In-furrow Starter Fertilization Enhances Growth and Maturity in Early Sweet Corn

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Abstract. Field studies were conducted in 1994 and 1995 to evaluate the effects of in-furrow-placed (i.e., applied directly in the seed channel) starter fertilizer on the emergence, maturity, and yield response of early sweet corn. In both years, three starter fertilizer treatments were applied: APP, with N and P at 13 and 19 kg·ha⁻¹, respectively (13N–19P kg·ha⁻¹), either banded (5 cm below and 5 cm to the side of the seed) or placed in-furrow, and a control (no starter fertilizer). Additionally, in 1995, the rate of APP was increased to supply 26N–38P kg·ha⁻¹ in combination with either band (5 × 5 cm) or in-furrow placement. Seedling emergence was delayed whenever starter fertilizer was applied with the seed; however, significant reductions (≈21%) in plant stand occurred only at the high rate of in-furrow placement. In both years, all starter treatments had a positive effect on seedling dry-matter production, and hastened silking. In-furrow application of 13N–19P kg·ha⁻¹ increased marketable ear yields 34% in 1995, but had no effect in 1994. Lack of yield response to the high rate of in-furrow fertilizer in 1995 was primarily a function of reduced stand, as ear number and ear mass per plant, and average ear size were similar to those in the other starter treatments. Based on these results, in-furrow APP at 13N–19P kg·ha⁻¹ appears to be an effective starter fertilization regime for early sweet corn, comparable in effect to banded 26N–38P kg·ha⁻¹. However, high rates of in-furrow APP may reduce stands. Although significant yield response to in-furrow starter fertilizer may not always be realized, the increased early seedling growth may itself be a benefit, since fast-growing seedlings are more likely to be tolerant of adverse environmental conditions than are less vigorous plants. Chemical name used: ammonium polyphosphate (APP).

Placing small amounts of soluble N and P fertilizer close to the seed (i.e., starter fertilizer) has traditionally been used to increase nutrient availability and subsequent crop response in cool, wet soils. The most common starter placement method is banding fertilizer 5 cm below and 5 cm to the side of the planted seed. The purpose of the 5 × 5 placement is to place the fertilizer close enough so that it is easily accessible by small seedlings, but far enough away from the seed to prevent salt injuries to roots (Mortvedt, 1983).

Another option available to growers is placement of starter fertilizer directly in the furrow with the seed. Commonly referred to as “pop-up” fertilizer, the intent of this practice is to promote more vigorous seedling growth, especially during adverse conditions, by providing an immediate supply of available nutrients to plant roots (Rehm, 1983). However, when placing fertilizers in contact with the seed, the rate of application must be kept relatively low to avoid salt injury to germinat-

ing seeds and seedlings (Raun et al., 1986). Recommendations generally prescribe that no more than a total of 11 to 17 kg·ha⁻¹ of N + K be applied with the seed (Anderson et al., 1993; Randall and Hoeft, 1988), although Howard and Tyler (1987) reported no adverse effects with 34 kg·ha⁻¹ of in-furrow N in corn.

In addition to the rate of fertilizer applied, the effectiveness of in-furrow starter fertilization can also be influenced by other factors, including fertilizer source and soil conditions. Fertilizers, such as urea and diammonium phosphate, that have high potential to release ammonia are not recommended for in-furrow fertilization because small amounts of ammonia can be toxic to seedlings (Creamer and Fox, 1980). Because of rapid drying in the root zone, crops grown on sandy soils are generally more susceptible to salt injury from in-furrow starter placement than are those grown on fine-textured soils (Richards et al., 1985). Subsequently, soil moisture content will markedly influence crop response to in-furrow starter fertilization, with less injurious effects from salts, as well as ammonia, when ample moisture is present (Raun et al., 1986; Yerokun and Christenson, 1989). The effectiveness of in-furrow starter fertilization may also vary with genotype. In recent work with field corn, Mascagni and Boquet (1996) reported that some hybrids responded consistently to in-furrow starter fertilizer, while the response in

others differed significantly across planting dates and years. In general, the interaction of these and other factors on crop response to in-furrow starter fertilization is complex, and research reports have been mixed, with positive (Howard and Tyler, 1987; Mascagni and Boquet, 1996), negative (Walker et al., 1984), and little or no (Howard and Mullen, 1991) or inconsistent (Yerokun and Christenson, 1989) results reported.

