# KANSAS FERTILIZER RESEARCH 2011

Report of Progress 1067

K-STATE Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

KANSAS STATE UNIVERSITY

# KANSAS FERTILIZER RESEARCH 2011

## Contents

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## Introduction

The 2011 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.

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# Precipitation Data

| Month | Manhattan | SWREC Tribune | SEARC Parsons | ECK Exp. Field Ottawa |
|---|---|---|---|---|
| | ------------------- | ------------------- in. ------------------- | ------------------- | ------------------- |
| 2010 | | | | |
| August | 4.04 | 3.79 | 0.82 | 1.38 |
| September | 3.52 | 0.34 | 5.89 | 6.55 |
| October | 1.15 | 0.32 | 1.26 | 1.64 |
| November | 1.90 | 0.11 | 2.69 | 1.58 |
| December | 0.07 | 0.27 | 0.68 | 0.27 |
| Total 2010 | 33.34 | 18.88 | 42.22 | 38.95 |
| Departure from normal | -1.46 | +1.54 | +0.13 | -0.26 |
| | | | | |
| 2011 | | | | |
| January | 0.69 | 0.33 | 0.18 | 0.90 |
| February | 0.89 | 0.69 | 3.07 | 3.62 |
| March | 1.20 | 0.88 | 4.37 | 2.45 |
| April | 2.89 | 1.36 | 4.07 | 2.60 |
| May | 5.48 | 0.80 | 6.28 | 5.99 |
| June | 5.20 | 4.80 | 2.11 | 3.45 |
| July | 2.18 | 5.15 | 1.22 | 1.79 |
| August | 2.80 | 3.40 | 4.16 | 2.70 |
| September | 1.37 | 0.95 | 2.79 | 1.76 |

*continued*

# Precipitation Data

| Month | NCK Exp. Field Belleville | KRV Exp. Field | SCK Exp. Field Hutchinson | ARC–Hays |
|---|---|---|---|---|
| | --------------------------------------------in.-------------------------------------------- | | | |
| 2010 | | | | |
| August | 3.58 | 1.02 | 4.75 | 5.40 |
| September | 5.10 | 3.74 | 1.31 | 2.11 |
| October | 0.10 | 0.73 | 0.53 | 0.07 |
| November | 2.20 | 1.32 | 3.75 | 0.86 |
| December | 0.06 | 1.13 | 0.08 | 0.18 |
| Total 2010 | 32.36 | 26.98 | 35.46 | 22.95 |
| Departure from normal | +1.47 | -8.66 | +5.14 | -0.54 |
| | | | | |
| 2011 | | | | |
| January | 0.36 | 0.53 | 0.20 | 0.35 |
| February | 0.72 | 2.50 | 0.80 | 0.57 |
| March | 0.63 | 2.82 | 0.91 | 0.67 |
| April | 1.57 | 2.16 | 0.39 | 1.03 |
| May | 8.21 | 5.12 | 1.88 | 2.41 |
| June | 5.03 | 2.66 | 2.30 | 2.41 |
| July | 4.62 | 0.88 | 0.18 | 1.95 |
| August | 5.54 | 2.42 | 3.31 | 4.09 |
| September | 0.87 | 2.43 | 0.71 | 0.86 |

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.

# Land Application of Gasification Biochar

*N.O. Nelson, A. Fink, A. Bontrager, and A. Bennett*

## Summary
Biochar, a co-product of thermochemical bioenergy production, may be a valuable soil amendment, but little is known about its effects on plant growth and soil fertility. The objectives of this research were to determine the effects of biochar on forage sorghum production, nitrogen (N) response, available phosphorus (P), and available potassium (K). The study was carried out at the Sandyland Experiment Field. Severe drought limited yields. Treatments had no effect on sorghum yield; however, biochar did increase soil pH, total carbon (C), total N, available P, and available K. Biochar may be an effective means of adding nutrients to soil. Additional years of research are needed to determine effects on crop growth.

## Introduction
Gasification is a method of bioenergy production in which biomass feedstocks (such as crop residues, wood chips, or other bio-based products) can be converted into advanced biofuel through incomplete combustion. This produces a co-product, commonly referred to as biochar, that is high in carbon and other minerals found in the feedstock, such as P, K, calcium (Ca), and magnesium (Mg). Land application of biochar could improve crop growth by returning P, K, and other nutrients to the soil. Land application of biochar also can increase soil C content and enhance C sequestration, but high C inputs may reduce N availability due to increased N immobilization. Many claims have been made about the effects of biochar on crop growth, but very little field-scale research demonstrates these effects.

The goal of this study was to determine the effects of biochar on soil properties and sorghum growth. Specific objectives were to determine the effects of biochar on (1) soil pH, (2) P and K availability in soil, (3) N fertilizer requirements, and (4) biomass sorghum yield.

## Procedures
A field study was conducted at the Sandyland Experiment Field near St. John, KS. The soil series is mapped as a Carwile fine sandy loam (0 to 1% slopes); initial soil analysis is listed in Table 1. The experiment was a split-block study with whole-plot treatments consisting of a control (no lime, P, or K applied), a fertilizer treatment (lime, P, and K applied), and a biochar treatment. Sub-plot treatments were N fertilizer rates of 0, 54, 107, and 161 lb/a N. Treatments were replicated three times.

Biochar from the gasification of wheat middlings was applied at 16.6 ton/a (dry weight) to the biochar treatments and ag-lime was applied to the fertilizer whole-plots at 1,150 lb/a effective calcium carbonate (ECC) on April 5, 2011. Biochar properties are listed in Table 2. Biochar and lime were incorporated with two passes of an offset disk on the day of application. On May 19, 2011, 92 lb/a $P_2O_5$ and 193 lb/a $K_2O$ were surface-applied to the fertilizer whole-plots as triple super phosphate and potassium chloride. On May 23, 2011, hybrid forage sorghum 1990 (Sorghum Partners, Inc., New

Deal, TX) was planted at 63,000 seeds/a on 30-in. row spacing. Nitrogen fertilizer was applied the same day as ammonium nitrate. Sorghum biomass was harvested on October 26, 2011. Soil samples were collected at 0 to 6, 6 to 12, and 12 to 24 in. deep from every subplot on November 21, 2011.

## Results

Growing season precipitation was limited, with only 6.5 in. of precipitation from April 1 to October 31 and only 0.3 in. from June 15 to July 31 (Figure 1), so sorghum yields were greatly reduced and treatments had no effects on sorghum yield (Figure 2). Due to the drought, N rate did not affect sorghum yield and biochar did not influence sorghum response to N; therefore, the data from this year are inconclusive with respect to biochar effects on crop growth and N response.

Although biochar did not affect yield, it did have a significant impact on soil nutrients, C, and pH (Table 3). Biochar increased the extractable P and K present in the soil, thus indicating that it may be used as an alternative nutrient source. Biochar also increased soil pH, indicating that it has liming value. Biochar also increased the total C content and total N content of the soil; however, previous work has shown that the N present in biochar is not plant-available. Biochar effects on N availability are under continued investigation.

**Table 1. Initial soil analysis**

| Cation exchange capacity | Total C | Total N | pH | Mehlich III P | Exchangeable K |
|---|---|---|---|---|---|
| meq/100 g | % | % | | ppm | ppm |
| 5.2 | 0.4 | 0.04 | 5.2 | 34 | 102 |

**Table 2. Concentration of C, N, P, and K in biochar and respective application rates for the biochar treatment**

| | C | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|---|
| Concentration (%) | 63 | 4.0 | 2.8 | 1.3 |
| Application rate (lb/a) | 21,100 | 1,330 | 930 | 440 |

**Table 3. Treatment effects on soil properties**

| Treatment | Total C | Total N | pH | Mehlich III P | Extractable K |
|---|---|---|---|---|---|
| | % | % | | ppm | ppm |
| Control | 0.31 | 0.04 | 5.2 | 40 | 124 |
| Lime and fertilizer | 0.36 | 0.04 | 5.5 | 60 | 174 |
| Biochar | 0.90 | 0.08 | 6.4 | 191 | 395 |
| | | | | | |
| LSD | 0.20 | 0.01 | 0.5 | 31 | 99 |
| *P*-value | <0.001 | <0.001 | 0.003 | <0.001 | 0.003 |

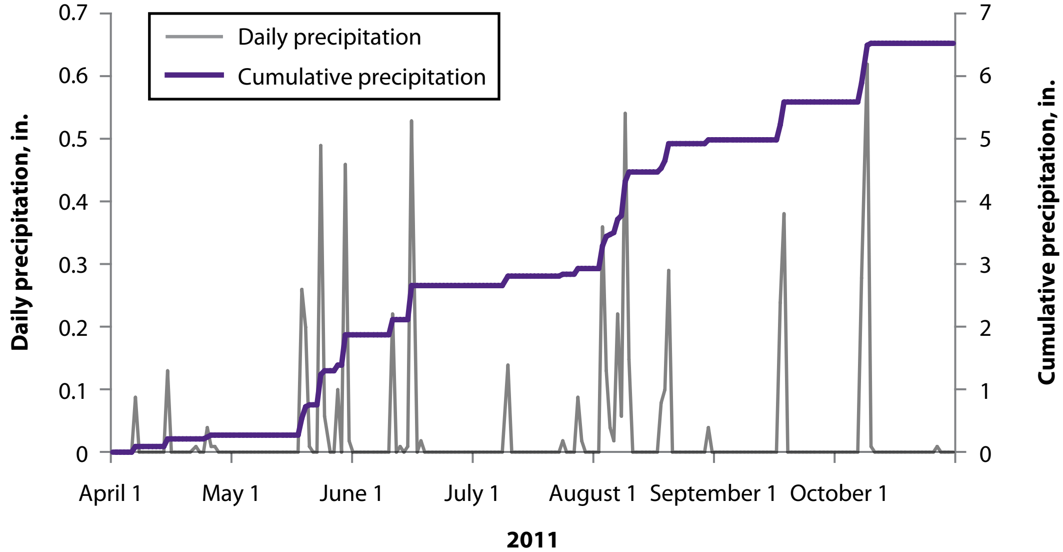


**Figure 1. Precipitation at the Sandyland Experiment Field near St. John, KS, from April 1 through October 31, 2011.**

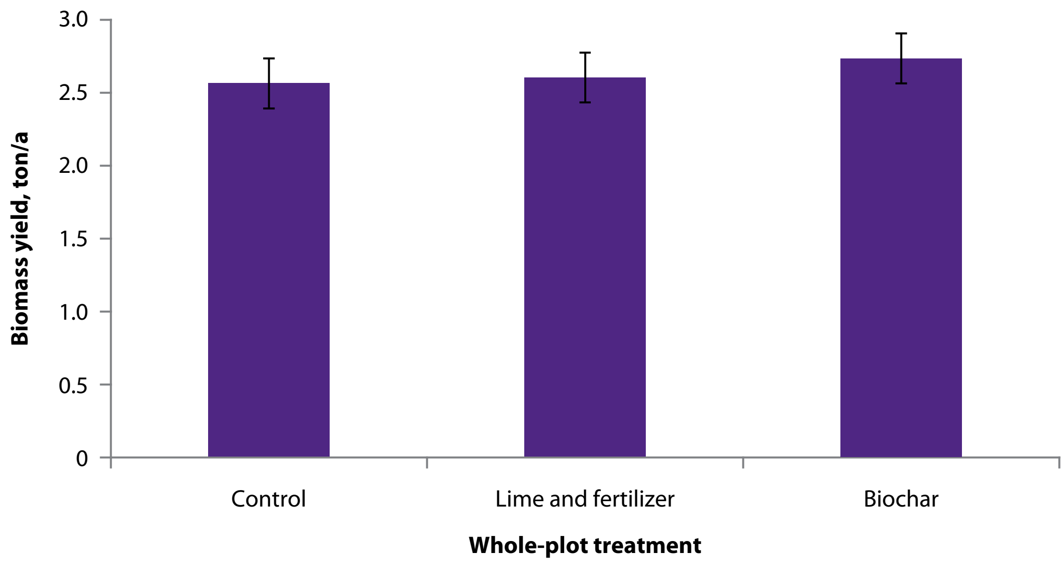


**Figure 2. Effect of biochar on yield compared with lime, phosphorus, and potassium fertilizer and the control (no fertilizer). Yields are averaged across nitrogen rates.**

