No-Till Row Crop Response to Starter Fertilizer in Eastern Nebraska: I. Irrigated and Rainfed Corn

C. S. Wortmann,* S. A. Xerinda, M. Mamo, and C. A. Shapiro

ABSTRACT

Early corn (*Zea mays* L.) growth is often slowed by cool soil temperatures in no-till production systems. This inhibitory effect may be reduced through use of starter fertilizer and result in increased grain yield, but research findings have been inconsistent. Field research was conducted in four counties of eastern Nebraska to determine the probability and magnitude of corn response to starter fertilizer under varying field conditions for different combinations of nutrients and placement methods. Soils at trial sites included Typic Eutrudepts, Udic Ustorthents, and several Mollisols. Placements of N + P and N + P + S in-furrow, over-the-row, and 50×50 mm were compared for effects on early growth and grain yield. Early growth was increased with starter fertilizer by 30% over all irrigated trials and by 10% for three of five responsive rainfed trials. In the irrigated trials, starter fertilizer increased grain yield by 0.86 Mg ha^{-1}. Starter fertilizer had a minimal effect on grain yield in rainfed trials. Including S in the starter fertilizer did not result in increased yield. In-furrow and over-the-row were as effective as 50 × 50 mm placement in increasing yield. Grain yield response to starter fertilizer was greatest and most profitable with irrigated corn produced under low soil test P (STP ≤ 15 mg kg^{-1}) conditions. Conversion of early growth response into yield response to starter fertilizer appears to depend on soil water availability and on STP.

Corn production under continuous no-till is common in eastern Nebraska. In the high-residue environments of no-till, cooler soil temperature can slow germination and root growth and reduce nutrient availability, resulting in slow early plant growth. Barber et al. (1987) found the rate of corn root growth at soil temperature of 15°C to be one-fourth the rate of growth at 25°C. Placement of relatively small amounts of nutrients with or near the seed during planting, that is the use of starter fertilizer (SSSA, 1997), may accelerate early plant growth under these conditions.

Results of past unpublished research in Nebraska found that, in tilled conditions, starter fertilizer was not profitable for corn. Yield response to starter fertilizer is often profitable for no-till conditions (Scharf, 1999; Riedell et al., 2000; Vetsch and Randall, 2000), but not in all no-till situations (Bundy and Andraski, 1999; Bermudez and Mallarino, 2002; Bermudez and Mallarino, 2004). These inconsistencies are not well understood.

Research results on the effects of starter fertilizer placement also have been inconsistent. In Kansas, Lamond and Gordon (2001) compared broadcast application of all N with placement of some of the applied N, 11.2 kg ha^{-1}, either in direct seed contact (in furrow), dribbled in a band directly over the row (over the row), or placed at 50 by 50 mm (banded 50 mm to the side of the seed furrow and 50 mm deep). Yield was less when all N was broadcast-applied. Bordoli and Mallarino (1998) did not find P placement to be important but response to applied K varied with placement position. Riedell et al. (2000) reported more grain yield increase with in-furrow or 50- by 50-mm placement of P than with over-the-row placement. These results were expected since seminal roots and the radical are important to nutrient uptake until the V3 stage (Ritchie et al., 1993). With nodal root development, access to surface-applied immobile nutrients improves.

Yield increases to S applied in starter fertilizer have been observed in no-till situations where response to S is otherwise not commonly observed (Woodard and Bly, 2001; Niehues et al., 2004; Rehm, 2005). Rehm (2005) reported a yield response to S starter fertilizer in a conservation tillage system when soil organic matter was less than 20 g kg^{-1} in coarse- to medium-textured soil. Residue decomposition and mineralization of organic S, as well as N, is delayed with cool soils in the spring.

Response to starter fertilizer may vary with topographic position, possibly due to differences in microclimate, nutrient supply, soil organic matter, soil water availability, and soil physical properties. Woodard and Bly (2001) evaluated no-till corn response to starter fertilizer across topographic positions that differed in soil organic matter. Starter fertilizer application increased average corn grain yield by 1.05 and 1.80 Mg ha^{-1} at the eroded shoulder and backslope positions, respectively, with no yield increase for the bottomland position, which had relatively more soil organic matter.