As sweet corn continues to be planted earlier in the spring, sweet corn growers in the upper Midwest have expressed renewed interest in in-furrow starter fertilization. If the early-season growth response is to be large and sustained, appreciable amounts of in-furrow fertilizer may be needed. However, research on in-furrow starter fertilization in sweet corn is limited. The objectives of this research were to evaluate the effects of various rates of in-furrow starter fertilizer on the emergence, maturity, and yield response of sweet corn, and to compare in-furrow vs. 5 × 5 banded methods of starter placement in early sweet corn production.

Materials and Methods

Field studies were conducted in 1994 and 1995 at the Univ. of Illinois St. Charles Horticultural Research Center in northern Illinois on a Proctor silt loam (fine-silty, mixed, mesic Typic Argiudolls) with an organic matter content of 2.3% and cation-exchange capacity of 14.0 meq·100 g⁻¹. In 1994, the sweet corn cultivar Sugar Ace was planted on 14 May using a Monosem planter (ATI Inc., Merriam, Kans.), with seeds 3.8 cm deep, in four-row blocks 10.6 m long, with rows spaced 0.9 m apart. Seed spacing within each row was 20 cm, resulting in a plant population of ≈218 plants/plot or 55,590 plants/ha. Treatments consisted of three starter fertilizer regimes: APP at 93.5 L·ha⁻¹, providing 13 and 19 kg·ha⁻¹ N and P, respectively (13N–19P kg·ha⁻¹), applied either banded (5 cm below and 5 cm to the side of the seed) or in-furrow with the seed, and a control (i.e., no starter fertilizer). Since sweet corn growers in Illinois typically use banded APP in their early-season fertilization programs, this fertilizer source was selected for this study. Potentiometric analysis indicated a solution conductivity of ≈700 dS·m⁻¹ in each of the APP treatments. The starter APP treatments were applied using a calibrated liquid fertilizer delivery system mounted on the planter. Soil moisture content in the seed bed (0 to 10 cm) at planting was measured at 8.5% (g/g) by gravimetric methods (Gardener, 1986). The experimental design was a randomized complete block, with each treatment replicated four times in four-row blocks as described above. In addition to the starter fertilizer treatments, all plots received 134 kg·ha⁻¹ of N broadcast 10 d prior to planting. No additional P or K fertilizer was applied, since tests indicated high soil levels of both nutrients. Supplemental overhead irrigation was applied to all plots to provide a total (including rainfall) of ≈38 mm of water per week.

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At 18 and 32 d after planting (DAP), plants in the inner two rows of each plot were counted. At 32 DAP, eight plants were harvested from the outside rows, with shoots cut off at the soil line; at 62 DAP, ear-leaves were collected from 10 plants in the inner two rows of each plot. Tissue samples were air-dried at 70 °C, and later assayed for dry mass and total N, P, and K concentrations using standard laboratory methods. Beginning at initial silk appearance, counts of plants silking in the inner two rows in each plot were taken. Silking date was established in each plot as days after planting when 50% of the plants in the inside two rows had silks emerged. Ears were harvested from all plants in the middle two rows of each plot 20 d after the respective silking date, with data recorded for marketable ear number and unhusked fresh mass.

In 1995, the study was expanded to include five starter fertilizer regimes. The first two APP treatments and control were similar to those used in 1994. In addition, the rate of APP was increased to 187.0 L·ha⁻¹, supplying 26 and 38 kg·ha⁻¹ of N and P, respectively (26N–38P kg·ha⁻¹), with the fertilizer either banded (5×5 cm) or applied with the seed. Conductivity in each of the APP solutions was similar to that in 1994 at ≈700 dS·m⁻¹. The experimental design was a randomized complete block, with each block replicated four times. In addition to starter treatments, all plots were fertilized with N and K at 134 and 112 kg·ha⁻¹, respectively, broadcasted 3 weeks before planting. Overhead irrigation was supplied throughout the growing season when necessary.

