THE STATE OF THE ART OF STARTERS

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ABSTRACT

Interest in reduced tillage has caused a resurgence in the use of starter fertilizer. Starter fertilizer research has been conducted on many crops across the country. The purpose of this paper is to highlight recent research on a variety of crops including corn, cotton, sorghum, soybean, canola, sugar beet, and potato. Increased yields from starter fertilizers are common in low P soils and several factors may lead to increased yields even when soil P and K levels are high. Geographic trends in yield response to starter composition were noted. Studies indicate that seed placed fertilizer (pop-up) should be used with caution, especially on sandy soils. The conclusion from several researchers is that local guidelines for maximum salt application to seed should be followed to avoid germination damage. Banded P placed to the side and below seeds represents a lower risk potential while maintaining the benefits of localized placement.

INTRODUCTION

The idea of placing a concentrated source of nutrients near the seed at planting time predates the birth of the commercial fertilizer industry. The basic concept of starter fertilization hasn't changed for centuries, but changes in agriculture have caused substantial peaks and valleys in starter popularity over time.

It appears that we have once again entered an era of increased interest in starter fertilization. Today's high yields translate into increased residue production and reduced tillage is leaving more of that residue on the surface, often resulting in nutrient stratification. These are conditions that suggest an increased importance of starter fertilizers. The high efficiency associated with starter fertilizer has appeal to many producers who have made great progress in improving their overall nutrient use efficiency. Also, equipment manufacturers have made great progress in offering planter banding equipment that is durable and can handle residue with a minimal increase in planting time requirements.

The objective of this paper is to review recent research on starter fertilizer use for row crops. The review will not be comprehensive but an attempt will be made to make it reflect our current general understanding of starter fertilizer use in the U.S.

STARTER FERTILIZATION OF CORN

Corn has traditionally been viewed as a very responsive crop to starter fertilization. Corn is planted earlier than most other row crops and often encounters less than optimum soil temperatures for nutrient uptake. Early in the season, corn utilizes photosynthate for

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growth of shoots at the expense of roots leading to very high nutrient uptake rates per unit of root length present (inflow) (Mengel and Barber, 1974).

Early season nutrition of corn can be inadequate in today's high residue farming systems especially during years with cooler than normal springs. In the upper Midwest, 1992 was such a year. The results of a survey of 80 corn fields at approximately the V5 growth stage are summarized in Table 1. These sampling results were part of a soil test correlation project conducted by the Potash & Phosphate Institute, Montana State University, Minnesota Valley Testing Labs, Inc., A&L Midwest Laboratories, Unocal, and South Dakota State University. Over all, 50% of the fields sampled tested insufficient in P while 75% were insufficient in at least one nutrient. Corn in ridge-plant and no-till systems generally tested lower in N and K and higher in P than in other systems. The fields selected represented a cross section of soil parent materials, soil test levels, and starter fertilizer use. Such data clearly indicate the relevancy of the topic of this paper to today's growers.

Table 1. Corn nutrient concentrations at the V5 growth stage in the upper Midwest in 1992.

	Sufficiency	Measured	% of fields below sufficiency level			
Nutrient	level (V5)	range	All	Minim.	Ridge Plant	No-till
N, %	3.40	1.60-4.70	23	16	40	26
P, %	0.35	0.14-0.63	53	62	40	32
K, %	2.70	1.00-6.30	26	18	40	26
S, %	0.16	0.11-0.29	31	31	40	26
Zn, ppm	20	16-46	8	9	0	11
Number of fields			80	45	10	19

80 fields sampled: 35 in IA, 30 in MN, 15 in SD. In each field, 32 plants were collected from a 100 ft x 100 ft area of the major soil series.

Optimum starter composition for corn

Several studies have recently been conducted that focus on the composition of starter fertilizer. The relative importance of specific nutrients appears to vary with geography, making summarizing generalizations difficult.

The best N-P combinations in starters for corn on the sandy Coastal Plain soils of Alabama testing very high in available P were 40-20 or 60-0 (N-P_2O_5, lb/A) (Touchton, 1988). Fertilizers were formulated from urea ammonium nitrate (UAN) solution, phosphoric acid, and water and mixed in the upper 2-4" of soil in the row area. In each of 4 years, N improved early season plant growth while P added with N had a positive effect on early growth in only 1 year. Starter fertilizer increased yields by up to 39 bu/A when averaged over the 4 years.

In summarizing recent research on optimum N and P rates for starters in the Southeast, Zublena (1991a) stated: 1) N and P rates in corn starters can affect grain yields; 2) starter

N rates should be higher than the conventional use rate of around 10 lb/A; 3) the optimum N rate appears to be between 30 and 40 lb/A; 4) on high P testing soils, starter P is less critical for yield with optimum P rates around 10 lb/A; 5) on soils testing medium or low in P, higher starter P rates may be beneficial.

Response to N in starter fertilizers is also common in the central Midwest. Indiana research showed that N is the nutrient responsible for many starter fertilizer responses in conservation tillage (Mengel, 1990). However, Purdue University guidelines suggest that the amount of $N+K_2O$ in a 2x2 band for corn not exceed 40 lb/A (Purdue University, 1993).

