



# KANSAS FERTILIZER RESEARCH 2013

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# KANSAS FERTILIZER RESEARCH 2013

## Introduction

The 2013 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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## Kansas Precipitation Data, 2012–2013

Month	Manhattan	SWREC Tribune	SEARC Parsons	ECK Exp. Field Ottawa
----- in. -----				
2012				
August	4.31	0.65	4.26	0.95
September	2.83	0.98	5.09	5.41
October	0.62	0.71	2.02	0.76
November	0.62	0.00	1.43	1.35
December	0.35	0.54	0.15	0.27
Total 2012	21.88	7.49	39.21	20.94
Departure from normal	-12.92	-10.41	-3.76	-19.36
2013				
January	0.94	0.17	2.36	1.88
February	1.71	0.61	3.84	3.25
March	1.19	0.47	1.84	2.63
April	3.50	0.15	9.34	3.69
May	4.02	1.93	5.63	4.62
June	3.77	1.82	4.00	5.99
July	4.22	2.02	5.98	2.43
August	3.25	6.35	2.45	5.16
September	5.76	2.79	6.76	2.39

*continued*

## Kansas Precipitation Data, 2012–2013

Month	NCK Exp. Field Belleville	KRV Exp. Field	SCK Exp. Field Hutchinson	ARC-Hays
----- in. -----				
2012				
August	0.95	4.53	0.95	3.37
September	5.41	0.82	5.41	1.07
October	0.76	0.94	0.76	0.94
November	1.35	1.19	1.35	0.00
December	0.27	0.28	0.27	0.78
Total 2012	20.94	20.75	20.94	14.39
Departure from normal	-9.66	-14.89	-9.38	-8.52
2013				
January	1.88	0.35	1.88	0.76
February	3.25	0.73	3.25	1.19
March	2.63	1.67	2.63	0.78
April	3.69	2.82	3.69	1.06
May	4.62	7.45	4.62	2.16
June	5.99	1.77	5.99	2.74
July	2.43	2.12	2.43	7.08
August	5.16	3.85	5.16	0.59
September	2.39	3.19	2.39	2.98

SWREC = Southwest Research Extension-Center; SEARC = Southeast Agricultural Research Center; ECK = East Central Kansas; NCK = North Central Kansas; KRV = Kansas River Valley; SCK = South Central Kansas; ARC = Agricultural Research Center.

# Nitrogen Fertilizer Source and Placement Effects on Grain Yield in No-Till Corn

*L.M. Bastos and C.W. Rice*

## Summary

Global nitrogen (N) fertilizer use in agriculture is projected to increase to meet increasing demand for food. Strategies that attempt to better match nutrient availability and plant needs, such as N fertilizer source and placement and the use of enhanced-efficiency fertilizers, are recognized as a means to avoid N losses and increase crop yield. The objective of this study was to assess the impact of an N source and its placement on corn grain yield. The treatments consisted of broadcast urea (BC-Urea), broadcast urea-ammonium nitrate (BC-UAN), broadcast coated urea (BC-CU), surface-banded UAN (SB-UAN), subsurface-banded UAN (SSB-UAN), subsurface-banded UAN + nitrification inhibitor (SSB-UAN+I), and a zero-N control. The treatments were arranged in a randomized complete block design with four replicates. The highest grain yields were obtained with SSB-UAN (170 bu/a) and SB-UAN (162 bu/a), whereas the lowest yield occurred in the control (62 bu/a). Fertilizer source and placement management have the potential to promote high yields in corn.

## Introduction

Nitrogen fertilizer management, including the correct rate, source, placement, and timing, has been recognized as a means to promote adequate yields while managing N losses to the environment (Snyder et al., 2009). Several studies have found that N fertilizer source and placement can affect N losses (Bijesh et al., 2013; Halvorson and Del Grosso, 2013; Venterea et al., 2011; Sistani et al., 2011) with little impact on grain yields.

The use of enhanced-efficiency fertilizers (EEF), such as a coated urea and nitrification inhibitors, affect how N is released to the crop. This is done in an attempt to match crop N demand and fertilizer supply in a timely manner and avoid losses to the environment (Olson-Rutz et al., 2009). Although some studies have found EEF to be effective in reducing losses, others have shown limited to no effectiveness (Sistani et al., 2011; Venterea et al., 2011; Parkin and Hatfield, 2010). Effects of EEF on grain yield are also varied. If effective, however, EEF can replace split-application practices. Assessing the best combination of N fertilizer source and placement for improved yields can be of use for farmers when determining a nutrient management plan based on crop return.

The objective of this study was to assess how different N fertilizer sources and placements affected corn grain yields in Northeastern Kansas.

## Procedures

The experimental site was located at the Kansas State University North Farm, Manhattan, KS. The experiment was established in May of 2013 on a moderately well drained Kennebec silt loam (Table 1). Corn planting and N fertilizer application were performed on May 16, 2013. The experiment was a randomized complete block design



with four replicates. The treatments consisted of broadcast urea (BC-Urea), broadcast urea-ammonium nitrate (BC-UAN), broadcast coated urea (BC-CU), surface-banded UAN (SB-UAN), subsurface-banded UAN (SSB-UAN), subsurface-banded UAN + nitrification inhibitor (SSB-UAN+I), and a zero-N control. All treatments were applied at a rate of 150 lb N/a. Corn ears were harvested from 50 ft<sup>2</sup> after black layer formation to estimate grain yield at 15.5% moisture content.

## Results

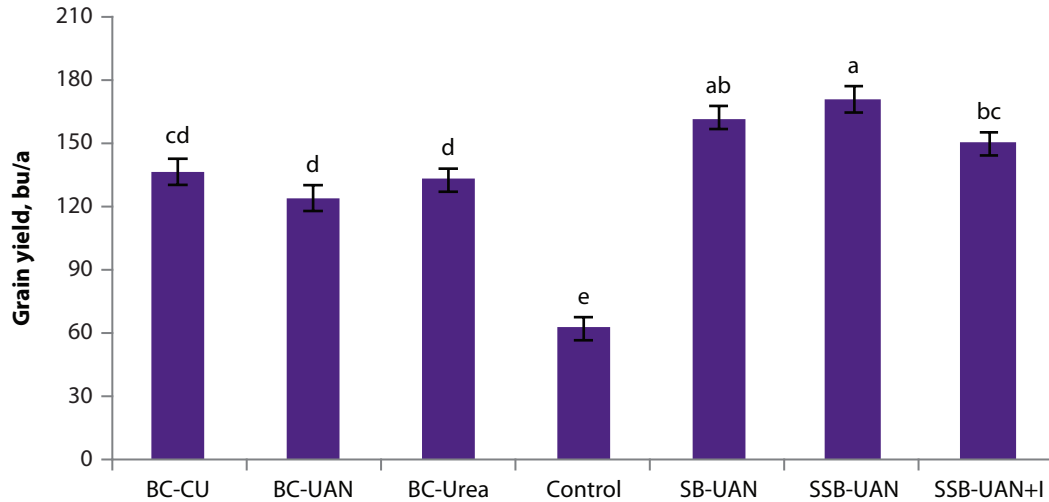
Grain yield differed depending on the treatment (Figure 1). Subsurface-banded UAN and surface-banded UAN were the highest-yielding treatments, followed by subsurface-banded UAN + nitrification inhibitor. Three out of four treatments that had UAN as the N source had the highest yields, suggesting that N source might affect grain yield in corn. The zero-N control was the lowest-yielding treatment. The use of nitrification inhibitor resulted in a lower grain yield compared with the fertilizer alone, but the nitrification inhibitor treatment had considerably lower N gas losses to the environment (data not shown). The use of coated urea did not promote additional yield compared to regular urea.

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**Table 1. Preplant soil test results at different depths**

Depth (in.)	pH	P (Mehlich-3)	----- ppm -----		
			K	NH <sub>4</sub> <sup>+</sup> -N	NO <sub>3</sub> <sup>-</sup> -N
0-2	7.4	43.7	465	0.45	0.25
2-4	7.0	11.4	325	0.46	0.16
4-8	6.9	10.5	235	0.42	0.09
8-12	6.8	12.9	198	0.42	0.07



**Figure 1. Grain yield for each treatment. Bars represent standard error. Treatments followed by a different letter were statistically significantly different ( $P < 0.05$ ).**

BC-CU = broadcast coated urea; BC-UAN = broadcast urea-ammonium nitrate; BC-Urea = broadcast urea; SB-UAN = surface-banded UAN; SSB-UAN = subsurface-banded UAN; SSB-UAN+I = subsurface-banded UAN + nitrification inhibitor.

# Use of Time of Application and Nitrification Inhibitors with Anhydrous Ammonia as Tools to Increase Nitrogen Use Efficiency in No-Till Corn

*T.J. Foster and D.B. Mengel*

## Summary

Two of the avenues of nitrogen (N) loss common in Kansas soils are denitrification and leaching. By minimizing these losses, producers can maximize corn yield with lower input costs and less impact on the environment. The use of nitrification inhibitors with anhydrous ammonia (AA) 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 AA as tools for reducing N loss from both fall and spring N applications. 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 yielding silt loam site at the East Central Kansas Experiment Field near Ottawa, KS, with a high potential for denitrification loss; and a high-yielding irrigated, coarse silt loam site near Rossville, KS, with a very high potential for leaching loss. Moisture was not extreme in the two years that the study was conducted, but periods of N loss were notable. As a result, differences in performance from when the N was applied and the use of a nitrification inhibitor was noted.

## Introduction

As input costs increase each year, methods to increase production efficiency, 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 AA. Ammonia is one of the cheapest sources of nitrogen fertilizer currently available to Kansas farmers and is widely used for corn production. The objectives of this study were to evaluate fall versus spring timing of AA applications and to compare two nitrification inhibitors as potential tools for reducing potential N loss. AA is beneficial because it enhances N use efficiency of the applied N by inhibiting the conversion of ammonia (less mobile N form) to nitrate (more mobile N form) until the plant has an opportunity to take up the N. This could increase the flexibility for timing of application of AA as well as decrease the potential for loss of N through denitrification or leaching. N-Serve, manufactured by Dow Chemical (Midland, MI), was compared with a new experimental nitrification inhibitor. The experimental product was applied at three different rates to determine the optimal level.

## Procedures

This study was initiated in the fall of 2011 and ended in 2013. This report discusses both years of site data collected. The study was conducted at three locations: Agronomy North Farm in Manhattan, KS; Kansas River Valley Experiment Station near Rossville, KS; and East Central Kansas Experiment Station near Ottawa, KS. All of the field plots were arranged in a randomized complete block design with four replications. Important information regarding each of the plots is summarized in Table 1.

Soil samples were taken in the fall prior to the growing season to measure the residual N level in the soil, as well as basic soil test levels for P, K, pH, and OM. 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.

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-ft measured travel area. All nitrification inhibitor treatments were applied at a 100 lb N rate at 6 mph to a depth of 4 in. Differing N rates were accomplished by changing the speeds of application from the 100 lb N/a rate calibrated at 6 mph. Due to calibration and distribution issues, however, the 50 lb N/a rate was calibrated to apply at 7 mph. In 2013, all speeds were increased 1 mph to assist in distribution of the inhibitors. N-serve was applied directly into the AA distribution system using a Raven Sidekick variable rate injection system (Raven Industries, Sioux Falls, SD) at a rate of 32 oz/a. The experimental NI product (Exp) was applied ½ in. behind the AA stream in the furrow. The different nitrification inhibitor rates were changed directly from the Sidekick monitor in the cab. Urea-ammonium nitrate (UAN) was applied using the Sidekick to balance N rates across all treatments and account for the differences in N content at different NI rates. 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 site in 2012–2013. The Ottawa location received a broadcast application of monoammonium phosphate (MAP) and potash one month prior to planting. At the Ottawa location in 2012, a broadcast application of 80 lb/a MAP, 80 lb/a KCl, and 9 lb/a ZnSO<sub>4</sub> were made over the entire study a few weeks prior to planting. In 2013 at Ottawa, 90 lb/a diammonium phosphate (DAP) was broadcast one day prior to planting. At Rossville in 2012, a broadcast application of 40 lb/a MAP, 20 lb/a potassium chloride (KCl), and 40 lb/a gypsum was made a couple of weeks prior to planting. 100 lb/a MAP was broadcast over the 2013 Rossville site late in the fall prior to the growing season.

Throughout the growing season, measurements were taken to evaluate crop performance. Ear leaves at silking, whole-plant samples approximately one week before black layer, and grain samples at harvest were collected to determine each treatment's performance. The procedure for collecting the ear leaves at R1 growth stage 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 R5.5. 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, which sampled two rows the length of the plot. At Manhattan, the plots were hand-harvested; 17.6 ft of two rows were hand-picked and machine-shelled. The 2012 Manhattan plots were only 10 ft × 45 ft, whereas the plots at all other study site years were 10 ft × 50 ft. Yield was adjusted to 15.5%

moisture. A complete list of the treatments, timings, and products is in Tables 2, 3, and 4.

Of the six site-years of data collected, all but Ottawa 2012 will be discussed. The Ottawa 2012 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. Three treatments were added in 2013, so 2012 will not have those units of data in the tables below.

## Results

All the locations had different outcomes due to the interacting factors such as weather, soil texture, and other soil characteristics. In the six site-years in which this study took place, different responses to yield and total N uptake were found each year. Reduced N uptake values and yields were seen under prolonged moisture events where leaching was extensive or denitrification was high.

In terms of the comparison between fall and spring preplant AA applications in corn, no significant difference was seen at any location except Rossville in 2012. Moisture at four of the six total sites during the winter period was minimal and had little effect on overall N losses. In 2012, Rossville experienced extensive fall N losses under the highly leachable environment in which the soil texture was coarse and organic matter (OM) content was very low. Rossville did not display the same loss effect in 2013 because of reduced moisture over the winter months and because a subsurface clay lens was present in the soil where the study that year was established. Nevertheless, in Kansas under moderate to low moisture conditions, fine-textured silt loams like those in Manhattan and Ottawa with 2–4% OM were able to hold the fall-applied N in the soil at levels that meant spring applications provided no added benefit or the benefit was very slight. Fall applications of N for corn on coarse-textured soils with low OM that have a high potential for N loss through leaching are not recommended in Kansas. Ottawa in 2013 received a much higher amount of moisture between fall and spring applications than Rossville in 2012 and still had no benefit from the use of spring applications compared with fall. Soil characteristics play a major role in this outcome. Finer textured soils have a higher cation exchange capacity (CEC), and the potential for N losses through denitrification are reduced under the lower temperatures from winter periods. Nitrification is also greatly reduced during the winter months, so N removal from the system is significantly diminished. Moisture, finances, and time are restricted commodities in Kansas, so methods to balance all these concerns are greatly desired.

The performance of N-Serve as a nitrification inhibitor when used with fall AA applications was quite variable. Only two sites benefitted from N-Serve. Manhattan, in 2012, received a significant benefit from N-Serve added to fall AA applications. One prolonged wet event that started a few days after application likely resulted in some N loss. As a nitrification inhibitor, N-Serve reduced the amount of N lost during that event. In 2013 at Ottawa, N-Serve applied in the spring also increased yield and total N uptake compared with the spring AA applied at the similar N rate. After spring applications, a prolonged wet period 10 days later moved N out of the profile via denitrification. N-Serve is a beneficial product that can be used as a risk management strategy. Previous research has shown it to work, but its performance is variable and its

success is not extensive under Kansas conditions. In 2 out of 12 applications made with N-Serve, performance was evident. Only one other site, Rossville in 2012, was expected to show increased performance because of a high N-loss situation, but because of the site's very low OM, the N-Serve likely moved away from the N applied, thus reducing performance. Under sandy soils with low OM, N-Serve would not be a proper use of resources. Sites with high potential N loss with more than 2% OM would be better potential targets for the use of N-Serve as a risk management strategy.

Assessment of the experimental nitrification inhibitor, Exp, as a valid tool for reducing losses of N was variable in results. On an individual site evaluation, N-Serve performed on 2 of the 12 total applications. The experimental product produced similar performance to N-Serve during the fall application at the Manhattan 2012 site. At the Manhattan site in 2013, the experimental product applied in the spring increased total N uptake compared with spring N alone at the 100 lb rate as well as compared with N-Serve; however, Exp did not provide improved or at least comparable performance at the Ottawa 2013 site, when N-Serve improved yields and total N uptake. Performance from inhibitor usage was not extensive in the six sites in which the study was implemented, mainly due to low levels of N loss. Similar results under sandy soils with low OM have been noted compared with N-Serve. Sandy soils are definitely not recommended for usage with Exp. Selecting the high rate or even making higher rate applications is recommended in future research to determine the effectiveness of the product.

Use of AA, timing of applications, amount or rates applied, and use of a nitrification inhibitor all play specific roles in an overall N management system. Each strategy is site-specific in its performance, however, and is based on future weather conditions. No accurate way to determine specific weather conditions for the growing season is currently available, so risk management tactics must be implemented to reduce losses. A balance between risk, profitability, time, and environmental impacts is of great concern and should be taken into consideration when implementing the strategies discussed above.