Sweet corn cultivar Sugar Ace was seeded on 19 May in a similar manner as in 1994. Soil moisture content in the seed bed (0 to 10 cm) measured 8.2% (g/g) at planting. However, rain began within 24 h, and continued for 2 weeks with a total of 118 mm of rain received in six separate events (Table 1). During this period, soil moisture content in the seed bed averaged ≈14% to 19% (g/g). Procedures for conducting plant-stand counts, tissue sampling and analysis, plant-silking counts, and harvest in 1995 were similar to those in 1994, with measurement of plant-stand counts made at 21 and 32 DAP, and harvest taking place ≈22 d after the respective silking date in each plot. Data were subjected to analysis of variance (ANOVA) procedures. When ANOVA indicated significant treatment effects, mean separations were determined by least significant differences.

Results and Discussion

In both years, mean air temperatures during the growing season were comparable to the 30-year average (Table 1). Monthly rainfall in 1994 was appreciably below normal during May, and more than double the average for June. This pattern was reversed in 1995, with rainfall totals above normal in May, and about one-half the average for June.

Seedling plant count and stand establishment showed mixed response to starter fertilization regime (Table 2). Band placement of APP had little effect on seedling standcount in

either year, whereas in-furrow application of 13N–19P kg·ha⁻¹ decreased seedling plant count at the early sampling date in 1994 but not in 1995. In both years, plant counts at 32 DAP with in-furrow 13N–19P kg·ha⁻¹ were comparable to those in the control or with banded 13N–19P kg·ha⁻¹. Increasing the rate of starter fertilizer in 1995 decreased seedling number significantly at both dates when applied in-furrow, but had no effect when banded. In general, seedling vigor, as indicated by the relative number of plants at 18 or 21 DAP, appeared to be repressed whenever starter fertilizer was placed with the seed, as seedling number at the early sampling dates accounted for 70% of the final standcount with in-furrow placement, compared with 95% in the control, and 92% with band placement (calculations averaged over starter fertilizer rates).

Each of the starter treatments had a significant positive effect on seedling dry-matter production, with the relative response in dry mass dependent on fertilizer rate and placement (Table 2). At the low rate of starter fertilizer, seedling dry mass at 32 DAP was higher in both years when the fertilizer was placed with the seed than when banded. Increasing the rate of starter fertilizer in 1995 increased seedling dry-matter production in conjunction with band placement only. At the high rate of starter fertilizer, placement method had no effect on seedling dry mass. Overall, highest seedling dry-matter production was obtained with in-furrow 13N–19P kg·ha⁻¹ in 1994, and with either in-furrow 13N–19P, banded 26N–38P, or in-furrow 26N–38P kg·ha⁻¹ in 1995.

Plant N concentrations 32 DAP tended to increase, while tissue K concentrations decreased, and P levels either remained relatively unchanged (1994) or increased (1995) in response to application of starter fertilizer (Table 2). Differences between the various starter fertilization regimes in their effects on tissue N and P were small. The lower K concentrations in the respective starter treatments were attributed to a dilution effect; plants that had the higher growth response generally had lower tissue K concentrations. These data, however, do not indicate whether the growth response to the starter fertilizer was due to the N or the P component of the APP, or to both. At the later sampling date (62 DAP), tissue P was the only nutrient significantly affected by starter fertilization, with ear-leaf P concentrations in 1995 higher with banded 26N–38P kg·ha⁻¹ than in the other treatments (data not shown). Ear-leaf N, P, and K concentrations at 62 DAP averaged 3.86%, 0.35%, and 2.66% in 1994, and 3.45%, 0.31%, and 2.32% in 1995, respectively, and were within reported optimal ranges (Geraldson et al., 1973).

All starter fertilizer regimes had a positive effect on sweet corn maturity, as indicated by a decrease in silking dates in the respective treatments (Table 3). Differences in silking response among the individual starter APP treatments were nonsignificant, with silking dates averaging ≈63 DAP with application of starter fertilizer, and ≈68 DAP in the control (calculations represent means of 2 years).