A cooperative research effort between the University of Nebraska and the University of Minnesota showed considerable flexibility exists in the N to P ratio of starters for corn in these states (Table 2). Some treatments were included at 7 site-years while others were included at all 11-site years across the 3-year period (1989-1991). Fluid starters were used in a 2x2" placement in conservation tillage (not no-till or ridge-till) on soils testing low or medium in P. Yields of the no-starter checks ranged from 110 to 174 bu/A with an average of 149 bu/A. The greatest average early growth enhancement occurred with the 1:1 $N:P_2O_5$ ratio but the 1:3, 1:2, and 1:1 ratios all had very similar effects and were essentially agronomically equal. The 2:1 and 3:1 ratios produced less early growth enhancement than the lower N starters. Grain yield increases were similar for all ratios with the possible exception of the 3:1 ratio which tended to be somewhat less effective. The average yield increase for the 4 lower N:P ratio starters was 9% or 13 bu/A.

Table 2. Effect of N:P ratio on 2x2 starter response by corn in Nebraska and Minnesota.

P_2O_5	No. of	Early growth, N:P					Grain yield, N:P				
rate	site-yrs	1:3	1:2	1:1	2:1	3:1	1:3	1:2	1:1	2:1	3:1
lb/A		%					%				
20	11	41		47	31		6		3	8	
40	11	55		62	37		12		11	11	
Avg	11	48		55	34		9		7	10	
20	7	43	29	48	30	22	7	5	6	7	3
40	7	47	57	59	31	11	10	10	10	12	8
Avg	7	45	43	54	31	17	9	8	8	10	6

Increase over the no-starter treatment. Summarized from progress reports by Wiese & Penas, 1989; Rehm et al., 1989, 1990; Rehm & Shapiro, 1991.

Nebraska studies employing isotopically tagged N demonstrated that utilization of N from starter fertilizer can be improved by a nitrification inhibitor (Francis et al., 1993). Nitrate was leached from the young corn plant's rooting zone before it could be fully utilized. Ammonium nitrified rapidly and was also leached from the root zone. The nitrification inhibitor, dicyandiamide (DCD), increased crop uptake and microbial immobilization of the fertilizer N (Table 3). Under conditions favoring N loss, both DCD and nitrapyrin (N-Serve®) increased yields over unamended starters.

In a summary of important nutrients in starter fertilizers for the Southeastern US, Gascho (1991) indicated that N, P, and K were all frequently beneficial in corn starters. Sulfur, Zn, and B were also listed as good candidates for inclusion in starters. Magnesium and manganese were reported as being beneficial in some studies in the Southeast but some compatibility problems were noted.

Several studies in the Midwest have indicated that the importance of banded K increases with reduced tillage (Rehm, 1992; Rehm and Fixen, 1990). These studies have also shown that the traditional quantities of K used in starters (often less than 10 lb K_2O/A) may not be enough banded K even at high soil test levels on some soils.

Table 3. Average percentage utilization by corn of ^{15}N applied in starter fertilizer at planting (Francis et al., 1993).

Growth	1989		1990			
stage	NO_3	NH_4	NO_3	NO_3+DCD	NH_4	NH_4+DCD
			% utilization			
V3	1.0	11.1	2.9	4.4	8.4	16.3
V8	10.1	20.6	51.5	49.7	61.2	62.6

Placement of starter fertilizer for corn

Starter fertilizer placement studies have verified the superiority of the traditional 2x2 (2" to the side and 2" below the seed) placement for corn in the Southeastern US (Zublena, 1991b). Other placements were effective but were generally not as consistent in stimulating early growth as the 2x2 (Table 4).

Table 4. Effect of starter placement on corn plant height (Zublena, 1991b).

Placement	Year			
method	1985	1986	1987	1988
	---------- plant height (in.) ----------			
No starter	---	13.9	14.4	10.0
2x2	12.9	17.1	27.3	18.3
2" below	12.5	16.8	22.5	14.4
4" below	12.4	16.5	19.7	12.8
6" below	11.4	15.3	17.3	10.8
14" surface band	---	14.3	22.0	12.6
Surface dribble	---	---	26.8	15.6
LSD(.05)	0.68	0.96	1.82	1.1

Starter response at high soil test levels

The probability of response of corn to starter at low soil test levels is typically very high due to the combined benefits of limiting soil-fertilizer contact and the placement of a concentrated band near the row to assist in early plant nutrition (true "starter" effect). As the soil test climbs, a level is eventually reached where the only functional mechanism of response is the "starter" effect. Therefore, the probability of response at high soil test levels is determined by a host of environmental, cultural, and soil properties that influence soil nutrient supplying capacity, plant capacity for absorption, and plant nutrient demand. Examples can be found in the tillage, hybrid, and droughty conditions sections of this review. A few additional examples follow.

Several Minnesota studies have demonstrated starter response at high fertility if certain conditions exist. Rehm et al. (1988) conducted placement studies that included starter treatments and measured significant starter response at high fertility only when cool, wet conditions followed planting. Randall and Swan (1990) reported starter response by corn at very high soil test levels under conservation tillage (see next section). Moncrief et al. (1991) reported corn responses to starter P of 23 and 11 bu/A at Bray P1 tests of 30 and 70 ppm (both VH) in spring disc systems on soils with restricted internal drainage.

Kansas researchers measured an average starter (10+38+19, $N+P_2O_5+K_2O$) response of 13 bu/A for irrigated no-till corn that was not influenced by soil test levels (Maddux and Barnes, 1986). Bray P1 levels ranged from 6 to 34 ppm and extractable K levels ranged from 122 to 187 ppm.

In South Dakota studies, starter response appeared to be related to soil test P level in some years and not in others. Studies conducted in 1984-1986 resulted in starter response regardless of tillage system or soil test level (Fixen et al., 1987). In fact, at one location in 1986, yield response to starter in no-till appeared to increase as soil test P level increased.

