OPTIMIZING P BASED IN-FURROW STARTER FERTILIZER IN FIELDS WITH VARIABLE SOIL TEST P LEVELS

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ABSTRACT

Soils in Minnesota are highly variable in chemical properties, particularly pH which can range from acidic to basic within a single field. In-furrow starter fertilizer is popular if fields with variable- and high (>7.5) pH fields to enhance early plant growth. The purpose of this study was to determine if in-furrow starter fertilizer rate should be varied in fields with varying pH and if starter fertilizer can increase yield in the presence of broadcast P applied at a non-limiting rate. Eight field locations were established across Minnesota from 2012 to 2014. Treatments were arranged as a split plot design with sixteen replications. Main plots consisted of 0 or 120 lb P_2O_5 broadcast and incorporated before planting. Sub-plots were 0, 2.5, 5, and 7.5 gallons per acre of ammonium polyphosphate [APP (10-34-0)] applied directly on the corn seed (in-furrow). Data analysis was completed considering initial soil test (0-6") level but did not show any interaction where optimum starter fertilizer rate varied by soil test value. Overall, broadcast P resulted in more frequent yield increase in corn but only for soils testing medium or lower in P (<15 ppm Bray-P1 for a 0-6" sample). Starter fertilizer increased early corn plant mass regardless of whether broadcast P was or was not applied, increased corn grain yield over all the sites but only when broadcast P was not applied, and decreased grain harvest moisture in years where corn was wetter (tested >20%) at harvest. The data indicate that optimum starter rate varies from 2.5 to 5.0 gallons of APP per acre and that there is no advantage to 7.5 gallon per acre rate.

INTRODUCTION

Starter fertilizers containing phosphorus (P) have been found to enhance early growth and yield of corn, especially on poorly drained soils of the northern Corn Belt (Randall and Hoeft, 1988; Vetsch and Randall, 2002). The largest yield responses to starter P are often found where soil test P is less than optimum (Bermudez and Mallarino, 2004) and on P fixing soils (Rehm et al., 1988). Phosphorus fixation is usually associated with calcareous soils with pH values greater than 7.4. A significant proportion of soils in South Dakota, Minnesota and Iowa, which developed from glacial deposits from Des Moines Lobe till, are P fixing soils. The location and extent of P fixing soils varies significantly by geographic region within these states and more importantly it varies across the landscape within a given farm field. Identifying or mapping the extent of P fixing soils in a given field can be aided by several soil attributes. Soil test P, pH, calcium carbonates ($CaCO_3$) and soil, topographic and yield maps could all aid in identifying these areas in fields. Generally, grid soil samples, analyzed for pH and soil test P, are the first step toward identifying and mapping low P and potential P fixing areas of fields.

On P fixing soils a fluid starter fertilizer, like ammonium polyphosphate (APP), applied in-furrow may be an efficient and economical way to manage P compared with a traditional broadcast application. Especially, on farmland in short-term rental contracts, where the farmer is not necessarily interested in building soil test levels. Instead their primary goal is to maximize yield and profit while minimizing risk. Previous research has answered many questions on starter fertilizer sources, placements and rates. However, widespread adoption of variable rate fertilization and availability of variable rate controllers has led to two new questions. 1) Does the optimum rate of starter fertilizer vary enough within a field to require variable rates of starter? 2) What soil attributes or landscape parameters can be used to make variable starter rate application recommendations?

The goal of this study is to address these questions by measuring the response of corn to multiple rates of APP applied in-furrow to a field containing soil variability (pH, soil test P, etc.) typical of the region. The objectives of this study are: 1) to measure the effect of rate of application of APP on early growth of corn and grain yield and moisture at harvest; 2) to determine if the optimum rate of APP varies within a field; 3) to compare and contrast the effects of broadcast P addition on the response(s) observed in objectives 1 and 2.

MATERIALS AND METHODS

This field research study was performed using a modified strip trial design. This unique design uses traditional small plot methodology, which includes small plot equipment (planter and combine), experimental design, and appropriate statistical analysis. However, each two-three acre experiment was arranged like a traditional strip trial with strips running the length of the field. The primary difference was each strip was subdivided in 65 ft long segments with each treatment (rate of P fertilizer) randomly applied within each strip and replication using variable rate controllers and GPS guidance.