Given the lack of response to starter fertilizer under tilled conditions in Nebraska, the inconsistency of response under no-till conditions in other states, and the evidence that topographic position may be important to response on rolling land, more information is needed on factors affecting the probability of no-till corn response to starter fertilizer. The objective of this research was to determine no-till corn response to starter fertilizer for different combinations of nutrients and placement methods under irrigated and rainfed conditions at different topographic positions.

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Abbreviations: ARDC, University of Nebraska-Lincoln Agricultural Research and Development Center; S_{as}, sulfur supplied from ammonium sulfate; S_{ats}, sulfur supplied from ammonium thio-sulfate; STP, soil test phosphorus; 50 by 50 mm, starter fertilizer placed 50 mm deep and 50 mm to the side of the seed.

MATERIALS AND METHODS

Site Characteristics, Treatments, and Experimental Design

The study was conducted in 2002 and 2003 at four locations and included five irrigated and five rainfed corn trials (Table 1). The trial locations were at the University of Nebraska-Lincoln (UN-L) Haskell Agricultural Laboratory (42°23′ N, 96°59′ W) and the UN-L Agricultural Research and Development Center (ARDC) (41°23′ N, 96°49′ W) and near Blair (41°33′ N, 96°07′ W) and Waverly (40°23′ N, 96°52′ W). The Haskell and ARDC locations were irrigated, and the others were rainfed. One to three trials were conducted per location and placed in different topographic positions or with different slope aspects with slopes ranging from <1 to 6%. In 2002, the trial sites were on hillside at Haskell and bottomland and hilltop at Blair. In 2003, the trial sites were on bottomland at Haskell; bottomland, hillside, and hilltop at ARDC; and hilltop, hillside, and bottomland at Waverly. The seven soil series had textures ranging from silty clay loam to silt loam. All locations had a history of corn–soybean [*Glycine max* (L.) Merr.] rotation. No-till was practiced for at least the previous 5 yr for all but the Haskell location.

The trials had eight starter fertilizer treatments, including a 2 × 3 factorial arrangement. One treatment factor consisted of two nutrient combinations: N + P and N + P + S with S supplied from ammonium sulfate (N + P + S_{as}). The second treatment factor was starter fertilizer placement method: 50 mm to the side of the row and 50 mm deep (50 by 50 mm), over the row, and in furrow. Two additional treatments were the control with no starter fertilizer applied and N + P + S in furrow with ammonium thio-sulfate (N + P + S_{ats}) as the S source to compare with N + P + S_{as}. Fertilizer solutions were prepared using ammonium nitrate, ammonium sulfate, monoammonium phosphate, and ammonium thio-sulfate. The N, P, and S application rates were 22.4, 9.8, and 11.2 kg ha^{-1}, respectively, for 50- by 50-mm and over-the-row application and half these rates for in-furrow application to minimize risk of salt damage during germination. Potassium was not included in the starter fertilizer as soil test K was always very high (>250 mg kg^{-1}; Shapiro et al., 2003).

Six corn hybrids were used in the study. The cooperating producers selected the hybrid to be planted in the trials conducted in their fields. In 2003, a second hybrid of similar maturity as the first was selected by the researchers and included in the Waverly and ARDC trials by splitting the plots to evaluate hybrid × starter fertilizer interaction effects but not hybrid main effects. The seed of each hybrid was sown from two of the four planter boxes for the three trials at a location resulting in a nonrandom assignment of hybrids to subplots. At Haskell in 2003, hybrids and starter fertilizer treatments were assigned in a randomized complete block design with four rows per experimental unit.

Each trial had four replications. The plot size was 3.1 by 12.3 m. An area of 1.5 by 6.1 m was harvested per plot. For Waverly and ARDC, the plot was split with two rows per hybrid, and the harvested area was 0.76 by 6.1 m.

Starter fertilizer was applied during planting. The trials were planted in 0.76-m row spacing with a John Deere 7200 (Deere & Company, Moline, IL) four-row planter equipped for 50- by 50-mm, over-the-row, and in-furrow placement and able to apply one liquid fertilizer mixture at a time. All plots that received a specific starter fertilizer mixture were planted before switching to another mixture. The rate of application was controlled by the tractor speed while an electric pump maintained a uniform pressure and flow rate. A similar planter with a ground-driven squeeze pump was used at Haskell.