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**Table 1. Locations and important information about experiments**

Location	Manhattan		Rossville		Ottawa	
	2012	2013	2012	2013	2012	2013
Primary soils	Reading silt loam	Ivan-Kennebec silt loams	Eudora silt loam	Eudora silt loam	Woodson silt loam	Woodson silt loam
Irrigation?	No	No	Yes	Yes	No	No
Previous crop	Corn	Double-crop soybean	Double-crop soybean	Soybean	Double-crop soybean	Double-crop soybean
Corn hybrid	P1498HR (Pioneer)	DKC61-89RIB (Dekalb)	H-9138 3000GT (Golden Harvest)		DKC6269 (Dekalb)	552RR (Midland)
Plant population	28,600	27,500	25,000	30,400	21,300	26,500
Fall treatments	11/21/11	11/6/12	11/15/11	11/5/12	11/18/11	11/6/12
Spring treatments	3/15/12	4/4/13	4/16/12	4/5/13	4/17/12	5/17/13
Planted	4/10/12	4/30/13	4/23/12	4/29/13	5/9/12	5/18/13
Ear leaf sampling	7/1/12	7/9/13	7/2/12	7/12/13	7/16/12	8/1/13
Whole-plant sampling	7/23/12	8/21/13	7/24/12	8/19/13	-	9/5/13
Harvest	9/4/12	9/19/13	9/11/12	9/23/13	9/6/12	10/4/13

**Table 2. Results from the Manhattan sites**

Treatment	Nitrogen (N) rate	2012			2013		
		Ear leaf N	Total N uptake	Yield	Ear leaf N	Total N uptake	Yield
		%	lb/a	bu/a	%	lb/a	bu/a
Fall NH <sub>3</sub>	100	1.92	168	140	2.43	206	220
Fall NH <sub>3</sub> + Exp NI <sup>1</sup> 1x	100	2.17	186	156	2.39	222	232
Fall NH <sub>3</sub> + Exp NI 2x	100	1.92	183	156	2.46	219	233
Fall NH <sub>3</sub> + Exp NI 3x	100	1.86	179	155	2.45	211	227
Fall NH <sub>3</sub> + N-Serve <sup>2</sup>	100	2.02	184	154	2.41	203	219
Control	0	1.80	99	79	1.92	119	156
Spring NH <sub>3</sub>	50	1.80	146	130	2.21	174	201
Spring NH <sub>3</sub>	100	2.08	162	148	2.42	200	218
Spring NH <sub>3</sub> + Exp NI 1x	100	2.16	175	148	2.48	195	211
Spring NH <sub>3</sub> + Exp NI 2x	100	2.05	171	147	2.38	204	226
Spring NH <sub>3</sub> + Exp NI 3x	100	2.05	180	143	2.64	231	235
Spring NH <sub>3</sub> + N-Serve	100	2.02	182	151	2.43	217	235
Spring NH <sub>3</sub>	150	1.96	182	142	2.64	228	236
Spring NH <sub>3</sub>	200	2.12	190	148	2.48	249	245
Fall NH <sub>3</sub>	50	-	-	-	2.42	188	218
Fall NH <sub>3</sub>	150	-	-	-	2.41	220	234
Fall NH <sub>3</sub>	200	-	-	-	2.55	217	220
LSD (0.10)		0.16	17	12	0.21	17	16

<sup>1</sup> Experimental nitrification inhibitor.<sup>2</sup> Dow Chemical (Midland, MI).

**Table 3. Results from the Rossville sites**

Treatment	Nitrogen (N) rate	2012			2013		
		Ear leaf N	Total N uptake	Yield	Ear leaf N	Total N uptake	Yield
	lb/a	%	lb/a	bu/a	%	lb/a	bu/a
Fall NH <sub>3</sub>	100	2.40	155	155	2.65	201	224
Fall NH <sub>3</sub> + Exp NI <sup>1</sup> 1x	100	2.28	151	151	2.65	192	216
Fall NH <sub>3</sub> + Exp NI 2x	100	2.54	164	166	2.58	184	216
Fall NH <sub>3</sub> + Exp NI 3x	100	2.45	169	155	2.64	194	214
Fall NH <sub>3</sub> + N-Serve <sup>2</sup>	100	2.55	158	161	2.85	206	221
Control	0	2.08	123	110	1.87	109	129
Spring NH <sub>3</sub>	50	2.26	150	151	2.43	135	158
Spring NH <sub>3</sub>	100	2.54	184	180	2.78	198	225
Spring NH <sub>3</sub> + Exp NI 1x	100	2.64	173	175	2.51	207	216
Spring NH <sub>3</sub> + Exp NI 2x	100	2.52	188	171	2.64	201	219
Spring NH <sub>3</sub> + Exp NI 3x	100	2.45	174	165	2.81	205	225
Spring NH <sub>3</sub> + N-Serve	100	2.62	177	175	2.65	184	205
Spring NH <sub>3</sub>	150	2.64	200	189	2.80	195	218
Spring NH <sub>3</sub>	200	2.47	193	183	2.93	211	222
Fall NH <sub>3</sub>	50	-	-	-	2.32	149	185
Fall NH <sub>3</sub>	150	-	-	-	2.60	207	217
Fall NH <sub>3</sub>	200	-	-	-	2.60	190	208
LSD (0.10)		0.20	24	17	0.37	30	25

<sup>1</sup> Experimental nitrification inhibitor.<sup>2</sup> Dow Chemical (Midland, MI).

**Table 4. Results from the Ottawa sites**

Treatment	Nitrogen (N) rate	2012			2013		
		Ear leaf N	Total N uptake	Yield	Ear leaf N	Total N uptake	Yield
	lb/a	%	lb/a	bu/a	%	lb/a	bu/a
Fall NH <sub>3</sub>	100	-	-	-	2.03	96	102
Fall NH <sub>3</sub> + Exp NI <sup>1</sup> 1x	100	-	-	-	2.03	96	99
Fall NH <sub>3</sub> + Exp NI 2x	100	-	-	-	2.09	91	96
Fall NH <sub>3</sub> + Exp NI 3x	100	-	-	-	2.06	101	109
Fall NH <sub>3</sub> + N-Serve <sup>2</sup>	100	-	-	-	2.11	99	102
Control	0	-	-	-	1.33	49	46
Spring NH <sub>3</sub>	50	-	-	-	1.67	66	70
Spring NH <sub>3</sub>	100	-	-	-	2.06	100	100
Spring NH <sub>3</sub> + Exp NI 1x	100	-	-	-	2.00	96	101
Spring NH <sub>3</sub> + Exp NI 2x	100	-	-	-	2.11	97	95
Spring NH <sub>3</sub> + Exp NI 3x	100	-	-	-	2.03	96	98
Spring NH <sub>3</sub> + N-Serve	100	-	-	-	1.98	121	120
Spring NH <sub>3</sub>	150	-	-	-	2.21	126	121
Spring NH <sub>3</sub>	200	-	-	-	2.28	139	121
Fall NH <sub>3</sub>	50	-	-	-	1.87	74	85
Fall NH <sub>3</sub>	150	-	-	-	2.31	121	113
Fall NH <sub>3</sub>	200	-	-	-	2.41	131	104
LSD (0.10)		-	-	-	0.19	14	14

<sup>1</sup> Experimental nitrification inhibitor.<sup>2</sup> Dow Chemical (Midland, MI).

# Use of Time of Application and Nitrification Inhibitors as Tools to Reduce Nitrogen Loss 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 to 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. Nitrification inhibitors (NIs) used with ammonium N sources such as anhydrous ammonia (AA) is another. Reducing nitrification and keeping the N in the 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 NIs 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, winter, and spring precipitation varied widely across the locations and years but was generally limited in the late winter and early spring, key periods for N loss. In 2012, no difference was detected between fall ammonia and spring urea as methods of applying N to winter wheat, and using NIs with the AA also carried no advantages. In 2013, however, benefits to the use of a nitrification inhibitor as well as spring applications were noted.

## Introduction

As input costs increase each year, methods to increase production efficiency, 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 NI, to spring top-dress applications of urea as enhanced systems for applying N to winter wheat. The study also looked at the efficacy of two different NIs; N-Serve, produced by Dow Chemical (Midland, MI), and an experimental product from a second company. The experimental product was applied at three different rates to help in determining the optimal application level.

## Procedures

This study was initiated in the fall of 2011 and was ended in 2013. The study was conducted at three locations: the Agronomy North Farm in Manhattan, KS; Kansas River Valley Experiment Station (KRV) near Topeka, KS; and East Central Kansas Experiment Station near Ottawa, KS. All of the field plots were arranged in a randomized complete block design with four replications. Important information regarding each of the sites is summarized in Table 1.

Soil samples were taken in the fall of the growing season to measure the residual N level in the soil, as well as basic soil test levels for phosphorus (P), potassium (K), pH, and

organic matter (OM). 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 the 0–6-in., 6–12-in., 12–24-in., and 24–36-in. segments.

The fall AA treatments were applied approximately a 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 N/a at 6 mph using onboard weigh scales in a 300 to 600-ft measured travel area. N-Serve was applied directly into the AA distribution system using a Raven Sidekick variable-rate injection system (Raven Industries, Sioux Falls, SD) at a rate of 32 oz/a. The experimental NI was applied ½ in. behind the AA stream in the furrow, and rates were changed using the variable rate controller.

In 2012, starter fertilizer was applied with the drill at planting at a rate of 80 lb/a of MAP (40 lb/a P<sub>2</sub>O<sub>5</sub>) at the Manhattan and KRV 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). In 2013, 100 lb/a DAP was applied with the drill at planting at the Manhattan and KRV site. At the Ottawa location, a 50 lb/a starter application of 14-34-16 blend was applied with the drill; 100 lb/a of a 34-0-60 blend was broadcast 3 weeks after planting. In 2012, an N response curve was established in the spring at approximately Feekes 4 growth stage by broadcasting urea at rates of 30, 60, 90, 120 lb N/a. In 2013, a fall N curve was added. A complete description of the treatments with timings and products used can be found in Tables 2, 3, and 4.

Throughout the growing season, measurements were taken to evaluate crop performance. Flag leaves were taken at heading, and whole-plant samples were taken at late milk/early dough stage from each location. Fifty flag leaves were collected from outside the harvest area of each plot, dried, and analyzed by the Kansas State University Soil Testing Lab for percentage N. For whole-plant sampling, the vegetation from six linear feet of row was collected from each treatment, chopped, weighed, subsampled for drying and determination of dry matter content, and analyzed for whole-plant N content. Grain yield was collected from each location using a plot combine, harvesting a 5- or 6-ft section from the center of each plot for the length of the plot. The individual plot size used was 10 ft × 45 foot at Manhattan in 2012, and 10 ft × 50 ft at all other site years in 2012 and 2013. 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

Different outcomes resulted from each location in the six site-years of data collected for this study. In terms of fall application of AA preplant vs. spring application of urea as top-dress at Feekes 4, conclusions are site-specific. In environments with limited moisture, N loss mechanisms such as denitrification and leaching were reduced. Weather

patterns varied among the different sites across the two years. At the Manhattan sites, no added benefit was found from spring N applications, except for an increase in protein at the 60 lb N rate from spring applications. Losses from denitrification during the winter at both sites were minimal because of lower temperatures and a lack of moisture necessary for waterlogged, anaerobic conditions. As a result, only a slight increase in performance of the crop was seen from a later timing application. At the KRV site in 2012, data were collected, but no conclusions will be drawn because of many in-season complications. At the 2013 KRV site, however, leaching losses were noted. The soil was variable across the blocks and was much coarser than the other locations. A strong increase in performance was seen from spring applications due to the major losses of N from leaching observed through the winter months. This site was also irrigated directly after planting to improve germination and stand establishment, which may have assisted in N loss. The soil had a limited CEC and ability to hold N in the system for a prolonged period, so multiple timing applications later in season are normally recommended under these types of conditions. The last location utilized was the Ottawa site, where the soil was very poorly drained with high residue on the surface. Potential for ammonia volatilization from spring urea applications was high in 2013, leading to reduced yields and total N uptake. In 2012, both application timings were similar. No response was seen from in-season applications. In 2013, a strong performance after fall applications was observed at Ottawa. Overwinter N losses were minimal, and a large amount of N early in the season helped increase biomass levels before winter set. Between ammonia volatilization losses and a reduced biomass level in the spring, losses in yield and plant uptake were significant. As a result, fall N applications do play a role in Kansas agriculture. Spring applications are recommended under high-N loss environments; however, under low-N loss environments, a portion of N applied in the fall can increase yields. All N applied in the fall increases risk of loss, but losses were minimal under fine-textured silt loam soil conditions during the past two years in which the study was conducted.

The other objective included usage of NIs with fall applications to increase performance and reduce N losses. Only the 2013 KRV site showed extensive losses in N from fall applications due to its highly leachable soil. N-Serve did increase yield compared with fall N alone at KRV 2013 site. Yields were similar to spring N applications at the same N rate. N losses during the winter months at all other sites were greatly reduced because of a lack of moisture, but at the one location where N loss was high, N-Serve performed. Producers need to be mindful of soil type, because soils with very low OM (less than 1%) and very low levels of clay do not have the capacity to hold N-Serve or ammonium N in the profile. At the 2013 Manhattan and Ottawa sites, N-Serve increased protein content of the grain. This shows that some N losses were seen throughout the growing season, and that N-Serve did reduce loss. In the current market in which high protein content in winter wheat is not rewarded, N-Serve would not be profitable in dry, heavy-textured soil environments; however, as a risk management tool for those who decide to make fall AA applications, N-Serve showed acceptable results in 2013 across three sites.

Lastly, the experimental NI (Exp) compared with N-Serve showed similar results. At the site affected by high N loss and leaching (KRV 2013), performance was slightly reduced compared with N-Serve. At the Ottawa location in 2013, grain protein was significantly higher with N-Serve than with Exp. Performance was similar across other



sites, and Exp performance varied across rates and sites. The overall trend from all sites combined showed increasing performance with an increase in rate. The 3x rate displayed the best performance across the sites in terms of yield and total N uptake. Future research at higher rates will possibly provide more promising results, but the initial results observed in these studies are promising.

This research evaluated two alternative N management strategies, fall applications of AA or traditional spring applications of urea topdress as ways to increase yield, minimize N loss, and increase the nitrogen use efficiency of wheat in a time-sensitive production system. The results obtained suggest that N management strategies can play an important role in enhancing production and minimizing N loss to the environment, but the choice of management practices is a very site-specific tactic to employ. In the drier climate of Kansas, fall application of N can be an acceptable strategy on well drained, medium-textured soils. Nitrification inhibitors can also be a useful risk management tool in these situations. On high loss potential, sandy soils, however, particularly those with low soil organic matter, traditional topdressing, and potentially split spring application systems, would be preferred.

### **Acknowledgments**

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**Table 1. Locations and procedures of experiments**

Location	Manhattan		Kansas River Valley		Ottawa	
	2012	2013	2012	2013	2012	2013
Primary soils	Ivan-Kennebec silt loams	Ivan-Kennebec silt loams	Eudora silt loam	Eudora-Bismarckgrove silt loams	Woodson silt loam	Woodson silt loam
Previous crop	Soybean	Soybean	Soybean	Soybean	Soybean	Soybean
Tillage	No-till	No-till	No-till	No-till	No-till	No-till
Wheat variety	Everest	Everest	Everest	Everest	Everest	Everest
Seeding rate	110 lb/a	120 lb/a	110 lb/a	120 lb/a	120 lb/a	100 lb/a
Fall AA <sup>1</sup> applied	10/20/11	10/10/12	10/25/11	10/4/12	10/27/11	10/9/12
Planting date	11/3/11	10/19/12	11/5/11	10/11/12	10/31/11	10/19/12
Spring urea applied	3/17/12	3/29/13	3/17/12	3/20/13	3/17/12	3/20/13
Flag leaf sampling	4/18/12	5/20/13	4/19/12	5/20/13	4/19/12	5/18/13
Whole-plant sampling	4/30/12	6/3/13	4/30/12	6/3/13	5/4/12	6/6/13
Harvest	6/6/12	7/3/13	6/7/12	7/2/13	6/5/12	7/2/13

<sup>1</sup> Anhydrous ammonia.**Table 2. Results from the Kansas River Valley Experiment Field sites**

Treatment	Nitrogen (N) rate	2012			2013		
		Flag leaf N	Grain protein	Yield	Flag leaf N	Grain protein	Yield
		%	%	bu/a	%	%	bu/a
Fall NH <sub>3</sub>	60	3.42	16.25	23	3.14	10.80	64
Fall NH <sub>3</sub> + Exp NI <sup>1</sup> 1x	60	3.58	16.00	31	3.21	10.48	64
Fall NH <sub>3</sub> + Exp NI 2x	60	3.75	16.23	25	3.51	11.28	68
Fall NH <sub>3</sub> + Exp NI 3x	60	3.67	15.97	25	3.19	10.15	68
Fall NH <sub>3</sub> + N-Serve <sup>2</sup>	60	3.56	16.33	23	3.27	10.35	70
Control	0	3.48	16.50	11	3.17	11.15	50
Spring broadcast urea	30	3.89	15.73	17	3.23	10.85	69
Spring broadcast urea	60	3.97	16.94	15	3.33	10.63	72
Spring broadcast urea	90	3.89	17.06	24	3.64	11.40	79
Spring broadcast urea	120	3.95	17.69	18	3.90	12.35	78
Fall NH <sub>3</sub>	30	-	-	-	3.05	10.48	58
Fall NH <sub>3</sub>	90	-	-	-	3.34	10.98	76
Fall NH <sub>3</sub>	120	-	-	-	3.69	11.28	79
LSD (0.10)		0.29	0.75	9	0.30	0.71	6

<sup>1</sup> Experimental nitrification inhibitor.<sup>2</sup> Dow Chemical (Midland, MI).

