammonia in No-Till Corn

T.J. Foster and D.B. Mengel

Summary

Two avenues of nitrogen (N) loss common in Kansas soils are denitrification and leaching. By minimizing these losses, producers can maximize yield with lower input costs and have less impact on the environment. The use of nitrification inhibitors with anhydrous ammonia to retain N in the ammonium form can potentially lower these N losses and increase N uptake. This project was initiated in the fall of 2011 to compare the use of two nitrification inhibitors with anhydrous ammonia (AA) as tools for reducing N loss from both fall- and spring-applied ammonia. Three very different soils were chosen: a high-yielding silt loam site at the Agronomy North Farm near Manhattan, KS, with moderate potential for denitrification loss; a lower-yield silt loam site near Ottawa, KS, with a high potential for denitrification loss; and a very high-yielding irrigated, sandy loam near Rossville, KS, with a very high potential for leaching loss. Conditions in the eastern part of Kansas were not conducive to high losses of N through leaching or denitrification due to the low rainfall throughout the 2011 winter and 2012 growing season for no-till corn; however, approximately 3 in. of rain were received during a four-day period in May and early June. As a result, yield responses to the nitrification inhibitors were minimal, but some response to inhibition in yield and N uptake was seen with fall application at Manhattan. Differences between spring and fall N applications also were observed at Rossville.

Introduction

As input costs increase each year, increasing production efficiency through methods such as minimizing N loss are becoming increasingly important. Two tools available to enhance N use efficiency are time of N application and the use of nitrification inhibitors, especially with anhydrous ammonia, which is one of the cheapest sources of N fertilizer currently available to Kansas farmers. The objective of this study was to enhance N use efficiency of the applied N by inhibiting the conversion of ammonia to nitrate until the plant had an opportunity to take up the N. This approach could increase the flexibility for timing of application of AA and decrease the potential for loss of N through denitrification or leaching. The study also considered at timing of application, fall vs. spring preplant, as well as the efficacy of two different nitrification inhibitors; N-Serve, (Dow Chemical, Midland, MI), and an experimental product from a second company. The experimental product was applied at three different rates to determine the optimal level at which to apply the product.

Procedures

The study was initiated in the fall of 2011 and is planned as a multiple-year study; this report covers only the first year's work. The study was conducted at three locations: Agronomy North Farm in Manhattan, KS; Kansas River Valley Experiment Field near Rossville, KS; and East Central Kansas Experiment Field near Ottawa, KS. All of the field plots were arranged in a randomized complete block design with four replications. Information describing the experiment at each site is summarized in Table 1.

Soil samples were taken in the fall of 2011 to measure the residual N level in the soil as well as basic soil test levels for phosphorus (P), postassium (K), pH, soil organic matter content (SOM), calcium (Ca), and magnesium (Mg). Samples were taken to a depth of 36 in. using a hydraulic soil probe fitted with plastic inserts; the plastic tube with the soils were frozen until time allowed for the separation of the cores into their specified segments. Four composite samples were taken per site, one from each of the blocks. Twelve cores were taken per composite sample. The samples were separated into 0–6-in., 6–12-in., 12–24-in., and 24–36-in. segments.

All AA treatments were applied using a 2510H John Deere HSLD anhydrous ammonia applicator at 20-in. coulter spacing. The applicator was calibrated using onboard weigh scales at 6 mph in a 300- to 600-foot measured travel area. All nitrification inhibitor (NI) treatments were applied at a 100 lb/a N rate at 6 mph at a depth of 4 in. In the spring, the 150 and 200 lb/a N rates were accomplished by changing the speeds of application from the 100 lb/a N rate calibrated at 6 mph; however, due to calibration and distribution issues, the 50 lb/a N rate was calibrated to apply at 7 mph. N-Serve was applied directly into the AA distribution system using a Raven Sidekick variable-rate injection system (Raven Industries, Sioux Falls, SD) at 32 oz/a. The experimental NI product was applied ½ in. behind the AA stream in the furrow. The different NI rates were changed directly from the Sidekick monitor in the cab. To account for the differences in N content at different NI rates, urea-ammonium nitrate (UAN) was applied using the sidekick to balance the N rates across all treatments. The N-Serve treatment received two passes, one with UAN alone and the other with AA and N-Serve.

Starter fertilizer was applied with the planter at a rate of 15 gal/a of a 50/50 blend of 10-34-0 and 28-0-0 (N-P-K) at the Manhattan and Rossville locations. The Ottawa location received a broadcast application of monoammonium phosphate (MAP) and potassium chloride (Potash) 1 month prior to planting.

Throughout the growing season, measurements were taken to evaluate crop performance. Leaf firing notes, ear leaves at silking, whole-plant samples approximately 1 week before blacklayer, and grain samples at harvest were collected to determine each treatment's performance. Leaf firing notes were taken at V13 and R1 by counting all the leaves, then counting the fired leaves. The procedures for collecting the ear leaves at R1 was to collect 20 leaves from each plot, dry them at 60°C, and test for total N levels. Whole-plant sampling was completed at approximately R5.75. Ten plants were collected from each treatment. The ears were removed from the plant, leaving the husks on the plant. The plants were then processed in a yard chopper and a subsample was obtained, weighed, dried, weighed again, and analyzed for percentage N. The grain yield was collected from Rossville and Ottawa using a plot combine, sampling two rows the length of the plot. At Manhattan, the plots were hand-harvested; 17.6 ft of two rows were handpicked and machine-shelled. The plots at Manhattan were only 10 ft × 45 ft, whereas the plots at Rossville and Ottawa were 10 ft × 50 ft. Yield was adjusted to 15.5% moisture. A complete list of the treatments, timings, and products can be found on Tables 2 and 3.

Of the three locations, only the data from Manhattan and Rossville are presented. The Ottawa location failed due to intense drought conditions throughout the growing season. Ear leaf samples and grain yields were collected and recorded, but yields were less than 5 bu/a for all treatments. Also, the third block at the Rossville location was not included in the analysis due to a discontinuous clay lens in the subsoil, which had a great impact on yield and N loss due to leaching. To quantify this problem, the existence of and depth to a clay lens was determined for each plot. Block 3 had extensive variation in the soil type, which caused great variability in yield. As a result, only blocks 1, 2, and 4 at Rossville and all four blocks at Manhattan were used for analysis purposes in this report.

Results

The results from the Manhattan location are summarized in Table 2. A significant response to the addition of N fertilizer was observed at this site. All fertilized treatments yielded higher than the unfertilized control. In addition, the ear leaf N content and total N uptake by the plant were increased by the application of N fertilizer.

Fall applications of 100 lb/a N with N-Serve or the experimental NI product all produced significantly higher yields than a fall application of 100 lb/a N alone. The use of an NI with fall-applied ammonia increased yield an average of 15 bu/a compared with ammonia alone. Total N uptake also increased significantly with the 1x rate of the experimental NI and the use of N-Serve compared to fall ammonia alone, with similar trends noted with the higher rates of the experimental NI.

Similar yields were observed between fall-applied ammonia with an NI and spring-applied ammonia without an inhibitor. No yield response to the addition of a nitrification inhibitor was observed with spring applications of ammonia. In both spring and fall applications of N, the addition of an NI increased total N uptake. The yield response obtained to increasing rates of spring-applied N appears to show that the 100 lb/a N rate was about optimum for this site in 2012. This is considerably lower than the 160 lb/a N rate normally recommended using the Kansas State University fertilizer recommendations. One likely explanation for this observation is the lower than normal in-season precipitation, which reduced N loss potential. The K-State recommendations were developed using an implied nitrogen use efficiency (NUE) of 50%; however, at Manhattan in 2012, NUE measured by recovery was approximately 60% and 75% with an inhibitor. These significant increases in NUE would explain why optimum N rate at this site was substantially below normal recommended N fertilizer rates.

Results from the Rossville site differed substantially (Table 3). At this site a significant increase in yield was observed with spring applications of N compared with fall application, and no response to the use of an NI was observed with spring or fall N applications. In addition, the optimum spring N rate was approximately 150 lb/a N, very close to the normal K-State recommendation. Nitrogen use efficiency, or recovery of the applied fertilizer N by the crop at this site, ranged from 45–55%, which is in line with the long-term NUE values used to develop the K-State recommendation.

Another interesting result was that both NUE and yield observed with fall application of N, with or without the addition of a nitrification inhibitor, were significantly lower than that obtained with spring application of N on this sandy site prone to leaching. This supports the general recommendation that fall application of N is a risky practice on sandy soils prone to leaching loss, but it can be done successfully on medium- to heavy-textured soils when applied after soils have cooled, especially with the addition of an NI.

Even though 2012 was a dry year with little N loss at Manhattan on a silt loam soil, the lower water-holding capacity of the sandy soils at Rossville, together with the additional 12 in. of water applied as irrigation, resulted in substantial N loss, particularly when all N was applied in the fall. Previous work at this site has shown good responses to the use of split applications of N as a tool to better control N loss. In those studies, NUE as high as 70% was observed.

At both locations, no statistical difference was observed in performance between N-Serve and the experimental product, so the experimental product may help control nitrification when used with AA.

The data collected in 2012 are encouraging evidence that N management practices can be used to increase both N recovery and yield. The experimental compound may have merit as an NI and as a tool to minimize N loss from fall-applied N on appropriate soils.

Acknowledgments

We wish to thank Eric Adee, Agronomist-in-Charge of the KRV and Ottawa locations, and Charlie Clark, Bill Riley, and Jim Kimball, technicians at these locations, for their assistance with this project. We also wish to thank all of our industry partners, including John Deere and Dow Chemical, for providing equipment, products, and financial support for this study.

Table 1. Locations and procedures for individual experiments

	Manhattan	Rossville	Ottawa
GPS coordinates	39N 12'49.64 96W 35'34.66	39N 12'44.86 96W 35'56.14	38N 32'19.58 95W 14'41.83
Soil type	Reading silt loam	Eudora silt loam	Woodson silt loam
Irrigated or not	Not irrigated	Irrigated	Not irrigated
Previous crop	Corn	Double-crop soybean	Double-crop soybean
Corn hybrid	P1498HR (Pioneer)	H-9138 3000GT (Golden Harvest)	DKC6269 (Dekalb)
Plant population	28600	25000	21300
Fall treatments applied	November 21, 2011	November 15, 2011	November 18, 2011
Spring treatments applied	March 15, 2012	April 16, 2012	April 17, 2012
Planting date	April 10, 2012	April 23, 2012	May 9, 2012
Fire notes taken (V13)	June 19, 2012	June 19, 2012	Not collected
Fire notes taken (R1)	July 2, 2012	July 2, 2012	Not collected
Ear leaf sampling date (R1)	July 1, 2012	July 2, 2012	July 16, 2012
Whole-plant sampling date (5.75)	July 23, 2012	July 24, 2012	Not collected
Stalk nitrate sampling date (R5.75)	July 23, 2012	July 26, 2012	Not collected
Harvest date	September 4, 2012	September 11, 2012	September 6, 2012

Table 2. Results from the Manhattan experiment

Treatment applied	Nitrogen (N) rate	Ear leaf N	Total N uptake	Fertilizer N recovery	Yield
	lb/a	%	lb/a	%	bu/a
Fall ammonia	100	1.92	168	63.6	140
Fall ammonia + Exp NI[1] 1x	100	2.17	186	79.9	156
Fall ammonia + Exp NI 2x	100	1.92	183	77.1	156
Fall ammonia + Exp NI 3x	100	1.86	179	74.1	155
Fall ammonia + N-Serve[2] 1 qt/a	100		184	77.9	154
Control	0	1.80	99	---	79
Spring ammonia	50	1.80	146	79.7	130
Spring ammonia	100	2.08	162	58.1	148
Spring ammonia + Exp NI 1x	100	2.16	175	70.4	148
Spring ammonia+ Exp NI 2x	100	2.05	171	66.2	147
Spring ammonia + Exp NI 3x	100	2.05	180	74.4	143
Spring ammonia + N-Serve	100	2.02	182	76.8	151
Spring ammonia	150	1.96	182	52.2	142
Spring ammonia	200	2.12	190	43.9	148
LSD 0.10		0.16	16	15.5	12

[1] Nitrification inhibitor.
[2] N-Serve nitrification inhibitor (Dow Chemical, Midland, MI).

Table 3. Results from the Rossville experiment

Treatment applied	Nitrogen (N) rate	Ear leaf N	Total N uptake	Fertilizer N recovery	Yield
	lb/a	%	lb/a	%	bu/a
Fall ammonia	100	2.40	155	28.8	155
Fall ammonia + Exp NI[1] 1x	100	2.28	151	25.7	151
Fall ammonia + Exp NI 2x	100	2.54	164	37.7	166
Fall ammonia + Exp NI 3x	100	2.45	169	41.9	155
Fall ammonia + N-Serve 1 qt/a	100	2.55	158	32.1	161
Control	0	2.08	123	---	110
Spring ammonia	50	2.26	150	46.0	151
Spring ammonia	100	2.54	184	55.7	180
Spring ammonia + Exp NI 1x	100	2.64	173	45.7	175
Spring ammonia+ Exp NI 2x	100	2.52	188	59.4	171
Spring ammonia + Exp NI 3x	100	2.45	174	46.5	165
Spring ammonia + N-Serve[1]	100	2.62	177	49.2	175
Spring ammonia	150	2.64	200	48.1	189
Spring ammonia	200	2.47	193	33.5	183
LSD 0.10		0.20	23.8	21.1	17

[1] Nitrification inhibitor.
[2] N-Serve nitrification inhibitor (Dow Chemical, Midland, MI).

Use of Nitrification Inhibitors with Anhydrous Ammonia in No-Till Winter Wheat

T.J. Foster, D.B. Mengel

Summary

Two of the paths of nitrogen (N) loss from Kansas soils are denitrification and leaching. Several tools are available to producers reduce these losses and, in turn, lower input costs and enhance crop yields. Applying N as close as possible to the time of N uptake by the plant is one commonly used tool to avoid N loss. Using nitrification inhibitors with ammonium N sources such as anhydrous ammonia (AA) is another, because reducing nitrification and keeping the N in ammonium form prevents both leaching and denitrification. This project was initiated in the fall of 2011 to compare the use of fall-applied AA with and without nitrification inhibitors to the traditional spring practice of topdressing urea as methods of applying N to winter wheat. The study was conducted at three sites in Kansas. Fall and winter precipitation varied widely across the locations but was generally limited in the late winter and early spring, key periods for N loss. As a result, no difference was seen between fall ammonia and spring urea as methods of applying N to winter wheat, with no advantage to using nitrification inhibitors with AA.

Introduction

As input costs increase each year, increasing production efficiency through methods such as minimizing N loss are becoming increasingly important. Two tools available to enhance N use efficiency are time of N application and the use of nitrification inhibitors, especially with anhydrous ammonia, because AA is one of the cheapest sources of N fertilizer currently available to Kansas farmers. The objectives of this study were to compare fall preplant applications of AA, with and without a nitrification inhibitor (NI) , to spring topdress applications of urea as systems for applying enhance N to winter wheat. The study also looked at the efficacy of two different NIs: N-Serve, (Dow Chemical, Midland, MI), and an experimental product from a second company. The experimental product was applied at three different rates to determine the optimal level at which to apply the product.

Procedures

The study was initiated in the fall of 2011 and is planned as a multiple-year study; this report covers only the first year's work. The study was conducted at three locations: the Agronomy North Farm in Manhattan, KS; Kansas River Valley Experiment Field near Rossville, KS; and East Central Kansas Experiment Field near Ottawa, KS. All field plots were arranged in a randomized complete block design with four replications. The sites are summarized in Table 1.

Soil samples were taken in the fall of 2011 to measure the residual N level in the soil as well as basic soil test levels for phosphorus (P), postassium (K), pH, soil organic matter (SOM, calcium (Ca), and magnesium (Mg). Samples were taken to a depth of 36 in. using a hydraulic soil probe fitted with plastic inserts; the plastic tube with the soils were frozen until time allowed for the separation of the cores into their specified segments. Four samples were taken per site, one from each of the blocks. Twelve cores were taken per composite sample. The samples were separated into 0–6-in., 6–12-in., 12–24-in., and 24–36-in. segments.

The fall AA treatments were applied approximately 1 week before planting using a 2510H John Deere HSLD anhydrous ammonia applicator at 20-in. coulter spacing. All treatments were applied at 6 mph at a depth of 4 in. using a 60 lb/a N application rate. The applicator was calibrated to apply 60 lb/a N at 6 mph using onboard weigh scales in a 300-ft to 600-ft measured travel area. N-Serve was applied directly into the AA distribution system using a Raven variable-rate injection system (Raven Industries, Sioux Falls, SD) at a rate of 32 oz/a. The experimental nitrification inhibitor was applied ½ in. behind the AA stream in the furrow. The different rates for the experimental product were delivered using the variable-rate controller. To account for the differences in N applied as a component of the nitrification inhibitors, urea was broadcast in early January.

Starter fertilizer was applied with the drill at planting at a rate of 80 lb/a of monoammonium phosphate (MAP; 40 lb/a P_2O_5) at the Manhattan and Rossville plots; however, the drill available at the Ottawa location was not equipped to provide starter fertilizer, so 125 lb/a of a 75% diammonium phosphate (DAP)/25% potassium chloride (KCl) fertilizer blend was broadcast prior to planting and incorporated with the no-till drill (17-43-19 N-P-K). An N response curve was established in the spring at approximately Feekes 4 by broadcasting urea at rates of 30, 60, 90, 120 lb/a N. A complete description of the treatments with timings and products used can be found in Tables 2, 3, and 4.

Measurements were taken to evaluate crop performance throughout the growing season. Flag leaves were taken at heading, and whole-plant samples were taken at late milk/early dough from each location. Fifty flag leaves were collected from outside the harvest area, of each plot and were dried and analyzed by the Kansas State University Soil Testing Lab for percentage N. For whole-plant sampling, the vegetation from 6 linear ft of row was collected from each treatment, chopped in the field, weighed, and a subsample was collected, dried to determine dry matter content, and analyzed for whole-plant N content. Grain yield was collected from each location using a plot combine that harvested a 5-ft section from the center of each plot for the length of the plot. Plots were 10 ft × 45 ft at Manhattan and 10 ft × 50 ft at Rossville and Ottawa. A 2-lb sample of grain was collected from each plot and analyzed for percentage moisture, test weight, and grain protein content. Yields were adjusted to 12.5% moisture.