Regression analysis indicated a significant negative correlation ($r^2 = -0.78$; $P \leq 0.01$) between days to silking and early-season plant

Table 1. Mean monthly air temperatures and rainfall totals for 1994 and 1995 cropping seasons at St. Charles, Ill.

Month	Temperature (°C)			Rainfall (mm)		
	30-year mean (1961–91)	1994	1995	30-year mean (1961–91)	1994	1995
May	15.2	14.3	13.1	96.0	9.1	127.0
June	20.6	20.6	20.8	120.7	229.1	63.5
July	22.8	21.9	23.4	104.4	28.7	111.3
August	21.6	19.1 ^c	24.0 ^c	98.0	13.2 ^c	8.6 ^c

^cData ends on 2 Aug. in 1994, and 10 Aug. in 1995.

Table 2. Effects of starter fertilizer rate and placement on sweet corn seedling count, dry mass, and tissue N, P, and K concentrations in 1994 and 1995.

Starter fertilizer		Seedling plant count		Seedling	Tissue content ^t (% dry mass)		
N-P	Placement	(plants/ha × 1000)		dry mass ^z			
(kg·ha ⁻¹)		18–21 DAP ^y	32 DAP	(g/plant)	N	P	K
1994							
13–19	Banded	45.0 a ^x	49.6	1.24 b	4.50 a	0.55	4.07 ab
	In-furrow	35.9 b	44.3	1.41 a	4.74 a	0.58	3.88 b
0–0	---	44.8 a	46.3	1.01 c	4.18 b	0.53	4.34 a
LSD _(0.05)		6.1	NS	0.14	0.30	NS	0.33
1995							
13–19	Banded	41.5 a	44.5 a	1.10 b	4.22 ab	0.42 ab	4.24 b
	In-furrow	33.9 a	41.0 ab	1.29 a	4.17 ab	0.45 a	4.04 b
26–38	Banded	39.4 a	42.5 ab	1.34 a	4.46 a	0.49 a	3.98 b
	In-furrow	15.8 b	34.5 b	1.22 ab	4.57 a	0.48a	4.06 b
0–0	---	40.6 a	43.9 a	0.89 c	4.04 b	0.37 b	4.77 a
LSD _(0.05)		9.3	8.7	0.17	0.40	0.07	0.52

^a32 d after planting (DAP).

^b18 DAP in 1994; 21 DAP in 1995.

^cMean separation within columns and years by LSD, $P \leq 0.05$.

^{NS}F value nonsignificant at $P \leq 0.05$.

growth (Fig. 1). This relationship was consistent for both years, and is in general agreement with the results of Mascagni and Boquet (1996), who reported that in each year of a 3-year study, in-furrow starter application of APP at 5.8N–8.5P kg-ha⁻¹ significantly increased seedling dry-mass production in field corn while reducing days to silking by 3 to 5 d. However, in this previous work, differences in silking dates and early growth response to starter fertilizer decreased as planting date was delayed. The relatively strong relationship between silking date and seedling growth response to starter fertilizer in our present study was probably related to the early plantings dates of 14 May and 19 May in 1994 and 1995, respectively.

Overall sweet corn yield response in 1994 was unaffected by starter fertilizer application, as total ear number and marketable yield were similar among treatments (Table 3). Although in-furrow starter fertilizer increased average ear mass, the number and total mass of

marketable ears per plant in this treatment were comparable to those in the control. Plants in each treatment averaged more than one useable ear each. Individual plant productivity (total ear mass per plant) was higher with in-furrow placement than with band application.

In 1995, application of in-furrow 13N–19P or banded 26N–38P kg-ha⁻¹ increased total marketable yields 34% and 36%, respectively, but had no effect on total marketable ear number (Table 3). Analysis of the various yield components indicated that the yield increase with banded 26N–38P kg-ha⁻¹ was mostly related to increased average ear mass, while that with in-furrow 13N–19P kg-ha⁻¹ was the result of increases in both individual ear mass and ear number per plant. In both treatments, total ear mass produced per plant was enhanced significantly. There was no negative yield response to in-furrow 26N–38P kg-ha⁻¹, as total marketable yield and ear number in this treatment were comparable with those in the control. Individual yield components, in-

cluding total ear mass produced per plant, average ear mass, and ear number per plant, with in-furrow 26N–38P kg-ha⁻¹ were similar to those in the other starter treatments, indicating that the lack of yield response at the high rate of in-furrow APP in 1995 appeared to be primarily a result of reduced stand.