**Table 3. Results from the Manhattan sites**

Treatment	Nitrogen (N) rate	2012			2013		
		Flag leaf N	Grain protein	Yield	Flag leaf N	Grain protein	Yield
	lb/a	%	%	bu/a	%	%	bu/a
Fall NH <sub>3</sub>	60	3.13	10.86	53	2.95	10.10	61
Fall NH <sub>3</sub> + Exp NI <sup>1</sup> 1x	60	3.04	10.87	53	2.93	9.88	63
Fall NH <sub>3</sub> + Exp NI 2x	60	3.03	10.77	50	2.78	10.18	57
Fall NH <sub>3</sub> + Exp NI 3x	60	3.1	10.86	51	3.12	10.45	67
Fall NH <sub>3</sub> + N-Serve <sup>2</sup>	60	3.17	10.85	52	3.29	11.17	59
Control	0	2.58	10.47	38	2.44	11.05	30
Spring broadcast urea	30	3	10.52	47	2.55	10.10	51
Spring broadcast urea	60	3.26	11.26	51	2.91	11.10	60
Spring broadcast urea	90	3.57	11.85	53	3.22	11.78	63
Spring broadcast urea	120	3.6	12.44	52	3.38	12.88	73
Fall NH <sub>3</sub>	30	-	-	-	2.49	10.03	45
Fall NH <sub>3</sub>	90	-	-	-	3.51	11.85	67
Fall NH <sub>3</sub>	120	-	-	-	3.61	12.73	77
LSD (0.10)		0.13	0.31	3	0.26	0.72	8

<sup>1</sup> Experimental nitrification inhibitor.<sup>2</sup> Dow Chemical (Midland, MI).**Table 4. Results from the Ottawa sites**

Treatment	Nitrogen (N) rate	2012			2013		
		Flag leaf N	Grain protein	Yield	Flag leaf N	Grain protein	Yield
	lb/a	%	%	bu/a	%	%	bu/a
Fall NH <sub>3</sub>	60	3.06	11.68	41	3.25	12.28	62
Fall NH <sub>3</sub> + Exp NI <sup>1</sup> 1x	60	3.13	12.07	42	3.44	12.55	62
Fall NH <sub>3</sub> + Exp NI 2x	60	3.15	11.78	40	3.35	12.45	61
Fall NH <sub>3</sub> + Exp NI 3x	60	3.09	11.84	42	3.39	12.73	61
Fall NH <sub>3</sub> + N-Serve <sup>2</sup>	60	3.24	11.94	44	3.33	13.45	59
Control	0	2.69	12.64	19	2.55	11.63	35
Spring broadcast urea	30	2.85	11.08	32	2.84	11.95	48
Spring broadcast urea	60	3.17	11.66	39	3.10	12.30	53
Spring broadcast urea	90	3.35	12.23	48	3.39	13.45	55
Spring broadcast urea	120	3.43	13.08	51	3.41	13.00	59
Fall NH <sub>3</sub>	30	-	-	-	3.00	11.43	54
Fall NH <sub>3</sub>	90	-	-	-	3.60	13.73	68
Fall NH <sub>3</sub>	120	-	-	-	3.80	14.05	69
LSD (0.10)		0.15	0.72	3	0.23	0.60	4

<sup>1</sup> Experimental nitrification inhibitor.<sup>2</sup> Dow Chemical (Midland, MI).

# Evaluation of Corn Yield Response to Nitrogen Application Timing and Rate

*A.R. Asebedo and D.B. Mengel*

## Summary

Nitrogen (N) management is becoming one of the more complex aspects of modern corn production. Changes in plant genetics, earlier planting dates, larger farm size, equipment innovations, increasing fuel and N costs, as well as concerns with potential environmental contamination all contribute to this increased complexity. Balancing time and financial resources in an effort to maximize yield and profitability while still being a good environmental steward has become difficult for producers. The purpose of this study was to evaluate the effects of different N management systems on yield and nitrogen uptake by corn. Results indicate increased N uptake and yield can be achieved by changing the time, rate, and number of N applications to coincide with corn N demand and the potential for N loss in the current growing environment.

## Objectives

- 1) Measure the impact of N rate and time of application (N management system) on yield, profitability, and N uptake in high-yielding corn production.
- 2) Determine if the use of split application systems utilizing crop sensors or professional agronomists' judgment of N need late in the growing season can improve NUE compared with a fixed-rate system using current N-rate recommendations applied early in the growing season.

## Procedures

Experiments were established at four locations in Kansas during 2013 in cooperation with Kansas producers and the Kansas State University Agronomy Experiment Fields. The Scandia, Partridge, and Rossville, KS locations are all department experiment fields and were irrigated, whereas the Sterling location was a cooperating farmer's field and was rainfed. Crop rotations, tillage, cultural practices, and corn hybrids utilized were representative of each area. Each field study utilized individual 10-ft × 40-ft research plots. Treatments consisted of five N rates that were applied in single or split applications at different times during the growing season with urea-ammonium nitrate solutions (UAN) as the N source (Table 1). Treatments were placed in a randomized complete block design with four replications.

Soil samples, to a depth of 24 in., were taken by block prior to planting and fertilization, and 0–6-in. samples were analyzed for soil organic matter, Mehlich-3 phosphorus, potassium, pH, and zinc (Table 2). The 0–24-in. samples were analyzed for nitrate-N, chloride, and sulfate. Fertilizer needs other than N were applied near planting, based on the results of these samples.

Canopy reflectance of the corn was measured multiple times throughout the growing season; V4, V6, V10, and R1 were key corn growth stages for measurement. Optical

sensors used were the Greenseeker (Trimble Navigation, Ag Division, Westminster, CO), the CropCircle ACS-470 (Holland Scientific, Lincoln NE), and the Rapid Scan (Holland Scientific). Wavelengths used were 660, 670, 700, 710, 735, 760, 770, and 780 nanometers (nm). Canopy reflectance was used to calculate the normalized difference vegetation index ( $NDVI = \frac{\text{near-infrared [NIR]} - \text{visible}}{\text{NIR} + \text{visible}}$ ) and was averaged for each plot.

Ear leaf tissue samples were taken at R1 (tasseling) and whole-plant samples at R5.5 (half milk line) and analyzed for N content. Grain yield was measured by machine harvesting an area of 5 ft × 40 ft within each plot at the Partridge, Scandia, and Rossville locations. Harvest area for the Sterling location was 5 ft × 17.5 ft, and these plots were hand-harvested. Yields were adjusted to 15.5% moisture, and grain was analyzed for N content by the Kansas State University Soil Testing Lab. Statistical analysis was conducted using SAS software PROC GLM (SAS Institute Inc., Cary, NC) with 0.1 alpha used for mean separation.

## Results

Results from these experiments are summarized in Tables 3, 4, 5, and 6.

Moderately high yields and good response to applied N were observed at Partridge (Table 3). The greatest yields were observed from V4 and R1 N applications, whereas V10 and at-planting N applications resulted in lower yields. The at-planting treatments resulted in lower yields and decreased efficiency due to the time of N application not matching crop demand and resulting in increased N loss. The V4 180 lb/a treatment (treatment 7) was able to maximize ear size and carry enough N in the soil profile to obtain the third-highest yield, thus showing a marked improvement in efficiency by shifting the N application time to better coincide with N demand. The R1 120 lb/a treatment (treatment 14) obtained the highest yield but was not statistically different from treatment 7. Sensor treatments at the V10 and R1 time underestimated N need considerably, thus resulting in severe reductions in yield. The agronomist estimation of N need made an accurate assessment and achieved high yield and efficiency at this site.

Excellent yields and a moderate response to applied N was observed at Rossville (Table 4). No statistical differences were observed in yield between at-planting, V4, and R1 N application times with N rates greater than 120 lb/a. Yield had an increasing trend, however, with the earlier at-planting and V4 N applications of 120 lb/a or greater N rates. This was because of prevention of N stress during ear size determination starting at V6, indicating that the lack of starter N and the 60 lb/a N rate applied at V4 for the split application treatments was not adequate to prevent N stress at ear size determination (V6) and carry the corn to the next N application time at R1. The coarse-textured soil at the Rossville location creates an environment prone to N leaching losses, thus resulting in an overall reduction in potential N use efficiency at this site. The R1 sensor treatment resulted in yields equal to the agronomist assessment with higher NUE.

Although moderate yield and N response was observed at the Scandia location (Table 5), severe weed pressure resulted in increased variance and significantly decreased yield. Statistical response to applied N was observed only with treatments 2, 1, and 11. The

greatest NUE coupled with high yields was observed from the agronomist's assessment. Sensor treatments underestimated N need and therefore resulted in reduced yield.

No response to applied N was observed at the Sterling location (Table 6). High yields for this dryland site were obtained across all treatments, with a yield range of 110–133 bu/a. This lack of N response was not predicted by the preplant profile N soil tests, indicating that mineralization of organic N from soil organic matter and crop residues was the likely source. This is a common observation in Kansas following a drought such as that observed in 2012. Differences in yield observed across the study were likely due to soil variation across the site, which led to differences in water availability.

The N loss potential of the discussed sites differed significantly, and this is an issue Kansas producers are likely to observe across their farms. Side-dress applications at V4 can offer a significant advantage in N efficiency and increase yields at locations with higher loss potential. Intensive N management systems could improve NUE without sacrificing yield by implementing split N applications that utilize late season R1 applications. However, it is important that adequate levels of N are applied in the early season to ensure the corn crop doesn't come under N stress during ear size determination and adequate N is present to carry the corn crop to R1. This is difficult to achieve under a fixed-rate system, thus emphasizing the value of a trained agronomist to help assess N need throughout the growing season and determine right time and rate of N application. Sensor technology offers the potential to assist agronomists and producers with assessing N needs, but continued research and development is needed to improve sensor-based algorithms (recommendation systems) before they are field-ready for corn production. Increased N efficiency and yield can be achieved by changing the time, rate, and number of N applications to coincide with corn N demand and the potential for N loss in the current growing environment.



**Table 1. Locations and important information about experiments**

Location	Sterling	Partridge	Scandia	Rossville
Soil type	Saltcreek and Naron Fine Sandy loams	Nalim loam	Crete silt loam	Eudora sandy loam
Previous crop	Soybean	Soybean	Soybean	Soybean
Tillage practice	No-till	Conventional	Ridge till	Conventional
Corn hybrid	35F-50 Refuge	DK 64-69		H9138 3000GT
Plant population (plants/a)	19,000	25,700	29,500	30,400
Irrigation	No	Yes	Yes	Yes
Residual NO <sub>3</sub> lb/a N	26	46	48	24
Planting date	4/30/13	4/30/13	5/16/13	4/29/13
First treatment at planting	4/30/13	4/30/13	5/16/13	4/29/13
Second treatment V4	6/7/13	6/7/13	6/11/13	6/6/13
Third treatment V10	6/24/13	7/1/13	7/5/13	6/24/13
Last treatment R1	7/10/13	7/10/13	7/18/13	7/12/13
Harvest date	9/21/13	10/10/13	10/25/13	9/23/13

**Table 2. Location soil analysis**

Location	Sampling depth (in.)	Sterling	Partridge	Scandia	Rossville
pH	0-6	5.1	6.4	5.6	7.6
Organic matter, %	0-6	1.5	1.7	2.5	1.1
Mehlich-3 P, ppm	0-6	27.4	17.2	9	30.1
K, ppm	0-6	318	190	481	212
Zn, ppm	0-6	0.99	0.9	1.51	1.9
NH <sub>4</sub> -N, ppm	0-6	11.6	2.9	22.2	3.1
NO <sub>3</sub> -N, ppm	0-6	2.3	6.9	9.1	4.2
NO <sub>3</sub> -N, ppm	0-24	3.4	3.7	6.6	6.3
Cl, ppm	0-24	6.2	67.4	10.1	9.1
SO <sub>4</sub> -S, ppm	0-24	5.1	8.3	12.1	4.4

**Table 3. Effects of nitrogen (N) application timing on corn grain yield and N uptake, Partridge, 2013**

Treatment	Starter N	Planting N	V4 N	V10 N	R1 N	Total N	Grain yield <sup>1</sup>	Total N uptake
							bu/a	lb/a N
14	22	0	60	0	120	202	192A	194AB
12	22	0	60	0	180	262	191A	211A
7	22	0	180	0	0	202	190AB	196AB
Agronomist	22	0	60	0	130	212	190AB	190BC
9	22	0	0	120	0	142	181BC	184BC
4	22	180	0	0	0	202	180CD	197AB
10	22	0	0	180	0	202	180CD	189BC
13	22	0	60	0	60	142	179CD	176CD
6	22	0	120	0	0	142	176CD	186BC
5	22	0	60	0	0	82	173CD	158DEF
3	22	120	0	0	0	142	173D	194AB
2	22	60	0	0	0	82	162E	162DEF
Sensor	22	0	60	0	0	82	161E	157EF
8	22	0	0	60	0	82	159E	174CDE
Sensor	22	0	0	92	0	114	156E	148F
1	22	0	0	0	0	22	154E	147F

<sup>1</sup> Results with the same letter are not statistically different at 0.1 alpha.

**Table 4. Effects of nitrogen (N) application timing on corn grain yield N uptake, Rossville, 2013**

Treatment	Starter N	Planting N	V4 N	V10 N	R1 N	Total N	Grain yield <sup>1</sup>	Total N uptake
lb/a N							bu/a	lb/a N
6	0	0	120	0	0	120	239A	222AB
7	0	0	180	0	0	180	238A	219AB
3	0	120	0	0	0	120	235AB	218AB
4	0	180	0	0	0	180	234AB	233A
13	0	0	60	0	60	120	231ABC	213BC
Sensor	0	0	60	0	0	60	230ABC	206BCD
12	0	0	60	0	180	240	230ABC	213BC
14	0	0	60	0	120	180	224BCD	210BCD
Agronomist	0	0	60	0	60	120	222BCD	211BCD
8	0	0	0	60	0	60	221BCDE	193DEF
5	0	0	60	0	0	60	219CDE	193DEF
2	0	60	0	0	0	60	217CDE	187EF
9	0	0	0	120	0	120	215DE	204BCDE
Sensor	0	0	0	198	0	198	212DE	206BCD
10	0	0	0	180	0	180	207EF	197CDE
1	0	0	0	0	0	0	194F	177F

<sup>1</sup>Results with the same letter are not statistically different at 0.1 alpha.

**Table 5. Effects of nitrogen (N) application timing on corn grain yield and N uptake, Scandia, 2013**

Treatment	Starter N	Planting N	V4 N	V10 N	R1 N	Total N	Grain yield <sup>1</sup>	Total N uptake
lb/a N							bu/a	lb/a N
7	20	0	180	0	0	200	189A	161ABCD
13	20	0	60	0	60	140	184AB	163AB
Agronomist	20	0	60	0	7.5	87.5	183AB	159ABCD
10	20	0	0	180	0	200	182AB	165A
4	20	180	0	0	0	200	181AB	163ABC
3	20	120	0	0	0	140	179ABC	167A
8	20	0	0	60	0	80	179ABC	149CD
Sensor	20	0	60	0	0	80	179ABC	158ABCD
5	20	0	60	0	0	80	178ABC	146DE
6	20	0	120	0	0	140	178ABC	156ABCD
9	20	0	0	120	0	140	177ABC	150BCD
14	20	0	60	0	120	200	176ABC	154ABCD
12	20	0	60	0	180	260	175BC	164A
2	20	60	0	0	0	80	166CD	150BCD
1	20	0	0	0	0	20	161D	131E
Sensor	20	0	0	45.5	0	65.5	158D	133E

<sup>1</sup>Results with the same letter are not statistically different at 0.1 alpha.

**Table 6. Effects of nitrogen (N) application timing on corn grain yield and N uptake, Sterling, 2013**

Treatment	Starter N	Planting N	V4 N	V10 N	R1 N	Total N	Grain yield <sup>1</sup>	Total N uptake
							bu/a	lb/a N
4	7	180	0	0	0	187	118A	147A
Agronomist	7	0	0	110	0	117	133A	145AB
12	7	0	60	0	180	247	129A	144ABC
3	7	120	0	0	0	127	115A	136ABCD
6	7	0	120	0	0	127	125A	136ABCD
2	7	60	0	0	0	67	117A	135ABCD
14	7	0	60	0	120	187	120A	135ABCD
Agronomist	7	0	60	0	0	67	123A	134ABCD
10	7	0	0	180	0	187	118A	132CD
7	7	0	180	0	0	187	116A	132BCD
9	7	0	0	120	0	127	120A	130CD
13	7	0	60	0	60	127	115A	126DE
1	7	0	0	0	0	7	110A	115EF
Agronomist	7	0	60	0	0	67	119A	114EF
5	7	0	60	0	0	67	117A	113EF
8	7	0	0	60	0	67	118A	109F

<sup>1</sup>Results with the same letter are not statistically different at 0.1 alpha.

# Phosphorus Soil Test Correlation and Calibration of the Mehlich-3 Phosphorus Soil Test for Soybean in Kansas

*R. Florence and D.B. Mengel*

## Summary

Kansas currently uses the Mehlich-3 soil test for phosphorus (STP), with a general critical level for all crops of 20 ppm. This critical level was established in 2003 based on field research, primarily with wheat, corn, and grain sorghum, conducted in the previous two decades. A review of the limited research data available from Kansas suggests that soybean may not require an STP level as high as wheat for optimum yield. Other universities and researchers suggest a critical level for soybean of less than 20 ppm (Table 1). Plant analysis is becoming a more common tool for attempting to diagnose plant nutritional needs. Sufficiency levels for uppermost fully developed trifoliates at the R4 growth stage have been reported as 0.26–0.5% P (Jones Jr. et al., 1990) and 0.31% P (Bell et al., 1995). Mallarino et al. (2013) did not find a good relationship between trifoliolate P percentage at R2–R3 and relative yield in Iowa. Establishing the relationship between trifoliolate P and STP or relative yield would be beneficial in identifying fields deficient in P. Application of P beyond requirements for current soybean needs has a significant impact on a farmer's budget.

## Objectives

- 1) Define the relationship between STP levels, soybean relative yield, and soil test correlation using both historical and current data
- 2) Determine the response to fertilizer likely at a given STP level and ST calibration and determine if a clear relationship exists between trifoliolate P percentage and STP or P fertilizer applications.