Results

Data were collected from all three locations; however, the Rossville location did not perform very well due to a number of complications during the growing season. Poor initial stands, hail damage shortly after heading, and weed pressure as a result of the stand issues and hail hindered consistent yields across the study. The data are reported in Table 2, but no conclusions should be drawn from that specific location due to the many inconsistencies.

The data from the Manhattan study are reported in Table 3. A significant response to N as measured by both flagleaf N content and yield was found. Using yield obtained from the spring topdress N rates as a benchmark, the optimum yield of approximately 51 bu/a was obtained with a 60 lb/a N application applied as urea in the spring. No significant difference in yield occurred between 60 lb/a N applied in the fall as ammonia, with or without an NI and 60 lb/a N applied as urea topdressed in the spring, indicating that on a highly productive medium-textured soil, fall applications of N as ammonia were as effective as spring topdressing a similar rate of N.

K-State fertilizer N recommendations for a 50 bu/a yield goal for wheat following soybean are 90 lb/a N. The 60 lb/a N rate for comparison of fall vs. spring applications and the use of NIs was selected, because yield was expected to be slightly sub-optimal, but N losses were reduced because of below-average rainfall, so optimum N rate followed.

Significantly higher N levels in flag leaves (with the exception of where N-Serve was applied with the ammonia) and grain protein were seen from 60 lb/a applied in the spring than from 60 lb/a N applied in the fall. The accepted sufficiency level for wheat flag leaves used in Kansas is from 3.5–4.5% N. In all cases, although optimum yield levels were found with an application of 60 lb/a N, flag leaf N levels from all 60 lb/a N treatments were below the accepted 3.5% sufficiency level. This result raises questions about the reliability of current plant analysis calibrations.

Grain protein levels are another area of concern. The grain market currently desires wheat grain protein levels of 12% or above. The desired level was achieved at Manhattan in 2012 only at N rates above those needed to produce optimum yield (Table 3).

Results from the Ottawa location are presented in Table 4. Like Manhattan, a significant response to N was obtained; however, at the Ottawa location, using the spring-applied N rates as a benchmark, optimum yield was obtained with 90 lb/a N, with a strong trend toward higher yields with 120 lb/a N. The Woodson soil at the Ottawa site is very poorly drained, with a clay pan; thus, higher levels of N loss would be expected than at the Manhattan site. At this site, the 60 lb/a N rate was clearly suboptimal, and if differences in efficiency between fall or spring applications or the addition of a nitrification inhibitor were to occur, N rate at this site should be helpful in showing differences. Another difference was the level of residue present. At Ottawa, the site had a long history of no-till cropping, and significant levels of residue from previous corn and wheat crops could be identified. This older residue could have served as a sink for surface-applied N through immobilization or enhanced ammonia volatilization.

No significant differences in yield between fall-applied ammonia, ammonia with the experimental inhibitor, and the spring topdressing were observed. Yields from 60 lb/a N as fall ammonia with N-Serve were significantly higher, however, than yields obtained with the same rate of N spring applied as urea.

As at the Manhattan site, the N content of the flag leaf at optimum N rate for yield was not up to the accepted sufficiency level, raising further concerns over the validity of current plant analysis calibrations. Grain protein levels were at the desired minimum level of 12% at the 90 lb/a N rate, the same rate required for optimum yield at this site.

In this low-rainfall year, N losses from mechanisms such as denitrification or leaching would have been minimal, and N response was lower than normal; thus, the need for tools to enhance N utilization were reduced. Fall application of N as AA was an acceptable management practice at both Manhattan and Ottawa, and little need or additional response to using nitrification inhibitors was observed.

Table 1. Locations and procedures for individual experiments

	Manhattan	Rossville	Ottawa
GPS coordinates	39N 12'44.67 96W 35'42.21	39N 07'07.78 95W 55'24.33	38N 32'28.15 95W 14'29.44
Primary soils	Ivan and Kennebec silt loams	Eudora sandy loam	Woodson silt loams
Previous crop	Soybean	Soybean	Soybean
Variety planted	Everest	Everest	Everest
Seeding rate	110 lb/a	110 lb/a	110 lb/a
Fall AA[1] treatments applied	Oct. 20, 2011	Oct. 25, 2011	Oct. 27, 2011
Planting date	Nov. 3, 2011	Nov. 5, 2011	Oct. 31, 2011
Spring urea applied (Feekes 4)	March 17, 2012	March 17, 2012	March 17, 2012
Flag leaf sampling date (Feekes 10.1)	April 18, 2012	April 19, 2012	April 19, 2012
Whole-plant sampling date (Feekes 11.1)	April 30, 2012	April 30, 2012	May 4, 2012
Harvest date	June 6, 2012	June 7, 2012	June 5, 2012

[1] Anhydrous ammonia.

Table 2. Results from the Rossville site, 2012

Treatment	Nitrogen (N) rate	Flagleaf N	Grain protein	Yield
	lb/a	%	%	bu/a
Fall ammonia	60	3.42	16.3	23.3
Fall NH_3 with Exp NI[1] Rate 1x	60	3.58	16.0	31.0
Fall NH_3 with Exp NI Rate 2x	60	3.75	16.2	24.9
Fall NH_3 with Exp NI Rate 3x	60	3.67	16.0	25.2
Fall NH_3 with N-Serve[2]	60	3.56	16.3	23.4
Control	0	3.48	16.5	10.7
Spring broadcast urea	30	3.89	15.7	17.3
Spring broadcast urea	60	3.97	16.9	15.2
Spring broadcast urea	90	3.89	17.1	24.1
Spring broadcast urea	120	3.95	17.7	18.3
LSD 0.10		0.29	0.8	9.1

[1] Nitrification inhibitor.
[2] N-Serve, Dow Chemical, Midland, MI.

Table 3. Results from the Manhattan Site, 2012

Treatment	N rate	Flagleaf N	Grain protein	Yield
	lb/a	%	%	bu/a
Fall ammonia	60	3.13	10.9	53.4
Fall NH_3 with Exp NI Rate 1x	60	3.04	10.9	52.9
Fall NH_3 with Exp NI Rate 2x	60	3.03	10.8	50.3
Fall NH_3 with Exp NI Rate 3x	60	3.10	10.9	50.7
Fall NH_3 with N-Serve	60	3.17	10.9	51.6
Control	0	2.58	10.5	37.5
Spring broadcast urea	30	3.00	10.5	47.3
Spring broadcast urea	60	3.26	11.3	51.1
Spring broadcast urea	90	3.57	11.9	52.7
Spring broadcast urea	120	3.60	12.4	51.9
LSD 0.10		0.13	0.3	2.6

[1] Nitrification inhibitor.
[2] N-Serve, Dow Chemical, Midland, MI.

Table 4. Results from the Ottawa Site, 2012

Treatment	Nitrogen (N) rate	Flagleaf N	Grain protein	Yield
	lb/a	%	%	bu/a
Fall ammonia	60	3.06	11.7	41.4
Fall NH_3 with Exp NI[1] Rate 1x	60	3.13	12.1	42.0
Fall NH_3 with Exp NI Rate 2x	60	3.15	11.8	40.1
Fall NH_3 with Exp NI Rate 3x	60	3.09	11.8	41.5
Fall NH_3 with N-Serve[2]	60	3.24	11.9	44.3
Control	0	2.69	12.6	18.9
Spring broadcast urea	30	2.85	11.1	31.6
Spring broadcast urea	60	3.17	11.7	39.3
Spring broadcast urea	90	3.35	12.2	48.2
Spring broadcast urea	120	3.43	13.1	51.3
LSD 0.10		0.15	0.72	3.2

[1] Nitrification inhibitor.
[2] N-Serve, Dow Chemical, Midland, MI.

Phosphorus and Micronutrient Fertilizers on Soybean

R. Florence, J. Matz, and D. Mengel

Summary

Phosphorus (P) fertilizer is traditionally applied to corn only in a corn/soybean rotation. This leaves soybean to rely on residual P. Directly fertilizing soybean on low-P soil may increase soybean yields. The application of sulfur (S), zinc (Zn), iron (Fe), manganese (Mn), and boron (B) is also being recommended to soybean farmers by many fertilizer dealers/companies.

A preliminary study looking at the impact of direct fertilization with broadcast-applied P at two sites on soybean was initiated in 2011. The study was expanded to seven sites with a wide range of soil test P levels in eastern Kansas in 2012. The study, funded by the Kansas Soybean Commission and the Kansas Fertilizer Check-off Fund, was designed to compare broadcast P rates, the use of starter fertilizer with soybean, and the potential response to S, and micronutrient applications.

Soybean yields in the preliminary studies showed responses to broadcast P fertilizer when the 0–6-in. soil P was 4 and 18 ppm. Lack of a response when soil P was 13 ppm is attributed to other factors such as average yield was only 25 bu/a. The current study, conducted during a drought, observed a response only at one site where the soil test was 6 ppm. Lack of a response at other sites with soil P less than 20 ppm may be attributed to drought. There was no difference observed between banding or broadcasting applications of P. Addition of S or micronutrients did not increase yields above those obtained with no fertilizer or P alone.

Introduction

Kansas farmers commonly follow fertilized corn with unfertilized soybean. This practice relies on residual fertilizer or native soil phosphorus (P) to meet soybean demands. However, ongoing work at several locations in Kansas shows that at low P ST levels, soybean will respond to direct fertilization even when the previous corn crop was heavily fertilized. Corn is reported to have a higher critical soil test P value (CV) than soybean, which may explain why a yield response to fertilized corn but not to soybean would be expected at moderate to high soil test P levels. Direct P fertilization on soybean is currently recommended in Kansas when the soil test is less than 20 ppm Mehlich-3 P. This is based on a general correlation and calibration curve that is used for all crops, including corn, soybean, grain sorghum, and wheat. The critical P soil test value for soybean alone is suspected to be different, lower, than the pooled crop CV. Previous work in Iowa showed that soybean has a lower CV than corn, with the soybean CV being around 15 ppm (Dodd and Mallarino, 2005). The primary objective of this study is to examine soybean yield response on soils varying in soil test P and combine these results with past studies to build a soybean-specific soil test P correlation and calibration database so that more precise P fertilizer recommendation can be made for soybean in Kansas.

There is also interest in the value or importance of starter P fertilization for soybean at low soil test P levels. Past studies have not found that starter fertilizer gives a significant advantage in soybean as compared to corn. This observation has been attributed to the nature of the soybean root system, and the volume of fertilized soil the roots come into contact with (Bruulsema and Murrell, 2012). All P applications in this study were made with and without 20 pounds P_2O_5 as a surface-band starter application.

Sulfur deficiencies recently have been observed in many areas of eastern Kansas, particularly in wheat and corn. There is concern that S deficiencies will become more common in the future as rates of S deposition from rainfall decline. Micronutrients are also heavily marketed to Kansas farmers, although local data suggests only limited responses would be likely. Therefore, treatments with S or S plus Mn, Zn, Fe, and B were included in the study.

Procedures

Design

Preliminary experiments, in 2011, were conducted on two cooperating farmer's fields, Leeper and Pringle, in Cherokee and Woodson Counties in Kansas. Sites were chosen for their low soil test P (Table 1). Seeding rates and varieties are also provided in Table 1. Five rates of P (0, 20, 40, 60, 80 lb P/a) were broadcast to 15-ft (6 rows) × 40-ft plots, arranged in the field in a randomized complete block design. In 2012, seven sites were selected across eastern Kansas encompassing a broader range of soil test P, 4 to 40+ ppm (Table 1). Seeding rates and varieties varied used were those chosen by the cooperating farmers. Thirteen treatments were applied, both broadcast and broadcast plus starter P applications at rates from 0 to 100 pounds P_2O_5, along with S and micronutrient applications (Table 2). Monoammonium phosphate (11-52-0) was used as the broadcast P fertilizer, while ammonium polyphosphate (10-34-0) was used for banded P starter treatments. Gypsum was the source used for sulfur. Manganese, iron, and zinc were applied as granular sulfate products, and boron was applied as granular borate. The center two rows of each plot were harvested and weighed. Moisture was determined from a subsample collected at harvest using a Dickey John YAK 2000 moisture meter. Significance of yield differences were determined using PROC MIXED in SAS 9.2 (Cary, NC) with blocks being a random effect.

Soil samples were taken from the control, 100 lb broadcast and 20 lb starter + 60 lb P broadcast + 20 lb S + micronutrient plots every 6 weeks as weather permitted. Samples were taken from the 0–6-in. depth, air-dried, and ground to pass a 2-mm sieve. Soil test P was determined by scooping 2 g of soil into a plastic flask, adding 20 mL Mehlich-3 extractant, shaking for 5 min and filtering with Ahlstrom 642 filter paper. Colorimetric analysis was performed with a continuous flow LACHAT machine. Soil test Zn, Mn, and Fe were determined with 10 g of soil scooped into plastic flask, 20 mL of DTPA added, shaken for 5 min, filtered with Ahlstrom 74 filter paper and read on an ICP. Soil S was found by scooping 10 g of sample into a plastic flask, adding 0.5 scoop of charcoal, and 20 mL of calcium phosphate. Samples were shaken for 15 min and filtered with Ahlstrom 74 filter paper and concentration determined on an ICP.

Data from several earlier experiments was assembled and include with results from this study. Relative yield was calculated from experimental blocks with yields greater than 30 bu/a, and a correlation graph was plotted (Figure 1.)

Results

Broadcast P application effects on yield in 2011

There was a statistically significant response to broadcast P at Pringles (Pr > F 0.07) and in blocks 3 and 4 at South Leeper (Pr > 0.04), but not in blocks 1 and 2 (Pr > F 0.73). Soil test P at Pringles, in 2011, was 4 ppm, and a yield response was seen when 20 lb/a P was broadcast. Additional P did not increase yield above the 20 lb/a rate (Table 3). A response to fertilizer was expected at Pringles as the soil test P was 4 ppm. The South Leepers field was broken into two halves for analysis because blocks 1 and 2 had lower soil test P values and yields than blocks 3 and 4. Soil test P for blocks 1 and 2 was 12 and 13, but no fertilizer response was observed. Average yield for these two blocks was 21 bu/a, indicating another factor may have limited grain fill. Blocks 3 and 4, with soil test P at 17 and 20 ppm, responded to 80 lb P/a. This result also reinforces that another factor besides P caused the lower yield in blocks one and two.

Broadcast P application effects on yield in 2012

Soybean crops were stressed in 2012 as high temperatures prevented pod formation for several weeks, and little rain caused drought stress. A fertilizer response was only seen in blocks 2 and 3 at the Yates Center Lynx site (Pr > 0.01), with 6 ppm P in the 0–6-in. depth (Table 4). Fertilized plots in blocks 1 and 4 at Lynx were slightly higher than the control, but not statistically significant.

No response was seen at other low-P sites (Goff, Manhattan, Yates Center–Meadow and Lynx, and Leonardville). Low yields (<30 bu/a) at Goff, Leonardville, and Yates Center–Meadow suggest that P was not limiting grain fill. No response was seen on low soil P, 7 to 9 ppm, at Manhattan with yields >30 bu/a. This may be due to varying moisture levels in the soil occurring across blocks. Both flood-irrigated and dryland sites near Salina had soil P above 40 ppm and showed no yield response to P fertilizer. Variability in seed maturity and moisture was observed on the Salina dry land beans at harvest. The flood irrigated soybean field had an average yield above 30 bu/a and showed no response to P.

Banding and broadcasting P fertilizer

Banding 20 lb/a P did not seem to give an advantage over 20 lb/a broadcast alone at any sites (Table 5). Only at Yates Center–Lynx and Leonardville sites, and one rate, 40 lb/a of total P applied, did banding improve yield. When averaging across sites, splitting P applications into a 20 lb/a band and remaining as broadcast did not enhance yield.

Impacts of sulfur or micronutrients to yield

Sulfur additions of 20 lb/a with P fertilizer did not increase yield above P fertilizer alone (Table 6). Micronutrients applied with P and S fertilizers did not increase yield above P and S fertilizers without micronutrients. Soil test levels for P, S, and the micronutrient metals (Zn, Fe, and Mn) sampled 6 and 12 weeks after application are reported in Tables 7 and 8. Phosphorus, sulfur, and zinc soil tests taken after application reflect the addition of these nutrients; however, soil tests for Fe and Mn do not increase with added nutrients, which suggests a very poor relationship between nutrients present in soils and soil test levels.

P soil test correlation

A very preliminary soil test correlation curve is presented in Figure 1. Only experiments with yields greater than 30 bu/a were included, to minimize the effect of drought and other climatic and cultural factors from biasing the data. Although the number of site years of data is limited, it appears that the critical soil test P level for soybean is below the pooled value of 20 currently used. Indications are that it may be around15 ppm, in agreement with research from Iowa.

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Table 1. Location information for the preliminary 2011 and current 2012 study

Location	Soil test phosphorus (P)	Planting date	Variety	Seeding rate	Spacing	Plot size
S. Leeper, blocks 1 and 2	12, 13	6/7/11	Asgrow 5405	130,000	30 in.	15 × 40 ft
S. Leeper, blocks 3 and 4	17, 20	6/7/11	Asgrow 5405	130,000	30 in.	15 × 40 ft
Yates Center – Matz	4	6/3/11	Pioneer 94Y70	105,000	30 in.	15 × 40 ft
Salina – Flood	40 +	4/24/12	Pioneer 93Y70	144,000	30 in.	15 × 50 ft
Salina – Dry	40 +	4/24/12	Pioneer 93Y70	139,000	30 in.	15 × 50 ft
Yates Center – Lynx	6	5/17/12	Pioneer 94Y70	110,000	30 in.	15 × 50 ft
Yates Center – Meadow	7 to 9	5/17/12	Pioneer 94Y70	110,000	30 in.	15 × 50 ft
Goff	2 to 4	5/10/12	Midland 4339LL	177,000	30 in.	15 × 40 ft
Manhattan	7 to 9	5/16/12	3406	120,000	30 in.	15 × 50 ft
Leonardville	16	5/18/12			30 in.	15 × 40 ft

Table 2. Fertilizer treatments in 2012

	Starter	Broadcast		
Treatment	Phosphorus (P)	Phosphorus	Sulfur	Micronutrients
	---------- lb/a P applied ----------			
1	0[1]	0[2]		
2	0	20		
3	20	0		
4	0	40		
5	20	20		
6	0	60		
7	20	40		
8	0	80		
9	20	60		
10	0	100		
11	20	80		
12	20	40	20	
13	20	40	20	Yes[3]

[1] Broadcast P is applied as monoammonium phosphate.
[2] Starter P is applied as ammonium polyphosphate.
[3] 10 lb/a of manganese, zinc, and iron, along with 1 lb/a of boron.