# Winter Annual Weeds Affect Corn Response to Nitrogen

*N.D. Mueller, D.A. Ruiz Diaz, D.G. Hallauer, D. Shoup, and J.A. Dille*

## Summary

The effects of winter annual weeds on nitrogen (N) availability have not been adequately studied. The objective of this study was to determine winter annual weeds' effects on N availability for rainfed no-till corn following soybeans. Field research was conducted in 2010–2011 at 14 sites with heavy winter annual weed pressure in eastern Kansas. A two-factor factorial arrangement in a randomized complete block design with three replications included three herbicide application dates (November–March, April, and May) and five N rates (0, 15, 30, 60, and 120 lb/a N). Soil nitrate-N, early corn N uptake, N status at corn silking, and grain yield were assessed. Across site-years, winter annual weed aboveground biomass contained 16 lb/a N in May. Soil nitrate-N from a 0- to 24-in. depth in June was reduced by 11 lb/a from the earliest to the latest herbicide application dates. Early N uptake by corn at the V5 to V8 growth stages was higher with the earliest herbicide application date. The N status of corn at silking was reduced as herbicide application was delayed. Herbicide application for weed control prior to April increased corn yields. For no-till corn production in eastern Kansas, delaying control of winter annual weeds after March decreased N availability and grain yield.

## Introduction

A no-till corn-soybean rotation on well-drained soils in the United States Corn Belt is a highly profitable cropping system. Reduced tillage, lack of winter crops in the rotation, change in herbicide programs, and late spring weed control are some factors contributing to the increasing prevalence of winter annual weeds (WAWs) in no-till corn-soybean rotations. Winter annual weeds include both obligate (fall germination) and facultative (fall or early spring) species. No-till practices in a corn-soybean rotation help create a niche that favors winter annual broadleaf species. Producers and industry professionals perceive WAWs as an agronomic concern. Addressing the management of WAWs prior to no-till corn is particularly important. Studies suggest that dense stands of WAWs slow the warming of soil at planting time, cause allelopathic effects, increase damage from lepidopteron in corn, and reduce corn yield; however, the use of N by WAWs is an additional factor that may negatively affect no-till corn yields. Studies that have assessed N use by WAWs and the consequences for nitrogen availability for no-till corn in a corn-soybean rotation could not be found in the current body of literature. This study sought to determine how using different herbicide application dates to control WAWs affects N availability for corn in a rainfed no-till corn-soybean rotation.

## Procedures

Field research was conducted in cooperation with producers and Kansas State University staff at 14 sites in eastern Kansas from 2010 through 2011 (Table 1). All sites were rainfed no-till corn following soybeans. Experimental design was a two-factor factorial arrangement in a randomized complete block design with three replications. There were three different herbicide application dates per site: fall to early preplant (November through March), preplant (April), and late spring (May). The corn planting dates ranged from April 12 to June 1. After the collection of WAW biomass in May, five N rates of 0, 15, 30, 60, and 120 lb/a N were applied via broadcast urea. Plot size was 15 ft by 50 ft, except at Site 8, which was 10 ft by 50 ft. Soil samples from each block were taken to a 0- to 6-in. depth preplant and analyzed for P, K, pH, and organic matter (OM). This information was utilized in concert with Kansas State University recommendations for applying sufficiency rates of P and K. In early June when corn was assessed for aboveground biomass, composite soil samples for nitrate-N (KCL extraction) from each plot were collected at a 0- to 24-in. depth. Two 10.75 $ft^2$ polyvinyl chloride square frames were divided into nine small 1.2 $ft^2$ grids, and two grids in each frame were utilized to determine aboveground weed biomass and N uptake from two fixed locations in the front and back of each plot (outside the grain yield harvest area) prior to the last herbicide application treatment.

Weed biomass samples were oven-dried at 140°F for three days, weighed, and ground to pass a 0.08-in. screen. Plant analysis included total carbon and nitrogen by dry combustion. Winter annual weed control was performed with a backpack $CO^2$ sprayer with 30-in. nozzle spacing (three 110° nozzles, boom width of 7.5 ft). Burndown treatments consisted of glyphosate (0.77 lb/a a.i.) with or without 2,4-D (0.475 lb/a a.i.), acetochlor (0.94 lb/a a.i.), flumetsulam (0.03 lb/a a.i.), and clopyralid (0.10 lb/a a.i.), depending on planting and emergence timing of corn in accordance with the labels. A composite sample of whole corn plants from each plot was assessed for aboveground N uptake at the V5 through V8 growth stage. Whole corn plant samples were oven-dried at 140°F for three days, weighed, and ground to pass a 0.08-in. screen. Plant analysis for N was done with either the $H_2SO_4$-$H_2O_2$ method or dry combustion. Chlorophyll meter (CM) readings to determine N status were assessed at R1-R2 corn growth stage from the ear leaf of 20 corn plants in the middle two rows using a SPAD 502 Chlorophyll Meter (Minolta, Ramsay, NJ). Final corn yield was determined by harvesting 25 ft from each of the middle two rows for each plot. Grain yields were adjusted to 15.5% moisture. Data were analyzed using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC). For analysis across site-years, block and site were considered random in the model. Mean separation was performed by a BONFERRONI adjustment for the small number of planned comparisons to control the family-wise error rate. Statistical significance was evaluated at $P \leq 0.10$. Site 13 chlorophyll meter readings and grain yield data were not obtained due to crop death from extreme drought.

# Results

### *Winter Annual Weed N Uptake and C:N ratio*

The most common WAWs across site-years were henbit and field pennycress. Winter annual weed control was excellent at all sites. The aboveground N uptake from WAWs in May ranged from 6.2 to 28.5 lb/a N with a mean of 15.8 lb/a N. The C:N ratio ranged from 16 to 32 with a mean of 24. These findings on N uptake and C:N ratios for WAWs are similar to previous studies done in the southeastern United States. More recent research at Nebraska found that WAW N uptake by mid-April was 4 to 13 lb/a N and by mid-May was 21 to 33 lb/a N.

### *Soil Nitrate-N and Early Corn N Uptake*

Herbicide application dates and N rates significantly affected soil nitrate-N and early corn N uptake (Table 2). Soil nitrate-N to a 24-in. depth was reduced by delaying weed control from November–March until May and increased by higher N fertilizer rates (Figure 1). Early uptake of N by corn at the V5 to V8 growth stage was affected by the different rates of N fertilizer (Table 2). N fertilizer rates of 60 and 120 lb/a were not significantly different (Figure 2). These results suggest that applying 60 lb/a N was sufficient to maximize early N uptake. The November through March WAW control dates maximized early corn N uptake (Figure 2).

### *Chlorophyll Meter Readings and Grain Yield*

Herbicide application dates and N rates significantly affected CM readings and grain yield (Table 2). Chlorophyll meter readings increased significantly with each additional rate increase in N fertilizer (Figure 3). Lower CM readings on corn ear leaves were recorded with each subsequent delay in weed control (Figure 3). This suggests that the N accumulated into aboveground WAW biomass in April and May or N immobilized during the decomposition process was not available for uptake during vegetative growth stages of corn. To achieve comparable N status at silking for the November through March control dates at the zero N rate, equivalent to 15 and 30 lb/a N for April and May control dates were needed, respectively (Figure 3). The best management practice is to control WAWs early to minimize the need to increase N fertilizer inputs. Grain yields followed a trend similar to CM readings. Grain yield was increased by herbicide applications dates prior to April (Figure 4), contrary to other studies in Missouri, Illinois, and Indiana; however, a recent study in Nebraska found delaying WAW removal until mid-May reduced corn yield over early dates.

### *Application of Findings*

The results of this study were based on sites with heavy pressure of WAWs. The WAW N uptake and the corresponding C:N ratio by May was great enough at most sites to affect soil nitrate-N, early corn N uptake, N status at silking, and grain yield across N fertilizer rates. No significant interaction occurred between herbicide application date and N rate for the soil nitrate-nitrogen, early corn N uptake, and chlorophyll meter readings for analysis across all site-years. The determination of 120 lb/a N as the maximum N rate was based on realistic N rates used by producers in the area; however, a higher maximum N rate would have been helpful at some sites. The data from this study suggest that producers can increase N availability and grain yield for rainfed no-till corn following soybeans in eastern Kansas by controlling WAWs prior to April. Soil moisture and risk of soil compaction is generally higher in early spring than in the fall months following harvest. Starting WAW control in the fall would increase the window of application. We recommended that parts or all of a no-till field with heavy WAW pressure receive fall herbicide applications to decrease the probability of an inadequate supply of N available for corn.

**Table 1. Site information, dominant soil, and organic matter (OM)**

| Site | County | Soil series | OM |
|---|---|---|---|
| | | | % |
| 2010 | | | |
| 1 | Franklin | Woodsen | 2.9 |
| 2 | Jackson | Wymore | 3.2 |
| 3 | Jefferson | Grundy | 4.0 |
| 4 | Marshall | Wymore | 2.8 |
| 5 | Osage | Woodsen | 3.5 |
| 6 | Reno | Ost | 2.3 |
| 7 | Riley | Belvue | 1.4 |
| 2011 | | | |
| 8 | Atchison | Grundy | 3.0 |
| 9 | Franklin | Woodsen | 2.9 |
| 10 | Jefferson | Grundy | 3.5 |
| 11 | Jefferson | Grundy | 3.5 |
| 12 | Osage | Woodsen | 3.3 |
| 13 | Reno | Ost | 2.2 |
| 14 | Riley | Smolan | 2.7 |

**Table 2. ANOVA for dependent variables measured across site-years**

| | Fixed effects | | |
|---|---|---|---|
| Variable | Date (D) | N rate (N) | D x N |
| | ---------------------- | *P* > *F* | ------------------------ |
| Soil nitrate-nitrogen (N) | 0.027 | <0.001 | 0.449 |
| Early N uptake | <0.001 | <0.001 | 0.355 |
| Chlorophyll meter readings | <0.001 | <0.001 | 0.554 |
| Grain yield | <0.001 | <0.001 | 0.417 |

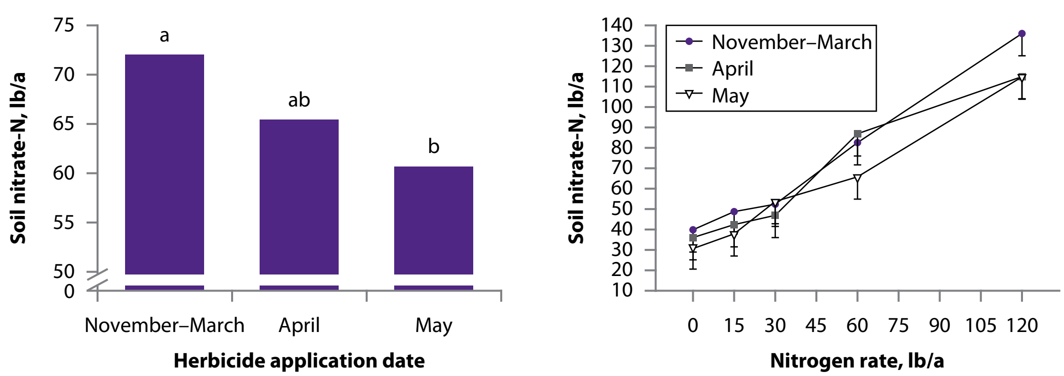


**Figure 1. Effects of winter annual weed herbicide application date and nitrogen (N) rate on soil nitrate-N.**
Bars with different letters are significantly different at $P < 0.1$.