Crop Management

Cooperating producers were responsible for fertilizer application, weed control, irrigation by center pivots, and other agronomic practices. The base preplant N application rates were determined by the cooperating producer and were 213 kg ha^{-1} at ARDC and 157 kg ha^{-1} at Waverly applied as anhydrous ammonia, 101 kg ha^{-1} at Blair as urea ammonium nitrate, and 78 and 112 kg ha^{-1} at Haskell in 2002 and 2003 as urea, respectively. The ARDC trials received as much as 15 kg ha^{-1} P applied as liquid manure through the irrigation system. The remaining fields did not receive P.

Field Measurements

Surface soil samples (0–0.20 m) were taken at all experimental sites before planting. One sample of 10 cores of 17.5-mm diameter was collected from two replications and another from the other two replications. Soil samples were air-dried, ground, and analyzed for $pH_{1:1}$, soil organic matter, and available P and K. Organic matter was determined by loss on ignition (Nelson and Sommers, 1996). Soil test P and K were determined following the methods of Bray and Kurtz (1945) and Helmke and Sparks (1996), respectively.

Table 1. Site information, including soil chemical properties (0–0.20 m), for 10 corn trials conducted in eastern Nebraska in 2002 and 2003.

Location†	Position	Soil series (Great Group)‡	Slope	Aspect	NT§	RC¶	pH	SOM#	K	Bray-P1	ST††
			%		yr	%	1:1	g kg^{-1}	mg kg^{-1}		°C
				Irrigated							
Haskell 2002	Hillside	Crofton (Udic Ustorthents)	6.0	East	1	68	7.3	25	737	14.0	15
Haskell 2003	Bottomland	Alcester (Cumulic Haplusdolls)	3.0	East	2	71	6.1	30	592	60.0	14
ARDC 2003	Bottomland	Olmitz (Cumulic Haplusdolls)	<1.0	None	5	73	5.9	28	722	15.0	11–15
ARDC 2003	Hillside	Pohocco (Typic Eutrudepts)	5.0	West	5	79	6.3	22	278	3.8	11–15
ARDC 2003	Hilltop	Pohocco (Typic Eutrudepts)	4.5	Northeast	5	81	6.4	19	378	5.5	11–15
				Rainfed							
Blair 2002	Bottomland	Marshall (Typic Haplusdolls)	1.5	West	>5	88	5.3	24	270	26.6	13–15
Blair 2002	Hilltop	Marshall (Typic Haplusdolls)	2.5	Northeast	>5	80	6.0	26	283	13.2	13–15
Waverly 2003	Hilltop	Aksarben (Typic Argiudolls)	1.5	East	15	68	5.5	34	468	34.7	13–15
Waverly 2003	Hillside	Aksarben (Typic Argiudolls)	6.0	Northeast	15	72	5.8	29	452	40.9	13–15
Waverly 2003	Bottomland	Zook (Cumic Vertic Endoaquolls)	<1.0	None	15	76	6.0	34	452	43.6	13–15

† Corn hybrids and planting dates: P-33P67 and P-33B50 were planted 26 Apr. 2003 at the University of Nebraska Agriculture Research and Development Center (ARDC); Golden Harvest 2551 and Pioneer 33P67 and Pioneer 33G66 were planted 17 May 2002 and 16 May 2003, respectively, at the Haskell Agricultural Lab; Pioneer 34R06 was planted 8 May 2002 at Blair; and Pioneer 33B50 and Dekalb C-6019 were planted 29 Apr. 2003 at Waverly.

‡ Soil textural classes were silt loam or silty clay loam.

§ NT, years under continuous no-till management.

¶ RC, ground cover by crop residue after planting.

\# SOM, soil organic matter.

†† ST, soil temperature range at 0.10-m depth on the day of planting.

Soil cover by crop residues was measured at all trial sites after planting using a line intersect method with two 30-m opposite diagonal measurements per trial and counting crop residue intersections at 100 points per diagonal (Shelton et al., 1993). Soil temperature at 0.10-m depth was measured at planting time for all trials. Soil temperature was also measured for at least 3 wk after planting at two topographic positions of two locations using sensors (Optic StowAway Temp, Onset Computer Corp., Bourne, MA) buried at the 0.10-m depth. Rainfall and temperature data were collected within 2 km for Haskell and ARDC. Rainfall and air temperature data from ARDC were used for the Waverly location (22 km) and data from Blair for the Blair location (12 km).