Table 3. Yield results in 2011 of five broadcast phosphorus (P) rates southeast Kansas soybean[1]

		P broadcast-applied (lb/a)						
Site	Soil P[2]	0	20	40	60	80	Pr > F	Std. error
	ppm	Yield (bu/a)						
Pringle	4	32a[3]	38a	37a	37a	37a	0.07	1.35
S. Leeper, blocks 1 and 2	12 to 13	22	22	21	23	20	0.73	2.45
S. Leeper, blocks 3 and 4	17 to 20	34bc	31c	36ab	35b	39a	0.04	1.5

[1] PROC MIXED (SAS Institute Inc., Cary, NC) with blocks as the random effect was used to analyze data.
[2] Soil P was measured at the 0–6-in. depth with Mehlich-3 extract.
[3] Different letters in same rows signify differences at the $\alpha = 0.10$ level.

Table 4. Yield results in 2012 of six broadcast phosphorus (P) rates to eastern Kansas soybean[1]

		P broadcast-applied (lb/a)							
Site	Soil P[2]	0	20	40	60	80	100	Pr > F	Std. Error
	ppm	---------------------------------- Yield (bu/a) ----------------------------------							
Goff	2 to 4	22	19	19	17	20	20	0.25	2.13
Yates Center – Lynx blocks 2, 3	6	45c[3]	45c	49b	53a	46c	45c	0.01	1.24
North Farm	7 to 9	31	26	33	37	40	27	0.59	9.01
Yates Center – Meadow	7 to 9	27	32	24	29	31	33	0.14	2.77
Yates Center – Lynx blocks 1, 4	8 to 10	48	53	51	49	51	52	0.47	2.49
Leonardville	16	19	21	17	20	21	20	0.89	3.9
Salina – Flood	40 plus	35	34	35	37	34	37	0.98	4.7
Salina – Dry	40 plus	15	17	13	12	14	12	0.43	2.54

[1] PROC MIXED (SAS Institute Inc., Cary, NC) with blocks as the random effect was used to analyze data.
[2] Soil P was measured at the 0–6-in. depth with Mehlich-3 extract.
[3] Different letters in same rows signify differences at the $\alpha = 0.10$ level.

Table 5. Comparison of phosphorus (P) fertilizer applied as all broadcast or split with 20 lb of starter band in 2012

		Total P applied (lb/a)									
		20		40		60		80		100	
Site	Soil P[1]	20 BC[2]	0 BC[3] + 20 Band	40 BC	20 BC + 20 Band	60 BC	40 BC + 20 Band	80 BC	60 BC + 20 Band	100 BC	80 BC + 20 Band
	ppm	Yield (bu/a)									
Goff	2 to 4	34	34	35	32	37	35	34	30	37	34
Yates Center – Lynx blocks 2, 3	6	17	15	13	15	12	13	14	15	12	13
Yates Center – Meadow	7 to 9	44	48	49	45	53	53	46	50	45	53
Northfarm	7 to 9	43a[4]	26b	33	29	37	45	40	35	27	48
Yates Center – Lynx blocks 1, 4	8 to 10	32	28	24b	31a	29	29	31	29	33	28
Leonardville	16	21	18	17b	24a	20	21	21	22	20	19
Salina – Flood	40 plus	53	51	51	49	49	44	51	42	52	52
Salina – Dry	40 plus	19	19	19	17	17	20	20	24	20	20

[1] Soil P was measured from the 0–6-in. depth with Mehlich-3 extract.
[2] Broadcast
[3] P was broadcast as monoammonium phosphate. P was banded as ammonium polyphosphate.
[4] Letters within rows and total P applied level denote significance at the 0.10 level using PROC MIXED LSMEANS (SAS Institute Inc., Cary, NC).

Table 6. Yield comparisons of phosphorus (P) alone, P with sulfur (S), and P with S and micronutrients in 2012[1]

		P vs. S			P vs. S + micros			P + S vs. micros		
Site	Soil P	P	P + S	*P*-value	P	P + S + micros	*P*-value	P + S	P + S + micros	*P*-value
	ppm	--- Yield (bu/a) ---			--- Yield (bu/a) ---			--- Yield (bu/a) ---		
Goff	2 to 4	20	21	0.32	20	20	0.77	21	20	0.57
Yates Center – Lynx	6	53	48	0.38	53a[2]	43b	0.05	48	43	0.43
Northfarm	7 to 9	45	38	0.55	45	31	0.47	39	31	0.6
Yates Center – Meadow	7 to 9	29	33	0.41	29	31	0.48	33	31	0.31
Yates Center – Lynx	8 to 10	44	51	0.23	44	49	0.38	51	49	0.3
Leonardville	16	21	16	0.13	20	19	0.65	16	19	0.4
Salina – Flood	40 plus	35	33	0.65	35	41	0.32	33	41	0.24
Salina – Dry	40 plus	13	16	0.17	13	14	0.65	16	14	0.67

[1] P applied at 20 lb/a ammonium polyphosphate band and 40 lb/a monoammonium phosphate broadcast. S applied as gypsum at 20 lb/a. Micros applied, in sulfate composition, at 10 lb/a for iron, manganese, and zinc, and 1 lb/a of boron.

[2] Letters indicate differences at $\alpha = 0.10$ level, calculated with contrasts in PROC MIXED with blocks as random effects (SAS Institute Inc., Cary NC).

Table 7. Soil test levels from 0–6-in. depth of control, phosphorus (P)-applied, and P + sulfur (S) + micronutrient–applied plots 6 weeks after application in 2012[1]

Site	Treatment	Mehlich-3 P	DTPA Zn	DTPA Fe	DTPA Mn	$CaPO_4$ S	Hot water - B
		ppm					
Yates Center – Lynx	Control	9	0.4b[2]	86b	26b	3.1b	0.5b
	100 lb P	14	0.7b	93b	31a	3.3b	0.6b
	60 lb P + 20 lb S + micros	18	4.9a	125a	32a	7.8a	0.8a
	Pr > F	0.32	0.05	0.04	0.04	< 0.01	< 0.01
Yates Center – Meadow	Control	6b	1.1b	54b	18b	2.3c	0.8
	100 lb P	13a	1.2b	60ab	19ab	6.0b	1.1
	60 lb P + 20 lb S + micros	8b	3a	63a	21a	9.1a	1.1
	Pr > F	0.05	0.05	0.11	0.03	< 0.01	0.59
Manhattan	Control	12b	0.7b	16	8	3.6c	
	100 lb P	4a	1.1b	13	11	6.1b	
	60 lb P + 20 lb S + micros	10b	3.6a	17	9	9.7a	
	Pr > F	<0.01	0.07	0.34	0.42	<0.01	
Goff	Control	4b	0.5b	38b	11	3.8b	0.9a
	100 lb P	22a	0.5b	43a	12	4.6b	0.5b
	60 lb P + 20 lb S + micros	16a	3.4a	39b	12	8.3a	0.9a
	Pr > F	<0.01	0.00	0.06	0.61	<0.01	0.03
Leonardville	Control	15b	0.4b	61	20b	3.3c	
	100 lb P	38a	0.7b	64	53a	5.7b	
	60 lb P + 20 lb S + micros	29a	4.9a	68	27b	10.5a	
	Pr > F	0.02	0.05	0.49	<0.01	<0.01	

[1] Micronutrients broadcast in sulfate form at 10 lb iron, 10 lb zinc, 10 lb manganese, and 1 lb boron/a. 100 lb P/a broadcast as monoammonium phosphate. 60 lb P/a applied as 40 lb monoammonium phosphate and 20 lb ammonium polyphosphate. Sulfur applied at 20 lb/a as gypsum.
[2] Letters signify differences at 0.10 level using PROC MIXED with blocks as the random effect (SAS Institute Inc., Cary, NC).

Table 8. Soil test levels from 0–6-in. depth of control, phosphorus (P)-applied, and P + sulfur (S) + micronutrient–applied plots 12 weeks after application in 2012[1]

Site	Treatment	Mehlich-3 P	DTPA Zn	DTPA Fe	DTPA Mn	$CaPO_4$ S
		ppm				
Yates Center – Lynx	Control	6b[2]	1.3b	60	20	6.1b
	100 lb P	16a	1.4b	64	19	6.4b
	60 lb P + 20 lb S + micros	9a	3.2a	65	20	8.3a
	Pr > F	0.03	<0.01	0.6	0.27	< 0.01
Yates Center – Meadow	Control	12b	1.5b	100	22	6.7b
	100 lb P	20ab	1.8b	101	26	6.8b
	60 lb P + 20 lb S + micros	24a	5.4a	133	27	8.4a
	Pr > F	0.06	0.04	0.18	0.4	< 0.01
Salina – Flood	Control	47	0.9b	10	3.4	12.3b
	100 lb P	58	1b	10	3.1	12.2b
	60 lb P + 20 lb S + micros	43	2.4a	10	3.2	16.0a
	Pr > F	0.32	0.06	0.54	0.15	< 0.01
Salina – Dry	Control	32	1.1b	6	2.9	7.7b
	100 Lb P	40	1.2b	7	2.9	8.0b
	60 lb P + 20 lb S + micros	44	1.9a	7	3.0	10.0a
	Pr > F	0.48	< 0.01	0.18	0.15	< 0.01
Goff	Control	4c	0.4b	47b	12	6.5c
	100 Lb P	17a	0.5b	50a	13	7.3b
	60 lb P + 20 lb S + micros	11b	2.5a	50a	13	8.2a
	Pr > F	< 0.01	0.01	0.03	0.55	< 0.01
Leonardville	Control	10	0.4b	74	23b	6.7b
	100 Lb P	21	0.5b	80	26ab	7.3b
	60 lb P + 20 lb S + micros	20	1.6a	79	29a	9.2a
	Pr > F	0.18	0.14	0.73	0.2	< 0.01

[1] Micronutrients broadcast in sulfate form at 10 lb iron, 10 lb zinc, 10 lb manganese, and 1 lb boron/a. 100 lb P/a broadcast as monoammonium phosphate. 60 lb P/a applied as 40 lb monoammonium phosphate and 20 lb ammonium polyphosphate. Sulfur applied at 20 lb/a as gypsum.
[2] Letters signify differences at 0.10 level using PROC MIXED with blocks as the random effect (SAS Institute Inc., Cary, NC).

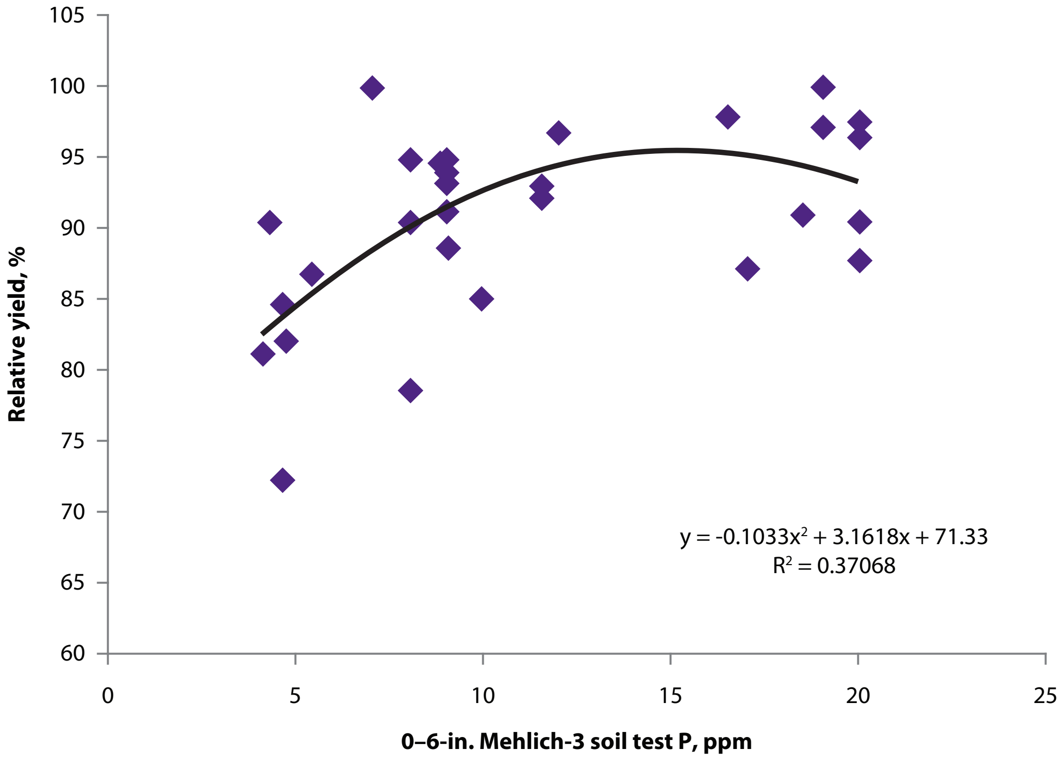

Figure 1. Relationship between soil test phosphorus (P) level and soybean yield with no P added.

The Effects of Foliar Nitrogen Fertilization on Wheat

D. Mengel and G. Harter

Summary
Foliar fertilizers are being sold as an efficient means of supplementing fertilizer supply, especially nitrogen (N), for crops in Kansas. A study was conducted in 2011 and 2012 at Manhattan to determine if the addition of foliar N would increase yield or grain protein content in winter wheat. Although the wheat responded to traditional topdress applications of N in both years, we observed no increase in yield or grain protein content from the addition of foliar N.

Introduction
A number of specialty fertilizer products designed to be applied to plant foliage rather than the soil have been introduced to the Kansas market in recent years. The intent of the products is to enhance recovery of nutrients applied by direct uptake of the nutrients into the leaf rather than relying on uptake from the soil by the root and translocation to the leaf, which carries potential for nutrient loss through competing chemical and microbial processes. In many cases, the labels for these products indicate replacement values compared with traditional fertilizers of 10 to 12 lb N/gal, with application rates of up to 3–5 gal/a.

Foliar application of micronutrients such as zinc, iron, and boron to correct deficiencies has been practiced for many years. The amount of these nutrients needed by the plant are extremely small, in most cases less than 1 lb/a, and these small quantities can be moved across the exterior leaf surface into the interior plant cells in adequate quantities, although not always with a high level of efficiency. In many cases, specifically formulated chelates or complexes are used to enhance movement across the cuticle and into the leaf.

Foliar application of secondary or macronutrients, however, has not been as successful. Very little research by land-grant universities has shown consistent yield increases with foliar application of N, phosphorus (P), or potassium (K) equal to or greater than those obtained with soil applications of similar rates. An excellent study in Canada using labeled 15N fertilizers showed that only 10% to 25% of foliar applied N fertilizers actually moved into the plant through the leaf, compared with 50% to 70% moving into the plant through the roots from normal soil application of N fertilizers.

The specific objective of the experiment was to determine the relative difference in yield, plant N content as measured by flag leaf N, and grain protein content of hard red winter wheat obtained over a range of N application rates, with and without the application of CoRoN 25-0-0 (Helena Chemical, Collierville, TN) foliar-applied N.

Procedures

The experiment was conducted at the Kansas State University Agronomy North Farm in 2011 and 2012 (Table 1). The sites used had a history of over 10 years of continuous no-till production. The primary soils at the site were Smolan and Wymore silt loams. Soil test results showed the pH to be slightly acid, with adequate P and K levels.

Everest HRW wheat was no-till seeded into recently harvested soybean stubble in mid-October of 2011 and 2012. Eighty pounds of 11-52-0 fertilizer (monoammonium phosphate, MAP) was applied with the drill at seeding. Seeding rate was 100 lb certified seed/a. Stands were good to excellent both years. Finesse herbicide (DuPont, Wilmington, DE) was applied in early March, shortly after greenup. Few weeds were present at greenup; henbit was the most common. Folicure fungicide (Bayer CropScience, Research Triangle Park, NC) was applied to control the minimal levels of foliar disease found.

Urea was broadcast by hand on individual plots at Feekes 3–4. All liquid fertilizer treatments were sprayed with a tractor sprayer using an offset boom at a 15 gal/a total spray volume, at Feekes 5–6 or Feekes 10.5.

Total N application given in the table above is the combined rate of the N present in the 11-52-0 (9 lb/a) applied at seeding, plus the N found in the topdress urea, plus the N content of the CoRoN 25-0-0 or UAN applied foliar. The experimental design was a randomized complete block with 4 reps. Plot size was 10 ft × 30 ft. Measurements made included flag leaf N content at flowering, grain yield at maturity, and grain N/protein content at harvest.

Approximately 40 flag leaves were collected from each plot when the heads were fully extended for N analysis. Yield was determined using a plot combine. Grain samples were collected at harvest to determine grain moisture, N content, and test weight.

Results

Yield, flag leaf N, and grain protein content results are summarized in Tables 2, 3, and 4, respectively. Yields were average for the area, ranging from 24.6 bu/a for the untreated control to 46.2 bu/a where 72 lb/a N as urea was applied in 2011 and 28.2 to 38.4 lb/a was applied in 2012. Drought was a serious factor and reduced yield in both years, and some mild freeze damage occurred around heading in 2011. Although official temperatures at reporting stations were above freezing, frost was present several mornings and "whiteheads" were observed; however, the primary yield-limiting factor was dry weather, particularly over winter and early spring, which limited tiller number and head size.

A near-linear response to N applied as urea at spring tillering stage (Feekes 3–4) was observed in 2011 (Table 2). At the highest rate applied, yields were increased 88% compared with the check. A clear but modest response to applied N was observed at this site, but no further enhancement of yields was seen with the foliar application of the foliar CoRoN fertilizer at Feekes 6 or Feekes 10.5 or with urea-ammonium nitrate (UAN) foliarly applied at Feekes 10.5.

A second year of drought affected this site in 2012, and yields reflected this problem. A significant response to the first 24 lb of N fertilizer was observed, but no additional response to topdress urea or foliar N was observed. The combined analysis across 2011 and 2012 showed a significant response to 60 lb/N topdress with no additional response to foliar N at jointing, Feekes 6, or flowering, Feekes 10.5, or the higher rate of topdress urea. No response to foliar N at jointing was seen with suboptimal topdress N rates.