The authors indicated that the large early growth stimulation from starter use may have increased the importance of having an adequate level of available P in the non-band soil for late season uptake. However, in 1987 in a different set of experiments that measured starter response at 19 locations, the major factor influencing response was soil test P level (Fixen and Farber, 1987). All 6 yield responses measured occurred at Bray P1 levels below 16 ppm. The specific weather factors causing the differences between years were not identified.

Studies using outdoor hydroponics in Ontario offer some insights into the importance of starter fertilizers in high yield environments even if soil test P levels are high (Barry and Miller, 1989). If tissue P concentration dropped below 0.5% prior to the V5 growth stage (Hanway system), fewer kernels were initiated per ear which translated into reduced grain yield. The researchers pointed out that if a small amount of kernel abortion occurs on ears that fill, final kernel number should be correlated with the number of kernels initiated. In high yield environments where stresses causing kernel abortion are minimal, kernel initiation should be correlated with grain yield as it was in this study. It is very difficult to obtain 0.5% P in the young corn plant without the use of some type of starter fertilizer.

Tillage/residue effects on starter response

Studies throughout the country have shown a marked increase in starter response with tillage reduction regardless of soil test levels (Mengel et al., 1992). For example, Indiana research at 11 sites across 3 years resulted in a yield increase from starter (2x2) at 1 site under conventional tillage and increases at 8 sites under no-till (Mengel, 1990). The average starter response across all 11 sites was 0.9 bu/A for conventional tillage and 7.8

bu/A for no-till. All the sites in these studies were high fertility locations where starter fertilizer would not have been recommended for conventional tillage.

A long-term study in southern Minnesota showed similar tillage system effects on starter response in a corn/soybean rotation (Randall and Swan, 1990). The average corn response across 4 years for the 4 conservation tillage systems was 9.1 bu/A compared to 5.5 bu/A for the fall plow system (Table 5). Average soybean response across all 5 tillage systems was 0.5 bu/A, reflecting the tendency for soybean to be less responsive to starter fertilization than corn. Soil test levels were very high for both P and K. The starter used was liquid 7-21-7 at a rate of 8+23+8 ($N+P_2O_5+K_2O$).

Table 5. Influence of tillage system on corn and soybean response to starter fertilizer in Southern Minnesota (Randall and Swan, 1990).

Tillage system	Residue cover in 1990 for corn after soybeans	Response to starter Corn	Soybean
	%	---------- bu/A	----------
Fall plow	4	5.5	0.8
Fall chisel	13	10.4	2.2
Spring disk 2x	62	7.5	-0.3
Ridge plant	60	7.2	-0.3
No-till	97	11.2	0.2

Average of 4 years for each crop, 1983-1990. Plots were continuous corn in indicated tillage systems from 1975-1982 except spring disk which was till-plant (flat).

A 3-year Wisconsin study indicated that tillage system effect on starter response may vary with planting date (Bundy and Widen, 1992). Corn response to starter P and K was measured in moldboard plow and no-till systems at 4 different planting dates each year varying from April 23 to May 24. Averaged across the 3 years, the largest starter response in the moldboard system (16 bu/A) occurred at the earliest planting date. In the no-till system, response averaged -2 bu/A for the earliest date and increased for each planting date to a maximum of 20 bu/A for the latest date. Though yields were higher for the earlier dates, these data show that use of starter fertilizer can reduce yield loss from delayed planting, especially in no-till systems.

Starter fertilizer use in droughty conditions

Starter fertilizer for dryland corn in the Plains states has produced mixed results. Studies have demonstrated the potential for yield increases, no effect on yield, and significant yield decreases especially at higher starter rates. For example, South Dakota State University recommends that starter P not exceed 30 lb P_2O_5/A due to yield reductions that have been measured in some years at higher rates (Gerwing et al., 1984).

Recent investigations in Kansas on the role of starter N and P in management of early maturing corn planted early illustrate the need for caution (Pierzynski et al., 1991).

Experiments across 4 site-years resulted in the 3 significant yield responses shown in Table 6. Yields trended higher at 2 sites for the 20 lb/A rate but were clearly reduced at the 40 lb/A rate. The authors noted that hot dry conditions prevailed prior to silking.

Table 6. Effect of starter N or P on corn grown under droughty conditions in Kansas (Pierzynski, 1991).

Applied P_2O_5	Site-year 90 Man	91 Man	Applied N	Site-year 91 Man
lb/A	------- bu/A -------		lb/A	bu/A
0	126	49	0	29
20	131	46	20	58
40	114	27	40	34
LSD(.05)	12	17		17

Fertilizer sources: UAN or APP applied 2" to the side & 2" below seed.

Starter experiments conducted at 9 sites in South Dakota during 1988, a hot dry year, resulted in early growth response at all sites and grain yield increases at 2 sites (Table 7). No indication of significant yield decreases occurred even at yield levels of 40 bu/A. One of the sites with a 13 bu/A response to starter, had a Bray P1 test of 54 ppm (>20 ppm considered VH in SD). The early growth responses and yield response at such high soil test levels under these environmental conditions does not fit the traditional thinking of the conditions leading to starter response. The authors suggested that the high temperatures may have increased shoot to root ratios resulting in elevated inflow requirements and the need for a concentrated band of nutrients to meet those requirements.

Table 7. Starter response of corn in a hot dry year in South Dakota (Fixen and Farber, 1988).