Plant Measurements

Aboveground plant samples were collected at V6 to V8 (Ritchie et al., 1993) for early plant biomass by taking every third plant in the two outside rows beginning 3 m from the end of the row until eight plants were obtained. Plant samples were oven-dried at about 71°C to constant weight and weighed. Plants in 12 m of row were counted at V6 to V8. The two middle rows were hand-harvested for grain yield determination for all trials except for the Haskell trial in 2003, which was machine-harvested. Corn ears were weighed and subsamples dried and shelled. The grain was weighed and percentage water measured to extrapolate grain yield on a 150 g kg^{-1} water basis.

Data Analyses

The data for irrigated and rainfed corn experiments were analyzed separately. Data were analyzed using SAS Institute (2000) PROC GLM for general linear models or PROC MIXED (Littell et al., 1996) for experiments with missing values for proper adjustment of the degrees of freedom. For locations with more than one trial, a combined analysis of variance was conducted. Trials at the Waverly and ARDC locations were analyzed as a split-plot design with hybrids in the subplots to test the treatment × hybrid interaction effect. All other trials were analyzed as randomized complete block designs. When the treatment × topographic position or treatment × hybrid interaction was significant, data were also analyzed by individual trial. Contrasts were used to test for differences between sets of treatments: control vs. the mean of the treatments with starter fertilizer applied; N + P vs. N + P + S_{as}; N + P + S_{ats} vs. N + P + S_{as}; 50- by 50-mm placement vs. the mean of over the row and in furrow; and in furrow vs. over the row. Contrasts were tested by individual trials in cases of significant interaction effects. All effects were considered to be statistically significant at $P \leq 0.10$ due to the applied nature of this research.

The interpretation of the results considered the economics of starter fertilizer use. Costs of starter fertilizer application were estimated using: N, P, and S priced at $0.50, $1.40, and $0.70 kg^{-1}, respectively; and in-furrow and over-the-row placement priced at $2.30 ha^{-1} and 50- by 50-mm placement priced at $3.00 ha^{-1}. Grain was valued at $100 Mg^{-1}. Therefore, the cost of starter fertilizer application expressed as grain mass ranges from 0.15 to 0.35 Mg ha^{-1}.

RESULTS

Site Characteristics

The amount of ground covered by crop residue after planting ranged from 68 to 88% (Table 1). The soils were moderately acidic for all but one location. The STP levels on half of the trials were adequate (>15 mg kg^{-1}) and low (≤15 mg kg^{-1}) for the other trials. Soil test K was always above 250 mg kg^{-1}.

Average soil temperatures at the 0.10-m depth at planting were less than 15°C (Table 1). The respective mean daily minimum and maximum air temperatures during the 3 wk following planting were 3.9 and 17.7°C at Blair, 11.5 and 25.0°C at Haskell 2002, 9.0 and 22.0°C at Haskell 2003, and 7.8 and 19.7°C at ARDC and Waverly. The daily minimum and maximum soil temperatures during the 3 wk after planting ranged from 11.4 to 13.7°C and from 15.2 to 17.9°C, respectively, for Waverly and ARDC. Soil temperatures were similar for hilltop and bottomland positions at each of these locations. Thus, any treatment × topographic position interaction effect was unlikely due to soil temperature differences.

Soil water deficits were avoided at the irrigated locations with timely water application. However, crop growth was constrained by water deficits in June and July 2002 at the Blair trials and in July and August 2003 at the Waverly trials (Fig. 1).

Corn Plant Biomass and Stand Density at the V6 to V8 Growth Stage

Early plant biomass was not affected by the topographic position by treatment, hybrid × treatment, and topographic position × treatment × hybrid interaction effects at all locations (Table 2). Early-season biomass was 1.5 to 3.3 g plant^{-1} more with starter fertilizer applied compared with the control for the irrigated trials. Early-season biomass was more with starter fertilizer applied for rainfed trials at the Waverly location but not at the Blair location. The mean increase in early growth was generally greater with STP ≤ 15 mg kg^{-1} than for the higher STP sites; if the Blair hilltop trial is excluded, the increase in early growth with starter fertilizer applied is negatively related to STP ($r = -0.74$). Early growth response to in-furrow starter fertilizer placement can occur independent of STP and soil K availability (Kaiser et al., 2005).