Table 1. Summary of soil test values for 0-6" soil samples collected prior to treatment application, from the starter studies in 2012 through 2014.

			Bray-		pH				Olsen-P		
Site	Year	Location	P1	K	Min	Avg.	Max	SOM	Min	Avg.	Max
			-----ppm-----					-%-	--------ppm-------		
1	2012	Gaylord	25	209	5.9	6.8	7.8	5.8	4	14	27
2		Stewart	19	208	6.4	7.6	8.0	5.0	4	13	28
3	2013	New Richland	16	251	6.2	7.3	7.8	5.7	5	10	29
4		Willmar	12	176	6.1	7.2	8.0	3.3	4	7	36
5		Janesville	27	171	5.3	5.8	6.5	5.8	6	19	38
6	2014	New Richland	13	135	5.8	7.0	8.0	4.7	3	8	24
7		St. Charles	11	98	6.3	6.8	7.3	2.6	5	8	11
8		Waseca	6	184	5.7	6.6	7.8	4.8	2	5	10

†Minimum (Min), Average (Avg.), and Maximum (Max) ph and Olsen phosphorus values for the soil samples collected at each location.

Research locations were established in the spring of each year. Six of the locations were in south-central Minnesota, one (Willmar) was in west-central Minnesota and one (St. Charles) in southeast Minnesota. Prior to fertilizer application, one composite soil sample (0-6 inch depth) was taken from two neighboring plots or an area about 20 ft. wide by 45 ft long. Each sample was analyzed for soil test P (both Bray P_1 and Olsen), pH, and exchangeable K. Fertilizer treatments (eight) were a factorial combination of broadcast and starter applied P fertilizer at multiple rates. Two rates (0 and 120 lb P_2O_5/ac) of triple super phosphate were broadcast-applied pre-plant and incorporated with tillage. Then four rates [0, 2.5, 5 and 7.5 gal/ac (0, 9.9, 19.7 and 29.6 lb P_2O_5/ac)] of APP were applied in-furrow at planting. Broadcast P rates were the main plots and starter rates were sub-plots in a split plot arrangement of a randomized complete block design. Other essential crop nutrients (nitrogen, potassium, sulfur and zinc) were applied prior to spring tillage at rates to optimize corn production. The majority of these experimental sites were corn following soybean; therefore, the authors feel the effect of nitrogen in the starter treatments would be minimal.

At the V5 growth stage of corn, eight whole corn plants were harvested from each plot, dried at 150° F., and weighed to determine dry matter yield. Corn grain yield was measured by combine harvesting the center two rows of each four-row plot. Grain yield is reported at 15.5% moisture.

RESULTS AND DISCUSSION

A summary of soil test data from initial soil samples taken at each location is presented in Table 1. Soil test P as measured by the Bray P1 test (0-6 inch samples) averaged in the High (16-20 ppm) to Very High (21+ ppm) categories/levels at the Gaylord, Stewart, New Richland-13 (2013) and Janesville locations (Kaiser et al., 2011). Bray P was considerably lower at other locations, especially Waseca. Mean Bray P was greatly influenced by the extent of high pH soils at each location; moreover, it would be expected that the Olsen P test would be a better predictor of crop response. Soil test K (ammonium acetate) levels in the 0-6 inch depth averaged in the High and Very High categories at all locations except St. Charles. The location average pH was near neutral at Gaylord, New Richland (both), Willmar, St. Charles and Waseca; calcareous at Stewart; and acid at Janesville. There were significant ranges in pH across all locations; therefore, for much of the analyses and discussion we will focus on the Olsen P test, which better represents the high pH (calcareous) soils. Average (0-6 inch depth) Olsen P levels were High (12-15 ppm) to Very High (16+ ppm) at Gaylord, Stewart and Janesville; Medium (8-11 ppm) at New Richland (both) and St. Charles; and Low (4-7 ppm) at Willmar and Waseca. Olsen P ranged from Low to Very High at all locations except St. Charles and Waseca. Locations differed in their extent of low P testing areas. At the Willmar, St. Charles and Waseca locations, most of the field tested Low to Medium in Olsen P (Figures C, G and H); whereas, at Janesville most of the field tested High or Very High (Figure D). The New Richland locations had nearly equal sizes of Low, Medium and High/Very High P testing areas (Figures E and F). This type of variability allowed us to look not only at the response to broadcast and starter phosphorus across the field, but within soil test P levels. Generally, fields were selected that had considerable variability in soil test P and potential for response to fertilizer P.