These results indicate that promoting early plant growth by applying in-furrow starter fertilizer should hasten maturity and promote good ear development in sweet corn. Despite a delay and even some loss in stand with in-furrow APP placement (primarily at the high rate), plants in these treatments were still able to make rapid growth comparable to, and in several cases greater than, band placement. The positive yield response to in-furrow starter 13N–19P kg-ha⁻¹ in 1995 but not in 1994 may have been environmentally related. Most yield responses to starter fertilizers usually occur under cold temperatures or other adverse conditions (Beauchamp and Lathwell, 1967; Bundy and Widen, 1992). Weather factors in 1995 were inconsistent, including a cool, very wet period early in the season, followed by high temperatures and wet, humid conditions during silking (Table 1). This effect was apparently stressful, as total yields in 1995 were ≈36% lower than those in 1994 (calculations represent means of common treatments in 1994 and 1995). These conditions were prevalent throughout northern Illinois in 1995, where yields of commercial dent corn averaged 32% lower than in the three previous years (Univ. of Illinois, 1995).

Based on these results, in-furrow APP at 13N–19P kg-ha⁻¹ appears to be an effective starter fertilizer regime for sweet corn, comparable in effect to banded 26N–38P kg-ha⁻¹. However, high rates of in-furrow fertilizer, such as 26N–38P kg-ha⁻¹, may present potential risk due to stand reductions. Although significant yield response to in-furrow starter fertilizer may not always be realized, the increased early seedling growth may itself be a benefit, especially for plantings made early in the season, since fast-growing young plants are more likely to be tolerant of adverse growing conditions than are less vigorous plants. The 5.8-d decrease in silking dates with in-furrow starter 13N–19P kg-ha⁻¹ in this study can have very important economic implications, since the market value of early sweet corn in northern growing areas can drop 20% to 40% over a 5- to 7-d period (H.G. Alton, personal communication). Practical advantages of in-furrow starter applications vs. 5 × 5 band placement include lower equipment costs and potentially faster planting speeds. Additionally, in-furrow applications of insecticides at planting can be made simultaneously with in-furrow starter fertilization.

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Table 3. Effects of starter fertilizer rate and placement on sweet corn silking date, marketable yield, and marketable yield components in 1994 and 1995.

Starter fertilizer			Ear no. (ears/ha × 1000)	Ear yield (t·ha ⁻¹)	Dry		Ear dry
N-P (kg·ha ⁻¹)	Placement	Silk date ^z			mass/ear (g)	Useable ears/plant	mass/plant (g)
1994							
13–19	Banded	64.3 b ^y	55.8	21.7	389 ab	1.13 b	438 b
	In-furrow	63.5 b	56.8	23.2	411 a	1.27 ab	518 a
0–0	---	69.0 a	62.0	21.4	345 b	1.34 a	480 ab
LSD _(0.05)		4.5	NS	NS	50	0.15	69
1995							
13–19	Banded	63.0 b	43.6	16.2 ab	373 b	0.98 b	365 bc
	In-furrow	61.5 b	47.3	18.5 a	393 ab	1.15 a	452 a
26–38	Banded	62.8 b	44.3	18.8 a	424 a	1.02 ab	442 ab
	In-furrow	63.8 b	35.2	13.6 b	386 ab	1.04 ab	394 ab
0–0	---	67.5 a	40.8	13.8 b	337 c	0.93 b	313 c
LSD _(0.05)		3.3	NS	4.3	35	0.13	74

^aSilk date (days after planting when 50% of the plants had silks emerged).

^yMean separation within columns and years by LSD, $P \leq 0.05$.

^{NS}F value nonsignificant at $P \leq 0.05$.

Fig. 1. Relationship between seedling dry mass 32 d after planting and sweet corn silking date. Data are combined for 1994 and 1995; r^2 significant at $P \leq 0.01$.

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