Early-season biomass was greater with N + P + S_{as} than with N + P in the irrigated trials of Haskell 2002

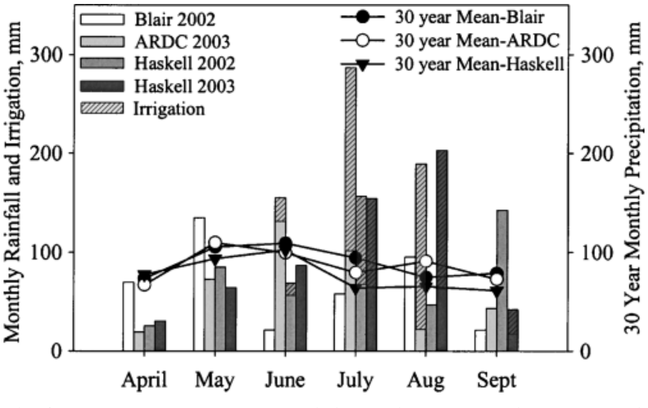

Fig. 1. Monthly and 30-yr mean rainfall during the cropping seasons of 2002 and 2003 of three research locations. University of Nebraska-Lincoln Agricultural Research and Development Center (ARDC) rainfall data were used for the Waverly location. Hatched bars show the amounts of irrigation for respective years at the Haskell and ARDC locations.

Table 2. Starter fertilizer effect on no-till corn growth at V6 to V8 in eastern Nebraska, 2002 and 2003.

	Irrigated			Rainfed	
Treatments†	**Haskell 2002**	**Haskell 2003**	**ARDC 2003**	**Blair 2002**	**Waverly 2003**
			g plant^{-1}		
Control	**23.0**	**5.1**	**9.1**	**11.0**	**16.7**
N + P, 50 by 50 mm	**25.4**	**6.8**	**11.7**	**11.6**	**18.0**
N + P, over the row	**23.4**	**6.6**	**12.3**	**11.0**	**18.1**
N + P, in furrow	**25.4**	**6.4**	**11.8**	**11.2**	**18.1**
N + P + S_{as}, 50 by 50 mm	**29.1**	**6.4**	**13.0**	**11.8**	**18.6**
N + P + S_{as}, over the row	**25.2**	**6.6**	**13.3**	**13.3**	**18.1**
N + P + S_{as}, in furrow	**27.3**	**6.5**	**12.5**	**12.2**	**18.9**
N + P + S_{ats}, in furrow	**25.8**	**6.0**	**12.0**	**11.7**	**17.8**
			P > F		
Treatment (Trt)	**	**	**	‡	**
Trt × topographic position (TP)	**NA§**	**NA**	**NS¶**	**NS**	**NS**
Trt × hybrid	**NA**	**NS**	**NS**	**NA**	**NS**
Trt × TP × hybrid	**NA**	**NA**	**NS**	**NA**	**NS**
$LSD_{0.10}$	**2.9**	**0.7**	**0.8**	**1.9**	**1.4**
No. of trials	**1**	**1**	**3**	**2**	**3**
			contrasts and mean differences		
Starter mean vs. control	**2.9***	**1.5*****	**3.3****	**0.9**	**1.6‡**
N + P vs. N + P + S_{as}	**−2.5***	**0.3**	**−1.0****	**−1.3***	**−0.4**
S_{as} vs. S_{ats}	**1.5**	**0.6**	**0.6**	**0.4**	**1.1**
50 by 50 mm vs. over the row and in furrow	**1.9‡**	**0.2**	**−0.1**	**−0.2**	**0.0**
In furrow vs. over the row	**2.1‡**	**−0.3**	**−0.6**	**−0.4**	**0.4**

*** Significant at the 0.05 level.**

**** Significant at the 0.01 level.**

***** Significant at the 0.001 level.**

† S_{as}, sulfur supplied from ammonium sulfate; S_{ats}, sulfur supplied from ammonium thio-sulfate; 50 by 50 mm, fertilizer placed 50 mm to the side and 50 mm deep.