Daily precipitation and average air and soil temperatures are not shown. Early growing season conditions in 2012 were warm and relatively wet; whereas, very cool and wet conditions occurred in 2013 and 2014 which delayed planting. Starter fertilizer is generally used to increase early season plant growth in cool and wet soils. Therefore, the weather in 2012 was less conducive for promotion of early plant growth by starter fertilizer than the weather in 2013 and 2014. Research has shown early growth differences are still possible even in warm springs. Excessive rainfall in June of 2014 resulted in drown out areas at New Richland and Waseca. Unfortunately, data from these areas had to be discarded. All locations had a period during the growing season with less than ideal rainfall, especially in 2012. These dry periods increased variability but did not dramatically reduce yields.

Statistical analysis of these data was difficult due to adverse environmental conditions that affected response at some locations. Early season flooding of plot areas at several locations was the primary concern and late season drought stress at Stewart was also a factor. Of the 16 replications at each site, data from six replications were discarded at Gaylord, seven at Stewart, two at New Richland in both 2013 and 2014, four at Willmar, five at Janesville and two at Waseca. Further analysis will be conducted to see if some of the excluded data can be further used but the overall yield averages between plots with and without broadcast P indicated problems with plots within the excluded replications. For example, in several replications at Stewart the yield difference between treatments with and without broadcast P was as large as 40 bu/ac. These extreme differences were not reasonable, thus the data were not included in the final analyses.

Table 2. Mass of V5 corn plants as affected by broadcast and starter fertilizer P rates.

	10-34-0 Rate (gallons ac^{-1})†					lb. P_2O_5 Broadcast ac^{-1}†		
Site	0	2.5	5.0	7.5	Starter	0	120	Bdcst.
	---------------grams $plant^{-1}$---------------				--*P*>F--	----grams $plant^{-1}$----		--*P*>F--
1	8.13	8.26	7.77	7.43	0.16	7.98	7.81	0.47
2	5.85	5.96	5.70	6.01	0.78	5.79	5.98	0.36
3	6.28c	7.55b	8.32a	8.15ab	**<0.001**	7.43	7.72	0.46
4	4.76b	5.15ab	5.40a	5.28a	**0.02**	4.99b	5.31a	**0.05**
5	6.31c	7.13b	7.79a	7.94a	**<0.001**	6.69b	7.90a	**<0.01**
6	8.66b	9.43a	9.17b	9.72a	**0.02**	8.88b	9.62a	**<0.001**
7	7.99b	8.55a	8.52a	8.80a	**0.002**	8.15b	8.78a	**<0.01**
8	5.09b	7.33a	7.45a	7.92a	**<0.001**	6.27b	7.62a	**0.02**

†Within each row, small letters following numbers indicate treatment significance at $P \leq 0.05$ for the main treatment effects of IF-starter and broadcast (Bdcst) P.