## Procedures

Each year the Kansas State University Department of Agronomy publishes fertilizer reports of ongoing studies. Results from soybean P fertilizer trials from 1966 through 1988 found in these reports were compiled as a source of historical data. From this historical data, a correlation graph was made of the check plot's relative yield vs. its corresponding Bray-P1 or Mehlich-3 colorimetric STP levels. Previous unpublished lab data in Kansas has shown Bray-P1 and Mehlich-3 colorimetric readings are similar on soils with pH <7. Field verification of the current STP critical level began in 2011. To date, a total of 16 field trials have been completed on a cooperating farmer's production fields and on university experiment stations. Mehlich-3 colorimetric STP levels varied from 3 to 56 ppm, with the majority of the sites testing from 8 to 25 ppm. In 2011 and 2012, 0–6-in. soil samples for P were taken by block to determine initial STP levels. In 2013, soil sampling was intensified to each individual plot. A randomized complete block design was employed with four replications at all locations. Individual plots were 15 ft (6–30-in. rows) × 40 ft minimum length. In 2011, two sites were conducted using broadcast P rates of 0, 20, 40, 60, and 80 lb/a P<sub>2</sub>O<sub>5</sub>. In both 2012 and 2013, seven

experiments were conducted each year with a sixth treatment of 100 lb/a  $P_2O_5$ . Broadcast P treatments were applied as granular monoammonium phosphate (MAP; 11-52-0 N-P-K) immediately after the field was planted by the cooperating farmer or research staff. Trifoliolate P percentage was determined from 30 sets of trifoliolate leaves, without petiole, at growth stage R4. Yield was determined by combine-harvesting the two center rows of each plot. Moisture was measured and yield normalized to 13% moisture. Relative trifoliolate P percentage and yield were calculated for each block's check plot and measured against the block's STP in 2011 and check plot's STP in 2013. Treatment differences for each site were determined with PROC GLIMMIX in SAS (version 9.2; SAS Institute Inc., Cary, NC) with blocks as random effects. Dollar return on fertilizer was calculated assuming MAP (11-52-0) cost \$549 per short ton and soybean brought \$12/bu. Data from 2012 are not presented because severe heat and drought limited yield. This work is ongoing, and an additional seven experiments are planned for 2014.

## Results

### *Yield analysis*

Historical data of unfertilized soybean control plot relative yields correlated to STP suggest that the current critical value of 20 ppm may be too high (Figure 1A). Trials in 2011 and 2013 show that the critical level may be as low as 12 ppm P (Figure 1B). These findings are in agreement with those from other area universities and researchers who suggest a critical level of 15 ppm P or less. Of the nine new sites studied, only two provide a statistically significant response to P fertilizer (Table 2): Woodson County in 2011 responded to 20 lb/a  $P_2O_5$  with STP of 5 ppm, and Atchison County in 2013 responded to 100 lb/a  $P_2O_5$  with STP of 11 ppm. No response was observed at Lyon Co. with STP of 8 ppm, which may be due to water-logging after several high-rainfall events. Douglas County did not respond to P fertilizer even though STP was 11 ppm.

### *Trifoliolate analysis*

On low-STP blocks, relative trifoliolate P concentrations appear to increase until about 12 ppm STP (Figure 2A). This relationship appears to mimic relative yield correlations to STP. When trifoliolate P is charted against relative yield, a positive but scattered relationship seems to exist (Figure 2B). These findings suggest that relative amounts of control plot trifoliolate P to sufficiently supplied P plots may help indicate that soil P is deficient. Exact P trifoliolate concentrations may lend evidence of sufficient P in plants for optimum yields at high trifoliolate P concentrations. Scattering of the data at low concentrations may not be a good indicator of whether yield will be optimal.

### *Economic analysis*

Application of P to responsive sites at Woodson County in 2011 and Atchison County in 2013 did provide a positive return over the check (Figure 3). At Atchison County, 100 lb/a  $P_2O_5$  increased return over the check by \$67/a. At Woodson County, 20 lb/a  $P_2O_5$  increased return by \$61/a, but further P application to 80 lb/a  $P_2O_5$ , with no increase in yield, provided a return over the check of \$18/a. Lyon County had a low STP but excessive rainfall, and ponding limited yield. This shows that, barring any weather hazards, applying P fertilizer on low-testing soils can be profitable.



## Acknowledgements

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**Table 1. Current soybean critical or sufficiency levels consider by north central U.S. universities and studies**

Source	Term used	Mehlich-3 or Bray-P1	Sample depth
		ppm	in.
Kansas State University	Critical level	20	6
North Dakota State University	Critical level	15	–
South Dakota State University	Critical level	15	–
University of Nebraska	Critical level	12	–
Dodd and Mallarino (2005)	Critical level <sup>1</sup>	12	6
Borges and Mallarino (2000)	No yield response	9	6
Iowa State University	Optimum	16–20	6
Michigan State University	Begin maintenance fertilizer	15–30	8

<sup>1</sup> Critical level by linear plateau model.

**Table 2. Soybean yield response to P fertilizer at two sites in 2011 and seven sites in 2013, listed in order of increasing soil test P level**

Location	Mehlich-3	lb/a P <sub>2</sub> O <sub>5</sub>						<i>P</i> -value
		0	20	40	60	80	100	
County	ppm	Yield (bu/a)						
Woodson 2011	5	32B <sup>1</sup>	38A	37A	37A	37A	–	0.07
Lyon	8	17	17	18	17	19	18	0.57
Douglas	11	43	43	41	43	46	45	0.90
Atchison	11	48B	41C	50B	48B <sup>2</sup>	53AB	58A	0.00
Woodson, upland	16	32	36	37	34	33	34	0.42
Woodson, lowland	16	60	61	61	61	60	61	0.76
Cherokee 2011	16	28	26	28	29	29	–	0.66
Riley, Manhattan	21	53	51	54	53	51	56	0.65
Riley, Randolph	23	56	59	57	59	58	62	0.32

<sup>1</sup> Letters indicate a significant difference at  $\alpha < 0.10$  using PROC MIXED (version 9.2; SAS Institute Inc., Cary, NC).

<sup>2</sup> Plot 203 removed.

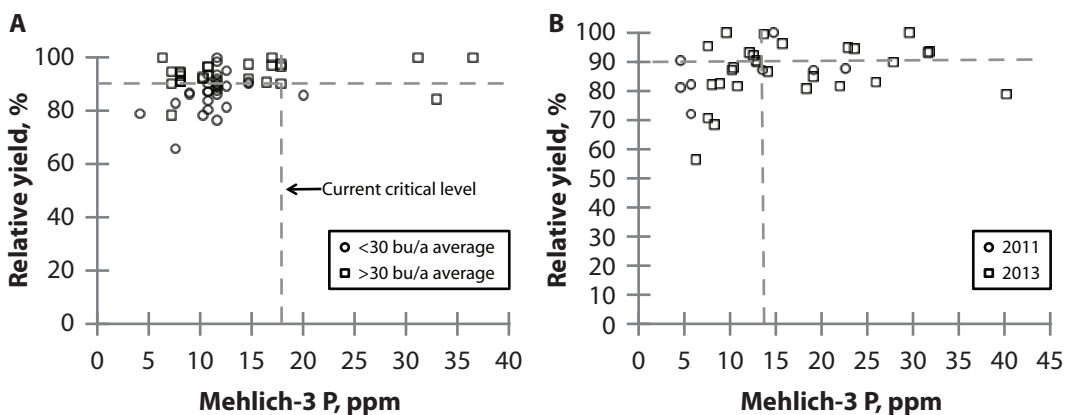


Figure 1A. Relative yield of control plots compared with STP level of Kansas P fertilizer trials from 1966 through 1988. Figure 1B. Relative yield of control plots compared with STP level of Kansas P fertilizer trials in 2011 and 2013.

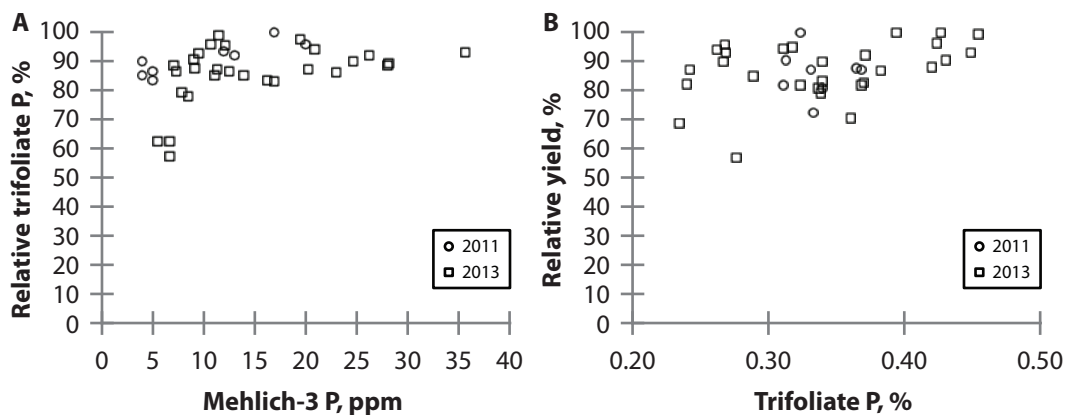


Figure 2A. Relative trifoliolate P percentage of control plots compared with STP for 2011 and 2013. Figure 2B. Relative yield of control plots compared with trifoliolate P percentage 2011 and 2013.

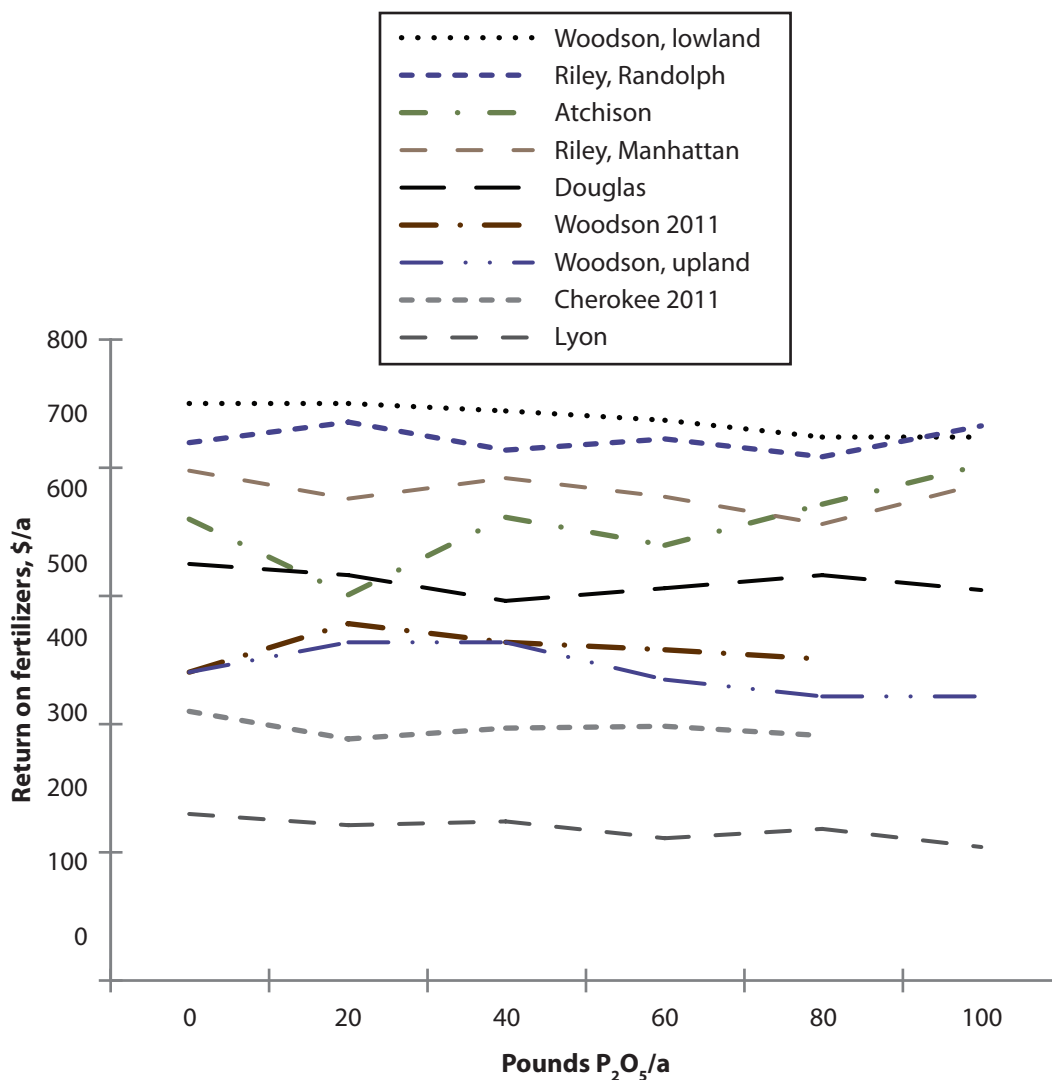


Figure 3. Return on fertilizer for nine sites in Eastern Kansas with varying soil test P and incremental rates of P<sub>2</sub>O<sub>5</sub> applied as monoammonium phosphate (MAP; 11-52-0 N-P-K) assuming MAP cost \$549 per short ton and soybean are \$12 per bushel. Return = (cost of fertilizer applied) – (yield income). Sites listed in order of highest fertilizer return at 100 lb/a P<sub>2</sub>O<sub>5</sub>.

# Correction of Sulfur Deficiency on Winter Wheat

*A.R. Asebedo and D.B. Mengel*

## Summary

In recent years, sulfur (S) deficiency in no-till wheat has become common in many areas of Kansas, particularly in North Central and Northeastern Kansas. Classic S deficiency symptoms, confirmed by soil and plant analysis, have occurred in many no-till wheat fields during periods of rapid growth in late spring, from spring greenup to jointing and stem elongation. The S-deficient wheat generally is yellow and stunted, and the problem is found in patches in the field, especially in areas where previous soil erosion has occurred. In severe cases, the plants will appear white. Distinguishing S deficiency from nitrogen deficiency is difficult.

Sulfur deficiencies occur for two reasons. First is a clear reduction in sulfur additions to the crop from atmospheric deposition and phosphorus fertilizer applications. The second is cooler soil temperatures as a result of no-till planting, which slows S mineralization. The net effect of these factors is a significant reduction in the crop-available S. One interesting observation is that the traditional profile 24-in. sample used for row crops to diagnose S status of soils may not be appropriate for wheat, because the problems seem to occur shortly after greenup in the spring before the wheat has rooted into the subsoil to utilize any S present.

In-season correction of sulfur deficiency requires the use of a sulfate fertilizer source because elemental S must be oxidized to sulfate by soil bacteria before it is available to plants. Common sources available include gypsum and ammonium sulfate (AMS). In the study described below, the addition of 20 lb of S as sulfate provided quick correction and proved cost-effective and highly profitable. At local spring prices for AMS, a 20-lb S application would have cost approximately \$20.75/a but would have delivered a \$70 increase in wheat sales per acre.

Regardless of the approach taken, S deficiency is an economic issue that needs to be addressed in many areas in Kansas.

## Objectives

- 1) Determine if the addition of sulfur fertilizer will give economic yield responses to sulfur-deficient winter wheat in early spring.
- 2) Determine the potential value of VitAg 16-0-0-17 (N-P-K-S), a biosolid-based sulfate fertilizer, as a sulfur source for S-deficient wheat.

## Procedures

A sulfur-deficient commercial wheat field was identified 25 miles northwest of Manhattan near Randolph, KS. As was typical of most sulfur deficiencies observed in winter

wheat, the symptoms were not uniform across the field, but rather consisted of a series of yellow, stunted areas interspersed within a dark green rapidly growing field.

A small plot field study was established on April 21, 2013. Small plots and a limited number of treatments were used due to the nature of the deficiency. Individual plot size used was 10 × 25 ft to allow plot combine harvest. The treatments were applied using a randomized complete block design with eight replications. Specific treatments used were (1) no fertilizer control, (2) 20 lb N as urea, (3) 20 lb N as urea plus 20 lb S as elemental S, (4) 20 lb N as AMS and urea plus 20 lb S as AMS, and (5) 20 lb N as VitAg 16-0-0-17 and urea, plus 20 lb S as VitAg.

The previous crop in the field in 2012 was soybean. The variety Everest was drill-seeded at a rate of 90 lb/a in mid-October. Twenty pounds of N and 40 lb of P<sub>2</sub>O<sub>5</sub> as a urea-monoammonium phosphate (MAP) blend were broadcast prior to seeding. An additional 60 lb of N as urea was broadcast on April 2, 2013. Finesse herbicide was applied for weed control. No fungicides or insecticides were used.

The field experiment was laid out in areas with the most consistent and uniform S deficiencies. Because of variability in color and growth, eight replications were used. Blocking consisted of randomizing the treatments in sets of two reps, 10 plots, in four areas with the most intense and uniform deficiency.

The fertilizer treatments were weighed in advance for each plot, mixed well, and broadcast by hand on April 21. At that time, normalized difference vegetation index (NDVI) was measured for each plot using a GreenSeeker II optical sensor to establish the relative yield potential of each plot and to make some estimate of the uniformity of the area. Plots were rescanned on May 2 to obtain a measure of response to the fertilizer treatments. This was deemed important because the overall color of the deficient areas was recovering, likely due to increasing rates of S mineralization as soil temperatures increased.

## Results

In early May, improved plant color and rapid growth response was evident where sulfate sulfur fertilizer had been applied. It was also visually clear that there was no response to the addition of N alone or to the addition of elemental S and N. Sensor measurements taken at the same time showed that the control, urea only, and urea plus elemental S treatments showed a modest increase in growth as indicated by increased NDVI from April 21 through May 1 (Table 1). NDVI increased from approximately 0.5 to 0.6 in these three treatments during that 10-day period. The VitAg and AMS treatments showed a substantially greater increase in growth and improvement in green color during that same time period. NDVI increased from approximately 0.5 to almost 0.7 for these treatments during that same 10-day period.

The experiment was combine-harvested using a Winterstieger plot combine on July 3, 2013. The yield results are summarized in Table 1.

