Corn Grain Yield and Early Nutrient Uptake As Affected by In-Furrow Application of Potassium Fluid Fertilizer

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Introduction

The placement of small amounts of nutrients in bands beside and below the seeds or in the seed furrow significantly increases the concentration of nutrients in the small soil volume where seedling roots grow. Common starter fertilizers are N-P or N-P-K products or mixtures, to which other nutrients often are added. Research summarized in thorough reviews (Randall and Hoeft, 1988; Bundy et al., 2005) indicated that starter fertilization often increases corn early growth and nutrient uptake more than similar or higher broadcast fertilizer rates. The growth response to starter usually is larger and more frequent in conditions that limit root growth or activity, the concentration in the soil of nutrient forms plants can absorb, or nutrient diffusion to the root. Research has shown, however, that starter effects on grain yield are not as consistent. Yield responses are more likely to occur with cool and wet soils and with reduced tillage because high residue cover keeps soil cooler and wetter in early spring (Kaspar et al., 1990; Mengel et al. 1998; Scharf, 1999; Wolkowski, 2000; Vyn and Janovicek, 2001). Inconsistent responses to starter often could not be clearly explained and were attributed to complex interactions between soil conditions, climate, and planting dates (Vetsch and Randall, 2002; Vyn et al., 2002; Bermudez and Mallarino, 2002; Bermudez and Mallarino, 2004; Bundy et al., 2005; Kaiser et al., 2005; Osborne, 2005).

Phosphorus is a relatively immobile nutrient, its diffusion to seedling roots is limited by cold soil temperature, and it is critical for plants especially early during growth. Therefore, it is not surprising that corn response to starter fertilizer mixtures often is explained by P. Research also has shown that N often explains corn response to starter, however, especially in soils testing high in P. In their review, Bundy et al. (2005) concluded that responses to starter N tend to be more frequent in northern areas of the Corn Belt. Research in high-P soils with no-till management and liquid fertilizers in Iowa (Bermudez and Mallarino, 2003) and with tilled or no-till management and granulated or liquid fertilizers in Pennsylvania (Roth et al., 2006) compared N and N-P-K starters and found that corn grain yield responses almost always were explained by starter N. The commonly used liquid N-P or N-P-K starter mixtures preclude firm conclusions about starter K effects on corn. Some of the aforementioned studies suggested that K may explain the early corn growth and yield response to starter in low-testing soils but provided poor evidence of a true starter K effect. Iowa research with granulated P or K fertilizers applied separately beside and below the seeds or broadcast showed a clear effect of band P on corn growth but not for K (Bordoli and Mallarino, 1998; Mallarino et al., 1999). Recent research with liquid 3-18-18 starter provided no clear clues, but suggested little or no true starter effects from K (Kaiser et al., 2005).

Knowledge of the existence of a starter K effect and the conditions in which it is more likely is important to improve the efficiency and economics of fertilizer use. This is because many producers' fields test optimum or high in soil-test K (STK) and most fertilization guidelines recommend starter for these soils only under certain conditions. Another reason very important for in-furrow starter application is that K compounds are the most common cause of salt damage, so some fluid fertilizers are expensive because they use low-salt K compounds to minimize seedling damage. A few decades ago the starter fertilizers used in the Corn Belt were mostly granulated products, but use of liquid starter fertilizers predominates today. Also, as corn planters became larger there has been a steady change from the classic "2x2" placement method to in-furrow application. Therefore, the goal of this study was to investigate corn response to in-furrow liquid starter K fertilizer without the confounding effects of other nutrients.