Flag leaf N content at bloom is reported in Table 3. Nitrogen fertilizer application at Feekes 4 increased flag leaf N levels in both years. The addition of the foliar-applied CoRoN fertilizer at Feekes 6 did result in a slight increase in flag leaf N in 2011 at the low topdress N rates. Applications at Feekes 10.5 of both UAN and CoRoN also showed an increase in flag leaf N compared with the 60-lb topdress rate alone.

Grain protein levels (Table 4) differed between years, with the protein levels lower in 2011, the higher yielding of the two years. In 2011, grain protein levels were not significantly affected by the addition of foliar N at Feekes 6 or Feekes 10.5. Although protein levels were higher in 2012, minimal effects of foliar application of N on protein were observed.

In summary, a significant effect of traditional topdress application of N at greenup, Feekes 3 to 4, on yield, flagleaf N content, and grain protein was observed in both 2011 and 2012, but only minimal response to foliar N application was observed in these studies.

Table 1. Specific treatments used

Trt. no.	Topdress material	Feekes 4 topdress nitrogen (N) rate	Foliar-applied N	Total N
		lb/a	lb/a	
1	None (control)	0	none	9
2	Broadcast urea	24	none	33
3	Broadcast urea	36	none	45
4	Broadcast urea	48	none	57
5	Broadcast urea	60	none	69
6	Broadcast urea	72	none	81
7	Broadcast urea	24	3 gal CoRoN[1] Feekes 5–6	40.4
8	Broadcast urea	36	2 gal CoRoN Feekes 5–6	50
9	Broadcast urea	48	1 gal CoRoN Feekes 5–6	59.5
10	Broadcast urea	60	1 gal CoRoN Feekes 5–6	71.5
11	Broadcast urea	60	1 gal CoRoN Feekes 10.5	71.5
12	Broadcast urea	60	4 gal UAN[2] Feekes 10.1	81

[1] Helena Chemical, Collierville, TN.

[2] Urea-ammonium nitrate.

Table 2. Wheat yields at Manhattan, KS, CoRoN[1] foliar nitrogen (N) test, 2011, 2012, and combined

Treatment	2011 yield[2]	2012 yield	Mean yield
	bu/a		
72 lb N as urea	46.2a	37.5ab	41.9a
60 lb N as urea	40.7bc	36.9abc	38.8abc
60 lb N as urea + 1 gal CoRoN at Feekes 10.5	43.6ab	35.2abc	39.4ab
60 lb N as urea + 4 gal UAN[3] at Feekes 10.5	40.6bc	33.1abcd	36.8bcd
60 lb N as urea + 1 gal CoRoN at Feekes 6	40.1bcd	38.4a	39.2ab
48 lb N as urea 4	38.6bcd	36.0abc	37.3bc
48 lb N as urea + 1 gal CoRoN at Feekes 6	38.7bcd	37.9a	38.3abc
36 lb N as urea	36.2cde	34.6abc	35.4cd
36 lb N as urea + 2 gal CoRoN at Feekes 6	34.9de	31.8dc	33.3de
24 lb N as urea	32.8e	37.8a	35.3cde
24 lb N as urea + 3 gal CoRoN at Feekes 6	31.0e	34.6abc	31.6e
No-N control	24.6f	28.2d	26.4f

[1] Helena Chemical, Collierville, TN.
[2] Treatment values within a column followed by the same letter are not statistically different at an alpha level of 0.05.
[3] Urea-ammonium nitrate.

Table 3. Wheat flag leaf nitrogen (N) content in Manhattan, KS, CoRoN[1] foliar N test, 2011, 2012, and combined

Treatment	2011 flag leaf N[2]	2012 flag leaf N	Average leaf N
	% N		
72 lb N as urea	2.63bcd	3.26 a	2.94bc
60 lb N as urea	2.53cde	3.21 ab	2.87cde
60 lb N as urea + 1 gal CoRoN at Feekes 6	2.69cb	3.39 a	3.04ab
60 lb N as urea + 4 gal UAN[3] at Feekes 10.5	3.17a	3.20 ab	3.19a
60 lb N as urea + 1 gal CoRoN at Feekes 10.5	2.77b	3.17 abc	2.97bc
48 lb N as urea	2.58bcde	3.19ab	2.88cd
48 lb N as urea + 1 gal CoRoN at Feekes 6	2.64bcd	3.35a	2.99bc
36 lb N as urea	2.47de	2.99bcd	2.73def
36 lb N as urea + 2 gal CoRoN at Feekes 6	2.55cde	3.03bc	2.79de
24 lb N as urea	2.38e	2.94cd	2.66gf
24 lb N as urea + 3 gal CoRoN at Feekes 6	2.65bcd	2.94cd	2.79def
No-N control	2.42e	2.78d	2.60g

[1] Helena Chemical, Collierville, TN.
[2] Treatment values within a column followed by the same letter are not statistically different at an alpha level of 0.05.
[3] Urea-ammonium nitrate.

Table 4. Wheat grain protein content at Manhattan, KS, CoRoN[1] foliar nitrogen (N) treatment means, 2011 and 2012

Treatment	2011 grain protein[2]	2012 grain protein	Mean grain protein
72 lb N as urea	12.7ab	15.7ab	14.2ab
60 lb N as urea	12.8a	15.1bc	14.0abc
60 lb N as urea + 1 gal CoRoN at Feekes 6	12.1abcd	14.2cd	14.1def
60 lb N as urea + 1 gal CoRoN at Feekes 10.5	12.2abc	15.6ab	13.9bcd
60 lb N as urea + 4 gal UAN[3] at Feekes 10.5	12.9a	16.5a	14.7a
48 lb N as urea	11.9cd	14.6bcd	13.3cdef
48 lb N as urea + 1 gal CoRoN at Feekes 6	12.5abc	14.7bcd	13.6bcde
36 lb N as urea	11.3d	14.0cde	12.6f
36 lb N as urea + 2 gal CoRoN at Feekes 6	12.0abcd	15.0bc	13.5bcde
24 lb N as urea	12.2abcd	13.8def	13.0ef
24 lb N as urea + 3 gal CoRoN at Feekes 6	11.9bcd	14.3cd	13.1ef
No-N control	12.8a	13.0efg	12.9ef

[1] Helena Chemical, Collierville, TN.
[2] Treatment values within a column followed by the same letter are not statistically different at an alpha level of 0.05.
[3] Urea-ammonium nitrate.

Determining the Recoverable Yield of Winter Wheat for Improving Sensor-Based Nitrogen Recommendations

A.R. Asebedo, A.N. Tucker, and D.B. Mengel

Summary

Increased interest in nitrogen (N) management over the past decade has stimulated interest in using optical sensors to predict N needs in a number of crops. Many universities have created N recommendation algorithms for winter wheat (*Triticum aestivum L.*) with slightly differing approaches. The current Kansas State University algorithm operates under the assumption that 100% of the yield potential difference between the N reference strip and the bulk field or farmer practice can be recovered. Experience has indicated this is not always possible. Severe N stress or attempts to correct N stress late in the growth cycle of the plant both appear problematic. The objectives of this study were to determine how much yield could be recovered at a given level of N deficiency, whether younger plants were more able to recover than older plants, and if a predictable relationship exists between response index (RI) and recoverable yield (RY). Field studies were conducted in 2006–2012 at 12 locations in Kansas using a factorial treatment structure in a randomized complete block design with four replications. Treatments included multiple N rates (0, 30, 60, 90, 120, 150 lb/a) and four application dates (fall–winter, Feekes 4, 7, and 9). Nitrogen was applied in single applications or in split applications. Current findings suggest that wheat's ability to recover from N deficiency decreases as the severity of N deficiency increases, and a similar decrease in recovery can be expected at later growth stages. Response index can be used to predict how much yield could be recovered by making an N application at a given growth stage. Utilizing RI for predicting RY in sensor-based N recommendation algorithms could direct them toward applying N for yields that can be obtained, thus increasing nitrogen use efficiency (NUE).

Introduction

In the past decade, interest in enhancing the efficiency of N management programs for wheat has increased because of increased fertilizer and application costs, increased wheat prices and the desire to increase yield, and environmental concerns over excess N application. A number of different approaches have been taken to find new ways to improve N management. One of these approaches has been the use of optical sensors. Kansas State University Agronomy first developed a sensor-based N recommendation algorithm in 2009. A downloadable version of that recommendation program can be found at www.agronomy.ksu.edu/SoilTesting/. This N recommendation program, designed for use with the current Trimble and AgLeader optical sensors using a red NDVI (normalized difference vegetation index) output, makes N recommendations based on the assumption that 100% of the yield potential difference between an N-rich reference strip and the bulk field farmer practice can be recovered by an appropriate N addition. Yield recovery of 100% may not always be possible, however, especially in cases where N deficiency is severe at critical growth stages. In these cases, the algorithm will be recommending N for yield that cannot be obtained. Although these N recommendation systems may provide a significant improvement over traditional soil test/yield goal–based systems, they may still have instances of overapplication, thus reducing the efficiency of the system. Improving the current K-State algorithm may therefore be possible by taking into account the ability of N-stressed wheat to respond and recover yield by making an N application.

Kansas State University has been working on a new approach for improving sensor-based N recommendation algorithms that is based on the RI of wheat and its impact on RY (RY = treatment yield/N reference strip yield). The basic definition of RY is how much yield can be recovered at a given growth stage and response index by making an N application compared with the yield potential of a well fertilized reference strip that has never experienced N stress. To determine the relationship between RY and RI, a series of N treatments were established (Table 1) to create a range of N stress levels at different growth stages and create a series of different response indexes, or ratios of N adequacy as measured by crop sensors. An RI is simply the NDVI value measured with a sensor in a reference area, divided by the NDVI of the surrounding farmer field to be fertilized. The bigger the RI, the more stress the bulk field area is under. By making these measurements and applying N applications at a range of rates at different growth stages, we could determine if N stress at or after a particular growth stage would limit the ability of the plant to fully recover and produce a yield as high as the well fertilized reference area.

The objectives of this study were to determine (1) what fraction of the obtainable yield at a site could be recovered by topdressing additional N on plants under N stress; (2) if that recoverable yield was influenced by level of N deficiency as measured by RI; and (3) determine if the RY level changed as the plant developed and became more mature.

Procedures

Twenty-one experiments were conducted starting in 2006–2012 at 12 locations throughout Kansas in cooperation with producers and K-State experiment stations. Each location was rainfed and used crop rotations, tillage, cultural practices, and wheat varieties representative of the area. Each field study utilized small research plots, normally 10 ft × 50 ft. Treatments consisted of multiple N rates (0, 30, 60, 90, 120, and 150 lb/a N) that were applied in single or split applications at different times during the growing season (fall–winter; Feekes 4, 7, and 9) with urea as the N source. Treatments were in a factorial arrangement and placed in a randomized complete block design with four replications. N reference strips were established at each location within each block and consisted of total applied N rates greater than 120 lb/a applied in the fall.

Soil samples were taken to a depth of 24 in. by block prior to planting and fertilization. Samples from 0 to 6 in. were analyzed for soil organic matter, Mehlich-3 phosphorus (P), potassium (K), pH, and zinc (Zn). Samples from 0 to 24 in. were analyzed for nitrate-N, chloride, and sulfate. Fertilizer needs other than N indicated by soil test were applied in the fall at or near seeding.

Optical sensors used were the Greenseeker (Trimble Navigation, Ag Division, Westminster, CO), the CropCircle ACS-210 (Holland Scientific, Lincoln NE), and Crop-

Circle ACS-470 (Holland Scientific, Lincoln NE). Upon receiving the CropCircle ACS-470, use of the ACS-210 was discontinued. The Greenseeker sensor utilizes two channels set for 656 nm and 774 nm. The CropCircle ACS-470 has 3 channels that allow changeable filters, and were set to 670 nm, 550 nm, and 760 LWP. Canopy reflectance was used to calculate the Red NDVI (Red NDVI = NIR-Red/NIR+Red) and was averaged for each individual plot. NDVI was used to calculate the Response Index (RI = N Rich Reference Strip NDVI/treatment NDVI). Canopy reflectance of the wheat was measured multiple times throughout the growing season, with Feekes 4, 7, and 9 being key points of measurement.

Flag leaf tissue samples were taken at Feekes 10.5 and analyzed for N content. Grain yield was measured by harvesting an area of 5 ft × 47 ft within each plot at all locations. Yields were adjusted to 12.5% moisture, and grain was analyzed for N content and protein.

Initial analysis of yield response to applied N was conducted using PROC MIXED in SAS (SAS Institute Inc., Cary, NC) with blocks set as random effects. From this procedure, the optimum N rate was determined for each location and would serve as the required minimum of the total applied N rate for establishing the relationship between RI and RY. This helped ensure that yield losses were due to prolonged N stress prior to N application and not due to an insufficient N rate utilized. Recovered yield was calculated for each plot, and its relationship with RI was established using PROC REG and PROC NLIN in SAS.

Results

The relationship between RY and RI from wheat plots sensed and fertilized from Feekes 4 through Feekes 9 growth stages is shown in Figure 1. The data in figure one suggest that maintaining RI less than 1.2 is important if a yield of at least 90% of the reference strip is to be attained by topdressing. Allowing the crop to become N-deficient to a point that the RI is greater than 1.2 will potentially result in a severe yield reduction. This is an important point, because many farmers in Kansas today apply little or no N fertilizers to wheat at planting because they plan to topdress before or immediately after greenup in the spring. If sensor technology is to be used to manage spring-applied N, sensing and topdressing performs best when delayed until the end of tillering (Feekes 4–5); thus, farmers will need to rethink their overall fertilization program and consider applying adequate N in the fall to support growth through tillering.

The data for early (Feekes 4–5) and late (Feekes 7–9) growth stages are separated into Figures 2 and 3, respectively. The relationships between recoverable yield and response index are quite different between these stages of growth. As should be expected, wheat at early stages of growth (Feekes 4 through 5) is more capable than older wheat of recovering yield caused by N stress if fertilized. If RI is less than 1.1, a 100% yield recovery can be obtained, but at Feekes 7 through 9, 10% or more yield loss is likely under the same conditions.

Other factors besides N deficiency could cause the difference in yield recovery as the plant matures. One possibility is that wheat is generally more resilient from being driven or walked on in its early growth stages than after it joints. Breaking stems and damage to the growing point from equipment traffic can result in lower productivity, reducing yield recovery despite making an N application to correct a deficiency. Another possibility could be that head size determination takes place at Feekes 5; therefore, an N application during Feekes 4–5 could increase head size, whereas a later N application after head size was set may translate to reduced head size and decreased yield.

In conclusion, applying adequate N early to support tillering and early spring growth will be important when using crop sensors to guide spring N applications for wheat. The inability of wheat to recover from severe N deficiency, especially at later growth stages, emphasizes the importance of having adequate N available to support important processes such as tillering and head size determination.

Table 1. Current nitrogen (N) treatment regimen

Fall N rate	Feekes 4 N rate	Feekes 7 N rate	Feekes 9 N rate	Total applied N
		lb/a N		
0	0	0	0	0
30	0	0	0	30
60	0	0	0	60
90	0	0	0	90
120	0	0	0	120
30	120	0	0	150
30	90	0	0	120
60	60	0	0	120
90	30	0	0	120
30	0	90	0	120
60	0	60	0	120
90	0	30	0	120
30	0	0	90	120
60	0	0	60	120
90	0	0	30	120
RefStrip	RefStrip	RefStrip	RefStrip	≥ 120

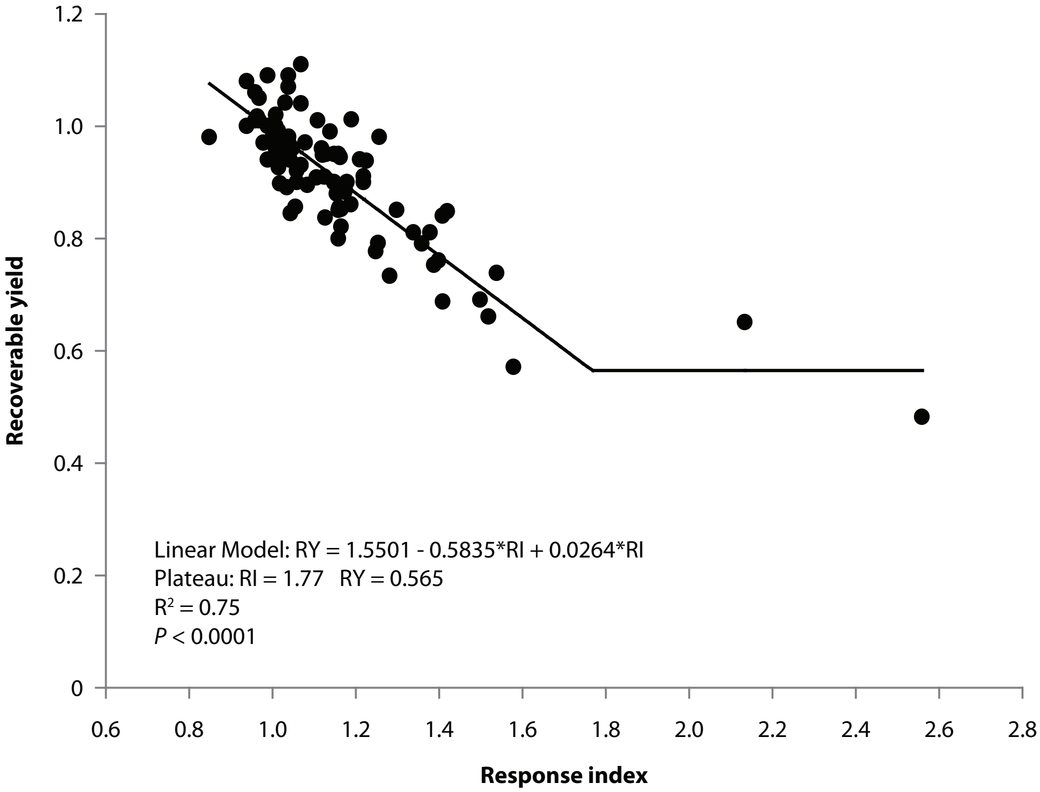

Figure 1. Feekes 4–9 recoverable yield of wheat as a function of response index at the time of nitrogen (N) application.