Parameter	Site number 72	86	73	71	37L	37H	82	70	77
May+June rain, In	0.6	0.7	0.8	1.3	1.5	1.5	4.7	5.5	8.8
Bray P1, ppm	49	25	33	14	6	13	54	19	49
V7 Growth resp.,%	54*	15*	48*	47*	15+	23*	119*	38*	46*
Check yield, bu/A	34	42	43	57	79	80	133	108	190
Start. resp, bu/A	-6	3	-1	13+	3	3	13*	1	6

* Significant at P=0.10. + Significant at P=0.20.

Corn silage responses to starter

On 3 out of 4 sites in Vermont with a combination of medium soil test P and/or K and poorly or somewhat poorly drained soils, use of starter fertilizer produced a significant silage yield increase (Jokela, 1992). The average response across all 4 sites was 1.5 t/A. On 1 out of 5 sites with a combination of medium-high or higher soil test P and/or K and poorly or somewhat poorly drained soils, use of starter fertilizer produced a significant silage yield increase (1.1 t/A). No starter yield increases occurred on the 3 well or somewhat excessively drained sites in the study. Starter fertilizer sources and rates varied across sites but all contained N, P and K. Nutrient analysis of early growth plant samples suggested that both P and K were important nutrients in the starters. Liquid dairy manure was applied and usually incorporated by moldboard plowing at all but 2 sites, both of which responded to starter.

Hybrid differences in starter responsiveness

Florida research on irrigated corn has demonstrated large differences in the responsiveness of hybrids to starter fertilizer containing 40 lb/A P_2O_5 as ammonium polyphosphate (Teare and Wright, 1990). In a 3-year study of 21 hybrids, 8 hybrids responded positively all 3 years while the response of the other hybrids varied by year. The range in average response was from 29 bu/A for a hybrid that responded positively each year, to -14 bu/A for a hybrid that responded negatively each year. Additional greenhouse research revealed that the hybrids that did not benefit from starter fertilization produced greater root mass than those that did benefit (F. M. Rhoads, 1993, personal communication).

Differences among hybrids in responsiveness to banded K have been measured in the northern corn belt (Rehm, G.W., 1992; Rehm and Fixen, 1990). Preliminary growth chamber studies have shown that the more responsive hybrids may have lower root to shoot ratios and less total root length than less responsive hybrids (Allan et al., 1992).

STARTER FERTILIZATION OF SOYBEAN

Most studies in the Midwest have shown soybean to be less responsive to starter fertilizers than corn (Randall and Hoeft, 1988; Randall and Swan, 1990). The early season inflow requirements of soybean are considerably lower than for corn and the physiological traits of soybean roots make them less able to utilize nutrients in a concentrated band. Soybean is traditionally planted later than corn when soil temperatures are more favorable for nutrient uptake.

Soybean failed to respond to starter P, K and S on Coastal Plain soils in North Carolina (Kamprath, 1989). Starter materials were concentrated superphosphate, KCl, and calcium sulfate applied at rates of 20 lb/A P_2O_5, K_2O, or S. Soil test P and K both ranged from medium to high at the 4 experimental sites. The author indicated that the lack of S response was likely due to adsorbed S in the B horizon of one of the soils and high amounts of S in the Ap horizon of the other soil. Leaf concentrations of P, K, and S were all in the sufficiency range at flowering.

In a study on the effects of N, P, and K in starter fertilizers for soybeans in the southern Coastal Plains of Alabama, Touchton and Rickerl (1986) concluded that the primary yield response was to K. The P, K, N-K, and P-K starter fertilizers increased yields 46% when residual P, K or both were low, and 26% when the residual P and K were high. The N, N-P, and N-P-K starter fertilizers resulted in less response. Fertilizer sources were prilled ammonium nitrate, concentrated super phosphate, and potassium chloride. Diammonium phosphate was the N-P source for the N-P and N-P-K combinations. The starter was applied at rates of 14 lb N/A, 38 lb P_2O_5/A, or 47 lb K_2O/A in a vertical band extending to a depth of 6-8" immediately below the row in a subsoiler channel. The authors suggested that poor performance of N-P and N-P-K starters may have been due to damage from the diammonium phosphate source used in these treatments.

Application of starter fertilizer 2-4" to the side or 8-10" deep in the in-row subsoil track resulted in increased soybean yields in 2 of 3 years in studies on soils testing high in P and K in the southern Coastal Plains of Alabama (Touchton, 1984). The starter fertilizer was applied as a 20-18-0 solution at a rate of 100 lb/A and was formulated from UAN and ammonium polyphosphate (APP). Although yields were increased, the in-row application reduced plant stand by 29% in one year. Yields averaged 14% higher for the 3-year period when starter fertilizer was used.

STARTER FERTILIZATION OF SORGHUM

A starter formulated from ammonium polyphosphate and urea ammonium nitrate (18-15-0) applied at a rate of 110 lb/A 2" to the side and below the seed resulted in inconsistent response by grain sorghum in the Coastal Plains of southeast Alabama (Touchton et al., 1989). At a high soil test P level, starter responses were +12, +2, and -7 bu/A across three years.

Kansas research has shown that sorghum will respond dramatically to seed placed starter fertilizer on low P clay loam soils (Lamond and Whitney, 1991). Sources used were 9-18-9 containing orthophosphate or 7-21-7 containing polyphosphate. The starter fertilizer sources performed similarly with both resulting in 5 to 10 fold increases in early plant growth and a 28 bu/A average yield increase across 3 years (Table 8).

Table 8. Effect of starter fertilizer rate on grain sorghum yield in Kansas (Lamond and Whitney, 1991).