Trials and Procedures

The study included two different set of trials with corn conducted on Iowa farmers' fields. One set used a conventional small-plot methodology to conduct six trials in two years (Table 1). Treatments replicated four times were (1) a control, (2), 3-18-18 in-furrow starter, (3) broadcast P-K in mixture, (4) broadcast P-K plus 3-18-18 starter, (5) 0-0-30 in-furrow starter, and (6) broadcast P-K plus 0-0-30 starter. The 3-18-18 starter was applied at 5-6 gal/acre (10 to 14 lb of P_2O_5 and K_2O/acre). The 0-0-30 starter was applied at a similar rate of K_2O/acre (3.0 to 3.6 gal/acre). The broadcast treatment was designed to apply once before corn the P and K needs of 2-year corn-soybean rotations based on current Iowa recommendations, but applied at least maintenance rates of 100 lb of P_2O_5/acre (triple super phosphate) and 120 lb of K_2O/acre (potassium chloride) even in high-testing soils. A uniform rate of 50 lb N/acre (ammonium nitrate or urea) was broadcast at planting time in addition to the farmers' normal N rate. Site 1 was managed with no-tillage. Corn row spacing was 30 inches. Soil samples (6-inch depth) were taken before applying fertilizer and planting corn from the top 6-inch layer of soil. The aboveground parts of corn plants were sampled at the V5 to V7 growth stage. Grain was harvested by hand.

Another set of trials used a strip-trial methodology based on GPS, yield monitors, and GIS to conduct eight field-scale trials in two years (Table 2). Treatments replicated three times were a non-fertilized control, broadcast K that supplied the K needed for the 2 years of corn-soybean rotations (but at least 120 lb K_2O/acre), 0-0-30 in-furrow starter K that applied 15 to 22 lb K_2O/acre across fields, and broadcast K plus starter K. The size of each trial was approximately 17 to 27 acres. The treatments and replication layout followed a randomized complete block, split-plot design, with broadcast rates in large plots and starter rates in subplots. Sites 3 and 4 were managed with no-till. Corn row spacing was 30 inches. Soil samples (6-inch depth) were collected before applying K treatments from grid cells whose size varied among fields from 0.33 to 1 acre. A composite sample of the above-ground portion of ten corn plants was collected at the V5 to V7 growth stage from areas delimited by the width of a strip and the length of the soil-sampling grid cell (0.1 to 0.33 acres). Grain was harvested with combines equipped with calibrated yield monitors, moisture sensors, and GPS receivers with differential correction. The yield monitor spatial accuracy was checked in several field locations with a hand-held GPS receiver, and yield data were unaffected by borders because at least 120 ft at each strip end were harvested but not used. ArGIS software was used to identify common yield monitor problems (such as unplanned combine stops or effects of waterways) and to delete affected data.

The soil samples were analyzed for K and other routine tests. In this article we will use the Iowa interpretation classes to classify STK values (Sawyer et al., 2002). The boundaries are ≤ 90 ppm for Very Low, 91 to 130 ppm for Low, 131 to 170 ppm for Optimum, 171 to 200 ppm for High, and ≥ 201 ppm for Very High. The guidelines recommend maintaining STK in the Optimum class by applying K rates similar to K removal with harvest. No K fertilizer is recommended for the high-testing classes except for a common starter mixture for corn with wet and cool soil, crop residues on the soil surface, or late planting dates with full-season hybrids. The plant-tissue samples were dried at 140 °F, weighed, and ground to pass through a 2 mm screen. The total plant P and K concentration was analyzed by an acid, wet-digestion method and measuring K by inductively-coupled plasma emission spectroscopy.

For the small-plot trials, the data for each site were analyzed statistically by analysis of variance for a randomized complete block design. For the strip trials, the GPS coordinates of the field layout, georeferenced digitized soil survey maps, and the collected data were imported into ArcGIS. The data were averaged for areas defined by the replications, treatment strips, and digitized soil survey maps. Analysis of variance for a randomized complete block, split-plot design were conducted for data collected along the entire length of the strips and for data corresponding to each soil series that encompassed at least two field replications.

Results from the Small Plot Trials

Early corn growth responded ($P \leq 0.10$) to one or more fertilizer treatment at five sites (Table 3). The only exception was Site 1, which was managed with no-till, soil P was Optimum and STK was Low, and the planting date was the latest of all sites. Starter P-K applied alone increased early growth in the five responsive sites while starter K alone increased growth in two sites but decreased it in three sites. Although the broadcast P-K rate was almost ten times higher than the starter rate, broadcast fertilization alone increased growth more than starter P-K only at Site 4 while starter P-K increased growth more than broadcast in Site 5. Application of starter P-K in addition to broadcast P-K increased corn growth further in two sites (Sites 5 and 6), but starter K in addition to broadcast fertilizer never increased growth further and decreased it at three sites. Therefore, the results demonstrated that starter P can stimulate early growth as much as or more than much higher broadcast rates and even in addition to broadcast fertilization, but this was not the case for starter K.