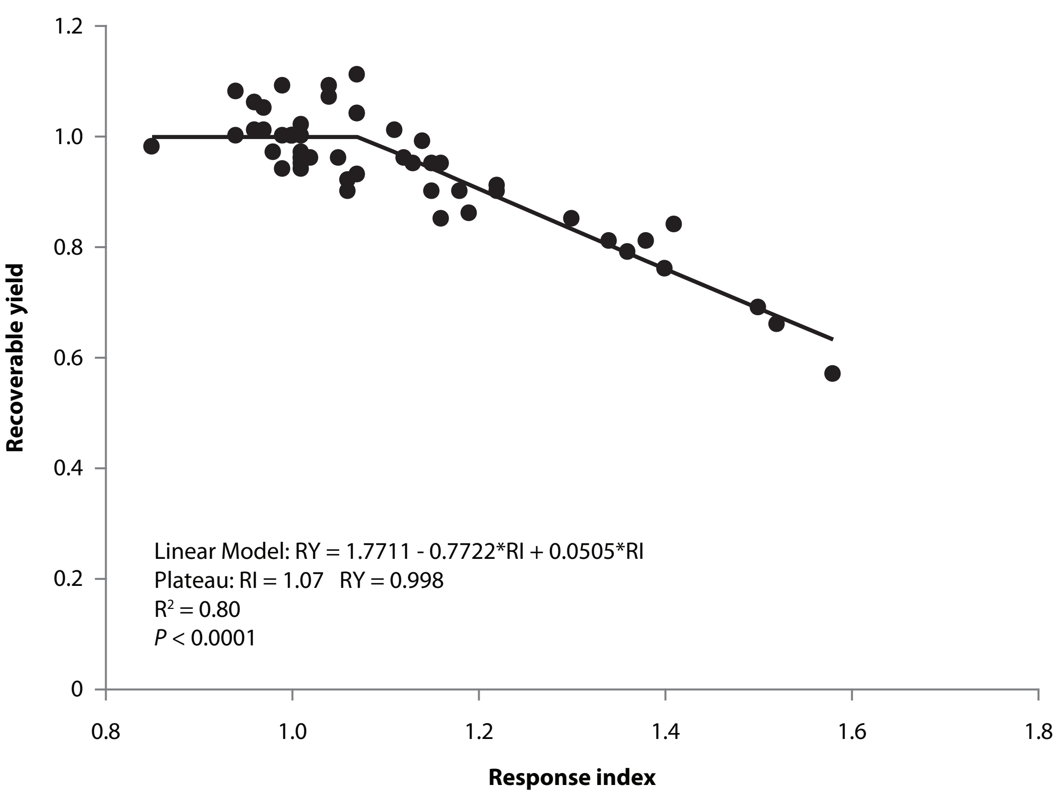

Figure 2. Recoverable yield of wheat fertilized at Feekes 4–5 growth stage as a function of response index at fertilization.

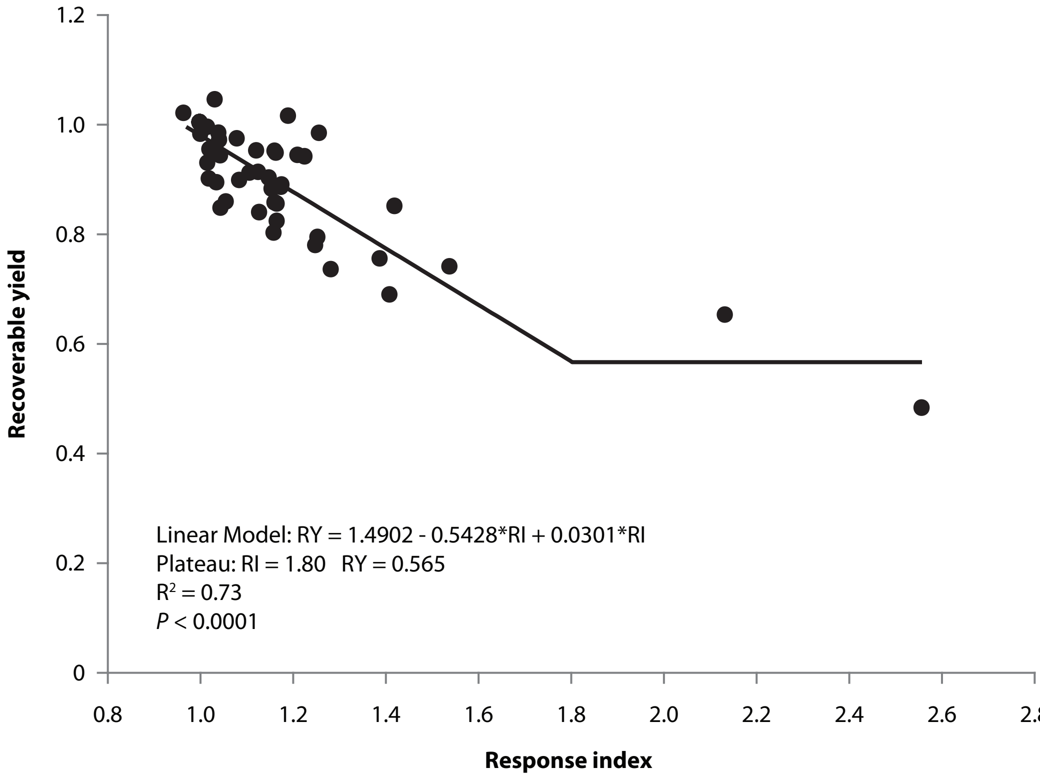

Figure 3. Recoverable yield of wheat fertilized at Feekes 7–9 growth stages as a function of response index at time of fertilization.

Optimizing Nitrogen and Irrigation Timing for Corn Fertigation Applications Using Remote Sensing

J.R. Nelson and A.R. Asebedo

Summary
The 2012 growing season was abnormally dry in North Central Kansas, resulting in early irrigation initiation and frequent irrigation events throughout. At the second study site, high nitrate levels in the irrigation water reduced the effects of all nitrogen application treatments; however, significant response to applied nitrogen (N) was observed at the first study site. Initial results indicate that optical sensors have the potential to improve N recommendations for fertigation applications, but the ability of optical sensors to make accurate N recommendations depreciates due to sensor saturation after the formation of the crop canopy. Current findings show that sensor sensitivity can be increased after canopy formation by changing the sensor position from over the canopy to inside the canopy. Therefore, additional research will be conducted to increase the efficacy of optical sensors.

Introduction
Nitrogen use efficiency (NUE) in high-yield irrigated corn production systems has many economic and environmental implications. In the sub-humid region of North Central Kansas (NCK), risk of in-season N loss is higher than in drier irrigated corn production regions of the Great Plains. Because of the unique environmental conditions in NCK, the practice of fertigation could improve NUE by reducing in-season N loss and providing adequate fertility at peak demand; however, the sub-humid environmental characteristics of NCK introduce the possibility of irregular irrigation events throughout the growing season. This may affect the ability of a producer to make a fertigation application in a timely manner if irrigation requirements do not correspond to N demand, so characterizing how irrigation scheduling and N application timing are related is important to maximize NUE. The use of canopy sensor systems to make N prescriptions has been shown to improve NUE in several crops, including corn, in Kansas. This study was designed to understand the relationship between water and N demand and to develop an efficient system for making fertigation decisions based on irrigation scheduling and sensor-based N prescriptions.

Procedures
The study was initiated in 2012 at two sites in Republic County. Site 1 was located at the Irrigation Experiment Field in Scandia, KS. Site 2 was located on a producer's field ~3.5 miles south of Scandia. Soils at Sites 1 and 2 were Crete silt loam and Carr fine sandy loam, respectively. Irrigation events were scheduled using the KanSched2 evapotranspiration-based irrigation scheduling tool (http://mobileirrigationlab.com/kansched2). Sidedress N applications were made prior to scheduled irrigation events to simulate an N fertigation system. Application timing methods implemented at each site consisted of single preapplication; split application between preplant and corn growth stage V4; and split application between preplant and variable treatments based on

plant reflectance taken over the canopy using the Greenseeker optical sensor (Trimble Navigation, Ag Division, Westminster, CO). After the formation of the crop canopy, additional plant reflectance readings were taken inside the crop canopy with a 45° head angle and at a height equal to the ear.

The single preplant application treatments consisted of three N rates of 60, 140, and 230 lb/a. The split-application treatments divided 40, 160, and 210 lb/a N between preplant and growth stage V4. The three sensor-based treatments had preplant N applications of 40, 80, and 125 lb/a. Before each scheduled irrigation event, sensor readings were taken in the sensor-based treatment plots to determine N recommendations for that particular preplant rate. This particular method simulates a sensor-based N fertigation system that relies on irrigation scheduling to time in-season N applications. Site 1 was machine-harvested for yield, test weight, and moisture on October 24. Site 2 was hand-harvested on September 25.

Results

Data analysis from Site 2 (Table 1) shows response to applied N was low. This is likely due to the abnormally high nitrate levels in the irrigation water at the field site. Because the growing season was uncharacteristically dry, irrigation was above normal, giving the crop an adequate N supply through the irrigation water. For this reason, the remaining discussion will concern Site 1.

There were significant N treatment effects on corn yield at Site 1 in 2012. In general, the treatments that split N applications between pre- and in-season resulted in the highest yields and the most efficient N use. The exception was Treatment 3 (230 lb/a preplant) (Table 2). This treatment was statistically equal to the three other highest-yielding treatments (Table 2), which may be explained by the abnormally dry weather resulting very little N loss from the preplant applications. Two of the three sensor-based N treatments (Treatments 7 and 8) yielded significantly lower than the preplant/V4 split applications (Treatments 5 and 6). The yield differences are likely attributed to the lower N rates recommended by the sensors, but a secondary explanation may be attributed to the slow N mineralization rates that are common in drier environments, similar to the conditions experienced in NCK during the 2012 growing season. It is possible that the N applied according to sensor recommendations did not become available to the plant to correspond with peak demand, resulting in reduced yield. In a more normal precipitation year in NCK, late-season N applications recommended by sensors could become available in a more timely manner, and yield and corresponding NUE could improve with the use of sensor-based N prescriptions.

The traditional over-canopy method for collecting Greenseeker readings was adequate for making N recommendations during the vegetative growth stages (Figures 1–3); however, the sensitivity of the sensor decreased as the corn plants increased in size due the saturation of sensor. After V-12 and the formation of the canopy, sensor saturation becomes more prevalent, and the effectiveness of optical sensors in making N recommendations comes into question. This poses a particular problem for using optical sensors for fertigation. One of the primary advantages to fertigation is the ability to make N applications later in the growing season when the corn crop is too tall to make an N application with conventional equipment. Therefore, for the use of optical sensors in fertigation to be justified, they would have to be effective throughout the entire growing season.

An alternative method was employed to achieve better optical sensor sensitivity. After canopy formation, sensor readings were taken inside the crop canopy. Figures 4–7 have shown that sensor sensitivity was more than adequate in the later vegetative and reproductive growth stages. Significant leaf firing due to N deficiency did not take place until R1 and continued to increase from R1 through R3 as shown in Figures 5–7. The traditional over-canopy sensing method was unable to detect these differences to an equal degree of sensing in canopy, which indicates that the efficacy of optical sensors in corn can be improved by moving the sensor head in the canopy after canopy formation.

Current results support the possibility of using optical sensors for fertigation management. Additional research is needed to analyze their effectiveness under normal precipitation years where there is less frequent irrigation and more N loss is experienced earlier in the growing season.

Table 1. Nitrogen (N) treatment effects on corn yield at Site 2

Treatment	Timing method	Starter N	Preplant N	In-season N	Total N applied	Yield[1]
		lb/a				bu/a
4	Preplant/V4	20	20	20	60	209a
9	Preplant/sensor	20	125	30	175	209abc
1	Preplant	20	60	0	80	203abc
2	Preplant	20	140	0	160	201abc
3	Preplant	20	230	0	250	199abc
7	Preplant/sensor	20	40	94	154	199abc
8	Preplant/sensor	20	80	86	186	198abc
5	Preplant/V4	20	80	80	180	197bc
6	Preplant/V4	20	105	105	230	193c
Check	Check	20	0	0	20	193c

[1] Yields with the same letter are not significantly different at $P > 0.05$.

Table 2. Nitrogen (N) treatment effects on corn yield at Site 1

Treatment	Timing method	Starter N	Preplant N	In-season N	Total N applied	Yield[1]
		---------- lb/a	----------	----------	----------	bu/a
6	Preplant/V4	20	105	105	230	188a
5	Preplant/V4	20	80	80	180	187a
3	Preplant	20	230	0	250	185a
9	Preplant/sensor	20	125	86	231	185a
8	Preplant/sensor	20	80	44	144	173b
7	Preplant/sensor	20	40	91	151	166bc
2	Preplant	20	140	0	160	166bc
1	Preplant	20	60	0	80	156c
4	Preplant/V4	20	20	20	60	138d
Check	Check	20	0	0	20	119e

[1] Yields with the same letter are not significantly different at $P > 0.05$.

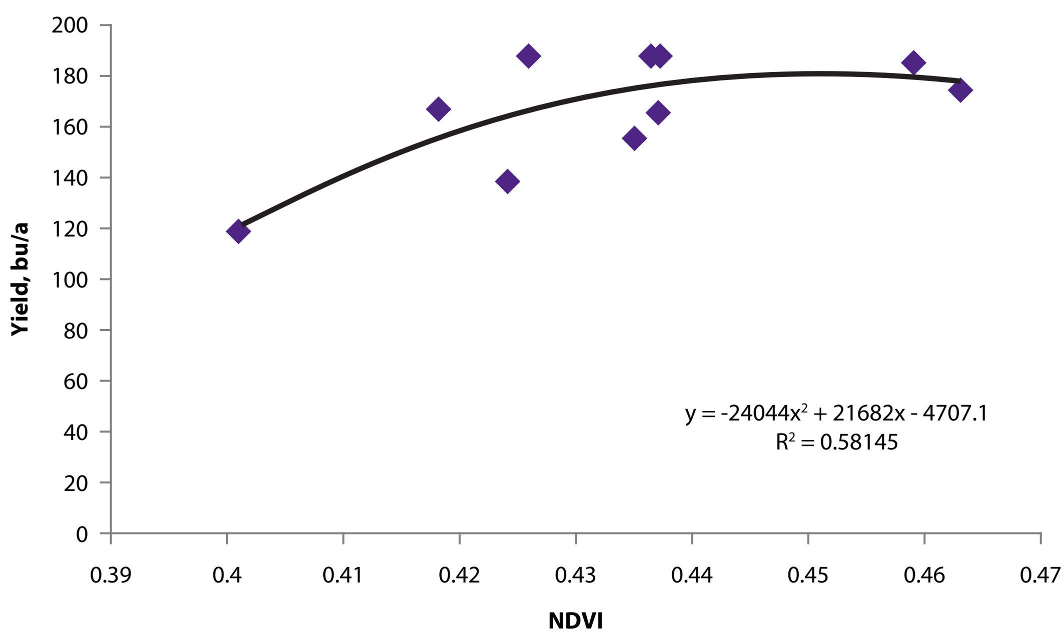

Figure 1. Relationship between corn grain yield and over-canopy normalized difference vegetation index (NDVI) readings at corn growth stage V5, Site 1.

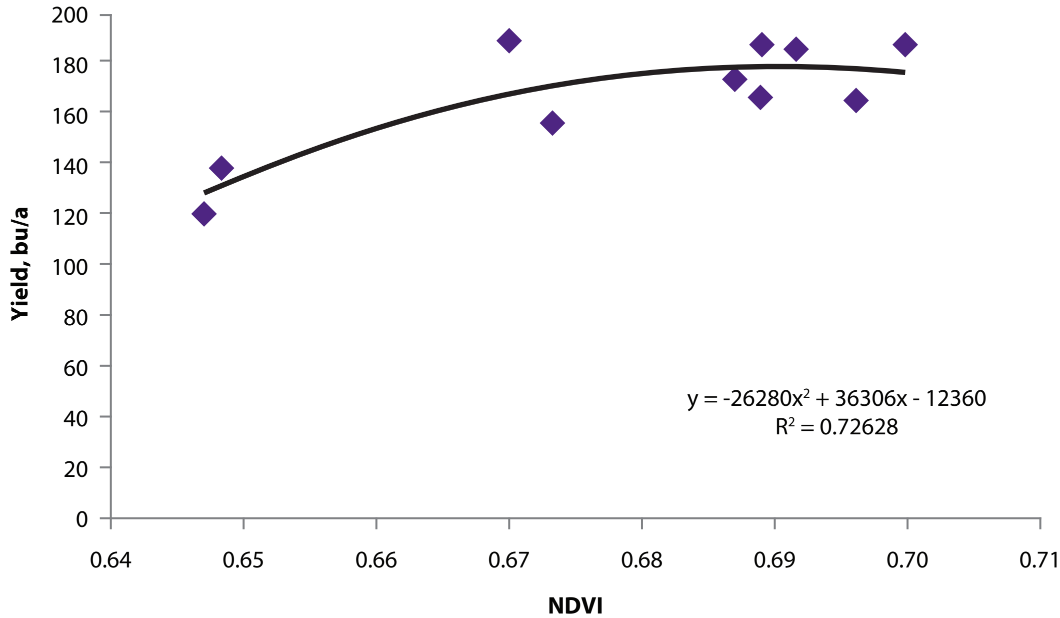

Figure 2. Relationship between corn grain yield and over-canopy normalized difference vegetation index (NDVI) readings at corn growth stage V8, Site 1.