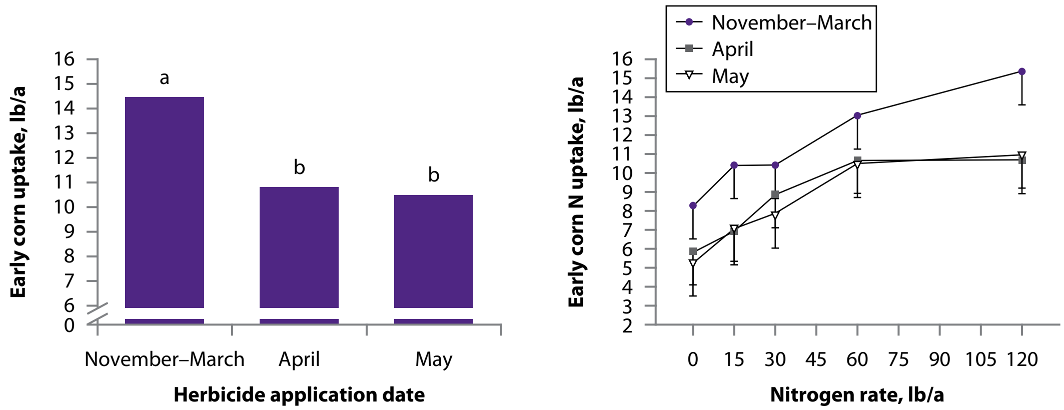


**Figure 2. Effects of winter annual weed herbicide application date and nitrogen (N) rate on early corn N uptake.**
Bars with different letters are significantly different at $P < 0.1$.

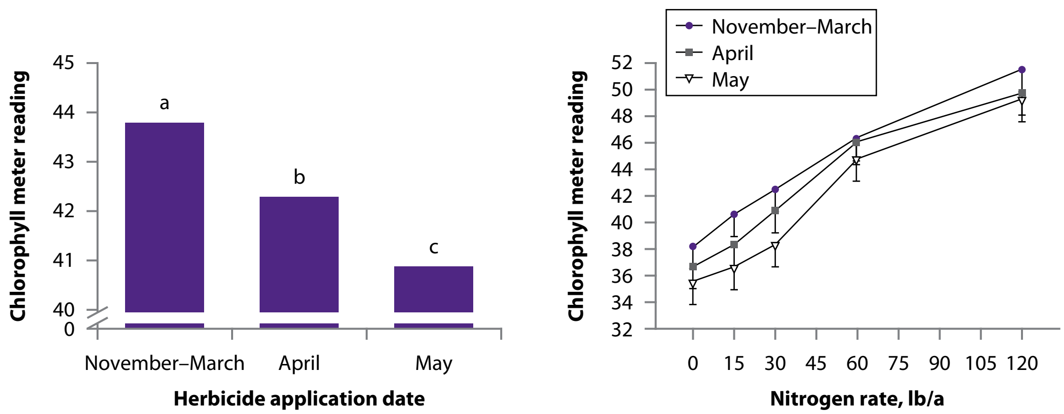


**Figure 3. Effects of winter annual weed burndown application date and nitrogen (N) rate on chlorophyll meter readings (greenness).**
Bars with different letters are significantly different at $P < 0.1$.

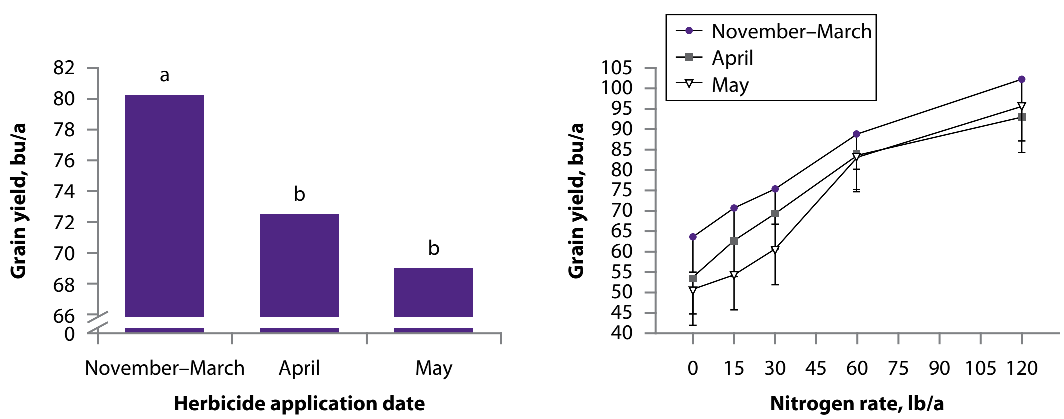


**Figure 4. Effects of winter annual weed herbicide application date and nitrogen (N) rate on grain yield.**
Bars with different letters are significantly different at $P < 0.1$.

# Corn Response to Starter and Foliar Fertilizers Under Irrigated Conditions

*N.D. Mueller and D.A. Ruiz Diaz*

## Summary
New corn genetics, high yields, and high corn prices have many questioning whether we should be applying micronutrients with nitrogen-phosphorus-potassium (NPK) starter fertilizers and using foliar fertilizers. The objective of this study was to evaluate corn response to starter fertilizers in combination with foliar application and the addition of micronutrients. Field research was conducted in Kansas at four sprinkler-irrigated sites in 2010–11. A factorial arrangement was used in which each factor (starter and foliar) included a control, NPK, and NPK plus a micronutrient mix (boron, copper, iron, manganese, and zinc). The addition of the micronutrient mix to the NPK starter fertilizer did not increase early corn growth or grain yield over NPK alone. Analysis across sites determined that the NPK starter fertilizer increased grain yield over the control. Foliar fertilizers did not increase grain yield. Farmers growing corn on productive soils under irrigation in Kansas are most likely to benefit from the use of an NPK starter fertilizer over these alternative strategies and nutrient sources.

## Introduction
Based on our current knowledge, the likelihood of increasing corn yield in Kansas with micronutrient application is generally highest for zinc (Zn), iron (Fe), and chloride (Cl), and less for boron (B), manganese (Mn), copper (Cu), and molybdenum (Mo). Corn Zn, Fe, Cl, and B deficiencies in Kansas have been documented, whereas Mn, Cu, and Mo deficiencies have not. Can we find yield responses to starter micronutrients and foliar fertilizers on productive soils under irrigation? Most micronutrients (except Cl and B) are considered relatively immobile in the soil and are needed only in small amounts by plants. Placement of these micronutrient fertilizers in a band application near seeds at planting can be an efficient method of soil application. Surface and subsurface banding of N, P, and K at planting have been demonstrated to provide significant improvements in early corn growth and yield. Some recent work in the area of phytoremediation has documented that vertical mobility of manganese, zinc, iron, and copper in the soil can be enhanced by chelation with EDTA. Furthermore, chelates (such as EDTA) can be 3 to 5 times more efficient than inorganic sources for zinc. How effective band placement of chelated micronutrients co-applied with N, P, and K starter fertilizers can be at increasing early growth and yield needs to be determined, and producers are increasingly interested in the potential yield benefits of foliar nutrient application. The overall objective of this study was to evaluate corn response to starter and foliar fertilizer applications including macro- and micronutrients.

## Procedures
Field research was conducted at four sprinkler-irrigated sites during 2010 and 2011 (Table 1). Corn followed soybeans at all sites. The experimental design was a factorial arrangement in a randomized complete block design with three replications. The starter fertilizer factor consisted of a control, NPK, and NPK plus a micronutrient mix

(NPK+micro). The rates were 4, 10, and 10 lb/a N, $P_2O_5$, and $K_2O$ in 2010 using a 4-10-10 starter fertilizer formulation. In 2011, the starter N rate was changed to 15 lb/a by adding urea ammonium nitrate to the 4-10-10 starter fertilizer formulation. The micronutrient mix contained boron derived from boric acid, copper EDTA, manganese EDTA, zinc EDTA, and iron HEDTA at rates of 0.5 elemental lb/a of each micronutrient. The starter was band-applied at 15 gal/a dribbled over the row. The foliar fertilizer factor consisted of a control, NPK, and NPK plus a micronutrient mix. The rates were 2, 2, and 2 lb/a of N, $P_2O_5$, and $K_2O$ in 2010 and 2011 using a 10-10-10 fertilizer formulation. The foliar micronutrient mix contained the same products utilized for starter at rates of 0.2 elemental lb/a of each micronutrient. The foliar fertilizers were applied at 20 gal/a when corn was at the V6 to V8 growth stage. The starter and foliar factorial arrangement resulted in nine treatment combinations. Small plot size was 35 or 50 ft by 10 or 15 ft with 30-in. row spacing. For each of the four sites, composite soil samples, consisting of 10 to 12 cores, were collected from each small plot from the 0- to 6-in. depth prior to planting. Soil samples were handled and analyzed following standard soil-testing procedures for pH, cation exchange capacity (CEC), organic matter (OM), P, K, Cu, Fe, Mn, Zn, and B (Table 2). Aboveground whole corn plants were collected at the V6 to V8 growth stage from each small plot prior to foliar application. Corn plant samples were handled and analyzed (N, P, K, Ca, Mg, S, Cu, Fe, Mn, Zn, and B) following standard procedures. Yield was determined from the two center rows of each small plot and adjusted to 15.5% moisture. Data were analyzed using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC). For analysis across sites, site and block within site were considered random factors. Statistical significance was determined at $P \leq 0.10$.

## Results

### *Early corn growth response to starter fertilizer*

The early growth (V6 to V8) of aboveground parts of corn plants were increased by the addition of starter fertilizers (NPK and NPK+micro) across sites (Table 2), but no additional growth was gained with the micronutrient mix. Soil test K was high at all sites, and K seldom has a starter effect in this situation. Nitrogen and phosphorus are likely responsible for the increased early growth. Furthermore, increased early growth occurred at Sites 2, 3, and 4, which were low in soil test P, unlike Site 1, where no response was measured (Tables 2 and 3).

### *Plant analysis*

Across sites, Zn and Cu concentration increased in young corn plants (aboveground parts at V6 to V8) with the addition the micronutrient mix over NPK alone (Table 4). No significant changes were found between starter fertilizer treatments for Fe and Mn concentration at any site. No differences were found in boron concentration at Sites 1 and 3. When the starter micronutrient mix was added, a slight decrease in boron concentration at Site 2 and a slight increase at Site 4 occurred. Site 2 in 2010 and Site 4 in 2011 were both located at the Kansas North Central Research Station on the same soil series. The difference in response between years cannot be explained. Zinc, Cu, Mn, and Fe for the control plots all fell within their established nutrient sufficiency ranges, whereas B would be considered sufficient to high (Figure 1). Corn P concentration is considered low at Sites 2 and 3. Based on plant analysis, early growth and yield increases due to micronutrient (Zn, Cu, Mn, Fe, and B) fertilizers are not expected.