The K concentration of young corn plants was increased by one or more treatments at all sites (Table 3). Plant P concentration and uptake data are not shown or discussed. Broadcast fertilization was more effective at increasing K concentration than either starter P-K or K at all sites, probably due to the higher amount of K applied. Starter P-K increased K concentration more than starter K in two sites (Sites 5 and 6). Starter P-K applied in addition to broadcast P-K increased K concentration further in four sites, starter K in addition to broadcast fertilization increased K concentration further in three sites. Early corn K uptake data integrated results for growth and concentrations (Table 3). Starter alone P-K increased K uptake over the control in five of six sites, but starter K alone increased uptake in one site (Site 2) and decreased in another (Site 5). Starter P-K applied in addition to broadcast P-K increased K uptake further at three sites (Sites 2, 5, and 6), but starter K decreased it at Site 4 and increased it at Site 5. Therefore, these results show that P, or P and K together, play a major role in early growth and K uptake.

Corn grain yield was increased by one or more treatments at five sites (Table 3). The only non-responsive site had the highest soil-test values (Site 3). According to current Iowa State University soil-test interpretation categories, the probability of corn response is 80% for Very Low, 65% for Low, < 25% for Optimum, and < 5% for High (Sawyer et al., 2002). At Site 1, all treatments increased yield over the control and the increases were statistically similar. At Site 2, all treatments increased yield but the increase was less for starter K applied alone (soil P was Very Low). At Site 4, broadcast fertilization increased yield while the starter fertilizers did not. We do not understand the reason why starter fertilizer did not increase yield at this field (there was a small increasing trend) because soil-test P and K were Very Low. At Sites 5 and 6, broadcast fertilization increased yield more than the two starter fertilizers. At Site 5 both soil P and K were Low while at Site 6 P was Low and K was Optimum. Applying starter in addition to broadcast P-K fertilizer never increased yield further. These results showed that early growth and nutrient uptake responses to starter do not necessarily result in grain yield increases.

Results from the Strip Trials

<u>Whole-Field Corn Responses</u>

Potassium fertilization effects on corn early growth were significant ($P \leq 0.10$) in five sites, but the effects were inconsistent (Table 4). In Field 2 starter K alone increased early growth slightly but all other treatments decreased it. In Field 3 (a no-till site), broadcast K increased growth slightly, starter K did not affect it, and application of starter in addition to broadcast decreased growth compared with broadcast applied alone. In Field 4 (the other no-till site), broadcast K did not affect growth but starter K decreased it when was applied alone or in addition to broadcast K. In Field 5 all K treatments decreased growth. In Field 8 broadcast K did not affect growth but starter K applied alone decreased it.

The inconsistent and small early growth responses to broadcast or starter K fertilization across fields could not be explained by the STK level or any other measurement taken. Salt effects on roots and water uptake might explain a growth reduction from applied K, but we doubt this was the case in our study. Field observations indicated that no treatment reduced corn plant population significantly at any field. The broadcast rate of 120 lb K_2O/acre as potassium chloride did not decrease early growth at the no-till fields and decreased it in some fields managed with tillage. This K rate incorporated into the soil with tillage should not affect growth. The low-salt 0-0-30 fertilizer (potassium carbonate) applied to the seed furrow a rates of 15 to 22 lb K_2O/acre did not result in obvious salt effect symptoms or decreased stands. Therefore, we believe that the results reflect no K effect on early corn growth, and that the inconsistent (and often small) increases or decreases resulted from variation in other growth factors. The results of the small-plot studies also showed infrequent and inconsistent effects of starter K on early corn growth.