Treatment effects on total dry weight (mass) of whole corn plants at the V5 stage are presented in Table 2. The main effect of broadcast P application increased V5 plant mass at Willmar and Janesville in 2013 and for all of the 2014 locations. When averaged across broadcast P rates, the mass of small corn plants was increased with starter P application at all locations in 2013 and 2014 (cool and wet springs). In 2013, the greatest mass generally occurred with 5 and 7.5 gal/ac rates, the 0 gal/ac control had the least mass and the 2.5 gal/ac rate was intermediate. In 2014, plant mass was greater than the control (0 gal/ac rate) with 2.5, 5.0 and 7.5 gal/ac rates but no differences among the 2.5, 5.0 and 7.5 gal/ac rates were observed. Starter fertilizer application did not affect plant mass at either location in 2012 (a very warm spring). Considerable variability in V5 plant mass was observed at Gaylord. One treatment, 120 lbs of broadcast P plus 7.5 gal/ac of starter, had unusually lower mass. A few plots at this location were affected by flooding or by water running across the plots early in the growing season which may have contributed to the variability. We hypothesized that because the broadcast rate of 120 lb P_2O_5/ac was so much greater than the needs of corn early in the growing season, it may diminish the early growth effects of starter fertilizer P. However, no significant broadcast P × starter P interactions were found in these data. The lack of significant interactions suggests that both P application methods contribute to greater mass of small corn plants; furthermore, their contributions are an additive effect and one application method did not substitute for the other in these data.

Table 3. Corn grain yield as affected by broadcast and starter fertilizer P rates.

	10-34-0 Rate (gallons ac^{-1})†					lb. P_2O_5 Broadcast ac^{-1}†		
Site	0	2.5	5.0	7.5	Starter	0	120	Bdcst.
	---------------bushels ac^{-1}---------------				--*P*>F--	---- bushels ac^{-1}----		--*P*>F--
1	186	188‡	190‡	189‡	0.43	189	189	0.09
2	227	231	230	230	0.69	226b	233a	**0.05**
3	214b	219ab	224a	220ab	**0.03**	215b	224a	**<0.01**
4	156	160	156	158	0.92	145b	170a	**<0.001**
5	194	191	194	196	0.39	193	195	0.43
6	157	162	162	163	0.16	155b	167a	**<0.01**
7	175	177	176	175	0.97	175	177	0.35
8	128b	145a	151a	146a	**0.03**	131b	155a	**<0.01**

†Within each row, small letters following numbers indicate treatment significance at $P \leq 0.05$ for the main treatment effects of IF-starter and broadcast (Bdcst) P
‡Indicates that starter increased yield but only when no broadcast P was applied.

Treatment effects on corn grain yield at each location are summarized in Table 3. When averaged across starter P rates, broadcast P application increased corn yields 7, 9, 25, 12 and 24 bu/ac at the Stewart, New Richland-13, Willmar, New Richland-14 and Waseca locations, respectively. Starter P increased corn yields at only two of eight locations (New Richland-13 and Waseca-14), when averaged across the main effect of broadcast P rate. Starter rate had minimal effect on corn yield at those responsive locations. This finding contradicts our experimental hypotheses that yield response would be affected by starter rate and starter rates should be varied based on soil attributes. A significant broadcast P × starter P interaction at Gaylord showed starter fertilizer increased yields only when no broadcast P was applied. At Willmar the observed yield differences, a large (25 bu/ac) response to broadcast P but no response to starter, were concerning; therefore, Willmar data were excluded from the across location analyses.

Relative yield as affected by treatment main effects and soil test levels across locations (Willmar excluded) are presented in Table 4 and Figures 1, 2 and 3. For this analysis the plot areas were divided into zones based on soil test levels or categories. Five levels (Very Low, Low, Medium, High and Very High) are used in the University of Minnesota fertilizer recommendations bulletin. After preliminary analysis showed there were very few Very Low areas, we reduced the number of levels to four (Low Medium, High and Very High). The Very Low areas were pooled into the Low level group and to better balance the amount of data in each group.

Table 4. Relative corn yield as affected by treatment main effects including soil test P levels, when analyzed across locations (Willmar location excluded).