‡ Significant at the 0.10 level.

§ NA, not available.

¶ NS, not significant.

and ARDC and in the rainfed trials of Blair, but the contrast was not significant for the other locations (Table 2). Early-season biomass was not affected by S source. Rehm (2005) reported that S response in conservation tillage was mostly probable in coarse- to medium-textured soil with organic matter ≤ 20 g kg^{-1}. Soils in this research were mostly silty clay loam to silt loam with organic matter > 20 g kg^{-1} (Table 1).

Starter fertilizer placement at 50 by 50 mm did not differ from the mean of the other two placement methods except in the Haskell 2002 irrigated trial where it resulted in 1.9 g plant^{-1} greater early-season biomass than the average of in-furrow and over-the-row placement (Table 2). At Haskell 2002, in-furrow placement had greater early-season biomass than over-the-row placement.

Plant population at V6 to V8 ranged from 48 000 at Blair to 104 000 plants ha^{-1} at ARDC. Plant population with in-furrow placement was 10 and 15% more than with the control at ARDC and Waverly, respectively, but was not affected at other locations and with other placement methods (data not presented).

Grain Yield

Corn grain yield was not affected by the topographic position × treatment and topographic position × treatment × hybrid interaction effects at any locations. A treatment × hybrid interaction effect was found at the Waverly location, and the treatment means are presented by hybrid for this location (Table 3). There were treatment effects at all locations except for the rainfed location at Blair. Grain water content at harvest was not affected by treatments although others have reported that starter fertilizer use can result in less grain water at harvest (Wolkowski, 2000; Vetsch and Randall, 2002; Bermudez and Mallarino, 2004).

The mean effects of starter fertilizer on corn grain yield were significant for all irrigated trials, except Haskell in 2002, and grain yield increases were 0.66 to 1.21 Mg ha^{-1} (Table 3). Only one of the five irrigation trials had Bray-P1 > 15 mg kg^{-1}. Soil test P was 14 mg kg^{-1}, and soil organic matter was 25 g kg^{-1} at the one nonresponsive irrigated site.

The mean effect of starter fertilizer on grain yield was not significant at any of the rainfed locations (Table 3). Soil test P ranged between 4 and 60 mg kg^{-1}, and soil organic matter ranged between 19 and 30 g kg^{-1} for the responsive trial sites. However, four of the five rainfed trials had Bray-P1 > 15 mg kg^{-1}.

The mean magnitude of yield response for irrigated trials tended to be greater with Bray-P1 ≤ 15 mg kg^{-1} than with the one trial with Bray-P1 > 15 mg kg^{-1} (Fig. 2). Over all trials, grain yield response to starter fertilizer was not correlated with STP. Kaiser et al. (2005) also found that the magnitude of yield response to starter fertilizer was not related to STP although response was more likely with STP < 15 mg kg^{-1}.

Grain yield response was 1.03 Mg ha^{-1} more with N + P than with N + P + S_{as} at Haskell 2002, but the N + P vs. N + P + S_{as} contrast was not significant for the other irrigated and rainfed locations (Table 3). The only yield increases due to including S in the starter fertilizer for rainfed trials occurred at Waverly with N + P + S applied in furrow. Sulfur source did not affect yields in any trials except for one hybrid at Waverly where yield was more with N + P + S_{ats} than with N + P + S_{as}.

Table 3. Starter fertilizer effect on corn grain yield under irrigated no-till conditions in eastern Nebraska, 2002 and 2003.