Although the effects of the sulfur deficiency were partially mitigated through mineralization of organic S and likely deeper rooting as the soil warmed and the crop rooted

deeper looking for water during a dry late spring, a highly significant 12–13 bushel/a yield response to sulfate sulfur application was observed with both the applications of AMS and VitAg. This was clearly an S response, as no response was observed for N only. The need for available sulfate is also noted because the same rate of S applied as elemental S, the most common fertilizer S source used, provided no yield enhancement. This is likely due to the need for the elemental S to be oxidized to sulfate by soil bacteria prior to availability for uptake. If these same treatments had been applied in the fall prior to planting, it is likely that adequate time would have been available for the oxidation of the elemental S, and it would have been beneficial to the S-deficient plants. Other alternative sulfate fertilizer sources not tested in this study include gypsum, potassium sulfate, and ATS. Applications of elemental S in the fall with preplant broadcast fertilizer, or utilizing one of the S containing phosphate sources such as Mosaic's Microessentials 12-40-0-10 or Anchor D 12-40-0-7 are alternative options.

**Table 1. Increase in plant growth and yield due to sulfur (S) application, Randolph, 2013**

Treatment	Increase in NDVI <sup>1</sup> in 10 days	Yield, bu/a
Control	0.087	54
Urea only	0.094	54
Urea plus elemental S	0.109	56
Ammonium sulfate	0.187	66
VitAg	0.174	67
LSD 0.05		5

<sup>1</sup> Normalized difference vegetation index.



# Intensive Nitrogen Management of Grain Sorghum for Maximizing Grain Yield

*A.R. Asebedo and D.B. Mengel*

## Summary

Ammonia volatilization, denitrification, immobilization, and leaching are common nitrogen (N) loss mechanisms grain sorghum producers face in Kansas. These N loss mechanisms cause a reduction in N availability and yield and increase costs for Kansas grain sorghum producers. In 2013, a project was conducted at five locations in Kansas to evaluate different N management strategies for minimizing N loss and maximizing grain yield. The results from these trials suggest that those who wish to use early N application strategies and surface-apply N in high residue no-till production systems should consider a urease inhibitor such as Agrotain to minimize ammonia volatilization and increase nitrogen use efficiency (NUE). At sites with high loss potential from leaching or denitrification, producers should consider using split N applications and delaying the primary N applications to at least V2 growth stage or later. Intensive N management of productive dryland and irrigated grain sorghum can result in significant increases in grain sorghum yields.

## Objective

Determine under what conditions these products or practices would enhance N uptake in grain sorghum, thus maximizing grain yield.

## Procedures

This study was conducted in 2013 at three highly productive Kansas locations under irrigation (Scandia, Rossville, and Partridge, KS) and three dryland locations (Salina, Partridge, and Belleville). Each field study utilized small 10-ft × 40-ft research plots. Treatments were placed in a randomized complete block design with four replications.

Six factors for intensive N management were evaluated:

- Fertilizer placement
- Timing of fertilizer application
- N source
- The urease inhibitor NBPT, N-(n-butyl) thiophosphoric triamide applied in the products: Agrotain, Agrotain Plus, and Super U
- An NBPT urease inhibitor in combination with the nitrification inhibitor dicyandiamide (DCD) applied in the products Agrotain plus, and Super U
- A controlled-release polyurethane coated urea, ESN

Agrotain, Agrotain Plus, and Super U are produced and marketed by Koch Agronomic Services, Wichita, KS. ESN is a product of Agrium Fertilizers Inc., Calgary, Alberta, Canada.

Soil samples to a depth of 24 in. were taken by block prior to planting and fertilization; 0–6-in. samples were analyzed for soil organic matter, Mehlich-3 phosphorus,

potassium, pH, and zinc (Table 1). The 0–24-in. samples were analyzed for nitrate-N, chloride, and sulfate. Fertilizer needs other than N were applied near planting based on these soil samples.

Coulter band applications were applied at a depth of 2–3 in. in the row middles at rates of 30, 60, 90, 120, and 150 lb N/a. All other treatments were applied at an N rate of 60 lb/a. Broadcast applications of UAN solutions were sprayed using flat fan spray tips and a small tractor-mounted sprayer, and surface-banded UAN was applied using solid stream spray nozzles on 20-in. spacings. All dry materials were broadcast by hand. Additional data collected and not reported included flag leaf samples for N content at flowering and grain samples at harvest for moisture and N content. Plots were machine-harvested at all sites. Grain yield was adjusted to 13% moisture, and the grain was analyzed for N content. Statistical analysis was conducted using PROC MIXED in SAS with 0.1 alpha (SAS Institute Inc., Cary, NC).

## Results

The results from the Salina, Belleville, and Scandia locations are not reported because of extreme weather limiting N response and yield.

A significant response to applied N was observed at the Partridge irrigation site (Table 2). Applying N to two fully collared leaves (V2 growth stage) via coulter band produced the highest grain yield with N rates of 90 lb/a or greater. A response to the highest N rate, 150 lb N/a was obtained at this site. Broadcast preplant N (treatment 6) applications with urea-ammonium nitrate (UAN) as the N source resulted in the lowest yields out of all the applied treatments; however, the addition of Agrotain plus to the UAN significantly increased grain yield by 8 bu/a (treatment 7).

Nitrogen response to applied N was limited to 60 lb/a at the Partridge dryland site (Table 3). The use of Agrotain on urea applied preplant (treatment 3) resulted in an 11 bu/a increase over urea-applied preplant without Agrotain (treatment 2). Although this increase was not statistically significant, it was a strong upward trend in increasing grain yield. When making the same comparison of urea with or without Agrotain applied at V2 (treatments 9 and 10), the difference in grain yield between those treatments along with treatment 3 was less than 3 bu/a. Urea with no Agrotain applied at V2 (treatment 9), however, had a strong trend of increasing grain yield over preplant-applied urea without Agrotain (treatment 2). Treatments that used UAN as the N source had similar results, which shows delaying the N application or using products containing NBPT (urease inhibitor, Agrotain, Agrotain plus) or ESN had positive effects on grain yield.

Heavy N losses and high soil variability were observed at the Rossville irrigated location (Table 4). The Rossville site was a sandy loam soil and was conducive to leaching losses. Scattered throughout the study area, clay lenses located 24 in. or more in depth resulted in perched water tables that held up nutrients, thus slowing N leaching losses, but areas without these clay lenses experienced severe N losses. As a result, the yields obtained at this site reflect the absence or presence of a subsurface clay lens more than the difference due to N management practice utilized. For example, treatment 22, coulter-banded 150 lb/a applied N at V2, yielded only a 2-bu increase over treatment 1, the no-N check.

Results from the Partridge sites suggest that early N application strategies that surface-apply N should include a urease inhibitor product such as Agrotain to minimize ammonia volatilization and increase NUE. Sites with high loss potential should also consider delaying applications to at least V2 and/or conducting split N applications. Intensive N management of productive dryland and irrigated grain sorghum can result in significant increases in grain yield. Continuing research will be conducted in 2014 to evaluate N strategies with and without optical sensor technology.

**Table 1. Location soil analysis**

Location	Sampling depth (in.)	Partridge irrigation	Partridge dryland	Rossville	Scandia
Soil type	N/A	Nalim loam	Funmar-Taver loam	Bismarckgrove-Kimo complex	Crete silt loam
pH	0-6	7.0	5.9	5.4	6.2
Organic matter, %	0-6	2.3	1.5	1.9	2.2
Mehlich-3 P, ppm	0-6	12	67	25	13
K, ppm	0-6	258	334	235	555
Zn, ppm	0-6	1.0	N/A	N/A	N/A
NO <sub>3</sub> -N, ppm	0-24	5.1	4.2	15.5	7.3
Cl, ppm	0-24	51.7	4.4	9.7	16.4
SO <sub>4</sub> -S, ppm	0-24	13.0	6.1	6.5	12.4

**Table 2. Partridge irrigated location summary**

Treatment	Method	N source	Additive	Timing	N rate lb/a	Grain yield <sup>1</sup> bu/a
22	Coulter band	UAN	None	V2	150	152A
21	Coulter band	UAN	None	V2	120	143B
20	Coulter band	UAN	None	V2	90	139BC
13	Broadcast	AN	None	V2	60	138BCD
17	Surface band	UAN	Agrotain Plus	V2	60	136CDE
16	Surface band	UAN	None	V2	60	136CDE
12	Broadcast	Urea/ESN	None	V2	60	136CDE
11	Broadcast	Urea	Super U	V2	60	135CDEF
8	Broadcast	AN	None	Preplant	60	135CDEF
15	Broadcast	UAN	Agrotain Plus	V2	60	135CDEF
14	Broadcast	UAN	None	V2	60	135CDEF
19	Coulter band	UAN	None	V2	60	134CDEF
7	Broadcast	UAN	Agrotain Plus	Preplant	60	134CDEF
9	Broadcast	Urea	None	V2	60	134CDEFG
26	Broadcast	Urea	Agrotain	GS3	60	133CDEFG
2	Broadcast	Urea	None	Preplant	60	133CDEFGH
3	Broadcast	Urea	Agrotain	Preplant	60	132CDEFGH
25	Broadcast	Urea	None	GS3	60	132DEFGH
10	Broadcast	Urea	Agrotain	V2	60	131DEFGH
4	Broadcast	Urea	Super U	Preplant	60	131EFGH
18	Coulter band	UAN	None	V2	30	130EFGH
5	Broadcast	Urea/ESN	None	Preplant	60	130EFGH
24	Surface band	UAN	Agrotain Plus	GS3	60	129FGH
23	Surface band	UAN	None	GS3	60	127GH
6	Broadcast	UAN	None	Preplant	60	126H
1	NA	None	None	None	0	114I

<sup>1</sup> Grain yields with same letter are not statistically different, alpha = 0.1, LSD = 6.92 bu.

**Table 3. Partridge dryland location summary**

Treatment	Method	N source	Additive	Timing	N rate	Grain yield <sup>1</sup>
					lb/a	bu/a
15	Broadcast	UAN	Agrotain Plus	V2	60	158A
16	Surface band	UAN	None	V2	60	158A
21	Coulter band	UAN	None	V2	120	156AB
9	Broadcast	Urea	None	V2	60	154ABC
11	Broadcast	Urea	Super U	V2	60	154ABC
14	Broadcast	UAN	None	V2	60	153ABCD
3	Broadcast	Urea	Agrotain	Preplant	60	153ABCD
22	Coulter band	UAN	None	V2	150	153ABCD
7	Broadcast	UAN	Agrotain Plus	Preplant	60	152ABCD
19	Coulter band	UAN	None	V2	60	152ABCDE
10	Broadcast	Urea	Agrotain	V2	60	150ABCDEF
5	Broadcast	Urea/ESN	None	Preplant	60	149ABCDEF
12	Broadcast	Urea/ESN	None	V2	60	149ABCDEF
17	Surface band	UAN	Agrotain Plus	V2	60	147ABCDEF
20	Coulter band	UAN	None	V2	90	147ABCDEF
4	Broadcast	Urea	Super U	Preplant	60	146ABCDEF
18	Coulter band	UAN	None	V2	30	146ABCDEF
25	Broadcast	Urea	None	GS3	60	144BCDEF
26	Broadcast	Urea	Agrotain	GS3	60	143CDEF
6	Broadcast	UAN	None	Preplant	60	143CDEF
2	Broadcast	Urea	None	Preplant	60	142CDEF
24	Surface band	UAN	Agrotain Plus	GS3	60	141DEFG
23	Surface band	UAN	None	GS3	60	139EFG
1	NA	None	None	None	0	138FG
8	Broadcast	AN	None	Preplant	60	129G

<sup>1</sup> Grain yields with same letter are not statistically different, alpha = 0.1, LSD = 12.86 bu.

**Table 4. Rossville irrigated location summary**

Treatment	Method	N source	Additive	Timing	N rate	Grain yield <sup>1</sup>
					lb/a	bu/a
21	Coulter band	UAN	None	V2	120	165A
15	Broadcast	UAN	Agrotain Plus	V2	60	162AB
17	Surface band	UAN	Agrotain Plus	V2	60	158ABC
14	Broadcast	UAN	None	V2	60	157ABCD
16	Surface band	UAN	None	V2	60	156ABCD
26	Broadcast	Urea	Agrotain	GS3	60	154ABCDE
19	Coulter band	UAN	None	V2	60	153ABCDE
22	Coulter band	UAN	None	V2	150	153BCDE
11	Broadcast	Urea	Super U	V2	60	152BCDEF
1	NA	None	None	None	0	150CDEFG
6	Broadcast	UAN	None	Preplant	60	148CDEFG
25	Broadcast	Urea	None	GS3	60	148CDEFG
12	Broadcast	Urea/ESN	None	V2	60	146DEFG
20	Coulter band	UAN	None	V2	90	146DEFG
4	Broadcast	Urea	Super U	Preplant	60	144EFG
7	Broadcast	UAN	Agrotain Plus	Preplant	60	144EFG
10	Broadcast	Urea	Agrotain	V2	60	144EFG
24	Surface band	UAN	Agrotain Plus	GS3	60	142EFG
2	Broadcast	Urea	None	Preplant	60	141FG
23	Surface band	UAN	None	GS3	60	141G
18	Coulter band	UAN	None	V2	30	140G
9	Broadcast	Urea	None	V2	60	139G

<sup>1</sup> Grain yields with same letter are not statistically different, alpha = 0.1, LSD = 11.57 bu.

# Evaluation of Winter Wheat Yield and Protein Response to Nitrogen Fertilization Timing

*A.R. Asebedo and D.B. Mengel*

## Summary

Timing of nitrogen (N) fertilization is an important tool for optimizing yield and nitrogen use efficiency (NUE). There are two traditional methods for N fertilization: a full application in the fall or a split application with some N applied in the fall and the remainder in the early spring. Interest in creating and implementing more intensive N management practices in winter wheat to increase yield and NUE has increased. To optimize N management strategies, a timing study was established to evaluate the effects of full N applications in the fall and split applications that utilized late-season N fertilization in the spring on grain yield and protein. Results indicate that effective N applications can be made late in spring, at growth stages Feekes 7 through 9, and still obtain grain yield and protein levels equal or greater than those at Feekes 4 fertilization. This approach requires that an adequate level of N be available from the soil or fall fertilizer to support early spring growth. Kansas producers should consider a split application program that utilizes late-season N applications for their highly productive sites and/or for sites with greater potential for N loss. Delaying application of a portion of the fertilizer N until later vegetative growth stages offers more opportunities for evaluating growing conditions and yield potential of the wheat crop, which can enhance the efficiency of N management in winter wheat.

## Objectives

This study was conducted during the 2012–2013 growing season at five locations in Kansas: Pittsburg, McCune, Manhattan, Partridge, and Solomon. The objective was to evaluate grain yield and protein response to early and late-season N fertilization under different rates of fall-applied N.

## Procedures

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, normally 10 ft × 40 ft. Treatments consisted of multiple N rates (0, 30, 60, 90, and 120 lb/a) applied in single or split applications at different times during the growing season (Fall–Winter, Feekes 4, 7, and 9) with urea serving as the N source. Treatments were in a factorial arrangement and placed in a randomized complete block design with four replications.

Soil samples were taken to a depth of 24 in. prior to planting and fertilization; 0–6-in. samples were analyzed for soil organic matter, Mehlich-3 phosphorus, potassium, pH, and zinc (Table 1). The 0–24-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 × 37 ft within each plot at all



locations. Grain yields were adjusted to 12.5% moisture, and grain was analyzed for N content and protein. Data were analyzed using PROC MIXED in SAS with an alpha of 0.05 (2008; SAS Institute Inc., Cary, NC).

## Results

Results are summarized in Tables 2 and 3. At the Partridge location, heavy weed pressure and drought conditions were experienced during April. These conditions resulted in wheat becoming significantly water-stressed and created a yield-limiting environment. Fall soil test nitrate-N levels were at 62 lb/a, which proved a sufficient amount of N for maximizing yields in the water-limited conditions; therefore, no response to additional applied N was observed.

The McCune location had fall soil test nitrate-N levels of 197 lb/a. With these extremely high levels of residual N, no increase in grain yield was observed with applied N; however, additional applications of N resulted in lodging and grain yield loss due to excessive levels of biomass production. This result emphasizes the importance of utilizing soil testing and/or optical sensor technology for the regulation of biomass production and the prevention of overapplications of N.

The Pittsburg location experienced numerous heavy rainfall events during the spring that led to heavy denitrification. Yields in excess of 100 bu/a were observed from Feekes 4 to 7 fertilization, however, which indicates that the 120 lb/a total N rate was high enough to overcome the denitrification events and obtain maximum yield. Grain protein response was negligible but showed an increasing trend with late season N fertilization (Table 3). It is important to note that the Feekes 9 fertilization obtained yields that were 15 to 20 bu/a less than when N was applied earlier at Feekes 4 through 7. This result indicates that the wheat was N-stressed early and the Feekes 9 fertilization timing was too late to recover maximum yields.

The Manhattan location had low potential for N loss throughout the growing season, so we would not expect to see great benefits from late season N fertilization. The 120 lb/a N applied in the fall was able to obtain yields and protein levels as high as the spring applications (Table 2). The greatest yield response was observed by applying 90 lb/a N in the fall and 30 lb/a N at Feekes 7. Additional springtime N applications over 30 lb/a N did not give an additional yield response, but increasing spring N fertilization rates beyond 30 lb/a N did result in increased protein, with Feekes 9 fertilization providing the greatest improvement (Table 3).

Solomon had a potential for N loss through denitrification, immobilization, or both because of moderate levels of crop residue and heavier soil texture. Late-season N fertilization was clearly superior because it resulted in the greatest yields and protein levels through Feekes 9 fertilization (Tables 2 and 3). Late N fertilization exceeded early season Feekes fertilization by more than 15 bu/a.