Starter rate		Year			
P_2O_5	$N+K_2O$	1984	1985	1986	Average
	lb/A	bu/A			
0	0	53	63	55	57
6	4-6	68	82	84	78
12	8-12	72	82	93	82
18	12-18	74	85	98	86

Average of 7-21-7 and 9-18-9. 30" row spacing.
Bray P1 = 11 lb/A; Extr. K = 420 lb/A.

Response of grain sorghum to starter was minimal across 8 sites in Nebraska (Penas et al., 1988) in 1988. Bray P1 varied from 8 ppm to 96 ppm with 6 of the 8 sites between 17 and 42 ppm. Early growth was increased at 4 of 8 sites but the maximum increase was only 20%. Grain yield was not significantly affected (P = 0.10) at any individual site, however, the 8-site average response was 2 bu/A, suggesting that a slight positive response may have occurred. The data were generated by requesting that growers using starter fertilizers leave check strips in their fields. Growing conditions in 1988 were generally abnormally hot early in the season and dry later in the season.

STARTER FERTILIZATION OF COTTON

Cotton Growth Characteristics.

Cotton is a deep tap rooted species that responds well to nitrogen and side-banded phosphorus. Recommended nitrogen rates varies from 50 to 100 lb/A. The optimum range of nitrogen depends on soil texture, the preceding crop and the amount and distribution of rainfall. Producers use split N applications to maximize nitrogen use efficiency when nitrogen loss potential is high.

One bale of lint will remove approximately 70 pounds of nitrogen, 14 pounds of phosphorus, and 35 pounds of potassium. In spite of the relatively low amount of P taken up, phosphorus fertilization is very important. Cotton soils tend to be low in phosphorus. Adequate phosphorus is essential for seedling vigor, drought stress, proper boll maturity, and seed development.

Banded nutrients are generally more efficient than broadcast. Oklahoma State University recommends phosphorus be placed where soil is likely to be moist and root contact is eminent. Oklahoma state University does not recommend surface P applications because they are inefficient under Oklahoma conditions. The recommended placement is two inches beside and below the seed (2x2). However, band placement becomes less critical if soil test is rather high or P application rate is high (Thomas and Tucker, OSU Bulletin 2210).

Cotton responses to fertilizer nutrients placed near the seed at planting have been studied since the 50's. Early studies showed that cotton had greater resistance to adverse environmental conditions, such as lack of moisture, if starter was used. Patrick, et al. (1959) showed that 500 lb of a 12-12-12 fertilizer improved yield and root development under drought conditions. Still, there is only a limited number of studies about starter effects on cotton.

Research projects on starter effects on cotton are in progress at several Universities and fertilizer rate recommendations are being formulated. Consequently, the information to follow should serve as a guide and not a recommendation endorsed by all Universities in cotton producing states.

Starter research

A publication often sighted is that of Funderburg (1988). He conducted field trials on grower fields at different locations from 1985 through 1987 in Mississippi. Dr. Funderburg defined starter fertilizers as "an amount of nitrogen-phosphorus fertilizer banded near, but not on, the seed at the time of planting." He stressed that large amounts of starter fertilizer should not be in direct contact with seed and noted that fertilizer contact with seed can result in severe stand reductions. The average of 18 replicated trials at different locations showed lint yields from plots receiving starter were 1093 lb per planted acre while treatments receiving no starter yielded only 1000 lb of lint cotton per planted acre, a 93 lb/A yield increase due to starter. Many of the increases were statistically significant at greater than the .05 level of probability. He noted one decrease at a low yielding site. Dr. Funderburg observed that yield increases were more dramatic in higher yielding environments. He suggested that fields with a yield potential of about 850 lb/A were more responsive to planter applied phosphorus. The starter used at all 18 locations was either 10-34-0 or 11-37-0.

Since the starter fertilizer contained both nitrogen and phosphorus, Dr. Funderburg conducted another study to determine whether yield response originated from nitrogen alone, or from phosphorus in combination with nitrogen. Based on trials comparing N-P fertilizers with nitrogen alone, he concluded that the N-P combination significantly increased yields over check plots while nitrogen only treatments had little or no effect on yield.

Touchton, et al. (1986) studied starter fertilizer combinations and placement for conventional and no-tillage cotton on silt loam and sandy loam soils in Alabama. The studies were designed to address effects of nitrogen, phosphorus, and potash placed at different depths in different tillage systems. Tillage variables consisted of conventional till, no tillage, and no-till plus in-row subsoiling. Placement treatments consisted of deep fertilizer placement at 6 to 8 inches below the seed and 2x2 placement beside and below the seed. Fertilizer combinations were no starter fertilizer, 15-0-0, 15-15-0, or 15-15-5 applied at 150 lb./A.

Starter fertilizers did not affect early season plant heights on the silt loam soil, but starter fertilizers increased plant height each year on the sandy loam soil. In one year, N alone was adequate, but in the other two years, N-P combinations resulted in greater plant heights as compared to N alone. The 2x2 banded fertilizers were generally more effective than deep placed fertilizer.

Seed cotton yield did not correlate well with early season growth. Yield increases varied among soils, treatments, and over years. Starter fertilizers produced yield increases in two out of the three years on both soils. When comparing across years, the optimum treatment combinations for the silt loam soil were conventional and no-tillage being about equal with 2x2 placed N-P or N-P-K. In-row subsoiling produced mixed results. For the sandy loam soil, the best treatment combinations were conventional or no-tillage, in-row subsoiling regardless of tillage, and 2x2 or deep placed N-P and occasionally N-P-K. Averaging across tillage systems for the two years in which yield responses occurred showed that 2x2 placement resulted in yields of 2490, 2720, 2760, and 2790 lb/A seed cotton for no starter, N, N-P, and N-P-K, respectively.