	Irrigated			Rainfed		
Treatments†	**Haskell 2002**	**Haskell 2003**	**ARDC 2003**	**Blair 2002**	**Waverly 2003a**	**Waverly 2003b**
			Mg ha^{-1}			
Control	9.92	10.41	13.67	7.93	8.83	8.45
N + P, 50 by 50 mm	11.40	11.62	14.47	7.07	8.32	8.95
N + P, over the row	10.30	11.08	14.83	8.29	8.42	7.52
N + P, in furrow	11.58	10.97	14.94	8.28	8.91	9.03
N + P + S_{as}, 50 by 50 mm	9.74	10.88	14.39	7.30	8.44	9.63
N + P + S_{as}, over the row	10.87	11.32	14.35	7.88	8.39	8.72
N + P + S_{as}, in furrow	9.58	10.77	15.23	7.77	10.36	8.14
N + P + S_{ats}, in furrow	10.23	10.65	15.29	7.24	9.02	10.11
			$P > F$			
Treatment (Trt)	**	*	**	NS‡	§	§
Trt × topographic position (TP)	NA¶	NA	NS	NS	NS	NS
Trt × hybrid	NA	NS	NS	NA	§	§
Trt × TP × hybrid	NA	NA	NS	NA	NS	NS
LSD$_{0.10}$	0.91	0.58	0.77	1.13	1.52	1.52
No. of trials	1	1	3	2	3	3
			contrasts and mean differences			
Starter mean vs. control	0.66	0.69*	1.03**	−0.16	−0.20	0.20
N + P vs. N + P + S_{as}	1.03**	0.23	0.09	0.23	−0.41	−0.26
S_{as} vs. S_{ats}	−0.65	0.12	−0.06	0.53	0.85	−2.02**
50 by 50 mm vs. over the row and in furrow	−0.02	0.22	−0.41	−0.87**	−0.55	0.92§
In furrow vs. over the row	−0.01	−0.33	0.49	−0.06	1.07	0.29

* Significant at the 0.05 level.

** Significant at the 0.01 level.

† S_{as}, sulfur supplied from ammonium sulfate; S_{ats}, sulfur supplied from ammonium thio-sulfate; 50 by 50 mm, fertilizer placed 50 mm to the side and 50 mm deep.

‡ NS, not significant.

§ Significant at the 0.10 level.

¶ NA, not available.

Placement of starter fertilizer did not affect yield at any of the irrigated locations (Table 3). Grain yield was less with 50- by 50-mm placement than with other placements at Blair, but the opposite was true for one hybrid in the Waverly trials.

DISCUSSION

Starter fertilizer application generally increased early growth relative to no starter with a greater and more frequent effect for irrigated compared with rainfed corn. The irrigated trials had a lower mean STP than the rainfed trials, and the magnitude of early growth response was negatively correlated to STP. Increased biomass at V6 to V8 with starter fertilizer did not always convert into increased grain yield, and yield was increased less frequently with starter fertilizer applied than was early growth. Yield response to starter fertilizer was not related to STP, suggesting that conversion of early response into increased grain yield is less affected by STP than other growing conditions during the season, such as soil water availability. Mallarino et al.

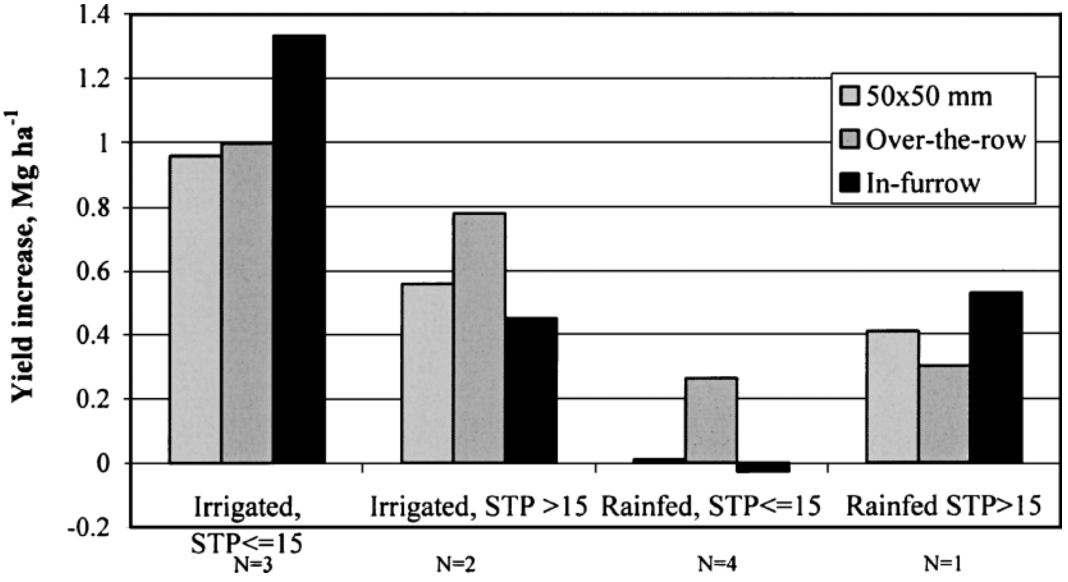

Fig. 2. Corn yield response (Mg ha^{-1}) to placement of starter fertilizer under no-till conditions in eastern Nebraska, 2002 and 2003, as affected by soil P level for irrigated and rainfed conditions. Significance of P level by placement interactions: $P = 0.17$ for irrigated and NS for rainfed.