The N loss potential at each of the discussed sites differed significantly. Many Kansas producers will observe similar differences across their farm due to soil and rainfall differences common across relatively small areas. Although a single N application applied in the fall may provide the maximum yield potential for a site, producers will have more

opportunities to evaluate the growing conditions and respond to N loss or yield potential changes by using a split application approach and delaying the last application to Feekes 7 or 8. When using this approach, however, it is critical that the wheat crop not come under N stress at early stages of growth, especially during Feekes 5, when the head size is being determined; otherwise, yield potential can be severely decreased as observed at the Pittsburg location with the Feekes 9 fertilization treatments (Table 2). Therefore, an increased rate of N will need to be applied in the fall or winter or both to ensure adequate N is available at Feekes 5.

Kansas producers should consider using split application systems that include late-season N applications for their highly productive sites or for sites with greater potential for N loss or for both. Late-season N fertilization offers opportunities for evaluating N loss and growing conditions and maximizing yield potential of the wheat crop and reducing the amounts of N utilized when N losses are low.

**Table 1. Location soil analysis**

Location	Sampling depth (in.)	Pittsburg	McCune	Solomon	Manhattan
Soil type	N/A	Cherokee silt loam	Parsons silt loam	Muir silt loam	Smolan silt loam
pH	0-6	7.0	4.6	5.9	6.9
Organic matter, %	0-6	1.8	1.9	2.6	2.4
Mehlich-3 P, ppm	0-6	22	24	34	44
K, ppm	0-6	130	140	133	401
Zn, ppm	0-6	1.3	4.7	0.8	1.3
NO <sub>3</sub> -N, ppm	0-24	11.6	27.3	5.7	1.3
Cl, ppm	0-24	23.3	20.6	3.3	4.0
SO <sub>4</sub> -S, ppm	0-24	4.0	9.5	7.3	5.7

**Table 2. Site grain yield summary<sup>1</sup>**

Fall	Feekes 4	Feekes 7	Feekes 9	Total nitrogen	Pittsburg yield	Manhattan yield	Solomon yield	Mean yield
----- N rate, lb/a -----					----- bu/a -----			
0	0	0	0	0	63E	41F	53F	52E
30	0	0	0	30	75DE	58E	59F	64D
60	0	0	0	60	81DC	65D	72E	73C
90	0	0	0	90	100A	70BCD	77CDE	83AB
120	0	0	0	120	93ABC	74AB	79CD	82AB
30	90	0	0	120	97AB	69CD	78CD	81AB
60	60	0	0	120	102A	72BC	76DE	83AB
90	30	0	0	120	100A	72BC	78CD	84AB
30	0	90	0	120	105A	71BC	83BC	86A
60	0	60	0	120	102A	70BC	80CD	84AB
90	0	30	0	120	97 AB	78A	78CD	84AB
30	0	0	90	120	85BCD	73BC	87AB	81AB
60	0	0	60	120	84BCD	73ABC	91A	83AB
90	0	0	30	120	81DC	73ABC	82BCD	79BC

<sup>1</sup> Yield results with same letter are not significantly different, alpha 0.05.

**Table 3. Site grain protein summary<sup>1</sup>**

Fall	Feekes 4	Feekes 7	Feekes 9	Total nitrogen	Pittsburg protein	Manhattan protein	Solomon protein	Mean protein
----- N rate, lb/a -----					----- % -----			
0	0	0	0	0	8.8H	10.5E	9.0EF	9.5H
30	0	0	0	30	9.2GH	10.3E	9.4F	9.3H
60	0	0	0	60	9.2GH	10.9DE	8.7F	9.6GH
90	0	0	0	90	10.3DEFG	11.3CDE	9.0EF	10.2FG
120	0	0	0	120	9.5FGH	12.7 AB	9.5DE	10.5EF
30	90	0	0	120	11.4ABCD	12.2BC	10.2C	11.3CD
60	60	0	0	120	11.1BCDE	12.6AB	9.6DE	11.1CDE
90	30	0	0	120	10.6 BCDEF	12.9AB	9.7CD	11.0CDE
30	0	90	0	120	11.4ABC	12.8A	10.2BC	11.5BC
60	0	60	0	120	10.0EFG	12.3BC	10CD	10.8CDEF
90	0	30	0	120	10.3DEFG	11.8BCD	9.5DE	10.6DEF
30	0	0	90	120	12.2A	13.5A	11.1A	12.5A
60	0	0	60	120	11.7AB	13.6A	10.9B	12AB
90	0	0	30	120	11.1BCDE	12.9AB	9.7CD	11.2CDE

<sup>1</sup> Protein results with same letter are not significantly different, alpha 0.05.

# Response to Phosphorus Rate and Placement after Long-Term Treatment Application

*C.L. Edwards and D.A. Ruiz Diaz*

## Summary

The objective of this study was to evaluate the effects of different placements and rates of phosphorus (P) fertilizer for corn and soybean. The study has been conducted at 3 locations since 2005, but only data from the 2013 year are presented here. Results from one year showed significant differences in grain yield for corn at two locations (Ottawa and Scandia). A significant treatment effect was also found at one location for soybean (Scandia). Corn grain yield was affected by P application rate and placement. Soybean yield response was affected by P application rate and placement at the low P fertilizer application rate. These results suggest that as soil test P decreases, the effect of fertilizer placement may become more significant, especially with low fertilizer rates.

## Introduction

No-till farming provides many benefits, including increased water-use efficiency and reduced soil erosion and on-farm energy use, and adoption of this system has increased significantly in recent years. However, some conditions of excessive residue accumulation, such as high-yielding irrigated fields, may require some level of tillage or residue management. Strip-tillage aims to combine no-tillage with conventional tillage so residue is incorporated in a narrow band and soil is loosened for planting, thus providing a good alternative for residue management. In the same pass, the addition of fertilizer in a deep band (6 to 8 in.) with strip-till allows for concentrated nutrients directly below the seed. When moisture is held in the topsoil in response to reduced tillage, uptake of P and other immobile nutrients from the soil surface can be increased.

Previous studies suggest that the P fertilizer rate has a greater effect on crop response than fertilizer placement under low soil-test P conditions, but placement may become more important under reduced-tillage systems such as no-till or strip-till. The effect of P rates and placement may also change over time as soil test levels change; therefore, long-term studies may provide a better estimation of the relative contribution of fertilizer rates and placement.

## Procedures

The experimental design was a randomized complete block design with four replications. Starter fertilizer was applied 2 × 2 in. for corn. Deep-band treatments were applied with the strip-till operation approximately 6 in. deep before planting corn using 10-34-0 (N-P-K). All other plots were strip-tilled to prevent tillage effects, even if P fertilizer was not applied. The strip-till operation was performed only before corn; soybean was planted without previous tillage. Broadcast application was applied on the soil surface before planting using triple superphosphate (0-46-0). Nitrogen (N) was applied as a deep-band application with urea-ammonium nitrate (UAN, 28-0-0) to balance N in all treatments, therefore preventing an N effect from the 10-34-0 fertilizer. Treatments are detailed in Table 1.

The center two rows of each plot were machine-harvested. Grain weight was recorded at the end of the growing season and adjusted to 155 and 130 g/kg moisture for corn and soybean, respectively. Data were analyzed by site and across site using site as a random variable for analysis. Corn and soybean yield parameters were analyzed using PROC GLIMMIX in SAS 9.1 (SAS Institute, Inc., Cary, NC, 2010) to determine if there was a significant response to P treatments. Treatment effects on least square means of corn and soybean yields were separated using Tukey's honestly significant difference test at a significance level of  $P = 0.10$ .

## Results

Based on initial soil tests taken in spring 2005, all locations show preexisting P stratification (Table 2). Crop response to P fertilization was expected at Scandia and Ottawa, but not at Manhattan. At the low rate, application of P fertilizer as a starter was shown to increase corn yields compared with broadcast (Tables 3 and 4). At high rates, corn yields were significantly greater with starter plus broadcast application than with a high rate that was only deep-banded. Soybean yield was more responsive to the treatments with high application rates (Table 5). These results suggest that low application rates may be below corn P removal rates and that soybean would require additional P fertilization. Soybean yield increased significantly with starter plus broadcast fertilizer application compared with starter that was deep-banded. At the Scandia location and across locations, the application of additional fertilizer before soybean planting contributed to an increase in average soybean yield.

**Table 1. Description of treatments**

Treatment	Total applied lb/a P <sub>2</sub> O <sub>5</sub>	Description
Control	0	Check plots
ST	20	Starter only
LOW BDCST	40	Broadcast only, low rate
LOW BDCAST+ST	40	20 kg broadcast + 20 kg starter, low rate
LOW BND	40	Deep-band only, low rate
LOW BND+ST	40	20 kg deep-band + 20 kg starter, low rate
HI BDCST	80	Broadcast only, high rate
HI BDCST+ST	80	60 kg broadcast + 20 kg starter, high rate
HI BND	80	Deep-band only, high rate
HI BND+ST	80	60 kg deep-band + 20 kg starter
HI BDCST+ST+SOY	120	60 kg broadcast + 20 kg starter + 40 kg broadcast soybean
HI BND+ST+SOY	120	60 kg deep-band + 20 kg starter + 40 kg broadcast soybean

**Table 2. Initial soil test data collected in spring 2005 before starting the experiment**

Depth	Manhattan			
	pH	Phosphorus	Potassium	Organic matter
--- in. ---		--- mg/kg---	--- % ---	
0-3	5.3	55.4	399	2.6
3-6	5.2	19.9	251	2.2
	Ottawa			
0-3	5.7	9.4	152	3.0
3-6	5.9	5.8	157	2.7
	Scandia			
0-3	6.8	9.5	585	2.8
3-6	6.3	5.7	445	2.3

**Table 3. Significance of F-values for the effect of treatments on corn and soybean yield**

Crop	Manhattan	Ottawa	Scandia	Average
	----- P < F -----			
Corn	0.488	0.050	<0.001	0.004
Soybean	0.833	0.234	0.002	0.284

**Table 4. Grain yield for corn as affected by phosphorus rates and placement treatments**

Treatment	Manhattan	Ottawa	Scandia	Average
	----- bu/a -----			
Control	134 abc <sup>1</sup>	105c	174f	136d
ST	133abc	125ab	203cd	154ab
LOW BDCST	126abc	118b	184ef	142cd
LOW BDCAST+ST	121bc	129a	209bcd	154ab
LOW BND	140ab	124ab	197de	153b
LOW BND+ST	140ab	127ab	224ab	164a
HI BDCST	135abc	121ab	199de	151bc
HI BDCST+ST	127abc	123ab	218abc	157ab
HI BND	143a	122ab	197de	153ab
HI BND+ST	122abc	123ab	212bcd	153ab
HI BDCST+ST+SOY	114c	122ab	233a	158ab
HI BND+ST+SOY	137ab	124ab	219abc	160ab

<sup>1</sup> Different letters within a column are statistically different at the 0.1 probability level.

**Table 5. Yield for soybean as affected by phosphorus rates and placement treatments<sup>1</sup>**

Treatment	Manhattan	Ottawa	Scandia	Average
	----- bu/a -----			
Control	29ab	44a	60f	44d
ST	26ab	40bcd	71de	46bcd
LOW BDCST	27ab	44a	70e	47abcd
LOW BDCAST+ST	26ab	42abcd	73bcde	47abcd
LOW BND	25ab	40bcd	76abcd	47abcd
LOW BND+ST	28ab	43ab	72cde	47abc
HI BDCST	27ab	42abc	78ab	49ab
HI BDCST+ST	20b	42abcd	72cde	45cd
HI BND	22ab	43ab	76abcd	47abcd
HI BND+ST	23ab	39cd	73cde	15cd
HI BDCST+ST+SOY	25ab	39d	77abc	47abcd
HI BND+ST+SOY	30ab	41abcd	80a	50a

<sup>1</sup>Different letters within a column are statistically different at the 0.1 probability level.



# Evaluation of Fertilizer Equivalent Value of Cellulosic Ethanol By-Product under Field Conditions

*D.A. Ruiz Diaz, G. Hettiarachchi, and D.B. Mengel*

## Summary

This study evaluates the fertilizer equivalent value of cellulosic ethanol by-product applied at field conditions for crop production. Field studies were established at two locations, but results from one location (Hutchinson) were invalid because grain yield was zero for most plots owing to severe drought. Growth and yield at the second location (irrigated) was optimal during the season. The parameters evaluated suggest equivalent nutrient supply from the by-product and commercial fertilizer. Furthermore, results indicated no negative effect on plant establishment and population. Nutrient analysis of the by-product is necessary for precise application rate. In our study, we found slightly lower nutrient concentration at the moment of application compared with previous analysis. Despite no statistically significant differences, this application generated average lower values of leaf nitrogen concentration and grain yield from the by-product treatment. Results indicate that the by-product has plant-available nutrients equivalent to commercial fertilizer under similar application. Precise application rate of by-product in the field can be affected by variability of the material (which requires laboratory analysis) and accurate field calibration.

## Introduction

Iogen is a cellulosic biofuels developer. The Iogen cellulosic biofuel process produces a by-product that contains nitrogen, potassium, and sulfur at levels that can serve as soil nutrients and potentially provide benefit to crops. Iogen confirmed these benefits by working in conjunction with Kansas State University to complete greenhouse and field trials where the by-product was land-applied. This report summarizes the results of the field trials.

The objectives of this study were to (1) evaluate corn plant population in the field as affected by commercial fertilizer and by-product, (2) measure early corn biomass and total nutrient uptake (nitrogen, phosphorus, potassium, and sulfur [N, P, K, S]) at the V6 growth stage as affected by commercial fertilizer and by-product, (3) evaluate corn grain yield levels with the use of by-product as a nutrient source, and (4) evaluate the fertilizer equivalent value of by-product applied at field conditions for crop production.

## Procedures

Fertilizer and by-product were applied at 5 rates to corn based on N (0, 50, 100, 150, and 200 lb N/a). Nitrogen fertilizer was applied as urea, and sulfur fertilizer was applied at equivalent rates supplied by the by-product using ammonium sulfate. Commercial fertilizer was incorporated similarly to the by-product. All fertilizer and by-product treatments were applied preplant. Individual plots in the field were 15 × 50 ft. A chisel was used to form ridges in the soil, and liquid by-product was manually applied to ensure uniformity. A disk operation followed to level the soil and incorporate the

by-product and fertilizer. Experimental design consisted of a randomized complete block with 4 replications. Statistical analysis was completed using PROC GLIMMIX in SAS (SAS Institute, Inc., Cary, NC).

Soil pH was measured in 1:2 soil:water extract (Watson and Brown, 1998). Soil-soluble salts were extracted using 1:2 volume soil extraction and electrical conductivity (EC) of the extraction measured using Mettler Toledo Inlab 731 electrode. Cation exchange capacity (CEC) was determined using summation methods described by Chapman (1965). Available fraction of N in soils was extracted using 1 M KCl and analyzed by spectrophotometry, as described by Keeney et al. (1982). Available K was extracted by 1 M  $\text{NH}_4\text{CH}_3\text{COOH}$  (pH=7.0) and analyzed using a flame atomic absorption spectrometer (flame-AAS). Available P in soils was determined following Mehlich-3 P procedure described by Frank et al. (1998) and analyzed using an inductively coupled, plasma-atomic emission spectrometry (ICP-AES). Organic matter content was determined by following the modified Walkley-Black method (Walkley and Black, 1934) as described by Combs and Nathan (1998).

At V6 growth stage, aboveground plant parts were harvested and weighed for the fresh weight. Plant materials were washed to remove soil particles and dried in a forced-air oven at 60°C for 4 days (or until constant weight was achieved). Once dried, plants were ground with a Wiley grinder and stored in appropriate airtight vials until digestions. Subsamples of ground plant materials were digested using a sulphuric acid and hydrogen peroxide method (Thomas et al., 1967) and analysed with ICP-AES for N, P, and K. Another subsample of ground plant material was digested using  $\text{HNO}_3$  and  $\text{HClO}_4$  (Blanchar et al., 1965) and analyzed for S by ICP-AES.

At Hutchinson, corn was planted using Pioneer 1151HR Aquamax hybrid. The field was sprayed with Harness Xtra (Monsanto, St. Louis, MO), dicamba, and glyphosate. Uneven crop development was observed due to poor soil moisture during planting. Post-emergent herbicide included Laudis (3 oz/a) and Roundup Weathermax (32 oz/a). At Rossville, the corn hybrid used was Dekalb 6323, and the previous crop was corn.

## Results and Discussion

Soil analysis prior to treatment application showed significant differences in soil type and texture, as well as nutrient concentration (Table 1). The Rossville location was relatively high in sand, and the Hutchinson location was high in silt (medium-fine textured soil). Severe drought affected most of Kansas during the 2012 growing season, which significantly affected plant growth at the Hutchinson location, so only results from the irrigated location (Rossville) will be discussed here.

Nitrogen application rates were estimated based on previous analysis; however, samples collected at the moment of application showed lower concentration and therefore lower final N application (Tables 2 and 3). This would explain some of the lower average N concentration in leaf tissue with the by-product treatment at some application rates. This may also resulted in lower grain yield, especially at the higher rates (Figure 5). Analysis of variance indicated that plant population was not affected by the application of fertilizer or by-product (Table 4 and Figure 1). This suggests that a negative effect

is not expected on seed germination and early plant establishment from fertilizer or by-product. Nutrient concentration in leaf tissue increased with increased application rates for N, P, and S (Table 4 and Figure 2), but there was no statistically significant difference between commercial fertilizer and the by-product. This result indicates that nutrient supply and plant availability are similar for these sources. Potassium concentration also showed an increase in concentration with an increased N application rate, but this effect was not statistically significant.

SPAD meter readings (chlorophyll meter) showed similar responses to both sources because of an increase in values coupled with an increase in application rate (Table 4 and Figure 4). SPAD meter readings provided an index of chlorophyll level in the corn leaf tissue, and this value is indicative of N level in the leaf. Low N supply will reflect in low SPAD meter readings. No SPAD difference between fertilizer and by-product indicate a similar N supply to the corn from both sources.