### *Grain yield*

Soil (Table 3) or plant analysis (Figure 1) from Sites 2, 3, and 4 suggest that P was a potential limiting factor in achieving higher grain yield, but yield was increased over the control only at Site 4 with a starter NPK fertilizer. When analysis across sites was conducted, grain yield was significantly increased by starter NPK fertilizer over the control (Table 5). Interestingly, a similar yield increase was not recorded with the NPK+micro starter treatment as found with NPK starter alone. Foliar fertilizer treatments did not significantly affect grain yield compared with the control, and no significant interaction was found between starter and foliar fertilizer treatments.

### *Application of Findings*

Grain yield and early growth increased with application of a surface-banded NPK starter fertilizer over the row. We found no additional benefits to adding a micronutrient mix to the NPK starter or utilizing foliar fertilizers at these sites under these conditions. Farmers growing corn on productive soils under irrigation in Kansas are most likely to benefit from the use of an NPK starter fertilizer over these alternative strategies and nutrient sources.

**Table 1. Site conditions summary**

| Site | County | Soil texture | Tillage[1] | Hybrid[2] | Planting date | Nitrogen rate | Plant population |
|---|---|---|---|---|---|---|---|
| | | | | | | lb/a | plants/a |
| 2010 | | | | | | | |
| 1 | Clay | Silt loam | nt | P 33D49 | April 27 | 180 | 28,715 |
| 2 | Republic | Silt loam | rt | G 83X61 | April 28 | 200 | 40,017 |
| 2011 | | | | | | | |
| 3 | Shawnee | Silt loam | ft | D 64-69 | May 4 | 150 | 28,065 |
| 4 | Republic | Silt loam | rt | P 33D49 | April 28 | 200 | 36,667 |

[1] Tillage: ft = field cultivate, spring and fall, nt = no-till, rt = ridge-till.

[2] Hybrid: D = Dekalb, G = Garst, P = Pioneer.

**Table 2. Early corn growth (V6 to V8 growth stage) response to starter fertilizer treatments**

| Site | Control | NPK | NPK+micro |
|---|---|---|---|
| | ---------------------------- | g/plant | ---------------------------- |
| 1 | 21.6 | 22.2 | 21.8 |
| 2 | 17.0 | 18.7 | 18.5 |
| 3 | 4.7b | 5.5a | 5.5a |
| 4 | 4.3b | 5.4a | 5.3a |
| Across sites | | | |
| All | 11.9b | 13.0a | 12.8a |

[ab] Treatment means within site followed by a different letter are significantly different at the 0.10 probability level.

**Table 3. Mean soil-test values for each site**

| | | | | | | Micronutrients[1] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Site | CEC | pH | OM | P[2] | K[3] | Zn | Fe | Mn | Cu | B |
| | $cmol_c/kg$ | | % | ------------ | ------------ | ------------ | ppm | ------------ | ------------ | ------------ |
| 1 | 9.7 | 7.4 | 1.8 | 114 | 389 | 2.5 | 19.6 | 4.9 | 0.4 | 0.3 |
| 2 | 14.4 | 6.7 | 2.9 | 11 | 462 | 1.4 | 31.2 | 28.3 | 0.9 | 0.5 |
| 3 | 17.8 | 6.4 | 1.8 | 13 | 244 | 0.6 | 34.7 | 36.5 | 0.9 | 0.5 |
| 4 | 19.3 | 6.3 | 2.4 | 10 | 563 | 1.7 | 43.5 | 45.7 | 1.0 | 0.9 |

[1] Zn, Fe, Mn, and Cu DTPA; B by hot water in 2010 and by Mehlich-3 in 2011.
[2] P, Mehlich-3 test, colorimetric.
[3] K, ammonium-acetate.

**Table 4. Starter fertilizer treatment effects on corn Zn and Cu concentration at V6 to V8 growth stage**

| | Zinc | | | Copper | | |
|---|---|---|---|---|---|---|
| Site | Control | NPK | NPK+micro | Control | NPK | NPK+micro |
| | ------------ | ------------ | ------------ | ppm | ------------ | ------------ |
| 1 | 33 | 34 | 37 | 5.6ab | 5.2b | 6.2a |
| 2 | 37b | 38b | 43a | 8.6b | 8.8b | 9.4a |
| 3 | 28a | 26b | 26b | 9.5 | 9.7 | 9.4 |
| 4 | 35 | 31 | 33 | 11.9 | 11.7 | 12.0 |
| Across sites | | | | | | |
| All | 33ab | 32b | 35a | 8.9b | 8.8b | 9.3a |

[ab] Treatment means within site for each nutrient (Zn and Cu) followed by a different letter are significantly different at $P = 0.10$.

**Table 5. Grain yield response to starter and foliar fertilizer applications**

| Site | Starter | | | Foliar | | |
|---|---|---|---|---|---|---|
| | Control | NPK | NPK+micro | Control | NPK | NPK+micro |
| | ---------- | ---------- | ---------- bu/a | ---------- | ---------- | ---------- |
| 1 | 228 | 236 | 226 | 230 | 231 | 229 |
| 2 | 212 | 212 | 209 | 213 | 212 | 208 |
| 3 | 224 | 229 | 229 | 225 | 229 | 228 |
| 4 | 229b | 244a | 236ab | 236 | 239 | 233 |
| Across sites | | | | | | |
| All | 223b | 230a | 225b | 226 | 227 | 225 |

[ab] Starter treatment means within a row followed by a different letter are significantly different at $P = 0.10$.

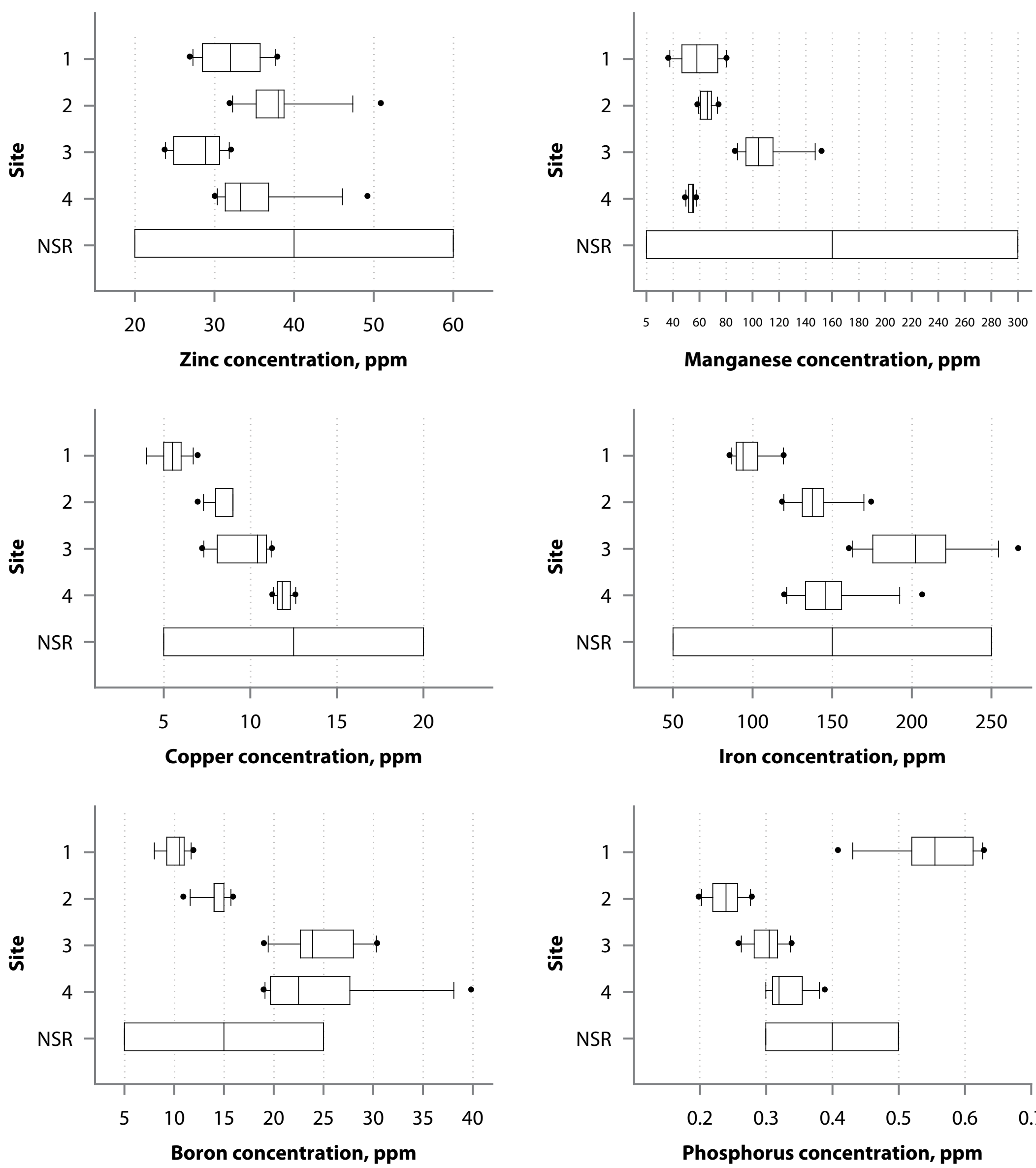


**Figure 1. Nutrient concentrations in aboveground parts of corn at the V6 to V8 growth stage from control plots at each site compared with nutrient sufficiency ranges (NSR).**

# Corn and Soybean Response to Starter and Broadcast Phosphorus

*I. Arns and D.A. Ruiz Diaz*

## Summary

The experiment was initiated 2011 at four locations in Kansas with two soybean and two corn locations. Sites 1 and 2 were managed under no-till for approximately six years before the experiment, whereas Sites 3 and 4 were managed under conventional tillage. Treatments were (1) unfertilized control, (2) 15-21-21 nitrogen-phosphorus-potassium (N-P-K) dribble starter, (3) 15-21-21 (N-P-K) dribble starter in combination with broadcast fertilizer (P and K), and (4) broadcast N-P-K before planting. Corn early growth increased at both corn sites with fertilization. Higher early plant biomass observed with the combined broadcast and starter was not indicative of higher grain yield in 2011. No statistically significant effect in corn grain yield was observed; however, lower average grain yield was found for the combined broadcast plus starter treatment. This trend may be due to the timing of very dry conditions later in the growing season, which was particularly unfavorable for plants slightly ahead in development (flowering and grain fill period). No significant effect in yield response was observed for soybean.

## Introduction

Optimum fertilizer placement and application method can substantially affect yield response, crop profitability, and potential nutrient loss. Starter and broadcast application or the combination of both has been evaluated by several research projects in the past. Generally, N-P-K starter mixture might be beneficial regardless of soil test level for corn and/or soybean when soil conditions are expected to be cooler and wetter than normal and with high residue cover (Leikan et al., 2003). Also, at soil test levels with low to very low P and K, band-applying at least 25 to 50% of total fertilizer can be beneficial in addition to broadcast application (Leikan et al., 2003). Several researchers have shown the benefits of starter fertilizer in early growth of corn (Mallarino et al., 1999; Vetsch and Randall, 2000; Wolkowski, 2000). Regardless of the frequent positive response in early growth to starter fertilizers, significant yield responses of no-till corn to starters (N and P) are more likely when soil test P is below optimum and/or preplant or sidedress N rates are deficient (Bermudez and Mallarino, 2002). Generally, the literature shows consistent early growth responses to fertilizer on high-testing soil sites but inconsistent yield responses (Bermudez and Mallarino, 2002; Mallarino et al., 1999; Randall and Hoeft, 1988).