(1999) and Kaiser et al. (2005) also found that increased early growth due to starter fertilizer application does not consistently result in higher yields.

Starter N + P + S, applied over the row or in furrow, was more consistent than N + P in increasing early-season growth, but including S in the starter fertilizer did not result in increased grain yield. In general, over-the-row and in-furrow placement promoted early-season growth and grain yield as well or better than 50- by 50-mm placement, the more expensive application method. Increased plant population with in-furrow placement at two locations was apparently due to increased seedling vigor and survival, which overcame any salt effects of the starter fertilizer.

Grain yield increase was greater and more frequent for irrigated than for rainfed corn. The crop in all rainfed trials experienced midseason water deficits that were more severe than typical (Fig. 1). The conversion of early growth response to grain yield response to starter fertilizer may be greater for rainfed conditions when soil water deficits are less severe although this is not supported by Bermudez and Mallarino (2004) and Kaiser et al. (2005). The results of this research do not allow us to determine how much rainfall is needed during the season to have an acceptable frequency of yield increase with starter fertilizer.

The mean yield response was greater for irrigated trials with STP ≤ 15 mg kg^{-1} than for the higher P sites. Others have reported yield responses to starter fertilizer in high-P environments (Howard and Essington, 1998; Bundy and Andraski, 1999; Scharf, 1999; Vetsch and Randall, 2000). The cooperating producers did not apply P to any of the trial sites except for the ARDC location when some P was applied in liquid manure. If P had been applied as recommended, the effect of the starter fertilizer may have been diminished.

Yield response to starter fertilizer application was similar across topographic positions within a field. More response was expected on hillsides and hilltops compared with bottomland positions due to being once eroded and having generally lower levels of STP, soil organic matter, and soil water availability throughout the season (Woodard and Bly, 2001).

In trials with two hybrids, there was no treatment × hybrid interaction for early growth, but an interaction occurred at only one location for grain yield. In that case, the interaction occurred in response to S source and placement of starter fertilizer rather than due to the mean effect of starter fertilizers compared with the control. Hybrid × treatment interactions may occur largely due to differences in maturity where longer-season hybrids are more responsive to starter fertilizer than shorter-season hybrids (Gordon et al., 1997; Bundy and Andraski, 1999). In our trials, the hybrids were selected to be of similar maturity.

The $LSD_{0.1}$ values were generally greater than the yield increase required for profitable starter fertilizer use. Yield increases are sufficient to pay the cost of starter fertilizer use if greater than 0.15 Mg ha^{-1} for in-furrow application of N + P and greater than 0.35 Mg ha^{-1} for N + P + S applied at 50 by 50 mm. Therefore, the probability of profitable response is likely to be greater than the probability of statistically significant response. Generally, starter fertilizer was profitable for no-till-irrigated corn, even for STP > 15 mg kg^{-1}, but not for rainfed corn. Adequate soil water availability during the growing season may have been important to grain yield response, but most of the sites with severe water deficits had relatively high STP. In-furrow application was most economical as it resulted in similar yield responses as the other placements even though the amount of fertilizer applied was half as much. It was the least costly method and the lower application rates implied that the producer will need to fill the applicator with fertilizer less frequently during planting.

CONCLUSIONS

Early corn growth increases with application of starter fertilizer are common, but this increased growth often does not convert into increased yield. There is a high probability (>80%) of grain yield increase with starter fertilizer for no-till corn if soil water is adequate and STP is low but a low probability if water deficits are severe. Topographic position is not an important determinant of response to starter fertilizer, but yield increases are likely to be greater with STP ≤ 15 mg kg^{-1} than with higher STP regardless of topographic positions and other soil differences. In-furrow placement is as effective as other placements and more economical. Including S in the starter fertilizer may cause additional early growth, but this may not convert into increased yield.

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