Leaf tissue collected at the tasseling stage (ear leaf) was analyzed for the main nutrients (Table 5). Results were similar for tissue analysis collected at the V6 growth stage (Table 4 and Figures 2 and 3), which indicates that N and S supply late in the season was significant from both fertilizer and by-product and there was no difference between sources (Figure 3). Phosphorus levels in the tissue were similar to those at V6 and were likely affected primarily by increase in N supply. Higher N rates also promote higher growth and P uptake.

Grain yield response was significantly affected by application rate (Table 4), with a significant increase in corn grain yield with the increase in N application rate (Figure 5). Statistical analysis shows no difference between N sources, but grain yield with the by-product averaged lower (Figure 5). These differences were due to the lower final N application rates with the by-product.

## Conclusions

Results from this study showed that the by-product material evaluated under field conditions provides similar levels of plant-available nutrients. Plant response including grain yield showed response similar to commercial fertilizer, so no adjustments need to be made based on plant availability assuming similar application methods and accurate rates.

Results indicate no negative effect on plant establishment and population early in the season with the application rate used in this study. Seed damage is possible with commercial fertilizer when application is in direct contact with the seed. Higher by-product application rates in direct contact with the seed could generate effects similar to commercial fertilizer, so by-product material should be applied following guidelines similar to those used for commercial fertilizer under field conditions.

Variability in nutrient analysis in by-product materials can be a factor to consider for precise application rates. In our study we found slightly lower nutrient concentration at the moment of application compared with previous analysis. Despite no statistically significant differences, this generated some average lower values of leaf N concentration for the by-product treatment and grain yield.

Results from this study showed that the by-product has plant-available nutrients equivalent to commercial fertilizer with similar applications. Precise application rates of by-product in the field can be affected by variability of the material (which requires laboratory analysis) and accurate field calibration. These studies confirm that land application of the by-product from cellulosic biofuels process is feasible, has no negative effects on plant establishment and population, and offers nutrient supply to the soil and crops equivalent to commercial fertilizer.

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**Table 1. Soil parameters at the two study locations before treatment application**

Parameter	Location	
	Hutchinson	Rossville
pH	5.2	6.8
Soil test phosphorus (ppm)	89	24
Soil test potassium (ppm)	302	114
CEC <sup>1</sup> (meq/100g)	20.6	4.5
NH <sub>4</sub> -N (ppm)	7.0	7.4
NO <sub>3</sub> -N (ppm)	7.3	3.7
Organic matter (%)	2.0	0.9
EC (mS/cm)	0.25	0.22
Sand (%)	27	80
Silt (%)	50	15
Clay (%)	23	5

<sup>1</sup> Cation exchange capacity.

**Table 2. Nutrient analysis of by-product used for the study; samples were collected immediately before application**

Nutrient	Location	
	Hutchinson	Rossville
Total nitrogen (%)	4.8	4.8
Phosphorus (%)	0.3	0.3
Potassium (%)	0.5	0.5
Calcium (%)	0.05	0.05
Magnesium (%)	0.5	0.5
Sulfur (%)	1.7	1.7
Copper (ppm)	4	4
Iron (ppm)	15	13
Manganese (ppm)	73	72
Zinc (ppm)	0.6	1.0

**Table 3. Final nitrogen application rate, adjusted based on sample analysis collected at the time of application**

Treatment	Fertilizer	By-product
	----- lb/a -----	
1	50	41
2	100	83
3	150	124
4	200	166

**Table 4. Significance of F-values for treatment effects on corn plant population, yield, chlorophyll meter (SPAD), and tissue nitrogen, phosphorous, potassium, and sulfur<sup>1</sup>**

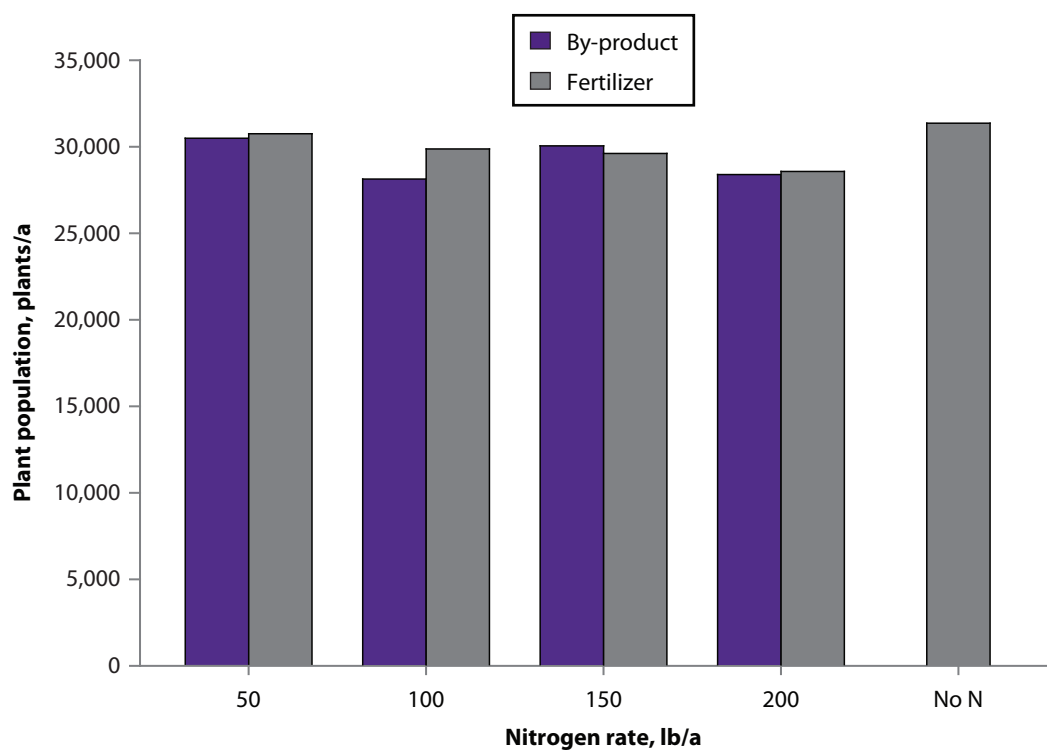
Fixed effect	Plant						
	population	Leaf N	Leaf P	Leaf K	Leaf S	SPAD	Yield
	----- P > F -----						
Nutrient source (S)	0.545	0.261	0.179	0.515	0.838	0.295	0.413
N rate (R)	0.187	0.001	0.001	0.128	0.001	0.008	0.013
S × R	0.737	0.474	0.136	0.125	0.975	0.709	0.661

<sup>1</sup> Statistically significant difference was established at  $P < 0.05$ . Values below 0.05 indicate statistically significant effect of the treatment factor.

**Table 5. Significance of F-values for treatment effects on ear leaf tissue nitrogen, phosphorus, potassium, and sulfur; samples were collected at the tasselling stage<sup>1</sup>**

Fixed effect	Ear leaf N	Ear leaf P	Ear leaf K	Ear leaf S
	----- P > F -----			
Nutrient source (S)	0.261	0.179	0.515	0.838
N rate (R)	0.001	<0.001	0.128	0.001
S × R	0.474	0.136	0.125	0.975

<sup>1</sup> Statistical significant difference was established at  $P < 0.05$ . Values below 0.05 indicate statistically significant effect of the treatment factor.



**Figure 1. Plant population as affected by fertilizer and by-product application rate based on N content. No N indicates no fertilizer or by-product application (control).**

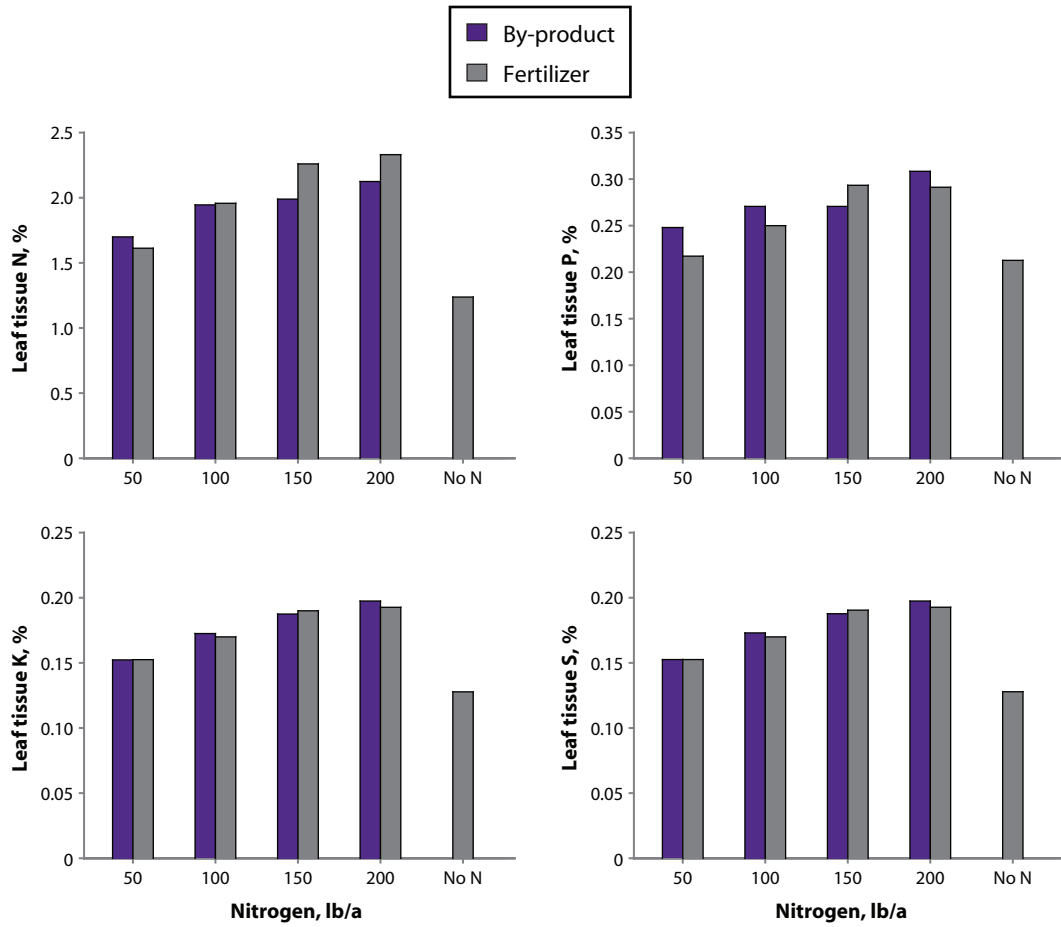


Figure 2. Leaf nitrogen, phosphorus, potassium, and sulphur concentrations as affected by application rate and nutrient source at the V6 growth stage. Units are percentage of dry weight. No N indicates no fertilizer or by-product application (control).



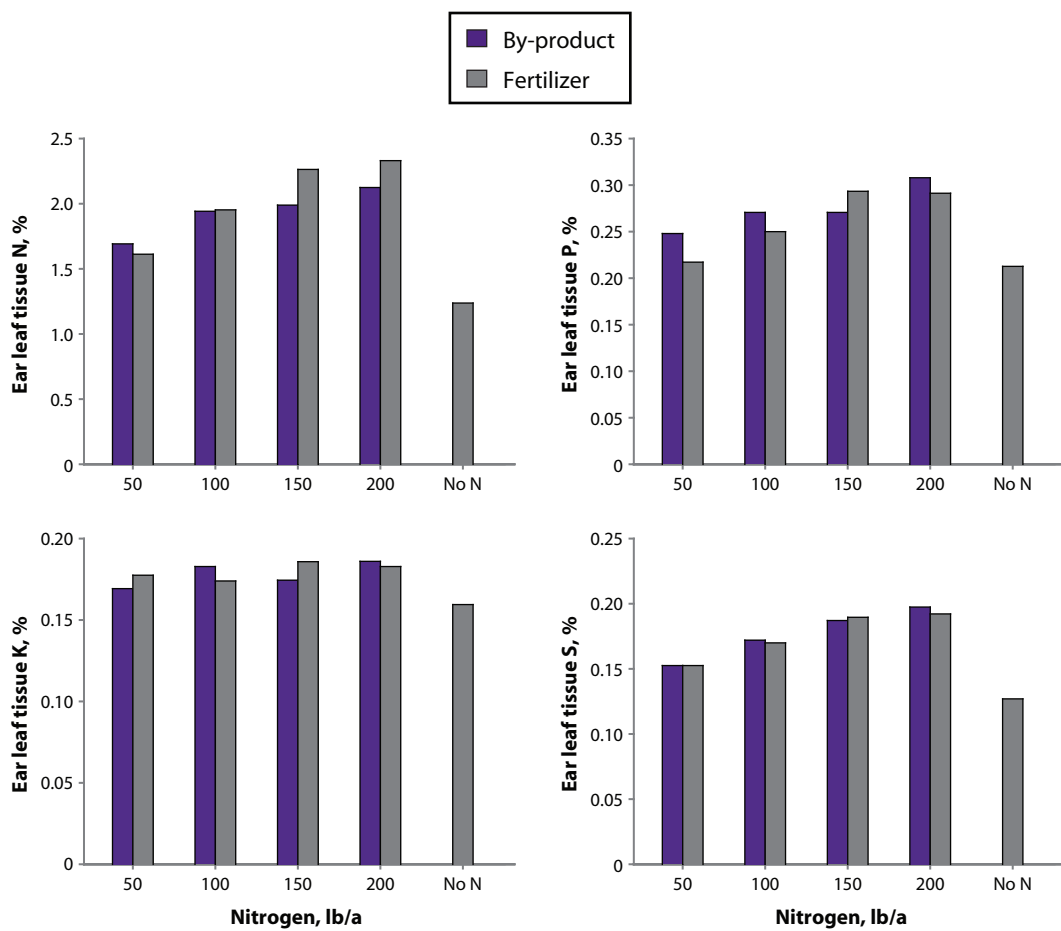


Figure 3. Leaf nitrogen, phosphorus, potassium, and sulphur concentrations as affected by application rate and nutrient source at the tasselling growth stage. Units are percentage of dry weight. No N indicates no fertilizer or by-product application (control).

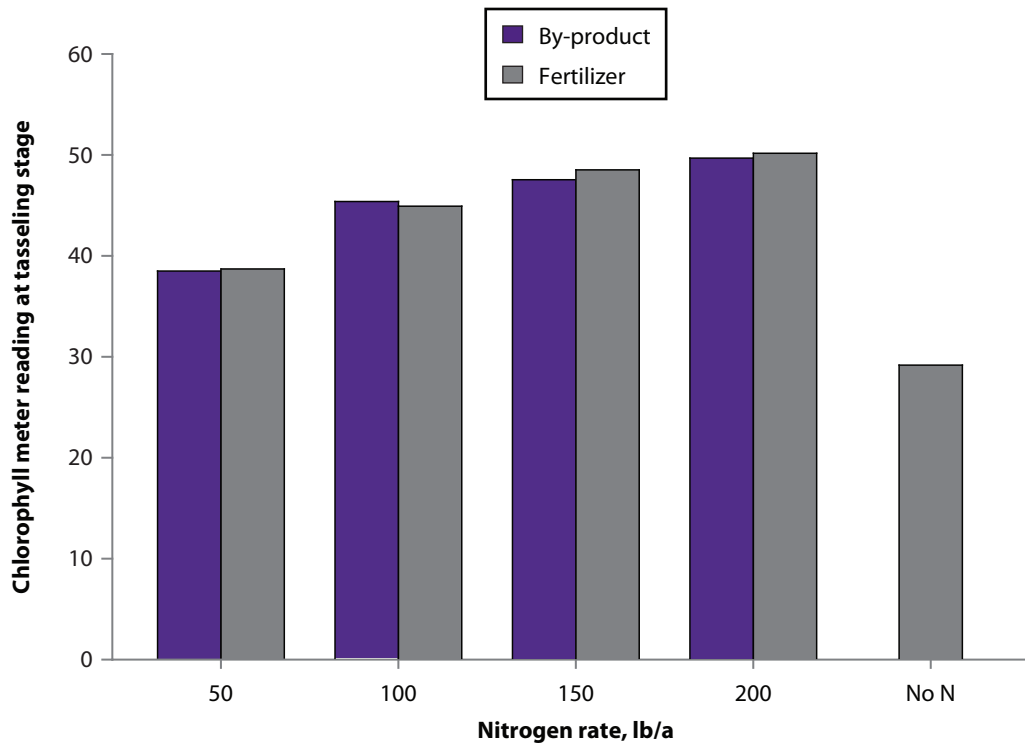


Figure 4. SPAD (chlorophyll meter) reading as affected by application rate and nutrient source. No N indicates no fertilizer or by-product application (control).