According to Howard and Mullen (1991), no-till corn showed a positive yield response to NPK fertilizer in low-P soils but no differences between banded, in-furrow, and broadcast fertilizer. For soybean, Bullen, Poper, et al. (1983) reported that yield and P uptake increased when P was applied in a band near the seed, and results were superior to broadcast applications in low-P soils. Ham, Nelson, et al. (1973) and Rehm (1988) reported no yield increases from different P and K fertilizer placement methods under conventional tillage systems for soybean when soil tests showed high P levels, but at low soil P levels, the largest response was from broadcast fertilizer in low rainfall conditions.

With adequate rainfall, the largest response was a combination of starter and broadcast fertilizer (Ham et al., 1973). The majority of research involving placement of P and K were conducted with corn in many regions of the United States, but similar studies for soybean are limited in some regions, including Kansas. The objective of this study was to evaluate the effect of combined starter and broadcast fertilizer application on corn and soybeans in a typical corn-soybean rotation in Kansas.

## Procedures

The experiment was initiated 2011 at two locations in Kansas. The study involved four trials, two with soybean and two with corn. Experimental sites, soil types, and soil test levels are listed in Table 1. The experimental design consisted of a factorial arrangement in a complete randomized design with four treatments and four replications. Plots were 50 ft by 10 ft (4 rows spaced 30 in.). Sites 1 and 2 were managed under no-till for approximately six years before the experiment, whereas Sites 3 and 4 were managed under conventional tillage. Treatments were (1) unfertilized control, (2) 15-21-21 (N-P-K) dribble starter, (3) 15-21-21 (N-P-K) dribble starter in combination with broadcast fertilizer (P and K), and (4) broadcast N-P-K before planting. Starter 15-21-21 was a mixture of commercial formula 3-15-15 and 28% urea-ammonium nitrate (UAN). Broadcast fertilizer was a combination of monoammonium polyphosphate (MAP) (11-52-0) and potassium chloride (KCl, 0-0-62) for a total application rate of 100 lb/a for both $P_2O_5$ and $K_2O$. The broadcast application rates are commonly used rates by producers before corn in a corn-soybean rotation and are intended for both crops in the rotation (Leikan et al., 2003). Broadcast fertilizer was spread 1 to 2 weeks before planting at all sites. Broadcast fertilizer was incorporated at Sites 2 and 4 before planting and was non-incorporated at the no-till sites (1 and 3). Nitrogen fertilizer was applied in spring one month prior to planting and injecting anhydrous ammonium at a rate of 150 lb/a for Site 4. At Site 2, 180 lb/a N were applied as side-dress urea.

Composite soil samples (10 cores) were collected from each small plot before planting and fertilizer application. Samples were collected at the 0- to 6-in. depth. Soil samples were analyzed for pH in 1:1 soil:water, Mehlich III-extractable P (measure on ICP), ammonium acetate-extractable K, and organic matter (OM). Corn was planted on April 29 and May 4 for Sites 1 and 2, respectively, and soybean was planted May 11 and 16 for Sites 3 and 4, respectively. Plant population was measured for both corn and soybean. The aboveground parts of 10 corn plants were collected at V6 to V7 growth stages to evaluate early growth, nutrient content, and uptake. Corn ear leaves were collected at silking (R1) and analyzed for P and K concentration. Soybean leaf samples consisting of the most recently developed, fully expanded trifoliolate leaf (petiole excluded) were collected at full bloom (R2) and analyzed for P and K. After corn and soybean reached physiological maturity, grain yield was determined by harvesting the center two rows of each plot. Grain yield was adjusted to a moisture content of 15.5% for corn and 13% for soybean. Statistical analysis was completed using the generalized linear mixed model (GLIMMIX) procedure of SAS (SAS Institute Inc., Cary, NC) and assuming random block and site effects. Statistically significant differences were established at $P = 0.10$. When significant, plant population was used as a covariate in the analysis.

## Results

Corn early growth increased at both sites with fertilization (Table 2). A significant interaction effect was measured in early plant biomass at Sites 1 and 2, but analysis across location indicates no significant interaction. The interaction effect of starter and broadcast fertilizer was different for Sites 1 and 2 (Figures 1 and 2). Site 1 was under no-till with no incorporation of broadcast fertilizer. Under this condition, only the combined broadcast and starter increased biomass significantly, with no significant change in biomass observed for broadcast or starter only (Figure 1). Conversely, Site 2 under conventional tillage showed an increase in biomass with starters and a relatively higher biomass for a combined broadcast plus starter (although the difference was not statistically significant). Overall, similar early corn biomass was observed for all combinations of treatments except lower values in the control with no broadcast or starter fertilizer (Figure 2). These differences can be related to the effect of tillage and incorporation of broadcast fertilizer.

Higher early plant biomass observed with the combined broadcast and starter was not indicative of higher grain yield (Tables 2 and 3). No statistically significant effect on corn grain yield was observed; however, lower average grain yield was found for the combined broadcast plus starter treatment (Table 3). This trend may be due to the timing of very dry conditions later in the growing season, which was particularly unfavorable for plants slightly ahead in development (flowering and grain fill period). No significant effect in yield response was observed for soybean.

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**Table 1. Selected site and soil information**

| Site | County | Soil classification | | STP | STK | pH | OM | Variety[3]/ |
|---|---|---|---|---|---|---|---|---|
| | | Series[1] | Subgroup[2] | | | | | hybrid[4] |
| | | | | ------- ppm ------- | | | % | |
| Corn | | | | | | | | |
| 1 | Riley | Eudora SL | F. Hapludolls | 24 | 449 | 6.2 | 2.45 | DK-6342 |
| 2 | Shawnee | Eudora SL | F. Hapludolls | 17 | 228 | 6.8 | 1.60 | DK-6449 VT3 |
| Soybean | | | | | | | | |
| 3 | Riley | Rossville SL | C. Hapludolls | 12 | 306 | 6.7 | 2.17 | KS 3406 RR |
| 4 | Shawnee | Smolan SL | P. Argiustolls | 16 | 161 | 6.2 | 1.57 | LG C3616 RR |

[1] SL, silt loam.
[2] F, fluventic; C, cumulic; P, pachic.
[3] Soybean variety: LG, LG SEEDS; KS, Kansas Agricultural Experiment Station.
[4] Corn hybrid: DK, DeKalb.

**Table 2. Significance of *F* values for the fixed effects of starter and broadcast fertilizer for corn early growth and yield, and for soybean yield for each site and across sites**

| Site | Fixed effects | | |
|---|---|---|---|
| | Starter (S) | Broadcast (B) | S × B |
| | ------------------------------ | *P* > *F* | ------------------------------ |
| Corn (early biomass) | | | |
| 1 | 0.075 | 0.072 | 0.047 |
| 2 | 0.003 | 0.007 | 0.049 |
| 1 and 2 | 0.003 | 0.006 | 0.582 |
| Corn (grain yield) | | | |
| 1 | 0.908 | 0.395 | 0.206 |
| 2 | 0.169 | 0.899 | 0.398 |
| 1 and 2 | 0.165 | 0.659 | 0.080 |
| Soybean (grain yield) | | | |
| 3 | 0.956 | 0.647 | 0.947 |
| 4 | 0.536 | 0.156 | 0.267 |
| 3 and 4 | 0.984 | 0.530 | 0.408 |

**Table 3. Fertilizer treatment effects on corn early growth and yield and on soybean yield**

| | Corn | | | | Soybean | |
|---|---|---|---|---|---|---|
| | Yield | | Early growth | | Yield | |
| Treatment | Site 1 | Site 2 | Site 1 | Site 2 | Site 3 | Site 4 |
| | -------- bu/a -------- | | -------- g/plant -------- | | -------- bu/a -------- | |
| Control | 59 | 146 | 8.4 b† | 6.5 b | 31 | 50 |
| Starter (S) | 63 | 143 | 8.3 b | 10.4 a | 31 | 54 |
| Broadcast (B) | 61 | 152 | 8.3 b | 10.1 a | 33 | 49 |
| S + B | 56 | 139 | 9.9 a | 11.2 a | 34 | 48 |

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

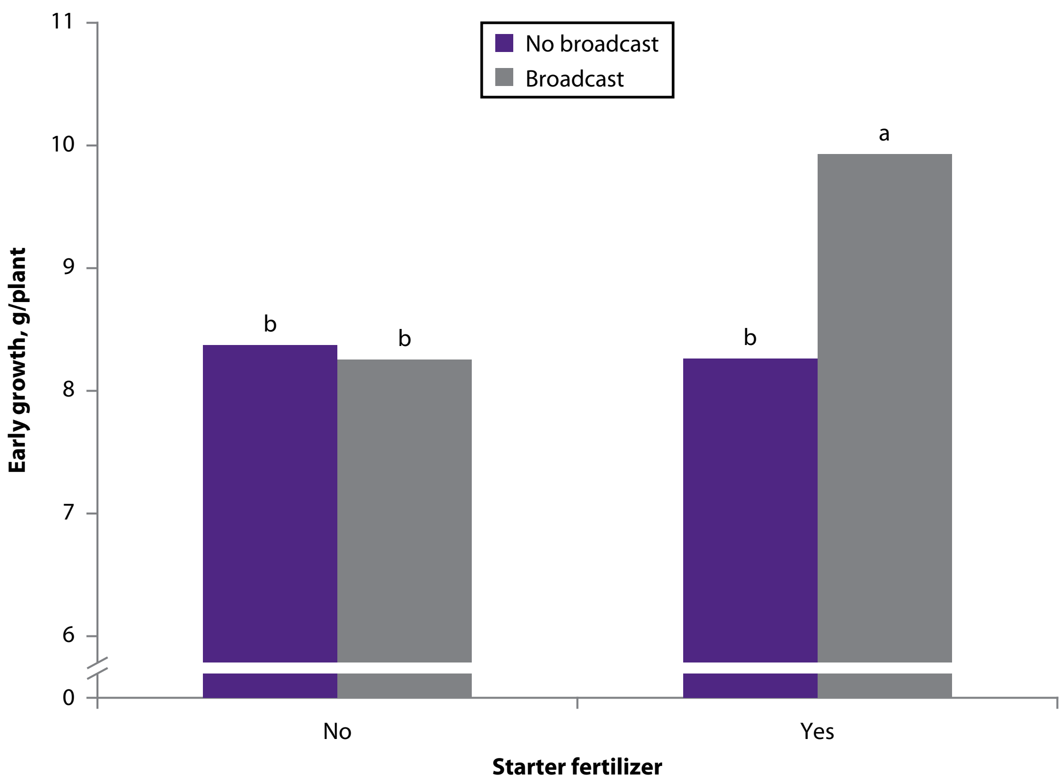


**Figure 1. Fertilization effects on corn early growth at Site 1.**
Letters represent differences between treatments when the main treatment effect was significant at $P \leq 0.10$.