Howard and Hoskinson (1990) studied the effects of starter nutrient combinations and nitrogen rate on no-tillage cotton at three locations over four years on a Memphis silt loam. Combinations of nitrogen, phosphorus, or potash were either broadcast or applied as a broadcast plus band combination. No-tillage cotton yields were usually higher with band applications of 15-15-0, 15-0-0, or 30-30-0 than with 60-30-30 broadcast application.

They concluded that banding 15-15-0 plus broadcasting 15-15-30 increased yields when compared with broadcasting 30-30-30. Yields increased when N rate increased from 30 to 60 lb N/A. The authors observed differences over environmental conditions in each year but, based on their observations, they concluded that "it would appear that phosphate needs to be included in the band for those periods and years of moisture stress." Since weather is unpredictable at planting time, the no-till or reduced tillage producer needs to band N and P.

Rickerl, et al. (1987) evaluated starter fertilizer effects on cotton production in legume residues. This study combined field and greenhouse work to identify starter fertilizers that would enhance cotton seedling survival, growth, and seed cotton yield growing in legume residues. They used conservation tillage planting units equipped with in-row subsoilers to plant the cotton. Starter fertilizers were applied 8 to 10 inches deep in the subsoil track.

Cotton populations in the field studies were lower in legume mulched soils than in fallow soils. Application of starter fertilizers, particularly the N-K combination, generally increased harvest populations. Seed cotton yields were consistently higher with P starter, although P did not always improve cotton stands and growth.

Greenhouse studies indicated that starter fertilizer improved cotton emergence in legume soils, but decreased emergence in fallow soils. Starter fertilizer increased disease rates of emerged seedlings. Thus, starter fertilizer increased greenhouse grown cotton emergence and survival, despite higher disease ratings.

Boquet et al. (1989) demonstrated that combinations of starter fertilizer and Temik had a small plant growth enhancing effect on cotton planted early but had only minor effects on cotton yield. Their study indicated that injected fertilizers resulted in a somewhat higher yield trend than surface applied fertilizers.

Guthrie (1991) evaluated the effects of cotton planting date and side-banded starter fertilizer. Cotton was grown on four sites; two sites on Norfolk loamy sands and two sites on Craven fine sandy loams. Ammonium polyphosphate fertilizer was applied either broadcast or side-banded at a rate of 17 lb N and 57 lb P_2O_5/A. His results showed fertilizer placement had minor effects on plant population. Side-banded fertilizer placement increased lint yield by 9 percent. He concluded that applying a side-banded starter fertilizer can benefit producers irrespective of planting date. Starters increased yields regardless of environmental conditions or planting date. The 9 percent average yield increase agrees with that reported by Funderburg (1988). However, Guthrie's results do not agree with Funderburg's finding that yield responses to starter fertilizers were greatest where lint yields exceeded 850 lb/A. In Guthrie's study, starter fertilizer consistently improved yields, although overall yields declined with later planting dates. So, the data from this study suggest that response to side-banded starter fertilizer does not depend on the presence of early season environmental stress.

Cotton is mildly sensitive to low soil zinc. Starter fertilizers are an ideal way to cost effectively add zinc. Inexpensive raw materials, easy application, and high nutrient availability make banded soil zinc applications the preferred method. Some producers use "catch-up" foliar sprays when zinc deficiencies show up during the growing season. Foliar sprays help the crop produce but yield potential has already decreased as compared to having zinc available during the entire life cycle. Joham and Rowe (1975) point out that fruiting index increased with additions of zinc under cool conditions. Early planted cotton may require additional zinc to achieve maximum productivity and quality.

Summary

Cotton, like most other crops, has displayed a range of responses to starter fertilizer. In the East, starter fertilizers appear to enhance yields regardless of planting date. There is a greater probability of yield increase on lighter textured soils and where there are substantial legume residues. Using starter on cotton grown in legume residue may enhance seedling vigor. Placement beside and below the seed (2x2) appears to optimize yields. Soil conditions will predict the efficacy of subsoiling. In addition, 15 lb N/A plus 15 lb P_2O_5/A was the preferred nutrient ratio. Occasionally, small amounts of K_2O increased yields.

In the South, N-P starters have shown to increase yields even when soil P levels are very high (Kovar and Funderburg, 1993). There may be a soil type where surface band applications outperform in-furrow placement. More research is needed. Placement of N-P-K mixes enhance root growth and drought resistance. Finally, it is relatively easy to setup cotton planters for starter fertilizers and the economics appear to favor a small amount of strategically placed starter to augment the regular fertilizer program.

STARTER FERTILIZATION OF SUGAR BEET

Starter fertilizer interests sugar beet growers for a variety of reasons. Producers can apply less nitrogen with a starter program. Adding starter may help disease resistance of some high sugar type varieties that are prone to reduced seedling vigor. Growers see a need for faster seedling growth. Starter may enable earlier application of post emergence herbicides. Improvements in starter equipment make application simpler and more reliable. Finally, adoption of payment systems based on sugar beet quality offer incentives for growers to manage their crop to produce proportionately higher sugar content.