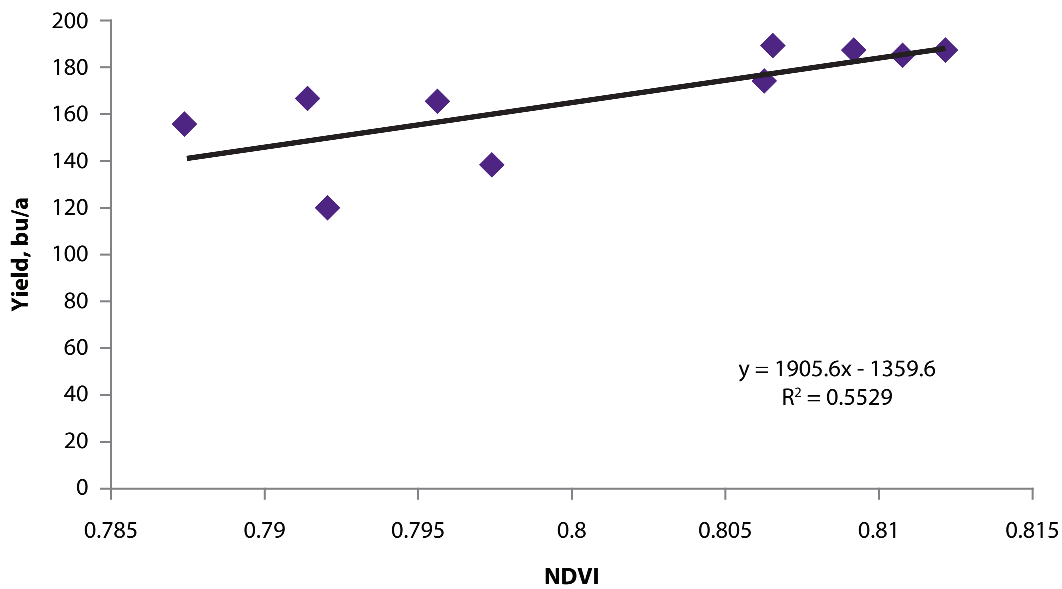

Figure 3. Relationship between corn grain yield and over-canopy normalized difference vegetation index (NDVI) readings at corn growth stage V16, Site 1.

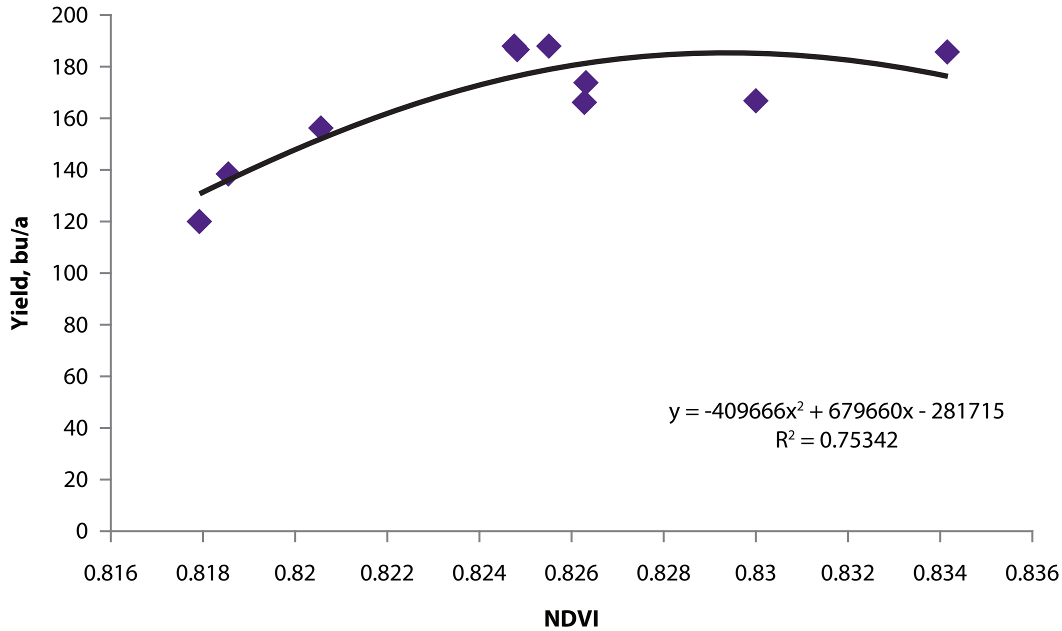

Figure 4. Relationship between corn grain yield and in-canopy normalized difference vegetation index (NDVI) readings at corn growth stage V16, Site 1.

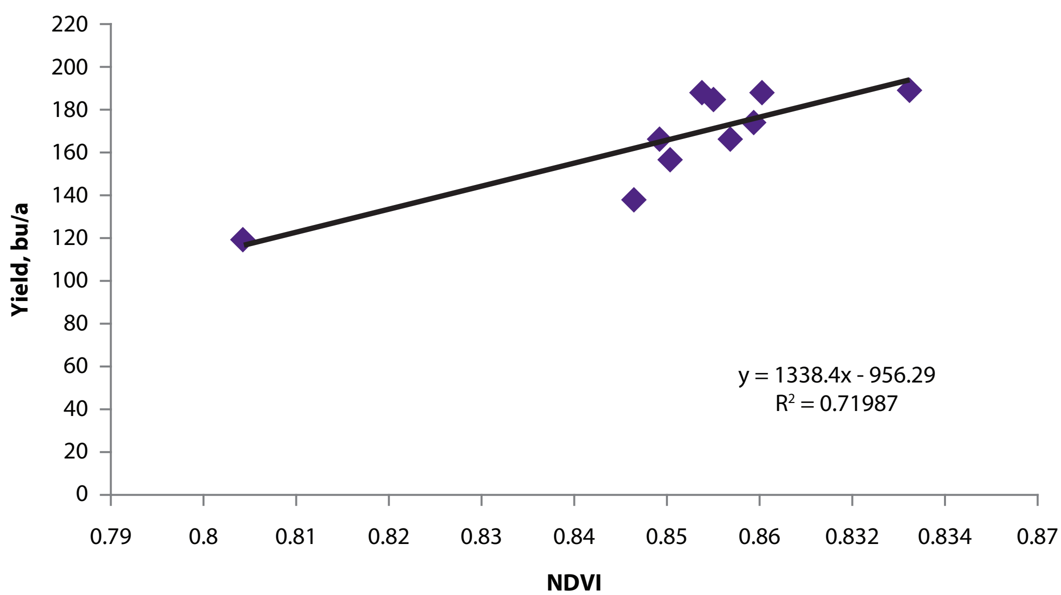

Figure 5. Relationship between corn grain yield and in-canopy normalized difference vegetation index (NDVI) readings at corn growth stage R1, Site 1.

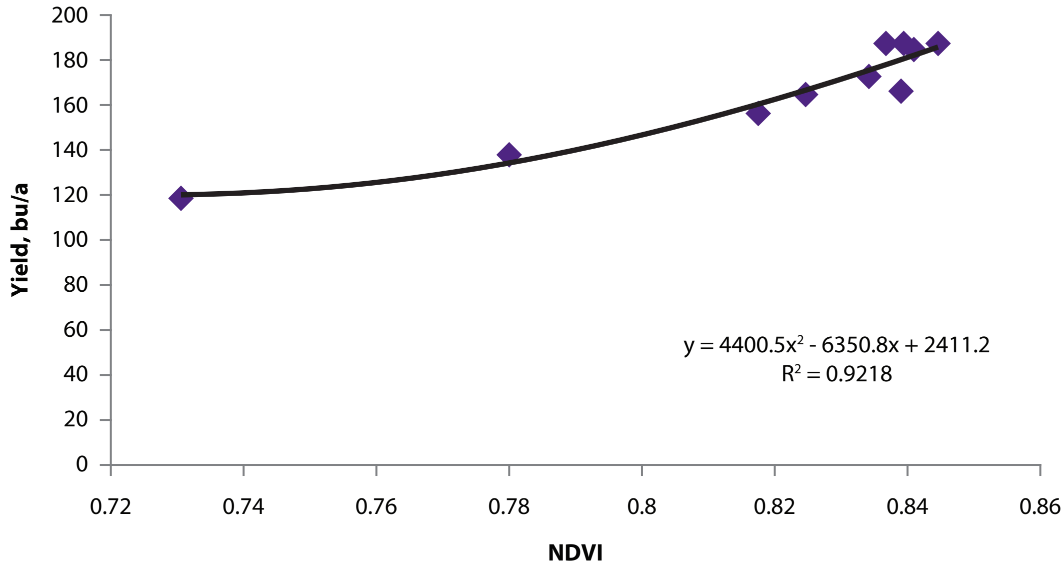

Figure 6. Relationship between corn grain yield and in-canopy normalized difference vegetation index (NDVI) readings at corn growth stage R2, Site 1.

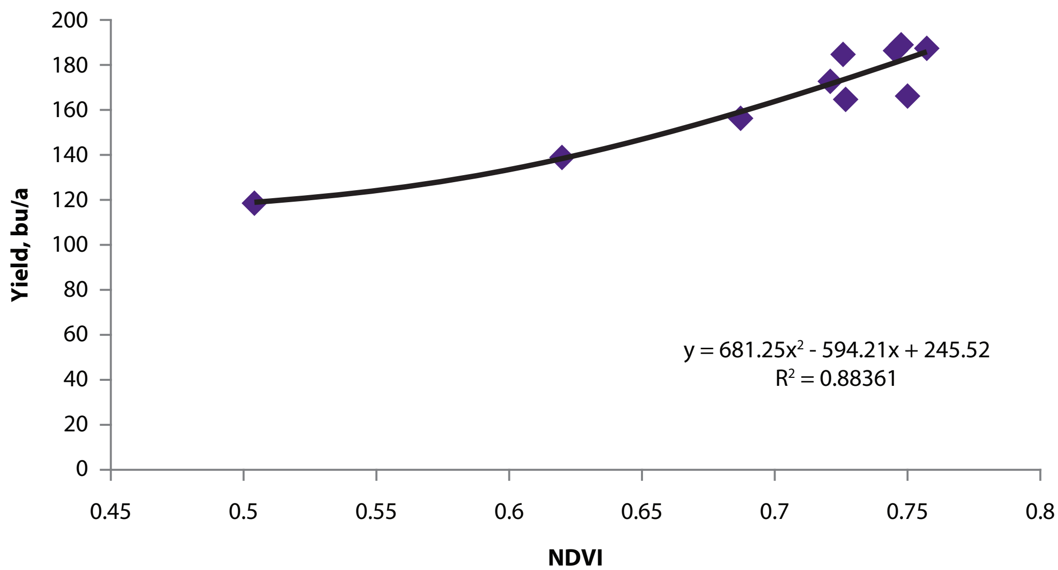

Figure 7. Relationship between corn grain yield and in-canopy normalized difference vegetation index (NDVI) readings at corn growth stage R3, Site 1.

Variation in Nitrogen Use Efficiency in 30 Winter Wheat Varieties

N. Dorsey, N.O. Nelson, B. Haverkamp, and A.K. Fritz

Summary

Two prevalent issues in the minds of those involved with agriculture are the high costs of nitrogen fertilizers and environmental issues resulting from their overapplication. A possible way to combat these issues is by increasing nitrogen use efficiency (NUE) in crops such as wheat. The objective of this study was to determine if there are differences in NUE among 30 wheat varieties commonly grown in the Great Plains. The experiment was a field study in Rossville, KS, with treatments consisting of N rate and variety. The wheat varieties were grown with two N rates, 0 lb/a N and 90 lb/a N. Nitrogen use efficiency was calculated as the grain yield per unit of available N (sum of soil N and fertilizer N). Although there appeared to be varietal differences in NUE, variability in the data was high and results were not statistically significant ($P > 0.23$). Nitrogen content in the grain and biomass production efficiency were the only two parameters significantly affected by variety ($P < 0.05$). This result suggests that some varieties may be able to produce biomass with less N and remobilize it to the grain during reproductive growth; however, more research will be needed to develop firmer conclusions.

Introduction

Wheat breeding historically has focused on increasing grain yield as a means to meet the rising demand for food worldwide (Foulkes et al., 1998). High-yielding varieties require substantial amounts of N fertilizer to produce at high levels. Fertilizer prices have risen sharply in the past decade, and many farmers in the United States and abroad simply cannot afford the rates required for their crops. This has caused many to be aware of the true amount of N their crops require and how much they may be losing to the environment. Losing N to the environment is common when high rates of N are applied. This can result in serious problems, such as leaching of nitrate into water bodies and the release of greenhouse gases, such as nitrous oxides, into the atmosphere (Tilman et al., 2002).

To meet the rising demand for food and safeguard the environment, researchers and breeders alike should turn their attention to increasing NUE in wheat cultivars. NUE is defined as the amount of grain produced per unit of N available from the soil and applied fertilizers (Moll et al., 1982). By increasing NUE, farmers can produce the same or higher yields with less fertilizer input. A plant with a high NUE will both remove N from the soil and use it efficiently to produce as much grain as possible. Selecting for varieties that have high NUE could be an ideal method to increase return on fertilizer investment and protect the environment from the harmful effects of N contamination (Arregui and Quemada, 2008).

Procedures

To determine N use efficiencies, 30 varieties commonly grown in Kansas were included in a field experiment. This experiment took place in the 2011/2012 growing season at the Kansas State University Agronomy research farm in Rossville, KS. The experiment was replicated four times at Rossville and laid out in a strip-plot design. Whole-plots were 60 ft × 5.5 ft and consisted of the various wheat varieties. Two N rates, 0 lb/a and 90 lb/a, were stripped across the field, creating subplots 30 ft × 5.5 ft. The N was split-applied, with 50 lb/a applied in the fall and 40 lb/a in the spring with surface-broadcast ammonium nitrate. Phosphorus was applied to all plots at planting in the form of triple super phosphate at a rate of 45 lb/a P_2O_5.

Biomass and tissue samples were collected both at anthesis (Feekes 10.51; April 23–26, 2012) and maturity (Feekes 11.4; June 8, 2012). Biomass samples were collected by harvesting 2 ft of the middle four rows of each plot. The biomass samples taken at maturity were used to calculate total biomass produced, then dried and threshed to determine harvest index. Samples of tissue and grain were taken and analyzed for total N content by combustion. The remaining plot areas were then harvested with a combine to determine grain yield. Stover yield and total biomass were calculated using the following equations 1 and 2, respectively. Nitrogen use efficiency and other related parameters were also determined as described in Table 1.

Equation 1 Stover yield = (grain yield) × ((1/HI)-1)
Equation 2 Total biomass = (grain yield)/HI

Some of the parameters, such as NUE and NUpE, required an accurate measurement for total N supply or N available in the soil. These were determined by taking preplant soil samples, which were then analyzed by the Kansas State University soil lab. Fertilizer rates were factored in as required. Treatment effects on NUE and other parameters were determined by using a mixed model procedure for analysis of variance using SAS PROC MIXED (SAS Institute Inc., Cary, NC).

Results and Discussion

Only two N use parameters were significantly affected by variety, N content in the grain and biomass production efficiency (Table 2). Values for NUE ranged from 11 to 23 and appear to be influenced by variety, but we observed no statistically significant difference due to high variability in the data (Table 2, Figure 1). This may be due to an unusually warm and dry growing season. Because of the large range in NUE values, there may be potential for breeding more efficient varieties, but further studies will need to be performed to provide evidence for this.

Biomass production efficiency was significantly affected by variety (Table 2, Figure 2). This result suggests that some varieties may be able to create more biomass, and possibly grain, with less N. Because N content in the grain is also significantly affected by variety (Table 2), differences in NUE may be due to the plants' ability to produce biomass and remobilize N from plant tissue to the grain during reproductive growth.

These data suggest that variety selection does play a part in N content in the grain and biomass production efficiency, both of which will influence NUE. Future research with more locations, check varieties, and methods will seek to decrease variability. With less variability in the data, a significant difference in NUE may be detected at $P < 0.05$. This information will be of great importance to breeders as they seek ways to produce more efficient crops and meet the global demand for food.

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Table 1. Definitions of NUE-related terms and methods of calculation

Measurement	Definition	Formula
Nitrogen use efficiency (NUE)	Weight of grain produced per unit of available N	NUE = grain weight/total N supply or UPE × UTE
Nitrogen uptake efficiency (NUpE)	How efficiently N is taken up by the plant from the soil	NUpE = N in grain/N supply in the soil
Nitrogen utilization efficiency (NUtE)	How efficiently N is absorbed from the soil and used to make grain	NUtE = grain weight/N in grain or HI*BPE
Harvest index (HI)	Weight of harvested grain as a percentage of total plant weight	HI = grain weight/ aboveground biomass
Biomass production efficiency (BPE)	Total plant weight compared with total plant N content at maturity	BPE = aboveground biomass/ total N at maturity
Nitrogen harvest index (NHI)	Nitrogen content in the grain compared with total plant N content at maturity	NA = N in grain/total N at maturity
Nitrogen uptake after anthesis (NUpAA)	Difference in total N from anthesis to maturity	NUpAA = total N at maturity – total N at anthesis
Nitrogen remobilization efficiency (NRE)	How efficiently N at anthesis was remobilized to the grain	NRE = (N in grain-NUpAA)/total N at anthesis
Fertilizer use efficiency (FUE)	Fraction of N applied as fertilizer that was absorbed by the plant	FUE = (N uptake with fertilizer-N uptake without fertilizer)/N applied as fertilizer

Table 2. Levels of significance (*P*-values) for the interactions of nitrogen (N) rate and variety on nitrogen use efficiency (NUE) and related measurements

	Yield	Ng	Ns	NUE	NUpE	NUtE	HI	BPE	NUpAA	NRE	FUE
N rate	<0.001	0.007	0.003	<0.001	<0.001	0.012	0.042	0.007	0.407	0.894	---
Variety	0.266	0.046	0.132	0.230	0.586	0.129	0.601	0.026	0.452	0.223	0.401
N rate × variety	0.815	0.408	0.037	0.534	0.389	0.564	0.653	0.045	0.340	0.319	---

Abbreviations: Ng, nitrogen content of the grain; Ns, nitrogen content of stover; NUE, nitrogen use efficiency; NUpE, nitrogen uptake efficiency; NUtE, nitrogen utilization efficiency; HI, harvest index; BPE, biomass production efficiency; NUpAA, nitrogen uptake after anthesis; NRE, nitrogen remobilization efficiency; FUE, fertilizer use efficiency.