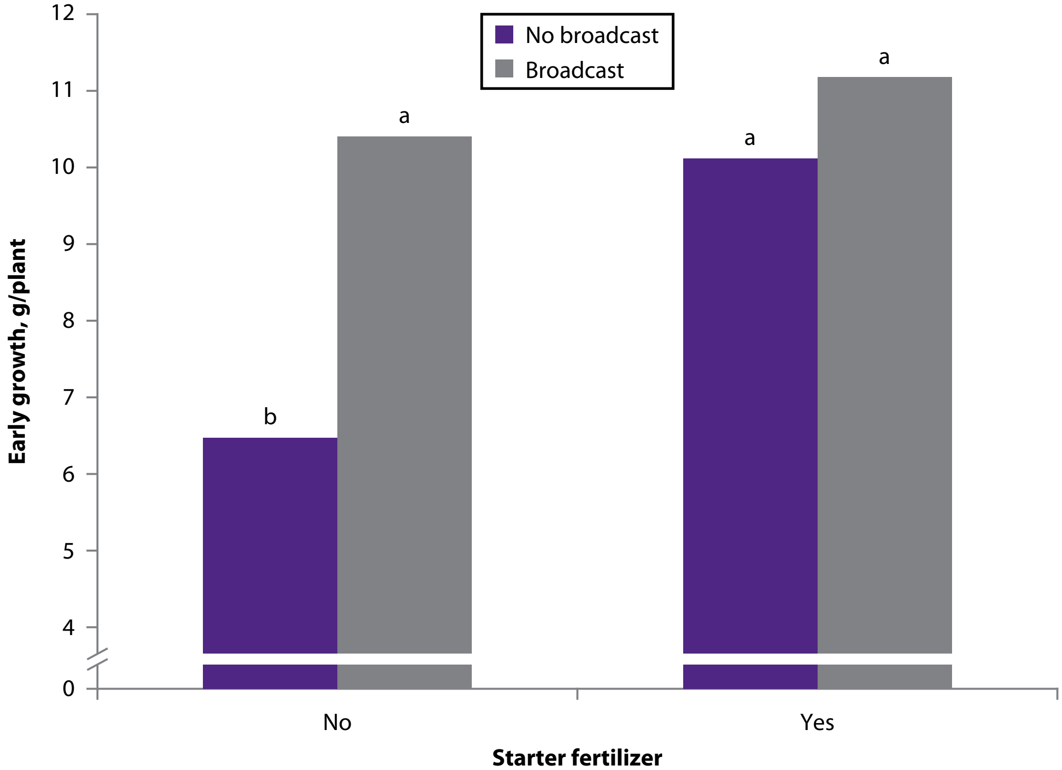


**Figure 2. Fertilization effects on corn early growth at Site 2.**
Letters represent differences between treatments when the main treatment effect was significant at $P \leq 0.10$.

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

*D.W. Sweeney and K.W. Kelley*

## Summary
Because of a poor stand, wheat was replaced with oats in 2010. Oat yield was increased by nitrogen (N) fertilization, but was unaffected by tillage, N application method, or their interaction. Double-crop soybean yields were unaffected by tillage or N fertilization.

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

## Procedures
A split-plot design with four replications was initiated in 1983 with tillage system as the whole plot and N treatment as the subplot. In 2005, the rotation was changed to begin a short-season corn/wheat/double-crop soybean sequence. Use of three tillage systems (conventional, reduced, and no-till) continued in the same areas as during the previous 22 years. The conventional system consists of chiseling, disking, and field cultivation. Chiseling occurred in the fall preceding corn or wheat crops. The reduced-tillage system consists of disking and field cultivation prior to planting. Glyphosate (Roundup) was applied to the no-till areas. The four N treatments for the crop were: 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 was 125 lb/a. The N rate of 120 lb/a for wheat was split as 60 lb/a applied preplant as broadcast, dribble, or knifed UAN. All plots except the controls were top-dressed in the spring with broadcast UAN at 60 lb N/a. In 2010, because the wheat stand was erratic and generally poor (visual estimate <50%), wheat was killed with glyphosate and plots were replanted with oats.

## Results
In 2010, adding fertilizer N, in general, tripled oat yields compared with yields in the no-N controls (Table 1), but oat yield was unaffected by tillage, N application method, or their interaction. Double-crop soybean yield was unaffected by tillage or N fertilization.

**Table 1. Effects of tillage and nitrogen (N) fertilization on oat and double-crop soybean yield in 2010. N fertilization effects for soybean are residual only, because no N fertilizer was applied to the soybean crop**

| | Oat yield | Soybean yield |
|---|---|---|
| | ------------------------ bu/a | ------------------------ |
| Tillage | | |
| Conventional | 32.2 | 25.9 |
| Reduced | 35.3 | 26.8 |
| No-till | 30.3 | 29.3 |
| LSD (0.05) | NS | NS |
| | | |
| N Fertilization | | |
| Control | 13.4 | 28.1 |
| Broadcast | 39.1 | 27.8 |
| Dribble | 37.0 | 26.8 |
| Knife | 40.8 | 26.4 |
| LSD (0.05) | 6.4 | NS |
| | | |
| Interaction | NS[1] | NS |

[1] NS, non-significant.

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

*D.W. Sweeney and K.W. Kelley*


## Summary
Conventional tillage resulted in higher yields than strip-till or no-till at one site, but the differences were not significant at a second site. These differences appear largely related to differences in plant stand. In general, although seeding rate increased plant stand, it had little corresponding effect on yield. Subsurface band (knife) fertilizer application resulted in greater yield than surface band (dribble) at both sites in 2010.


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

## Procedures
In 2010, the experiment was conducted at the Mound Valley Unit (Site 1) and the Parsons Unit (Site 2) of the Southeast Agricultural Research Center. The experimental design was a split-plot arrangement of a randomized complete block with three replications. The whole plots were three tillage systems: conventional, strip tillage, and no-till. Conventional tillage consisted of chisel and disk operations in the spring. Strip tillage was done with a Redball strip-till unit in the spring prior to planting. The subplots were a 5 × 2 factorial combination of five seed planting rates (18,000, 22,000, 26,000, 30,000, and 34,000 seeds/a) and two fertilizer placement methods: surface band (dribble) on 30-in. centers near the row and subsurface band (knife) at 4 in. deep. At the Mound Valley site, N and P nutrients were supplied as 28% urea ammonium nitrate and ammonium polyphosphate (10-34-0) applied at 125 lb/a N and 40 lb/a $P_2O_5$. Based on initial soil tests, at the Parsons site only N was applied by the two placement methods.

## Results
Yield or yield components were not affected by any interaction among the tillage, seeding rate, and fertilizer placement treatments at either site. Overall, yields and yield components were less at the Mound Valley site than at Parsons. At Mound Valley, yield was 14 to 20 bu/a greater with conventional tillage than with strip-till or no-till (Table 1). This difference was due to a reduced stand with strip-till and no-till; less than 60% of the seed planted in no-till emerged and lived. Seeding rate had no effect on yield at Mound Valley. Stand increased with seeding rate as expected; however, when expressed as a percentage of planted seed, stand tended to decline with increased seed-

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

ing rate. Increased seeding rate decreased kernel weight and kernels per ear, but had no effect on the number of ears per plant. Knife fertilizer placement increased yields by 40% compared with dribble surface applications by increasing kernel weight, ears per plant, and kernels per ear.

At Parsons, conventional tillage tended to result in higher yield than strip-till and no-till, but the differences were not statistically significant (Table 2). The stand was similar for strip-till and conventional tillage, with no-till resulting in a lower stand. Corn seeded at 18,000 seeds/a yielded less than corn seeded at 22,000 to 34,000 seed/a. Increasing seeding rate increased the stand, but, in contrast to results from Mound Valley, the percentage of seed that produced live plants was not affected by seeding rate. Increasing seeding rate reduced the number of kernels per ear and somewhat reduced the number of ears per plant. Knife fertilizer placement improved corn yield by more than 10%, primarily by increasing the number of kernels per ear.

**Table 1. Effects of tillage, seeding rate, and fertilizer placement on yield and yield components in 2010 at Site 1, Mound Valley Unit of the Southeast Agricultural Research Center**

| | Yield | Stand | | Kernel weight | Ears/plant | Kernels/ear |
|---|---|---|---|---|---|---|
| | bu/a | plants/a | % of planted | mg | | |
| Tillage | | | | | | |
| Conventional | 73.7 | 22,000 | 85.5 | 244 | 0.97 | 370 |
| Strip | 59.3 | 17,500 | 68.4 | 245 | 0.98 | 368 |
| No-till | 53.7 | 14,200 | 56.2 | 252 | 1.05 | 380 |
| LSD (0.05) | 12.5 | 2,800 | 9.3 | NS | NS | NS |
| | | | | | | |
| Seeding rate, seeds/a | | | | | | |
| 18,000 | 60.1 | 14,000 | 77.7 | 254 | 1.03 | 422 |
| 22,000 | 64.6 | 16,300 | 74.1 | 255 | 1.02 | 391 |
| 26,000 | 62.3 | 17,900 | 69.0 | 247 | 0.99 | 373 |
| 30,000 | 66.1 | 19,100 | 63.7 | 245 | 0.96 | 379 |
| 34,000 | 58.1 | 22,300 | 65.7 | 235 | 1.01 | 298 |
| LSD (0.05) | NS | 2,100 | 7.4 | 11 | NS | 48 |
| | | | | | | |
| Fertilizer placement | | | | | | |
| Dribble | 51.9 | 17,800 | 69.6 | 240 | 0.97 | 335 |
| Knife | 72.6 | 18,100 | 70.4 | 254 | 1.04 | 410 |
| LSD (0.05) | 5.7 | NS[1] | NS | 7 | 0.07 | 30 |

[1] NS, non-significant

**Table 2. Effects of tillage, seeding rate, and fertilizer placement on yield and yield components in 2010 at Site 2, Parsons Unit of the Southeast Agricultural Research Center**

| | Yield | Stand | | Kernel weight | Ears/plant | Kernels/ear |
|---|---|---|---|---|---|---|
| | bu/a | plants/a | % of planted | mg | | |
| Tillage | | | | | | |
| Conventional | 108 | 22,900 | 88.4 | 256 | 1.03 | 471 |
| Strip | 100 | 22,200 | 86.0 | 248 | 1.07 | 451 |
| No-till | 102 | 20,500 | 79.2 | 254 | 1.04 | 494 |
| LSD (0.05) | NS | 1,400 | 5.6 | NS | NS | NS |
| | | | | | | |
| Seeding rate, seeds/a | | | | | | |
| 18,000 | 93 | 15,600 | 86.6 | 251 | 1.11 | 554 |
| 22,000 | 105 | 19,200 | 87.2 | 254 | 1.06 | 524 |
| 26,000 | 104 | 22,100 | 84.8 | 249 | 1.01 | 478 |
| 30,000 | 106 | 25,000 | 83.3 | 259 | 1.02 | 408 |
| 34,000 | 110 | 27,400 | 80.6 | 251 | 1.03 | 396 |
| LSD (0.05) | 10 | 1,300 | NS | NS | 0.06 | 46 |
| | | | | | | |
| Fertilizer placement | | | | | | |
| Dribble | 97 | 21,500 | 82.9 | 252 | 1.04 | 456 |
| Knife | 110 | 22,200 | 86.1 | 253 | 1.06 | 488 |
| LSD (0.05) | 6 | NS[1] | NS | NS | NS | 29 |

[1] NS, non-significant.

# Effect of Timing of Supplemental Irrigation and Nitrogen Placement on Late-Planted Sweet Corn

*D.W. Sweeney and M.B. Kirkham[1]*

## Summary

In 2010, late-planted sweet corn was little affected by irrigation or nitrogen (N) treatments.

## Introduction

Sweet corn is a possible value-added, alternative crop for producers in southeastern Kansas. Corn responds to irrigation, and timing of water deficits can affect yield components. Even though large irrigation sources, such as aquifers, are lacking in southeastern Kansas, supplemental irrigation could be supplied from the substantial number of small lakes and ponds in the area. However, information is lacking on the effects of irrigation management, N placement, and planting date on performance of sweet corn, which may hinder producers' adoption of this crop.

## Procedures

The experiment was established on a Parsons silt loam in spring 2008 as a split-plot arrangement of a randomized complete block with three replications. The whole plots were four irrigation schemes: (1) no irrigation, (2) 1.5 in. at VT (tassel), (3) 1.5 in. at R2 (blister), and (4) 1.5 in. at both VT and R2 growth stages. Subplots were three N treatments consisting of no N and 100 lb N/a applied broadcast or as a subsurface band (knife) at 4 in. Sweet corn target planting date was mid-May. Corn was picked on July 29 and August 3, 2010.