Smith (1985) examined the effects of starter fertilizers on sugar beet yield and quality. Table 9 shows sugar beet response to starter fertilizers for a two year period. Combined over years there was a significant increase in yield and recoverable sugar with starter fertilizers. Studies in previous years that evaluated starter fertilizers showed mixed results. Environmental conditions after planting had a large influence on the response obtained. The Crookston, Minnesota study produced the following trends over its six year duration: final yield increased significantly two out of six years; salts over 5.5 lb/A reduced stand; and starter increased early season growth and vigor 5 out of 6 years studied. The authors concluded that reducing applied nitrogen may trigger better early season growth and vigor due to starter fertilizers. The authors end with a warning that sugar beet seeds and seedlings are sensitive to fertilizer salts. Nitrogen or potash placed in direct seed contact may cause germination damage.

Table 9. Effect of starter P source and rate on sugar beet yield (1983-1984).

Fertilizer	Rate	Yield	Sugar	Recoverable sugar			Stand
	gal/A	t/A	%	lb/A	%	lb/t	% of check
Check	--	16.8	15.3	4343	87.5	268	100
9-18-9	3	18.8	15.2	4802	88.0	267	96
9-18-9	6	18.5	15.1	4710	87.4	266	80
10-34-0	3	19.3	15.2	4947	87.4	268	94
10-34-0	6	20.4	15.2	5223	87.7	268	78
10-34-0	12	18.2	14.9	4448	85.9	258	41
B.L.S.D (0.05)		2	NS	477	NS	NS	16

STARTER FERTILIZATION OF POTATO

Florida researchers (Locascio and Rhue, 1990) examined the effects of starter phosphorus sources and micro-nutrients on potato growth and marketable yield. Addition of micro-nutrients Cu, Fe, Mn, Zn, B, and Mo did not increase yield over treatments without micro-nutrients. To evaluate the effects of four P sources and four micro-nutrient sources on production, the researchers grew potatoes at two sites (both St. John's fine sandy loam soils) during 1980 and 1981. Phosphate sources were liquid ortho-P (10-34-0), liquid poly-P (10-34-0), dry diammonium phosphate (DAP 18-46-0), and dry triple super phosphate (TSP 0-46-0). Fertilizers were formulated as 8-18-9 (percent N-P_2O_5-K_2O) and applied at 1000 lb/A at planting. Fertilizer was applied in two bands, 3 inches to the side of the bed center and 2 inches below the seed piece level. A side-dress application of 80-0-80 pounds of N, P_2O_5,, and K_2O/A was banded on one side of the bed, 10 inches from the bed center, approximately 6 weeks after planting. Irrigation supplemented rainfall.

Phosphate application significantly increased potato tuber yields in both seasons. Soil P tests on the experimental site predicted a positive yield response. Phosphate source influenced tuber yields in both seasons (Table 10). Marketable potato yields were highest with liquid poly-P, significantly lower with liquid ortho-P and TSP and lowest with DAP during 1980. In the 1981 season tuber yields were also significantly lower with DAP than with the other P sources.

Table 10. Effect of P source on marketable yield of potatoes.

P source	1980	1981	Average
	------------------- tons/A	-------------------------	
Liquid Poly-P	15.1a	17.7a	16.4
Liquid Ortho-P	12.9b	17.1a	15.0
DAP	10.7c	14.8b	12.8
TSP	13.4b	18.0a	15.7
No Phosphorus	10.2	13.8	12.0

Mean Separations by Duncan's Multiple Range Test, P=0.05.

STARTER FERTILIZATION OF CANOLA

Balanced and effective fertility management is essential for producing high yielding, good quality canola. Canola uses more nitrogen than most other cereals. A 60 bu/A canola crop will take up about 180 lb./A N, 80 lb/A P_2O_5, 140 lb/A K_2O, and 35 lb/A S. Canola is extremely sensitive to seed placed nutrients. Seed placement is not recommended. For example, Grant and Bailey (1993) found that as little as 20 lb/A N or P_2O_5 placed directly on the seed at planting significantly reduced stand and yield on both sandy loam and silty clay loam soils. In contrast, Grant and Bailey (1992) showed that 20 lb/A phosphorus plus 60 lb/A N banded just before seeding optimized yields on both sandy loam and silty clay loam soils.

Canola is very responsive to P fertilization, producing large yield increases on low P soils. Response to P fertilization can vary, depending on soil type, soil moisture, and the amount of available soil P. Canadian research shows good responses from starter P application, even on soils testing high in available P.

STARTERS PLACED WITH THE SEED

The inconvenience and expense of placing fertilizer away from the seed continues to draw interest to placing fertilizer with the seed as a "pop-up". The use of no-till or ridge-till systems that tend to have higher soil moisture contents at planting and use of no-till drills for planting of both corn and soybeans in narrow rows have increased interest in with-seed placement. The major concern with pop-up use is stand loss from salt injury and the limitation the potential for salt injury places on the amount of N and K that can be included in the starter.

Research in Nebraska on a Sharpsburg SiCL soil showed that pop-up rates exceeding 7 lb of salt ($N+K_2O$)/A in a 30" row will probably produce an unacceptable loss of corn stands unless precipitation occurs soon after planting (Raun et al., 1986). The salt index method ($N+K_2O$) appeared to adequately evaluate both fertilizer source and rate effects on corn seedling emergence and resulted in a linear relationship between index and stand loss. Seedbed conditions and weather following planting influenced stand loss from the pop-up applications (Table 11).

Table 11. Effect of pop-up salt rate on corn stand in Nebraska (Raun et al., 1986).