Table 3. Mean values for nitrogen use efficiency and related parameters for included winter wheat varieties at Rossville, 2011–2012 growing season

Variety	NUE	Yield	Ng	Ns	NUpE	HI	BPE	NUpAA	NRE	FUE
	lb/lb	bu/a	--------- % ---------		------------- lb/lb -------------			lb/a	------- lb/lb -------	
2137	23.03	31.12	2.43	0.60	0.84	0.34	84.68	30.53	0.41	0.41
2174	16.12	20.02	2.68	0.78	0.87	0.30	75.04	38.53	0.12	0.22
2180	15.15	18.84	2.89	0.92	0.91	0.26	70.41	35.46	-0.05	0.17
Armour	22.17	27.80	2.44	0.82	0.87	0.29	78.57	26.16	0.29	0.18
Art	16.38	23.09	2.67	0.75	0.80	0.28	78.00	20.94	0.33	0.31
Billings	20.18	26.04	2.45	0.67	0.70	0.31	83.46	22.00	0.34	0.41
Cedar	19.38	25.48	2.40	0.74	0.78	0.29	83.21	33.25	0.20	0.43
Custer	18.37	23.56	2.58	0.82	0.87	0.29	75.38	29.14	0.27	0.21
Deliver	19.48	24.32	2.58	0.78	0.85	0.32	74.58	37.74	0.12	0.29
Duster	21.92	28.03	2.57	0.85	0.89	0.30	74.30	33.15	0.22	0.34
Endurance	19.31	23.60	2.51	0.70	0.84	0.30	81.99	34.05	0.27	0.35
Everest	22.21	27.65	2.57	0.80	0.91	0.31	74.54	38.27	0.15	0.30
Fannin	20.72	25.86	2.62	0.72	0.86	0.27	83.00	28.09	0.34	0.38
Fuller	14.40	18.39	2.66	0.72	0.70	0.26	84.28	18.08	0.38	0.35
Jackpot	20.95	27.39	2.50	0.78	0.91	0.30	76.00	35.34	0.20	0.23
Jagalene	17.01	22.28	2.62	0.89	0.88	0.31	70.25	33.93	0.22	0.21
Jagger	15.98	20.48	2.70	0.80	0.80	0.28	76.65	27.56	0.29	0.34
Karl 92	16.23	19.73	2.67	0.89	0.80	0.27	75.04	28.18	0.12	0.19
KS020319-7-3	18.22	22.48	2.53	0.86	0.77	0.30	74.43	31.87	0.14	0.39
Longhorn	18.55	24.35	2.54	0.90	0.90	0.29	73.19	40.28	-0.01	0.32
Ogallala	18.44	23.39	2.69	0.84	0.90	0.29	73.30	30.82	0.18	0.18
Overley	16.31	20.80	2.73	0.88	0.84	0.28	72.73	29.59	0.19	0.21
Post Rock	17.12	21.51	2.62	0.91	0.80	0.28	73.11	29.40	0.11	0.17
Santa Fe	14.65	18.77	2.72	0.87	0.71	0.27	72.83	28.43	0.14	0.29
TAM 105	16.94	21.40	2.51	0.95	0.92	0.23	76.80	35.81	0.01	0.33
TAM 110	17.10	21.35	2.52	0.87	0.89	0.30	74.31	32.71	0.12	-0.01
TAM 111	20.74	26.19	2.52	0.72	0.83	0.30	81.40	33.93	0.24	0.37
TAM 112	20.40	27.66	2.53	0.75	0.87	0.31	78.26	32.83	0.27	0.53
TAM 401	20.19	26.33	2.52	0.77	0.85	0.32	76.15	31.09	0.26	0.21
Weather Master 135	11.12	15.28	2.72	0.90	0.94	0.26	73.17	41.25	-0.04	0.32
LSD	NS	NS	1.99	NS	NS	NS	10.19	NS	NS	NS

Abbreviations: NUE, nitrogen use efficiency; Ng, nitrogen content in the grain; Ns, nitrogen content in the stover; NUpE, nitrogen uptake efficiency; HI, harvest index; BPE, biomass production efficiency; NUpAA, nitrogen uptake after anthesis; NRE, nitrogen remobilization efficiency; FUE, fertilizer use efficiency; NS, not statistically significant.

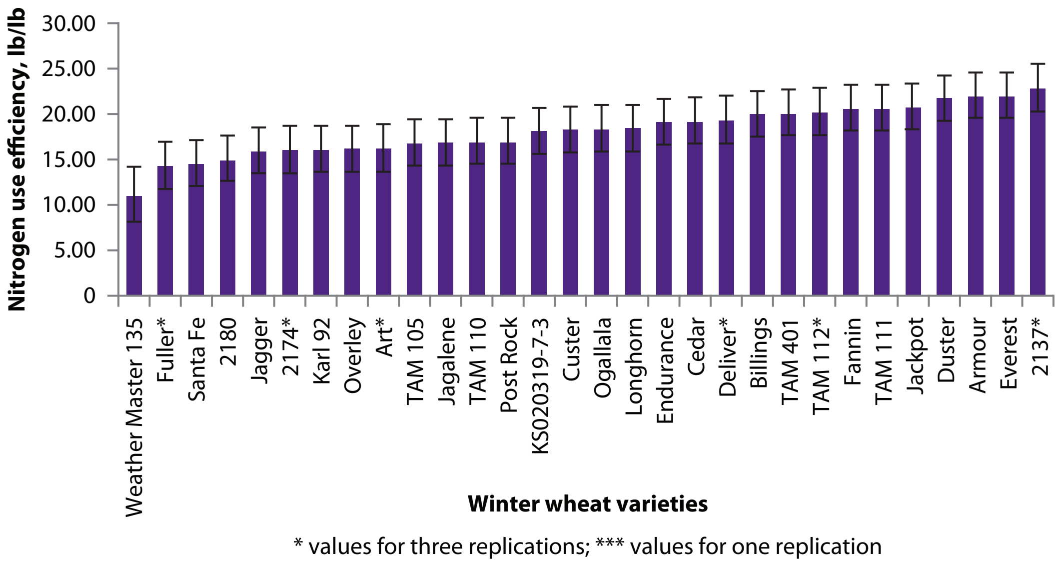

Figure 1. Nitrogen use efficiency of 30 common wheat varieties grown in the Great Plains region.

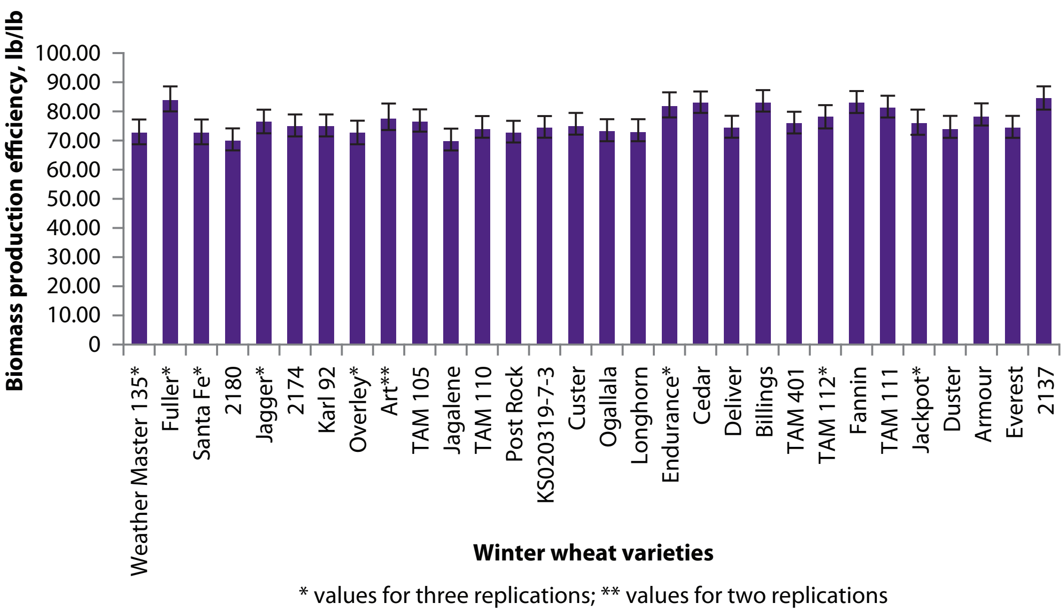

Figure 2. Biomass production efficiency of 30 common wheat varieties grown in the Great Plains region.

Tillage and Nitrogen Placement Effects on Yields in a Short-Season Corn/Wheat/Double-Crop Soybean Rotation

D.W. Sweeney and K.W. Kelley

Summary
In 2011, hot and dry conditions resulted in very low overall corn yields. Nitrogen (N) placement method did not affect corn yields. Adding N increased yields in the reduced and no-till systems, but not in the conventional tillage system.

Introduction
Many crop rotation systems are used in southeastern Kansas. This experiment is designed to determine the long-term effect of selected tillage and N fertilizer placement options on yields of short-season corn, wheat, and double-crop soybean in rotation.

Procedures
A split-plot design with four replications was initiated in 1983 with tillage system as the whole plot and N treatment as the subplot. In 2005, the rotation was changed to begin a short-season corn/wheat/double-crop soybean sequence. Use of three tillage systems (conventional, reduced, and no-till) continued in the same areas used during the previous 22 years. The conventional system consists of chiseling, disking, and field cultivation. Chiseling occurs in the fall preceding corn or wheat crops. The reduced-tillage system consists of disking and field cultivation prior to planting. Glyphosate (Roundup) is applied to the no-till areas. The four N treatments for the crop are: no N (control), broadcast urea-ammonium nitrate (UAN; 28% N) solution, dribble UAN solution, and knife UAN solution at 4 in. deep. The N rate for the corn crop grown in odd years is 125 lb/a. Corn was planted on April 12, 2011.

Results
In 2011, hot and dry conditions resulted in very low corn yields of less than 35 bu/a for any treatment (Figure 1). Broadcast, dribble, and knife application of N fertilizer produced similar yields that were more than 60% greater than with the no-N control in reduced and no-till systems. However, in the conventional tillage system where corn yield was less than 24 bu/a, N fertilization, regardless of application method, did not result in yield greater than that obtained with the no-N control.

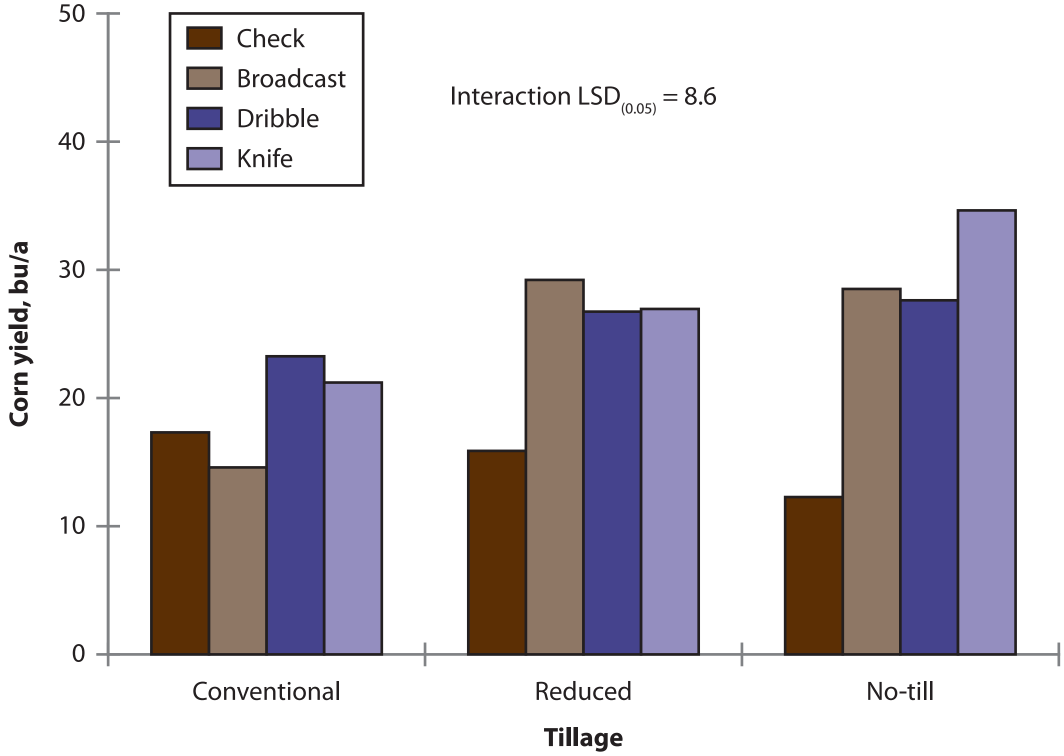

Figure 1. Effects of tillage and nitrogen placement on short-season corn yield in 2011.

Seeding Rates and Fertilizer Placement to Improve Strip-Till and No-Till Corn[1]

D.W. Sweeney and K.W. Kelley

Summary

In 2011, hot and dry conditions resulted in very low corn yields. Under these stressful environmental conditions, corn yield was reduced with increasing seeding rate, was increased by subsurface band (knife) applications, and was not affected by tillage system.

Introduction

Use of conservation tillage systems is promoted because of environmental concerns. In the claypan soils of southeastern Kansas, crops grown with no-till may yield less than crops grown in systems involving some tillage operation, often because of reduced plant emergence. Strip tillage provides a tilled seed-bed zone where early spring soil temperatures might be greater than those in no-till soils. But like no-till, strip tillage leaves residues intact between the rows as a conservation measure. Optimizing seeding rates for different tillage systems should improve corn stands and yields.

Procedures

In 2011, the experiment was conducted at the Mound Valley Unit (Site 1) and the Parsons Unit (Site 2) of the Southeast Agricultural Research Center. The experimental design was a split-plot arrangement of a randomized complete block with three replications. The whole plots were three tillage systems: conventional, strip tillage, and no-till. Conventional tillage consisted of chisel and disk operations in the spring. Strip tillage was done with a Redball strip-till unit in the spring prior to planting. The subplots were a 5 × 2 factorial combination of five seed planting rates (18,000, 22,000, 26,000, 30,000, and 34,000 seeds/a) and two fertilizer placement methods: surface band (dribble) on 30-in. centers near the row and subsurface band (knife) at 4 in. deep. At the Mound Valley site, N and P nutrients were supplied as 28% urea ammonium nitrate and ammonium polyphosphate (10-34-0 N-P-K) applied at 125 lb/a N and 40 lb/a P_2O_5. Based on initial soil tests, at the Parsons site only N was applied by the two placement methods. Corn was planted at Site 1 on April 13, 2011, and at Site 2 on April 12, 2011.

Results

In 2011, hot and dry conditions resulted in very low corn yields of less than 36 bu/a with any treatment at either location. Stressful environmental conditions resulted in yield reductions of 50 to 100% as seeding rate increased from 18,000 to 34,000 seeds/a at the two sites (Figure 1), but yield did not respond significantly to different tillage systems (data not shown). Even though overall yields were low, knife application resulted in more than 10% greater corn yield than dribble application at both sites (Figure 2). At the lower yielding site (Site 1), this response to knife placement was mainly evident in the no-till system.

[1] This research was partly funded by the Kansas Corn Commission.

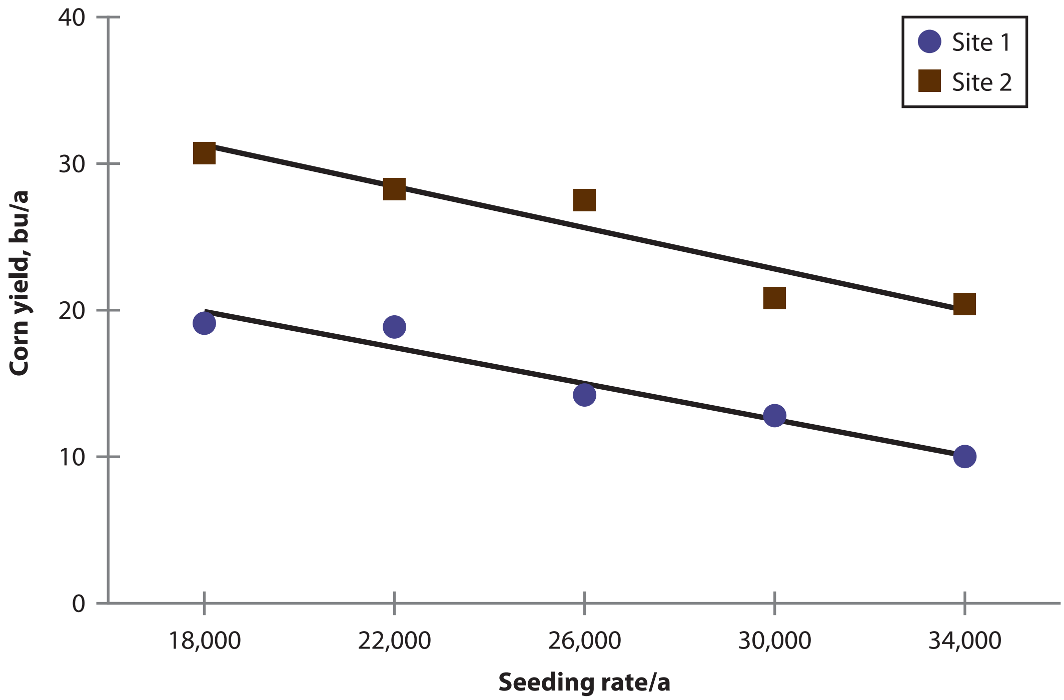

Figure 1. Effect of seeding rate on corn yield in 2011 at Site 1 (Mound Valley) and Site 2 (Parsons).

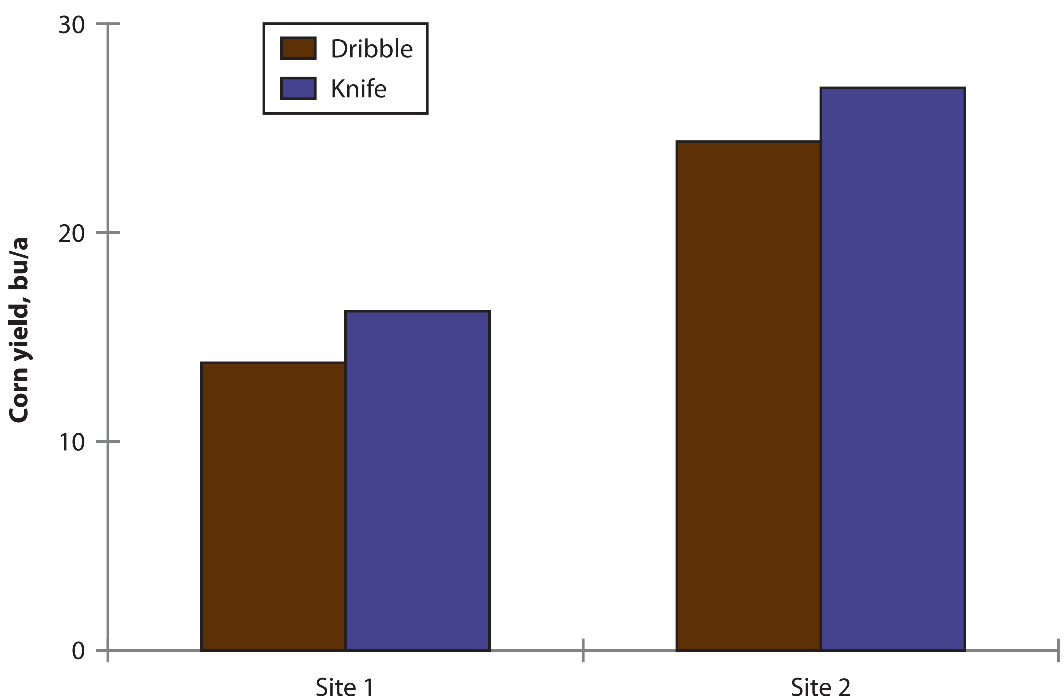

Figure 2. Effect of fluid fertilizer placement on corn yield in 2011 at Site 1 (Mound Valley) and Site 2 (Parsons). At each site, the placement methods are significantly different at the 0.05 probability level.