## Results

In 2010, irrigation had no effect on total ears, total fresh weight, or individual ear weight of sweet corn planted in mid-May (Table 1). Total number of ears, total fresh weight, and individual ear weight were greater with N application than with no N but were unaffected by N placement.

[1] Kansas State University Department of Agronomy, Manhattan.

**Table 1. Effect of irrigation scheme and nitrogen placement on sweet corn planted in mid-May, Southeast Agricultural Research Center, 2010**

| Treatment | Total ears | Total fresh weight | Individual ear weight |
|---|---|---|---|
| | ears/a | ton/a | g/ear |
| Irrigation scheme | | | |
| None | 15,800 | 4.47 | 244 |
| VT (1.5 in.) | 16,000 | 4.40 | 243 |
| R2 (1.5 in.) | 13,000 | 3.55 | 237 |
| VT-R2 (1.5 in. at each) | 12,900 | 3.45 | 211 |
| LSD (0.10) | NS | NS | NS |
| | | | |
| N Placement | | | |
| None | 8,000 | 1.83 | 197 |
| Broadcast | 18,200 | 5.03 | 248 |
| Knife | 17,500 | 5.04 | 257 |
| LSD (0.05) | 2,800 | 0.80 | 16 |
| | | | |
| Interaction | NS[1] | NS | NS |

[1] NS, non-significant

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

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

## Summary
Corn yield in 2010 was unaffected by potassium (K) or chloride (Cl) fertilization, but was increased by nitrogen (N). Severity of stalk rot was unaffected by K, Cl, or N fertilization. Early growth was increased by K fertilization, but the effect declined during the growing season. In contrast, N fertilization did not significantly affect early growth, but improved growth during late reproductive growth stages.

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

## Procedures
The experiment was initiated in 2010 at the Southeast Agricultural Research Center at Parsons, KS. The experimental design was a split-plot design with three replications. The whole plots were a 2 × 2 factorial of K and Cl fertilization. The K and Cl rates were 0 and 50 lb $K_2O$/a and 0 and 40 lb Cl/a. K and Cl fertilizer sources used to achieve these four fertility whole plots were potassium chloride, potassium sulfate, and calcium chloride and were spread using a small, handheld broadcast unit. The N rate subplots for corn were 0, 50, 100, and 150 lb/a surface-band-applied as urea ammonium nitrate (UAN) solution. In addition to K, Cl, and N treatments, all plots received uniform applications of phosphorus (P) at 50 lb $P_2O_5$/a applied with a drop spreader. Fertilizers were incorporated by disking prior to planting. Pioneer 35F40 Roundup Ready corn was planted at 28,000 seeds/a on April 15, 2010. Grain was harvested for yield on August 27, 2010, using a small plot combine equipped with a corn head. Before harvest, corn ears were removed from 10 plants in the harvest rows and were placed in the combine as the rest of the plot was harvested. Stalks from these plants were split, and the bottom five nodes above the brace roots were visually evaluated for stalk rot. At the

[1] Kansas State University Department of Plant Pathology.

V6, V12, R1 (silk), R4 (dough), and PM (physiological maturity) growth stages, whole plant samples were collected and dry matter determined.

## Results

Overall yields in 2010 were poor, averaging less than 100 bu/a. Corn yield was not affected by K, Cl, or any interactions with K or Cl. Yield was affected only by N, increasing from 57 bu/a with no N to 103 bu/a with 150 lb N/a (Figure 1). This yield increase with N was primarily due to increased kernels per ear and somewhat to increased kernel weight. Severity of stalk rot was unaffected by any fertilizer treatments.

Growth, as measured by dry matter samples taken from V6 to PM, was improved early in the growing season by K fertilization (Table 1), but this effect declined and became non-significant by PM. Even though N fertilization did not significantly affect early growth, by late reproductive stages dry matter production increased by more than 30% with 150 lb N/a compared with the zero-N control. These growth results help explain the lack of yield response to K and the yield response to N.

**Table 1. Effect of K and N fertilizer on corn dry matter production during the 2010 growing season taken at V6, V12, R1 (silk), R4 (dough), and PM (physiological maturity) growth stages**

| | Dry matter production | | | | |
|---|---|---|---|---|---|
| Treatment | V6 | V12 | R1 | R4 | PM |
| | ---------- lb/a ---------- | | | | |
| K (lb $K_2O$/a) | | | | | |
| 0 | 200 | 1,680 | 4,300 | 10,920 | 12,200 |
| 50 | 270 | 2,270 | 5,030 | 12,200 | 12,400 |
| *F*-value | *[1] | **[1] | ** | NS | NS |
| N (lb/a) | | | | | |
| 0 | 220 | 1,960 | 4,500 | 9,300 | 10,700 |
| 50 | 240 | 2,080 | 4,800 | 11,500 | 12,400 |
| 100 | 220 | 1,910 | 4,440 | 11,400 | 11,900 |
| 150 | 260 | 1,940 | 4,900 | 14,000 | 14,000 |
| LSD (0.05) | NS[2] | NS | NS | 2,000 | 1,300 |

[1] *, ** Significant at $P = 0.05$ and $P = 0.01$, respectively.

[2] NS, non-significant.

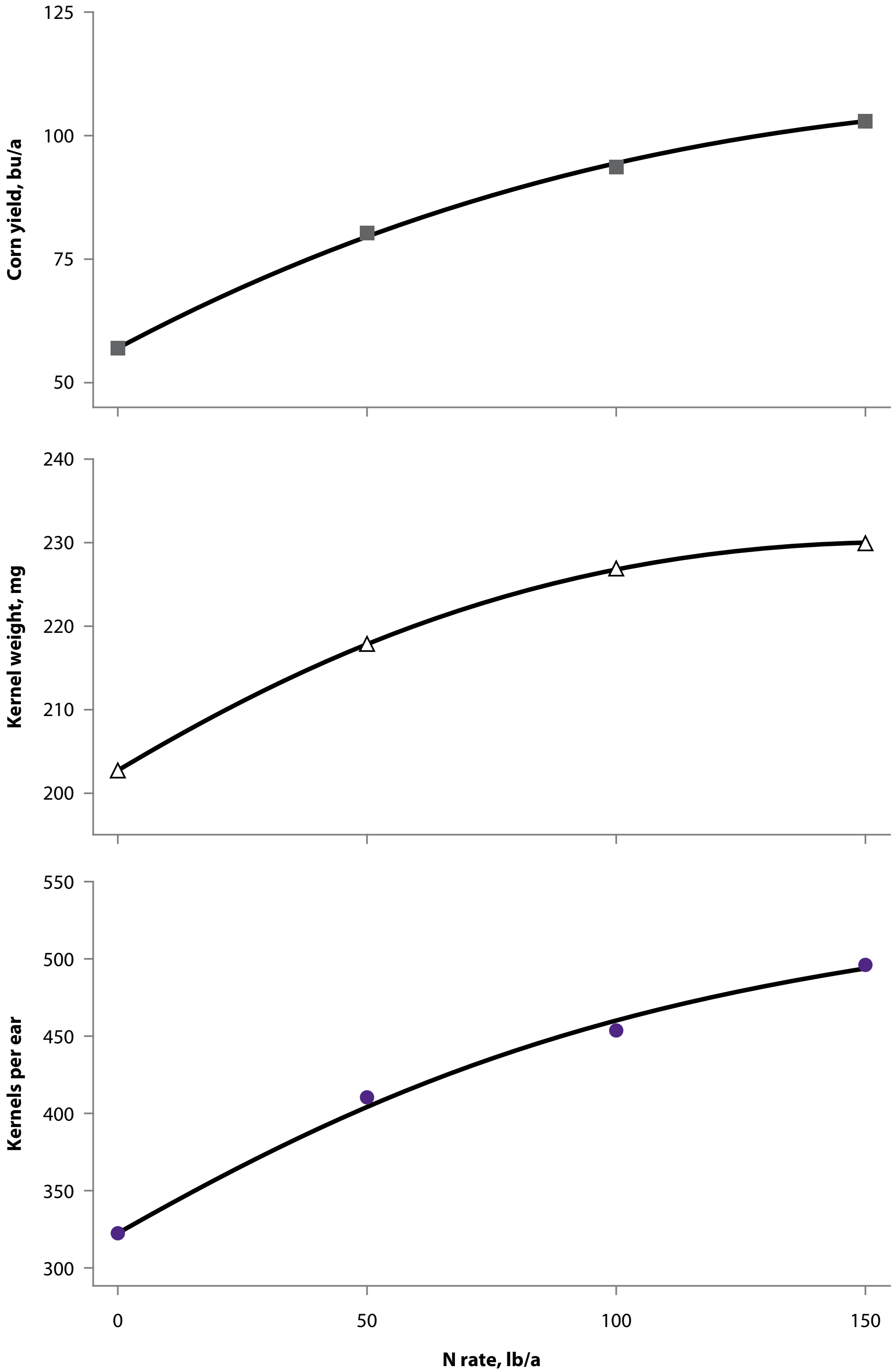


**Figure 1. Corn yield, kernel weight, and kernels per ear as affected by nitrogen (N) rate in 2010.**

# Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Corn

*A. Schlegel*

## Summary

Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize production of irrigated corn in western Kansas. In 2011, N applied alone increased yields 87 bu/a, whereas P applied alone increased yields 13 to 19 bu/a. Nitrogen and P applied together increased yields up to 139 bu/a. This is similar to the past 10 years, where N and P fertilization increased corn yields up to 130 bu/a. Application of 120 lb/a N (with P) was sufficient to produce about 95% of maximum yield in 2011, which was similar to the 10-year average. Application of 80 instead of 40 lb $P_2O_5$/a increased average yields only 2 bu/a in 2011.

## Introduction

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

## Procedures

This field study is conducted at the Tribune Unit of the Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a without P and K; with 40 lb/a $P_2O_5$ and zero K; and with 40 lb/a $P_2O_5$ and 40 lb/a $K_2O$. The treatments were changed in 1992; the K variable was replaced by a higher rate of P (80 lb/a $P_2O_5$). All fertilizers were broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. The corn hybrids (Pioneer 33R93 [2002], DeKalb C60-12 [2003], Pioneer 34N45 [2004 and 2005], Pioneer 34N50 [2006], Pioneer 33B54 [2007], Pioneer 34B99 [2008], DeKalb 61-69 [2009], Pioneer 1173H [2010], and Pioneer 1151XR [2011]) were planted at about 30,000 to 32,000 seeds/a in late April or early May. Hail damaged the 2002, 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 2011 were much greater than the 10-year average (Table 1). Nitrogen alone increased yields 87 bu/a, whereas P alone increased yields less than 20 bu/a; however, N and P applied together increased corn yields up to 139 bu/a. Only 120 lb/a N with P was required to obtain 95% of maximum yield, which is similar to the 10-year average. Corn yields in 2011 (averaged across all N rates) were only 2 bu/a greater with 80 than with 40 lb/a $P_2O_5$, which is slightly less than the 10-year average of 5 bu/a.