In contrast to results for early corn growth, K fertilization often increased early plant K concentration (Table 4). In four fields (Fields 3, 5, 6, and 7) all treatments increased plant K concentration with the increases being largest for broadcast K alone then for starter K alone, although the difference was not statistically significant in Field 6. Application of both broadcast and starter K resulted in the highest early K concentration increases except in Field 7. At Field 8, however, and for unknown reasons, application of broadcast or starter K alone did not affect plant K concentration and application of both decreased it. It is interesting that increases in plant K concentration were observed when fertilization decreased or increased early growth. The previous research with 3-18-18 and 0-0-30 starter fertilizers also showed large plant K concentration increases, even when 0-0-30 seldom increased early growth and sometimes decreased it. Early corn K uptake responses (Table 4) reflected mainly effects on plant growth and, therefore, effects were infrequent and inconsistent across fertilizers and sites. At Field 2, only starter K increased K uptake. At Field 3, both fertilizers increased K uptake but the increase was largest for broadcast K. At Field 8, broadcast K did not affect growth but starter K decreased it. These inconsistent results for starter K are in agreement with results from the other set of trials.

The K fertilization effects on corn grain yield were significant in three fields (Fields 1, 4, and 6), where both broadcast K and starter K applied alone increased yield (Table 4). In Field 1 broadcast K alone increased yield more than starter K, and the increase over the control were 11 bu/acre for starter and 21 bu/acre for broadcast. In Field 4 the effects of broadcast K alone and starter K alone on yield were statistically similar, although the increase seemed greater for starter K than for broadcast K (6 bu greater). In Field 6 the effects of broadcast K alone and starter K alone on yield also were statistically similar, but the increase seemed greater for broadcast K than for starter K (7 bu greater). An important result was that starter K applied in addition to broadcast K did not increase yield further at any field. Another important result was that there was no yield response to any K fertilizer at fields where at least some treatments increased early plant growth. The STK values for these fields (Table 2) and current interpretations in Iowa explained the yield responses only partially. A small or no yield increase was expected in Field 1 because mean STK borderline between High and Very High, but values across the field ranged from Low to Very High (Table 2). A yield increase was expected in Field 4 because mean STK was Low and values ranged from Very Low to borderline between Low and Optimum. A yield increase also was expected in Field 6, although smaller than for Field 4, because mean STK was borderline between Low and Optimum, although values ranged from Very Low to High. On the other hand, no statistically significant yield increase was observed in Field 2, where a small response was expected because mean STK was Optimum. The unexpected yield response (in Field 1) or lack of response (in Field 2) might be explained by variation in STK or soil types within the fields.

Corn Responses by Soil Type

Soil types may affect corn response to K fertilization within a field because of potential differences in STK and other properties that may affect crop growth and response to K fertilizer. There were two dominant soil types in seven of the fields, so we analyzed corn response to K fertilizer for each dominant soil. Fertilizer K effects on early corn growth and K uptake by soil type were as inconsistent as for the whole-field analysis, while both fertilizers usually increased early plant K concentration. Therefore, we show in Table 5 and discuss only results for grain yield for the four sites in which there was a differential yield response to K fertilization across soils.

In Field 1, a whole-field yield increase was explained by a response only in areas with Zook soil, and responses were similar for broadcast and starter K fertilizers. On average STK was Very High for both soils, being only slightly higher for Zook. Therefore, we believe that the higher response for the Zook soil is explained by properties that increase the likelihood of crop response to K, such as finer texture and poorer drainage. In Field 3 the whole-strip analysis showed no yield response, but the analysis by soil type showed a response for the Webster soil. In areas with Webster soil the broadcast K increased yield by 15 bu/acre compared with the control, but starter K did not increase yield. We cannot explain the lack of response to starter K. Although STK was similar (Optimum) for both soils, other soil properties may explain a yield response to K only for the Webster soil because it is more poorly drained and finer textured than Clarion. In Field 5 the whole-strip analysis did not show a yield response, but the analysis by soil type showed a yield response for areas with Tripoli soil. The yield increase was similar for broadcast and starter K, but application of both reduced yield to the control level. The magnitude of the yield increase was even larger for areas of Floyd, although STK was similar (Optimum) for both soils. Therefore, the statistically significant response for the Tripoli soil might be explained by a more consistent corn response across the replications. In Field 7 the whole strip analysis did not show a yield response but the analysis by soil type showed a response for areas with Mahaska soil, where broadcast or starter K increased yield by about 10 bu/acre compared with the control. A larger response for the Mahaska soil is reasonable because STK was borderline between High and Very High classes while areas of Taintor tested much higher. The yield response was higher than expected, but according to previous Iowa a response in a high-testing soil can occur with a 5% probability.