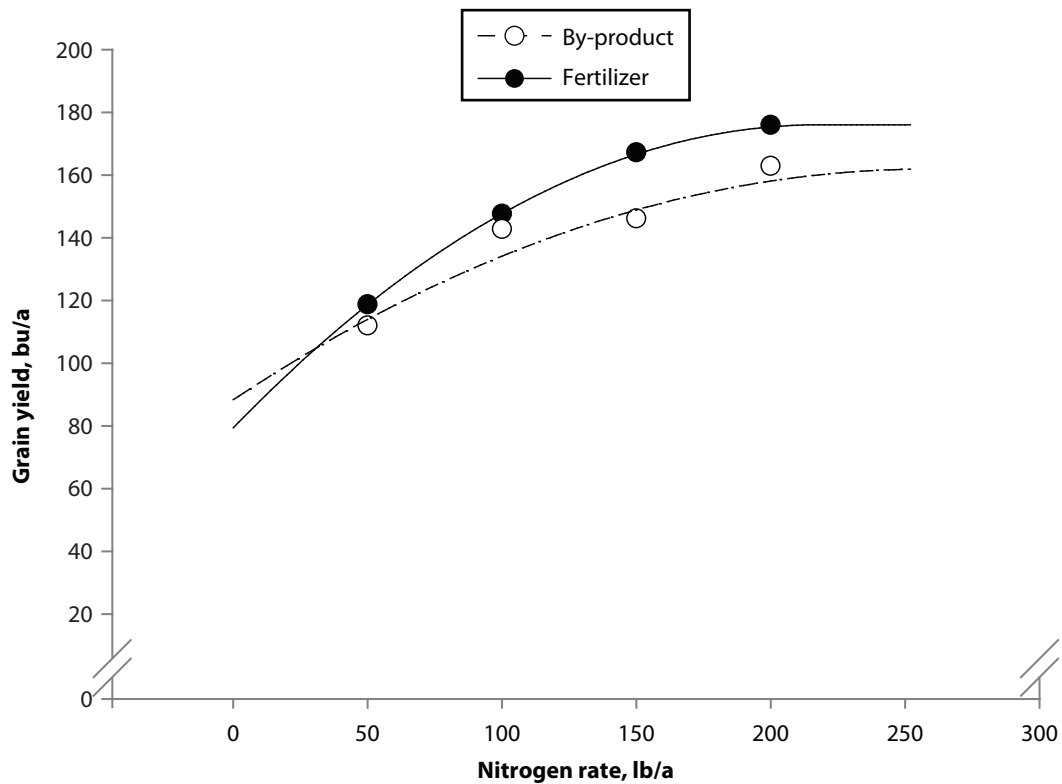


Figure 5. Corn grain yield as affected by application rate and nutrient source.

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

*D.W. Sweeney*

## Summary

Overall in 2012, adding nitrogen (N) doubled average wheat yields, but the advantage of knifing compared with broadcast and dribble placement was apparent only in the no-till treatment. Double-crop soybean yields were greatest following wheat unfertilized with N and grown with no tillage.

## 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

The experiment was initiated on a Parsons silt loam soil in 1983. The experimental design was a split-plot arrangement of a randomized complete block with four replications 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) continues in the same areas as 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; Monsanto, St. Louis, MO) 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-numbered years is 125 lb/a. The N rate of 120 lb/a for wheat is split as 60 lb/a applied preplant as broadcast, dribble, or knife UAN. All plots except for the controls are top-dressed in the spring with broadcast UAN at 60 lb/a N.

## Results

In 2012, wheat yields were excellent, with N fertilization approximately doubling the average yields obtained with no fertilization (Figure 1). Wheat yield was not affected by tillage alone, but was affected by a tillage and N fertilization interaction. Across tillage systems, there was little yield difference when the preplant N was subsurface (knife)-applied. Surface applications (broadcast or dribble) yielded less in the conventional tillage system than with no-till, although the reason for this was not apparent.

Although not measured, the potentially greater soil moisture levels in the control plots where wheat yield was less than in the N fertilized plots likely accounted for the subsequent greater double-crop soybean yields (Figure 2). Overall double-crop soybean yields were about 10 bu/a greater with no-till than with conventional or reduced tillage.

Soybean yield was lower following wheat fertilized by knifing N in the conventional tillage system but was not significantly lower in the reduced or no-till systems.

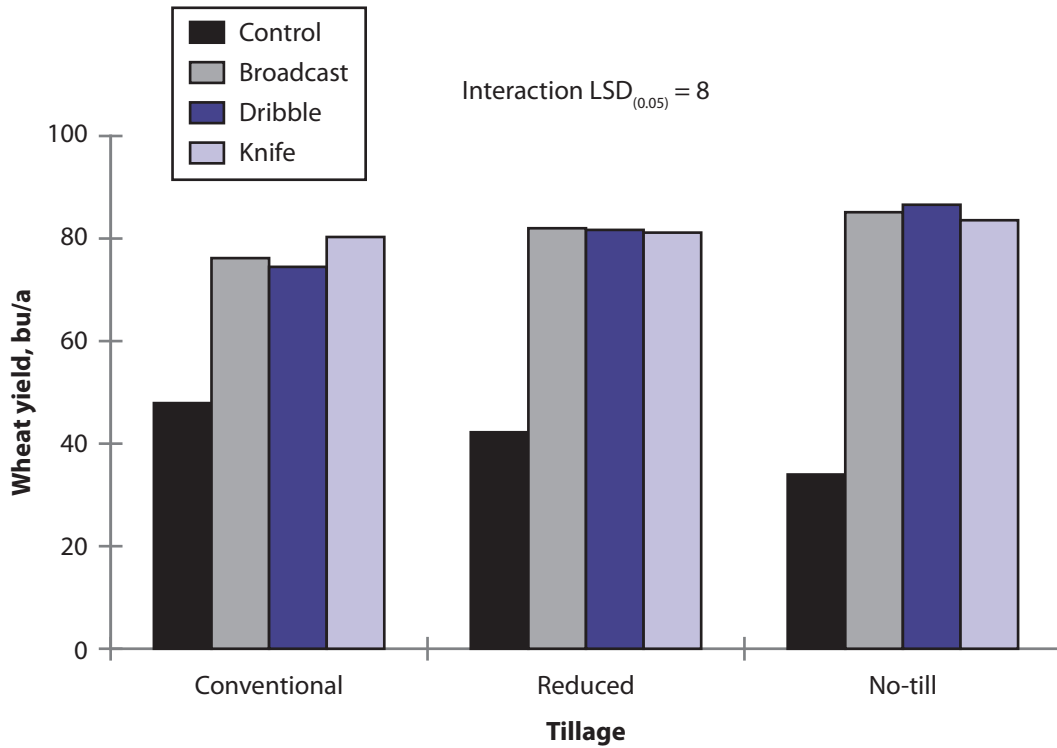


Figure 1. Effect of tillage and nitrogen placement on wheat yield, Southeast Agricultural Research Center, 2012.

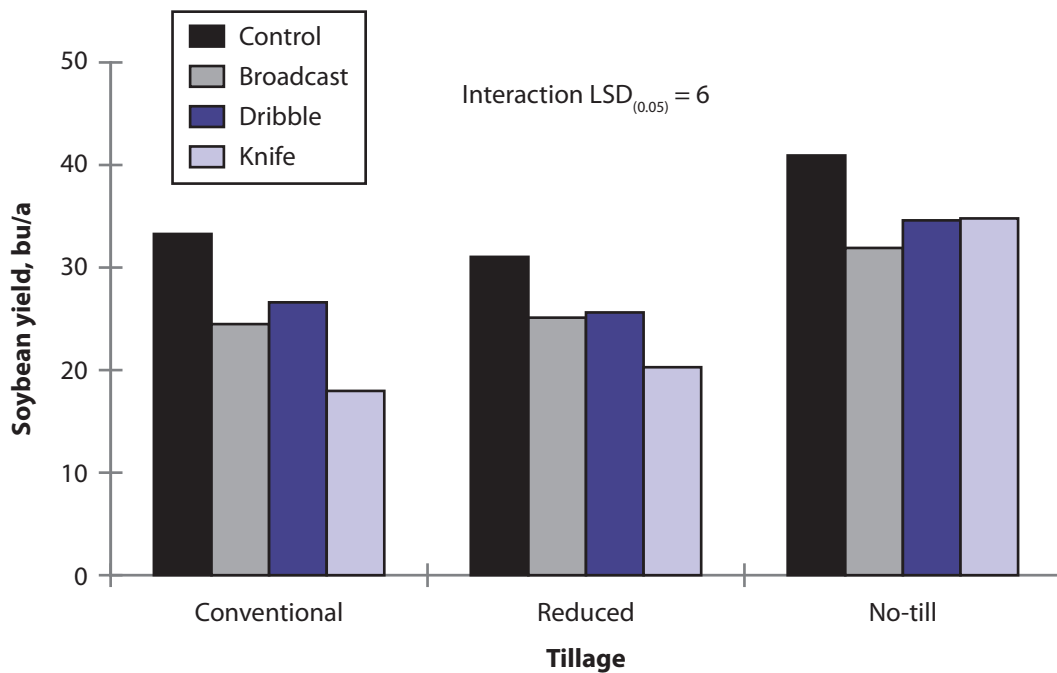


Figure 2. Effect of tillage and residual nitrogen placement on soybean yield planted as a double-crop after wheat, Southeast Agricultural Research Center, 2012.

# Seeding Rates and Fertilizer Placement to Improve Strip-Till and No-Till Corn<sup>1</sup>

*D.W. Sweeney*

## Summary

In 2012, hot and dry conditions again resulted in low corn yields. Under these stressful environmental conditions, corn yields at two sites were unaffected by tillage, seeding rate, or fertilizer placement.

## 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. 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 2012, the experiment was conducted on Parsons silt loam soils at the Mound Valley Unit (Site 1) and the Parsons Unit (Site 2) of the Southeast Agricultural Research Center. The background soil values for each site were: Site 1, 6.4 pH, 12 ppm Mehlich-3 phosphorus (P), and 87 ppm extractable potassium (K); and Site 2, 6.3 pH, 24 ppm Mehlich-3 P, and 107 ppm extractable K. 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<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O) applied at 125 lb/a N and 40 lb/a P<sub>2</sub>O<sub>5</sub>. Based on initial soil tests, at the Parsons site only N was applied by the two placement methods. Corn was planted at both sites on April 6, 2012.

## Results

In 2012, hot and dry conditions resulted in low overall corn yields averaging less than 60 bu/a at either location. Stressful environmental conditions resulted in no effect on yield by tillage, seeding rate, fertilizer placement or their interactions (data not shown).

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<sup>1</sup>This research was partly funded by the Kansas Corn Commission and the Kansas Fertilizer Research Fund.

# Nitrogen and Phosphorus Fertilization of Irrigated Corn

*A. Schlegel and H.D. Bond*

## 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 2013, N applied alone increased yields 69 bu/a, whereas P applied alone increased yields 21 bu/a. Nitrogen and P applied together increased yields up to 150 bu/a. This is similar to the 10-year average, where N and P fertilization increased corn yields up to 147 bu/a. Application of 120 lb/a N (with P) produced about 92% of maximum yield in 2013, which was similar to the 10-year average. Application of 80 instead of 40 lb P<sub>2</sub>O<sub>5</sub>/a increased average yields 3 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<sub>2</sub>O<sub>5</sub> and zero K; and with 40 lb/a P<sub>2</sub>O<sub>5</sub> and 40 lb/a K<sub>2</sub>O. The treatments were changed in 1992, when the K variable was replaced by a higher rate of P (80 lb/a P<sub>2</sub>O<sub>5</sub>). All fertilizers were broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. The corn hybrids [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 (2012-2013)] were planted at about 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 2013 were greater than the 10-year average (Table 1). Nitrogen alone increased yields 69 bu/a, whereas P alone increased yields 21 bu/a. However, N and P applied together increased corn yields up to 150 bu/a. Although maximum yield was obtained with the highest N and P rate, 160 lb/a N with 80 lb/a P<sub>2</sub>O<sub>5</sub> caused less than a 2% yield reduction. Corn yields in 2013 (averaged across all N rates) were 3 bu/a greater with 80 than with 40 lb/a P<sub>2</sub>O<sub>5</sub>, which is less than the 10-year average of 6 bu/a.

**Table 1. Effect of nitrogen and phosphorus fertilization on irrigated corn, Tribune, 2004–2013**

N	P <sub>2</sub> O <sub>5</sub>	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean
----- lb/a -----		----- bu/a -----										
0	0	67	49	42	49	36	85	20	92	86	70	60
0	40	97	60	68	50	57	110	21	111	85	80	74
0	80	98	51	72	51	52	106	28	105	94	91	75
40	0	92	63	56	77	62	108	23	114	109	97	80
40	40	154	101	129	112	105	148	67	195	138	125	127
40	80	148	100	123	116	104	159	61	194	135	126	127
80	0	118	75	79	107	78	123	34	136	128	112	99
80	40	209	141	162	163	129	179	85	212	197	170	165
80	80	205	147	171	167	139	181	90	220	194	149	166
120	0	103	66	68	106	65	117	28	119	134	114	92
120	40	228	162	176	194	136	202	90	222	213	204	183
120	80	234	170	202	213	151	215	105	225	211	194	192
160	0	136	83	84	132	84	139	49	157	158	122	114
160	40	231	170	180	220	150	210	95	229	227	199	191
160	80	240	172	200	227	146	223	95	226	239	217	199
200	0	162	109	115	159	99	155	65	179	170	139	135
200	40	234	169	181	224	152	207	97	218	225	198	191
200	80	239	191	204	232	157	236	104	231	260	220	207

*continued*



**Table 1. Effect of nitrogen and phosphorus fertilization on irrigated corn, Tribune, 2004–2013**

N	P <sub>2</sub> O <sub>5</sub>	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean
----- lb/a -----		----- bu/a -----										
<b>ANOVA (P &gt; F)</b>												
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
<b>Means</b>												
Nitrogen, lb/a												
0		87	53	61	50	48	100	23	103	88	80	69
40		132	88	103	102	91	138	50	167	127	116	111
80		178	121	137	146	115	161	70	189	173	143	143
120		188	133	149	171	118	178	74	189	186	171	156
160		203	142	155	193	127	191	80	204	208	179	168
200		212	156	167	205	136	199	89	209	218	186	178
LSD (0.05)		11	10	15	11	9	12	9	13	10	10	8
P <sub>2</sub> O <sub>5</sub> , lb/a												
0		113	74	74	105	71	121	36	133	131	109	97
40		192	134	149	160	122	176	76	198	181	163	155
80		194	139	162	168	125	187	81	200	189	166	161
LSD (0.05)		8	7	11	8	6	9	7	9	7	7	6

# Nitrogen and Phosphorus Fertilization of Irrigated Grain Sorghum

*A. Schlegel and H.D. Bond*

## 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 2013, N applied alone increased yields 57 bu/a, whereas N and P applied together increased yields up to 84 bu/a. Averaged across the past 10 years, N and P fertilization increased sorghum yields up to 70 bu/a. Application of 40 lb/a N (with P) was sufficient to produce about 80% of maximum yield in 2013, 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<sub>2</sub>O<sub>5</sub> and zero K; and with 40 lb/a P<sub>2</sub>O<sub>5</sub> and 40 lb/a K<sub>2</sub>O. All fertilizers are broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. Sorghum (Pioneer 8500/8505 from 2003–2007, Pioneer 85G46 in 2008–2011, and Pioneer 84G62 in 2012–2013) 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 2013 were similar to the 10-year average yields (Table 1). Nitrogen alone increased yields 57 bu/a, whereas P alone increased yields 15 bu/a. However, N and P applied together increased yields up to 84 bu/a. Averaged across the past 10 years, N and P applied together increased yields up to 70 bu/a. In 2013, 40 lb/a N (with P) produced about 78% of maximum yield, which is slightly less than the 10-year average of 85%. Sorghum yields were not affected by K fertilization, which has been the case throughout the study period.

**Table 1. Effect of nitrogen, phosphorus, and potassium fertilizers on irrigated grain sorghum yields, Tribune, 2004–2013**

Fertilizer			Grain sorghum yield										
N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	2004	2005 <sup>1</sup>	2006	2007	2008	2009	2010	2011	2012	2013	Mean
----- lb/a -----			----- bu/a -----										
0	0	0	57	58	84	80	66	64	51	75	78	62	68
0	40	0	73	53	102	97	60	70	51	83	90	77	77
0	40	40	74	54	95	94	65	76	55	88	93	72	77
40	0	0	60	63	102	123	92	84	66	106	115	94	92
40	40	0	112	84	133	146	111	118	77	121	140	114	117
40	40	40	117	84	130	145	105	109	73	125	132	110	114
80	0	0	73	76	111	138	114	115	73	117	132	102	106
80	40	0	103	81	132	159	128	136	86	140	163	136	128
80	40	40	123	92	142	166	126	108	84	138	161	133	129
120	0	0	66	77	101	138	106	113	70	116	130	100	103
120	40	0	106	95	136	164	131	130	88	145	172	137	132
120	40	40	115	98	139	165	136	136	90	147	175	142	136
160	0	0	86	77	123	146	105	108	74	124	149	117	112
160	40	0	120	106	145	170	138	128	92	152	178	146	139
160	40	40	113	91	128	167	133	140	88	151	174	143	134
200	0	0	100	86	134	154	120	110	78	128	147	119	119
200	40	0	115	108	143	168	137	139	84	141	171	136	135
200	40	40	123	101	143	170	135	129	87	152	175	138	137

*continued*

**Table 1. Effect of nitrogen, phosphorus, and potassium fertilizers on irrigated grain sorghum yields, Tribune, 2004–2013**

Fertilizer			Grain sorghum yield										
N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	2004	2005 <sup>1</sup>	2006	2007	2008	2009	2010	2011	2012	2013	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			0.018	0.005	0.004	0.001	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			0.121	0.803	0.578	0.992	0.745	0.324	0.892	0.278	0.826	0.644	0.999
N × P-K			0.022	0.195	0.210	0.965	0.005	0.053	0.229	0.542	0.186	0.079	0.071
Means													
Nitrogen, lb/a													
0			68	55	93	91	64	70	52	82	87	70	74
40			96	77	121	138	103	104	72	117	129	106	108
80			100	83	128	155	123	120	81	132	152	124	121
120			96	90	125	156	124	126	82	136	159	126	123
160			107	92	132	161	125	125	83	142	167	135	129
200			113	98	140	164	131	126	84	141	165	131	130
LSD (0.05)			11	10	11	9	7	11	5	8	9	8	5
P <sub>2</sub> O <sub>5</sub> -K <sub>2</sub> O, lb/a													
0			74	73	109	130	101	99	68	111	125	99	100
40-0			105	88	132	151	117	120	80	130	152	124	121
40-40			111	87	130	151	117	116	79	133	152	123	121
LSD (0.05)			7	7	7	6	5	7	4	6	6	5	4

<sup>1</sup> 2005 yields used only blocks 3, 4, and 5.

# KANSAS FERTILIZER RESEARCH 2013

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