Table 1. Effect of nitrogen (N) and phosphorus (P) fertilization on irrigated corn, Tribune, KS, 2002–2011

| N | $P_2O_5$ | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ---------- lb/a ---------- | | ---------- bu/a ---------- | | | | | | | | | | |
| 0 | 0 | 39 | 79 | 67 | 49 | 42 | 49 | 36 | 85 | 20 | 92 | 56 |
| 0 | 40 | 43 | 95 | 97 | 60 | 68 | 50 | 57 | 110 | 21 | 111 | 71 |
| 0 | 80 | 44 | 93 | 98 | 51 | 72 | 51 | 52 | 106 | 28 | 105 | 70 |
| 40 | 0 | 47 | 107 | 92 | 63 | 56 | 77 | 62 | 108 | 23 | 114 | 75 |
| 40 | 40 | 69 | 147 | 154 | 101 | 129 | 112 | 105 | 148 | 67 | 195 | 123 |
| 40 | 80 | 76 | 150 | 148 | 100 | 123 | 116 | 104 | 159 | 61 | 194 | 123 |
| 80 | 0 | 53 | 122 | 118 | 75 | 79 | 107 | 78 | 123 | 34 | 136 | 92 |
| 80 | 40 | 81 | 188 | 209 | 141 | 162 | 163 | 129 | 179 | 85 | 212 | 155 |
| 80 | 80 | 84 | 186 | 205 | 147 | 171 | 167 | 139 | 181 | 90 | 220 | 159 |
| 120 | 0 | 50 | 122 | 103 | 66 | 68 | 106 | 65 | 117 | 28 | 119 | 84 |
| 120 | 40 | 78 | 194 | 228 | 162 | 176 | 194 | 136 | 202 | 90 | 222 | 168 |
| 120 | 80 | 85 | 200 | 234 | 170 | 202 | 213 | 151 | 215 | 105 | 225 | 180 |
| 160 | 0 | 50 | 127 | 136 | 83 | 84 | 132 | 84 | 139 | 49 | 157 | 104 |
| 160 | 40 | 80 | 190 | 231 | 170 | 180 | 220 | 150 | 210 | 95 | 229 | 176 |
| 160 | 80 | 85 | 197 | 240 | 172 | 200 | 227 | 146 | 223 | 95 | 226 | 181 |
| 200 | 0 | 67 | 141 | 162 | 109 | 115 | 159 | 99 | 155 | 65 | 179 | 125 |
| 200 | 40 | 79 | 197 | 234 | 169 | 181 | 224 | 152 | 207 | 97 | 218 | 176 |
| 200 | 80 | 95 | 201 | 239 | 191 | 204 | 232 | 157 | 236 | 104 | 231 | 189 |

*continued*

**Table 1. Effect of nitrogen (N) and phosphorus (P) fertilization on irrigated corn, Tribune, KS, 2002–2011**

| N | $P_2O_5$ | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ---------- lb/a ---------- | | --- | --- | --- | --- | --- | bu/a | --- | --- | --- | --- | --- |
| ANOVA ($P>F$) | | | | | | | | | | | | |
| Nitrogen | | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Linear | | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Quadratic | | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Phosphorus | | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Linear | | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Quadratic | | 0.007 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| N × P | | 0.133 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Means | | | | | | | | | | | | |
| Nitrogen, lb/a | | | | | | | | | | | | |
| 0 | | 42 | 89 | 87 | 53 | 61 | 50 | 48 | 100 | 23 | 103 | 66 |
| 40 | | 64 | 135 | 132 | 88 | 103 | 102 | 91 | 138 | 50 | 167 | 107 |
| 80 | | 73 | 165 | 178 | 121 | 137 | 146 | 115 | 161 | 70 | 189 | 135 |
| 120 | | 71 | 172 | 188 | 133 | 149 | 171 | 118 | 178 | 74 | 189 | 144 |
| 160 | | 71 | 172 | 203 | 142 | 155 | 193 | 127 | 191 | 80 | 204 | 154 |
| 200 | | 80 | 180 | 212 | 156 | 167 | 205 | 136 | 199 | 89 | 209 | 163 |
| LSD (0.05) | | 8 | 9 | 11 | 10 | 15 | 11 | 9 | 12 | 9 | 13 | 8 |
| $P_2O_5$, lb/a | | | | | | | | | | | | |
| 0 | | 51 | 116 | 113 | 74 | 74 | 105 | 71 | 121 | 36 | 133 | 89 |
| 40 | | 72 | 168 | 192 | 134 | 149 | 160 | 122 | 176 | 76 | 198 | 145 |
| 80 | | 78 | 171 | 194 | 139 | 162 | 168 | 125 | 187 | 81 | 200 | 150 |
| LSD (0.05) | | 6 | 6 | 8 | 7 | 11 | 8 | 6 | 9 | 7 | 9 | 6 |

# Long-Term Nitrogen and Phosphorus Fertilization of Irrigated Grain Sorghum

*A. Schlegel*

## Summary

Long-term research shows that phosphorus (P) and nitrogen (N) fertilizer must be applied to optimize production of irrigated grain sorghum in western Kansas. In 2011, N applied alone increased yields about 50 bu/a, whereas N and P applied together increased yields up to 75 bu/a. Averaged across the past 10 years, N and P fertilization increased sorghum yields more than 60 bu/a. Application of 40 lb/a N (with P) was sufficient to produce about 80% of maximum yield in 2011, which was slightly less than the 10-year average. Application of potassium (K) has had no effect on sorghum yield throughout the study period.

## Introduction

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

## Procedures

This field study is conducted at the Tribune Unit of the Southwest Research-Extension Center. Fertilizer treatments initiated in 1961 are N rates of 0, 40, 80, 120, 160, and 200 lb/a N without P and K; with 40 lb/a $P_2O_5$ and zero K; and with 40 lb/a $P_2O_5$ and 40 lb/a $K_2O$. All fertilizers are broadcast by hand in the spring and incorporated before planting. The soil is a Ulysses silt loam. Sorghum (Pioneer 8500/8505 in 1998–2007 and Pioneer 85G46 in 2008–2011) is planted in late May or early June. Irrigation is used to minimize water stress. Furrow irrigation was used through 2000, and 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 2011 were greater than the 10-year average yields (Table 1). Nitrogen alone increased yields about 50 bu/a whereas P alone had increased yields less than 10 bu/a; however, N and P applied together increased yields up to 75 bu/a. Averaged across the past 10 years, N and P applied together increased yields more than 60 bu/a. In 2011, 40 lb/a N (with P) produced about 80% of maximum yields, which is slightly less than the 10-year average. Sorghum yields were not affected by K fertilization, which has been the case throughout the study period.

**Table 1. Effect of nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2002–2011**

| Fertilizer | | | Grain sorghum yield | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | $P_2O_5$ | $K_2O$ | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Mean |
| ---------------- lb/a ---------------- | | | ---------------- bu/a ---------------- | | | | | | | | | | |
| 0 | 0 | 0 | 73 | 80 | 57 | 58 | 84 | 80 | 66 | 64 | 51 | 75 | 69 |
| 0 | 40 | 0 | 81 | 93 | 73 | 53 | 102 | 97 | 60 | 70 | 51 | 83 | 77 |
| 0 | 40 | 40 | 82 | 93 | 74 | 54 | 95 | 94 | 65 | 76 | 55 | 88 | 78 |
| 40 | 0 | 0 | 82 | 92 | 60 | 63 | 102 | 123 | 92 | 84 | 66 | 106 | 88 |
| 40 | 40 | 0 | 120 | 140 | 112 | 84 | 133 | 146 | 111 | 118 | 77 | 121 | 118 |
| 40 | 40 | 40 | 121 | 140 | 117 | 84 | 130 | 145 | 105 | 109 | 73 | 125 | 116 |
| 80 | 0 | 0 | 97 | 108 | 73 | 76 | 111 | 138 | 114 | 115 | 73 | 117 | 103 |
| 80 | 40 | 0 | 127 | 139 | 103 | 81 | 132 | 159 | 128 | 136 | 86 | 140 | 125 |
| 80 | 40 | 40 | 131 | 149 | 123 | 92 | 142 | 166 | 126 | 108 | 84 | 138 | 127 |
| 120 | 0 | 0 | 86 | 97 | 66 | 77 | 101 | 138 | 106 | 113 | 70 | 116 | 98 |
| 120 | 40 | 0 | 132 | 135 | 106 | 95 | 136 | 164 | 131 | 130 | 88 | 145 | 127 |
| 120 | 40 | 40 | 127 | 132 | 115 | 98 | 139 | 165 | 136 | 136 | 90 | 147 | 130 |
| 160 | 0 | 0 | 116 | 122 | 86 | 77 | 123 | 146 | 105 | 108 | 74 | 124 | 109 |
| 160 | 40 | 0 | 137 | 146 | 120 | 106 | 145 | 170 | 138 | 128 | 92 | 152 | 135 |
| 160 | 40 | 40 | 133 | 135 | 113 | 91 | 128 | 167 | 133 | 140 | 88 | 151 | 129 |
| 200 | 0 | 0 | 113 | 131 | 100 | 86 | 134 | 154 | 120 | 110 | 78 | 128 | 117 |
| 200 | 40 | 0 | 136 | 132 | 115 | 108 | 143 | 168 | 137 | 139 | 84 | 141 | 131 |
| 200 | 40 | 40 | 143 | 145 | 123 | 101 | 143 | 170 | 135 | 129 | 87 | 152 | 134 |

*continued*

**Table 1. Effect of nitrogen (N), phosphorus (P), and potassium (K) fertilizers on irrigated grain sorghum yields, Tribune, KS, 2002–2011**

| Fertilizer | | | Grain sorghum yield | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | $P_2O_5$ | $K_2O$ | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Mean |
| --------------- lb/a --------------- | | | ------------------------------ bu/a ------------------------------ | | | | | | | | | | |
| ANOVA (*P*>*F*) | | | | | | | | | | | | | |
| Nitrogen | | | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Linear | | | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Quadratic | | | 0.001 | 0.001 | 0.018 | 0.005 | 0.004 | 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 | | | 0.920 | 0.694 | 0.121 | 0.803 | 0.578 | 0.992 | 0.745 | 0.324 | 0.892 | 0.278 | 0.839 |
| N × P-K | | | 0.030 | 0.008 | 0.022 | 0.195 | 0.210 | 0.965 | 0.005 | 0.053 | 0.229 | 0.542 | 0.013 |
| Means | | | | | | | | | | | | | |
| Nitrogen, lb/a | | | | | | | | | | | | | |
| 0 | | | 79 | 88 | 68 | 55 | 93 | 91 | 64 | 70 | 52 | 82 | 75 |
| 40 | | | 108 | 124 | 96 | 77 | 121 | 138 | 103 | 104 | 72 | 117 | 107 |
| 80 | | | 119 | 132 | 100 | 83 | 128 | 155 | 123 | 120 | 81 | 132 | 119 |
| 120 | | | 115 | 121 | 96 | 90 | 125 | 156 | 124 | 126 | 82 | 136 | 118 |
| 160 | | | 129 | 134 | 107 | 92 | 132 | 161 | 125 | 125 | 83 | 142 | 124 |
| 200 | | | 131 | 136 | 113 | 98 | 140 | 164 | 131 | 126 | 84 | 141 | 127 |
| LSD (0.05) | | | 9 | 10 | 11 | 10 | 11 | 9 | 7 | 11 | 5 | 8 | 5 |
| $P_2O_5$-$K_2O$, lb/a | | | | | | | | | | | | | |
| 0 | | | 94 | 105 | 74 | 73 | 109 | 130 | 101 | 99 | 68 | 111 | 97 |
| 40-0 | | | 122 | 131 | 105 | 88 | 132 | 151 | 117 | 120 | 80 | 130 | 119 |
| 40-40 | | | 123 | 132 | 111 | 87 | 130 | 151 | 117 | 116 | 79 | 133 | 119 |
| LSD (0.05) | | | 6 | 7 | 7 | 7 | 7 | 6 | 5 | 7 | 4 | 6 | 4 |

# KANSAS FERTILIZER RESEARCH 2011



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