General Conclusions

Starter containing P and K often increased early corn growth and uptake of both nutrients more than a higher broadcast fertilizer rate, even in high-testing soils, but this response did not translate into higher grain yield with starter. Starter K alone seldom increased early growth or K uptake (sometimes decreased it) and often increased early plant K concentration but this response often was not reflected in increased grain yield. Starter P-K or K applied in addition to broadcast fertilization rates commonly used by Iowa farmers uses never increased yield further. Larger and more frequent starter effects from P than for K are in agreement results of basic studies conducted during the 1970s and 1980s by S. Barber and collaborators under controlled conditions, which showed a higher maximum root uptake rate for K than P in the nutrient concentrated zone but more root proliferation for P. A grain yield response to broadcast or starter fertilizer sometimes was observed in soils testing high in K, but not with high in P. An important result was that liquid starter often resulted in corn yield increases similar to those from much higher broadcast fertilizer rates. However, in-furrow starter P-K fertilization for corn was not an effective practice when it was applied in addition to broadcast P-K fertilization rates planned to maintain or buildup soil-test values for 2-yerr corn-soybean rotations.

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Table 1. Small plot trials locations, years, and summary field information.

Year	Site	County	Soil	Soil-Test Values † STP	STK	pH	OM	Planting Date	Corn Hybrid
				--- ppm ---			%		
2004	1	Iowa	Sparta	16	103	7.7	3.2	8 May	NK 5299
	2	Bremer	Readlyn	5	103	7.3	3.8	28 Apr	DK C58-78
	3	Bremer	Readlyn	56	148	6.4	3.8	28 Apr	DK C60-19
2005	4	Bremer	Readlyn	4	82	6.6	3.2	18 Apr	DK C58-80
	5	Bremer	Marshan	15	117	6.8	6.6	18 Apr	DK C58-80
	6	Calhoun	Webster	13	143	5.6	5.5	2 May	P 35Y67

† STP, Bray-1 P; STK, ammonium acetate K; OM, organic matter.

Table 2. Strip trials locations, years, and summary field information.

Year	Site	County	Planting Date	Corn Hybrid	Soil-Test Values † Soil-Test K Min	Avg	Max	pH	OM
					------- ppm -------				
2007	1	Iowa	1 May	P 34A12	116	214	283	7.4	5.9
	2	Bremer	5 May	DK C58-13	111	156	229	6.5	3.8
	3	Greene	14 May	NT 2503HX	124	175	251	6.5	4.6
2008	4	Jasper	19 May	Crows 4940 T	71	102	133	5.7	2.7
	5	Bremer	15 May	DK 61-69	113	180	213	6.6	4.9
	6	Iowa	2 May	P 33F12	91	130	197	7.0	7.1
	7	Washington	8 May	DK 61-69	132	220	433	7.4	4.6
	8	Washington	8 May	DK 58-16	110	223	280	6.9	4.1

† Ammonium-acetate test for K; Min, minimum; Avg., average; Max, maximum; OM, organic matter.

Table 3. Phosphorus and potassium fertilization effects on early corn growth and K concentration (V5 to V7 stage) and grain yield for six small-plot trials.