Planting date	Seedbed condition	Soil moisture	Rain within 9 days of planting	Stand loss per lb of $N+K_2O$
		%	inches	%
June 8	Rough, cloddy	21	4.3	1.75
June 27	Good	7	1.2	0.68
July 24	Good	5	0.4	2.03

Average of 4 fertilizer sources: 7-21-7 (APP+KCl); 7-21-7 + ATS; 10-34-0 (APP); 9-18-9 ($NH_3+H_3PO_4$+urea+KOH).

South Dakota researchers conducted trials in 1992 under a wide range of conditions that normally impact pop-up injury (Table 12). The studies clearly show the greater sensitivity of soybean to salt injury and the effect of soil moisture at planting time. The data suggest that the maximum rate for soybean seeded in narrow rows in no-till systems may be higher than that for wide rows and conventional tillage. More data are needed to determine specific levels. Traditionally no N or K has been recommended for seed placement for soybeans.

Table 12. Effect of pop-up fertilizer use on corn and soybean stands in eastern South Dakota (Gelderman and Gerwing, 1992, unpublished data).

Fertilizer applied		Site A - Conv. till 14% soil moisture 30" row spacing		Site B - No-till 25% soil moisture	
				30" rows	7.5" rows
N	P_2O_5	Corn	Soybean	Corn	Soybean
lb/A		%	%	%	%
0	0	100	100	100	100
5-8	25	104	48	98	94
11-16	50	96	22	98	94
21	100	79	3	--	65

Source: 11-52-0 (MAP) except corn at site B was 10-34-0 (APP).

Use of pop-up starters on sandy soils can result in substantial stand loss and yield reductions. Application of either ammonium orthophosphate or ammonium polyphosphate with the seed on sandy soils in Georgia resulted in reduced corn yield even at 3 lb/A, the lowest N rate evaluated (Table 13).

Table 13. Impact of starter fertilizer placed with the seed on corn yield averaged over a 3-year period on sandy soils in Georgia (Walker et al., 1984).

Location	Average rate $N+P_2O_5$	Source: Liquid AOP	Source: Liquid APP	Source: Solid APP
	lb/A		bu/A	
Tifton	0+0	74a	74a	74a
(loamy sand)	3+8	54b	51b	---
	10.5+33.5	15c	52b	67a
Plains	0+0	139a	139a	139a
(sandy loam)	3+8	127b	131a	---
	10.5+33.5	101c	124b	124b

Means within a location followed by the same letter are not significantly different at the 0.05 level. AOP = ammonium orthophosphate (11-33-0), APP = ammonium polyphosphate (10-34-0).

Wisconsin research showed that low rates of pop-up fertilizers cannot substitute for a more conventional fertility program (Wolkowski and Kelling, 1985). Yields were lower and grain moisture was higher with the low starter rates compared to the conventional rates.

After 3 years, soil test P levels had declined below original levels indicating that soil fertility was being depleted (Table 14).

Greenhouse tests using a moist silt loam soil with 7.2 pH, demonstrated that 1.5" of fertilizer-seed separation was adequate to avoid corn or sorghum injury (Mortvedt, 1985). Treatments included fluid 10-34-0 and granular MAP or DAP alone or in combination with ammonium thiosulfate (ATS) at fertilizer rates varying from 50 to 200 lb/A. Sorghum was much more sensitive to fertilizer placed with the seed than corn.

Table 14. Influence of starter source, placement, and rate on corn yields, grain moisture, and soil test P level (Wolkowski and Kelling, 1985).

Starter			3-year avg.		Soil
Source	$N+P_2O_5+K_2O$	Placement	Yield	Moist.	test P
	lb/A		bu/A	%	lb/A
None	0+0+0	--	125	26.9	44
Conv-liquid	3+7+3	Seed	133	29.7	33
UR+PA+KOH	3+7+3	Seed	128	29.6	29
Conv-liquid	6+24+24	2x2	139	28.3	36
Conv-dry	6+24+24	2x2	137	28.6	37
Conv-liquid	12+48+48	2x2	141	27.1	50
Conv-dry	12+48+48	2x2	138	27.7	52
	LSD(.10)		11	0.9	11

Conv-liquid = conventional sources of urea, 10-34-0 (APP), and KCl. UR+PA+KOH = Urea + phos. acid + potassium hydroxide. Initial soil test levels: Bray P1 = 48 lb/A; Extr. K = 183 lb/A. Supplemental N PPI as urea at 150-180 lb/A/yr; 200 and 120 lb K_2O applied PPI as KCl in first and third year respectively to all plots.

SUMMARY

1. Early season nutrition of corn and other crops is often inadequate in today's cropping systems.
2. Starter composition and rate can influence performance and should be based on local research.
3. Recent data continues to support 2x2 placement of starter as the ideal. Alternatives may be nearly equal in specific situations.
4. Starter responses do occur at high soil test levels. Factors leading to such response:
   - Conservation tillage
   - Soils with restricted drainage
   - Cool, wet conditions following planting
   - Weather conditions favoring shoot growth over root growth
   - Hybrids with high shoot/root ratios
   - Early or late planting

5. Soybean and sorghum are generally less responsive to starter than corn, cotton, sugar beets, or potatoes, although responses do occur especially at medium or lower soil test levels.

6. Seed placed starter fertilizer should be used with caution especially on sandy soils or with salt-sensitive crops. Local guidelines for maximum rates should be followed. Major factors influencing injury:
   - Crop type
   - Soil moisture content/texture
   - Precipitation after planting
   - Seed bed condition
   - Salt ($N+K_2O$) rate
   - Row spacing

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