Effects of K, Cl, and N on Short-Season Corn, Wheat, and Double-Crop Sunflower Grown on Claypan Soil

D.W. Sweeney, D.J. Jardine[1], and K.W. Kelley

Summary
In 2011, wheat and double-crop sunflower were little affected by potassium (K) or chloride (Cl) fertilization. Increased nitrogen (N) rate increased wheat yield, heads/a, and dry matter production, but slightly decreased seed weight. Measured wheat and sunflower diseases were unaffected by K, Cl, and N fertilization.

Introduction
Corn acreage has been on the rise in southeastern Kansas in recent years because of the introduction of short-season cultivars that enable producers to partially avoid midsummer droughts that are often severe on the upland, claypan soils typical of the area. In addition, producing a crop after wheat and in rotation with corn potentially provides producers an increase in revenue by growing three crops in two years. Recent interest and developments in oil-type sunflower provide an alternative to soybean for growers to double-crop after wheat. All crops in this corn-wheat-double-crop sunflower rotation require adequate fertilization with N to obtain optimum yields. Also, these crops are potentially affected by diseases that affect the leaf and stalk structures and may reduce yields. Potassium and chloride fertilization of crops has often been found to reduce disease pressure, but how N, K, and Cl interact to affect disease suppression and crop production have not been well defined, especially for corn, wheat, and double-crop sunflower in a two-year rotation on a claypan soil in southeastern Kansas.

Procedures
The experiment was conducted in 2010 and 2011 at the Southeast Agricultural Research Center of Kansas State University at Parsons, KS. The soil was a Parsons silt loam with a claypan subsoil. For background soil samples taken in spring 2010 at the 0- to 6-in. depth, selected soil chemical analyses were 6.4 pH (1:1 soil:water), 64 ppm K (1 M $NH_4C_2H_3O_2$ extract), 3.1 ppm NH_4-N, 4.0 ppm NO_3-N, 2.1 ppm Cl, and 2.5% organic matter. The experimental design was a split-plot design with three replications. The whole plots were a 2 × 2 factorial of K and Cl fertilization. The K and Cl rates were 0 and 50 lb K_2O/a and 0 and 40 lb Cl/a for each crop. Potassium and chloride fertilizer sources used to achieve these four fertility whole plots were potassium chloride, potassium sulfate, and calcium chloride and were spread using a small, hand-held broadcast unit. The N rate subplots for wheat and double-crop sunflower were 0, 40, 80, and 120 lb/a surface band–applied as urea ammonium nitrate (UAN) solution for each crop. In addition to K, Cl, and N treatments, all plots received uniform applications of P at 40 lb P_2O_5/a for wheat and 30 lb P_2O_5/a for sunflower applied with a drop spreader. Fertilizers were incorporated by disking prior to planting. 'Jagger' wheat was planted on October 15, 2010, at 90 lb/a and grain was harvested for yield on June 17, 2011. At the soft dough stage (Zadok's 85), visual estimate of disease incidence (percentage of

[1] Kansas State University Department of Plant Pathology.

the number of flag leaves affected by leaf rust) and dry matter production (whole plant samples) were determined. Mycogen 8N510 sunflower was planted at 20,000 seeds/a on June 30, 2011, and was harvested on October 17, 2011. At R6 growth stage, dry matter production was determined. At R7 growth stage, incidence of *Rhizopus* head rot was determined from the visual percentage of infected heads in the harvest rows.

Results

In 2011, wheat yield and yield components were unaffected by the main effects of K or Cl fertilization. Chloride fertilization without K slightly decreased seed weight (data not shown), but had no effect on yield or other yield components. Increasing N rate from 0 to 120 lb/a increased wheat yield, heads/a, and dry matter production at the soft dough stage, but slightly decreased seed weight (Figure 1). Incidence of leaf rust was unaffected by K, Cl, N, or any interactions (data not shown). Following the wheat crop, average yield of double-crop sunflower in 2011 was low at 650 lb/a, likely because of hot and dry conditions and because approximately 50% of the sunflower heads were affected by *Rhizopus* head rot. Sunflower yield, yield components, and head rot disease incidence were unaffected by K, Cl, N, or their interactions (data not shown). Even though K fertilization increased dry matter production at the R6 growth stage by 40%, the poor growing conditions may have masked any subsequent effect on yield.

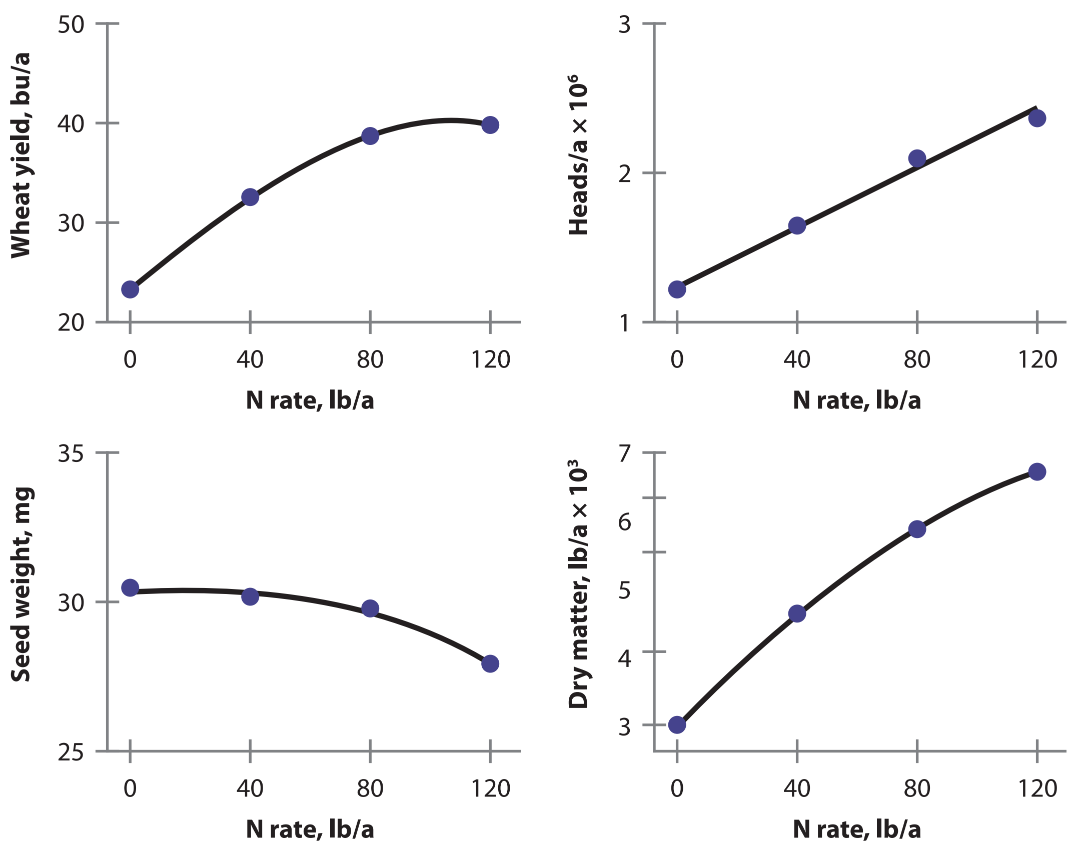

Figure 1. Wheat yield, heads/a, seed weight, and soft dough growth stage dry matter production as affected by nitrogen (N) rate in 2011.

Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Corn

A. Schlegel

Summary

Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize production of irrigated corn in western Kansas. In 2012, N applied alone increased yields 84 bu/a, whereas P applied alone increased yields less than 10 bu/a. Nitrogen and P applied together increased yields up to 174 bu/a. This is somewhat greater than the 10-year average, in which N and P fertilization increased corn yields up to 145 bu/a. Application of 120 lb/a N (with P) produced about 82% of maximum yield in 2012, which was less than the 10-year average of 94%. Application of 80 instead of 40 lb P_2O_5/a increased average yields 8 bu/a.

Introduction

This study was initiated in 1961 to determine responses of continuous corn and grain sorghum grown under flood irrigation to N, P, and potassium (K) fertilization. The study is conducted on a Ulysses silt loam soil with an inherently high K content. No yield benefit to corn from K fertilization was observed in 30 years, and soil K levels remained high, so the K treatment was discontinued in 1992 and replaced with a higher P rate.

Procedures

This field study is conducted at the Tribune Unit of the Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a without P and K; with 40 lb/a P_2O_5 and zero K; and with 40 lb/a P_2O_5 and 40 lb/a K_2O. The treatments were changed in 1992; the K variable was replaced by a higher rate of P (80 lb/a P_2O_5). All fertilizers were broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. The corn hybrids [DeKalb C60-12 (2003), Pioneer 34N45 (2004 and 2005), Pioneer 34N50 (2006), Pioneer 33B54 (2007), Pioneer 34B99 (2008), DeKalb 61-69 (2009), Pioneer 1173H (2010), Pioneer 1151XR (2011), and Pioneer 0832 (2012)] were planted at about 30,000 to 32,000 seeds/a in late April or early May. Hail damaged the 2005 and 2010 crops. The corn is irrigated to minimize water stress. Sprinkler irrigation has been used since 2001. The center two rows of each plot are machine harvested after physiological maturity. Grain yields are adjusted to 15.5% moisture.

Results

Corn yields in 2012 were much greater than the 10-year average (Table 1). Nitrogen alone increased yields 84 bu/a, whereas P alone increased yields less than 10 bu/a; however, N and P applied together increased corn yields up to 174 bu/a. Maximum yield was obtained with 200 lb/a N with 80 lb/a P_2O_5. Reducing N or P rates reduced yields by at least 8%, which is greater than the 10-year average of 4%. Corn yields in 2012 (averaged across all N rates) were 8 bu/a greater with 80 than with 40 lb/a P_2O_5, which is slightly greater than the 10-year average of 5 bu/a.

Table 1. Effects of nitrogen (N) and phosphorus (P) fertilization on irrigated corn, Tribune, KS, 2003–2012

N	P_2O_5	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Mean
--------- lb/a ---------		--- bu/a ---										
0	0	79	67	49	42	49	36	85	20	92	86	60
0	40	95	97	60	68	50	57	110	21	111	85	75
0	80	93	98	51	72	51	52	106	28	105	94	75
40	0	107	92	63	56	77	62	108	23	114	109	81
40	40	147	154	101	129	112	105	148	67	195	138	130
40	80	150	148	100	123	116	104	159	61	194	135	129
80	0	122	118	75	79	107	78	123	34	136	128	100
80	40	188	209	141	162	163	129	179	85	212	197	167
80	80	186	205	147	171	167	139	181	90	220	194	170
120	0	122	103	66	68	106	65	117	28	119	134	93
120	40	194	228	162	176	194	136	202	90	222	213	182
120	80	200	234	170	202	213	151	215	105	225	211	193
160	0	127	136	83	84	132	84	139	49	157	158	115
160	40	190	231	170	180	220	150	210	95	229	227	190
160	80	197	240	172	200	227	146	223	95	226	239	197
200	0	141	162	109	115	159	99	155	65	179	170	135
200	40	197	234	169	181	224	152	207	97	218	225	190
200	80	201	239	191	204	232	157	236	104	231	260	205

continued

Table 1. Effects of nitrogen (N) and phosphorus (P) fertilization on irrigated corn, Tribune, KS, 2003–2012

N	P_2O_5	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Mean
--------- lb/a ---------		-- bu/a --										
ANOVA (P > F)												
Nitrogen		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Phosphorus		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
N × P		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Means												
Nitrogen, lb/a												
0		89	87	53	61	50	48	100	23	103	88	70
40		135	132	88	103	102	91	138	50	167	127	113
80		165	178	121	137	146	115	161	70	189	173	145
120		172	188	133	149	171	118	178	74	189	186	156
160		172	203	142	155	193	127	191	80	204	208	167
200		180	212	156	167	205	136	199	89	209	218	177
LSD (0.05)		9	11	10	15	11	9	12	9	13	10	8
P_2O_5, lb/a												
0		116	113	74	74	105	71	121	36	133	131	97
40		168	192	134	149	160	122	176	76	198	181	156
80		171	194	139	162	168	125	187	81	200	189	161
LSD (0.05)		6	8	7	11	8	6	9	7	-9	7	6

Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Grain Sorghum

A. Schlegel

Summary
Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize production of irrigated grain sorghum in western Kansas. In 2012, N applied alone increased yields almost 70 bu/a, whereas N and P applied together increased yields up to 100 bu/a. Averaged across the past 10 years, N and P fertilization increased sorghum yields more than 65 bu/a. Application of 40 lb/a N (with P) was sufficient to produce about 80% of maximum yield in 2012, which was slightly less than the 10-year average. Application of potassium (K) has had no effect on sorghum yield throughout the study period.

Introduction
This study was initiated in 1961 to determine responses of continuous grain sorghum grown under flood irrigation to N, P, and K fertilization. The study is conducted on a Ulysses silt loam soil with an inherently high K content. The irrigation system was changed from flood to sprinkler in 2001.

Procedures
This field study is conducted at the Tribune Unit of the Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a N without P and K; with 40 lb/a P_2O_5 and zero K; and with 40 lb/a P_2O_5 and 40 lb/a K_2O. All fertilizers are broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. Sorghum (Pioneer 8500/8505 in 2003–2007, Pioneer 85G46 in 2008–2011, and Pioneer 84G62 in 2012) was planted in late May or early June. Irrigation is used to minimize water stress. Sprinkler irrigation has been used since 2001. The center two rows of each plot are machine harvested after physiological maturity. Grain yields are adjusted to 12.5% moisture.

Results
Grain sorghum yields in 2012 were 24% greater than the 10-year average yields (Table 1). Nitrogen alone increased yields 69 bu/a, whereas P alone increased yields 12 bu/a; however, N and P applied together increased yields up to 100 bu/a. Averaged across the past 10 years, N and P applied together increased yields more than 65 bu/a. In 2012, 40 lb/a N (with P) produced about 79% of maximum yields, which is slightly less than the 10-year average of 86%. Sorghum yields were not affected by K fertilization, which has been the case throughout the study period.

Table 1. Effects of nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2003–2012

Fertilizer			Grain sorghum yield										
N	P_2O_5	K_2O	2003	2004	2005[1]	2006	2007	2008	2009	2010	2011	2012	Mean
---------------- lb/a ----------------			---------- bu/a ----------										
0	0	0	80	57	58	84	80	66	64	51	75	78	70
0	40	0	93	73	53	102	97	60	70	51	83	90	78
0	40	40	93	74	54	95	94	65	76	55	88	93	80
40	0	0	92	60	63	102	123	92	84	66	106	115	92
40	40	0	140	112	84	133	146	111	118	77	121	140	120
40	40	40	140	117	84	130	145	105	109	73	125	132	117
80	0	0	108	73	76	111	138	114	115	73	117	132	107
80	40	0	139	103	81	132	159	128	136	86	140	163	129
80	40	40	149	123	92	142	166	126	108	84	138	161	131
120	0	0	97	66	77	101	138	106	113	70	116	130	102
120	40	0	135	106	95	136	164	131	130	88	145	172	132
120	40	40	132	115	98	139	165	136	136	90	147	175	135
160	0	0	122	86	77	123	146	105	108	74	124	149	113
160	40	0	146	120	106	145	170	138	128	92	152	178	139
160	40	40	135	113	91	128	167	133	140	88	151	174	134
200	0	0	131	100	86	134	154	120	110	78	128	147	120
200	40	0	132	115	108	143	168	137	139	84	141	171	135
200	40	40	145	123	101	143	170	135	129	87	152	175	137

continued

Table 1. Effects of nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2003–2012

Fertilizer			Grain sorghum yield										
N	P_2O_5	K_2O	2003	2004	2005[1]	2006	2007	2008	2009	2010	2011	2012	Mean
---------------- lb/a ----------------			---------- bu/a ----------										
ANOVA (P > F)													
Nitrogen			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Linear			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Quadratic			0.001	0.018	0.005	0.004	0.001	0.001	0.001	0.001	0.001	0.001	0.001
P-K			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Zero P vs. P			0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
P vs. P-K			0.694	0.121	0.803	0.578	0.992	0.745	0.324	0.892	0.278	0.826	0.888
N × P-K			0.008	0.022	0.195	0.210	0.965	0.005	0.053	0.229	0.542	0.186	0.033
Means													
Nitrogen, lb/a													
0			88	68	55	93	91	64	70	52	82	87	76
40			124	96	77	121	138	103	104	72	117	129	109
80			132	100	83	128	155	123	120	81	132	152	122
120			121	96	90	125	156	124	126	82	136	159	123
160			134	107	92	132	161	125	125	83	142	167	128
200			136	113	98	140	164	131	126	84	141	165	131
LSD (0.05)			10	11	10	11	9	7	11	5	8	9	5
P_2O_5-K_2O, lb/a													
0			105	74	73	109	130	101	99	68	111	125	101
40-0			131	105	88	132	151	117	120	80	130	152	122
40-40			132	111	87	130	151	117	116	79	133	152	122
LSD (0.05)			7	7	7	7	6	5	7	4	6	6	4

[1] 2005 yields used only blocks 3, 4, and 5.

Kansas Fertilizer Research 2012

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