		Broadcast	3-18-18 Starter		0-0-30 Starter	
Site	Control	P-K Alone	Alone	+ Broad P-K	Alone	+ Broad P-K
			Plant Dry Weight (g/plant)			
1	10.7	11.5	10.2	11.7	10.7	11.3
2	2.0a †	2.4c	2.5c	2.6c	2.2b	2.6c
3	1.2b	1.7d	1.8d	1.9d	1.1a	1.6c
4	2.5b	3.9d	3.2c	3.6d	2.0a	3.2c
5	2.7b	3.1b	3.5c	4.4d	2.4a	3.6c
6	3.3a	4.6c	4.6c	6.4d	3.5b	4.5c
			Plant K Concentration (%)			
1	2.53a	3.95c	2.17a	3.53b	2.55a	4.54d
2	2.40b	3.09c	2.38a	3.51d	2.38a	3.38d
3	4.17a	4.42b	4.07a	4.67d	4.08a	4.62c
4	2.25a	3.87b	2.61a	4.10b	1.91a	3.84b
5	2.34b	3.86d	3.22c	4.52e	2.22a	3.69d
6	1.62a	3.26e	2.47c	3.60f	2.10b	3.02d
			Plant K Uptake (mg/plant)			
1	281a	460b	237a	414b	267a	516b
2	48a	76c	59b	93d	53b	88c
3	50a	73b	71b	86b	46a	75b
4	57a	154d	87b	150d	39a	125c
5	69b	121c	117c	199e	57a	135d
6	55a	152b	133b	244c	74a	136b
			Grain Yield (bu/acre)			
1	161a	193b	182b	184b	185b	189b
2	159a	176c	176c	185c	171b	178c
3	179	177	183	183	173	183
4	171a	210b	172a	209b	175a	209b
5	169a	204d	184b	205d	184b	195c
6	129a	170c	147b	163c	154b	172c

Numbers in a row followed by no letter or a similar letter do not differ ($P < 0.10$).

Table 4. Potassium fertilization effects on early corn growth and K concentration (V5 to V7 stage) and grain yield for eight strip trials.

	No Broadcast K		Broadcast K	
Field	No K	Starter K	No Starter	Starter
	Plant Dry Weight (g/plant)			
1	11.1	10.7	11.2	10.0
2	4.1c	4.4d	3.5a	3.9b
3	3.5a	3.8a	4.3c	3.9b
4	6.6c	6.3b	6.6c	6.1a
5	15.1c	12.9a	12.0a	11.2a
6	9.9	9.5	8.6	8.6
7	3.9	4.3	4.1	3.9
8	6.4b	5.6a	6.8b	6.4b
	Plant K Concentration (%)			
1	4.3	4.3	4.7	4.6
2	4.1	4.2	4.5	4.3
3	3.6a	4.0b	4.2c	4.7d
4	3.0	3.3	3.2	3.7
5	3.0a	3.2a	3.5b	3.7c
6	2.8a	3.4b	3.6b	4.1d
7	4.1b	3.9a	4.2c	4.2c
8	4.0b	3.9b	3.8b	3.5a
	Plant K Uptake (mg/plant)			
1	465	456	536	461
2	165a	187b	160a	165a
3	127a	153b	182c	183c
4	196	208	205	218
5	455	412	416	411
6	296	331	326	357
7	162	169	173	165
8	260b	222a	266b	230a
	Grain Yield (bu/acre)			
1	174a	185b	195c	190c
2	149	151	149	149
3	133	133	140	141
4	172a	189c	183c	180b
5	200	206	211	204
6	205a	217b	224b	224b
7	222	231	230	230
8	221	222	222	224

Numbers in a row followed by no letter or a similar letter do not differ ($P < 0.10$).

Table 5. Potassium fertilization effects on grain yield for the two dominant soil types in four strip trials where responses differed across soils.

			No Broadcast K		Broadcast K	
Site	Soil Type	Soil-Test K	No K	Starter K	No Starter	Starter
		ppm	Grain Yield (bu/acre)			
1	Zook	236	154a	180b	187b	183b
	Koszta	213	181	183	179	189
3	Clarion	145	129	132	134	134
	Webster	180	138a	135a	151b	149b
5	Floyd	149	196	200	214	210
	Tripoli	155	202a	207b	211b	202a
7	Mahaska	214	220a	231b	229b	229b
	Taintor	268	232	240	233	238

Numbers in a row followed by no letter or a similar letter do not differ ($P < 0.10$).