	Phosphorus Soil Test Used to Delineate Management Zones	
Treatment Effects	Olsen P	Bray P
Main Effects	--------------- relative yield, % --------------	
Soil Test P Level		
Low	98.6	97.0
Medium	99.6	99.8
High	100.0	100.5
Very High	98.5	100.0
P > ***F***:	0.77	0.17
Broadcast Rate	--------------- relative yield, % --------------	
0 lb P_2O_5/ac	97.4b	97.4b
120 lb	101.0a	101.3a
P > ***F***:	**<0.01**	**<0.001**
Starter (10-34-0) Rate	--------------- relative yield, % --------------	
0 gal/ac	97.3b	97.2b
2.5 gal	99.0ab	99.3a
5.0 gal	100.2a	100.6a
7.5 gal	100.2a	100.2a
P > ***F***:	**0.04**	**<0.01**
Interactions,	---------------------*P* > F---------------------	
Level*Broadcast Rate	**0.04**	**0.05**
Level*Starter Rate	0.50	0.29
Broadcast Rate*Starter Rate	**0.09**	**0.10**
Level*Broadcast*Starter	0.96	0.84

Relative corn yield was not significantly affected by the main effect of soil test P level with either the Olsen or Bray tests, when averaged across the main effects of broadcast P and starter P rate. When averaged across soil test level and starter P, broadcast P application increased relative yields about 3.5 and 4.0 percentage points for the Olsen and Bray soil tests, respectively. The main effect of starter application rate increased relative yields: 1) about 3 percentage points with the 5 and 7.5 gal/ac rates of starter fertilizer compared with the control (0 gal/ac rate) for the Olsen test and 2) about 2-3.5 percentage points with the 2.5, 5 and 7.5 gal/ac rates of starter fertilizer are compared with the control (0 gal/ac rate) for the Bray test, when averaged across the main effects of soil test P levels and broadcast P application. The difference between the Olsen and Bray tests were minimal. We would have expected the Olsen P test to be a better predictor, since the majority of the locations had calcareous (high pH) areas in the field. A significant broadcast P × soil test P class/level interaction (Figure 1) showed the yield response to broadcast P fertilization only occurred at the Low and Medium soil test P levels. This finding is consistent with many other studies that show the greatest probability and magnitude of a yield response occurs at low soil test values and both probability and magnitude of a response diminish as soil test P increases. A significant broadcast P × starter P interaction showed starter fertilizer application increased relative corn yields only when broadcast P was not applied (Figure 2). This response to starter fertilizer occurred regardless of soil test P level (Figure 3). Furthermore, the rate of starter did not significantly affect yield response. This finding is contrary to our initial hypothesis that Low P and/or high pH (calcareous) areas of the field would require a greater starter rate.

Table 5. Corn grain moisture at harvest as affected by broadcast and starter fertilizer P rates.

Site	10-34-0 Rate (gallons ac^{-1})†				Starter	lb. P_2O_5 Broadcast ac^{-1}†		Bdcst.
	0	2.5	5.0	7.5		0	120	
	---------------------%---------------------				--*P*>F--	---------%--------		--*P*>F--
1	16.9	16.3	16.8	17.0	0.05	16.9	16.6	0.33
2	14.5	14.5	14.5	14.6	0.97	14.6	14.5	0.62
3	26.8a	26.3ab	25.9b	25.9b	**<0.01**	26.4	26.1	0.20
4	23.2	24.0	23.2	23.7	0.49	22.7	24.4	0.05
5	24.9a	24.4b‡	24.3b‡	24.2b‡	**<0.01**	24.7a	24.2b	**0.03**
6	16.9	16.8	16.9	16.8	0.93	16.8	17.0	0.25
7	17.1	16.7	16.6	17.3	0.09	17.0	16.8	0.35
8	22.5a	21.9b	21.9b	21.5b	**0.01**	22.2	21.8	0.09

†Within each row, small letters following numbers indicate treatment significance at $P \leq 0.05$ for the main treatment effects of IF-starter and broadcast (Bdcst) P.
‡Indicates that starter affected grain moisture but only when no broadcast P was applied.

Grain moisture at harvest varied among locations because of planting and harvesting date differences and was considerably drier in 2012 than other years (Table 5). No significant differences in grain moisture were observed in 2012 partly due to an early spring and dry summer which resulted in very dry grain at harvest. In 2013, grain moisture was reduced slightly with both broadcast and starter P application at Janesville. However, a significant broadcast P × starter rate interaction at Janesville showed starter fertilizer application reduced grain moisture only when broadcast P was not applied and had no effect when broadcast P was applied. Starter fertilization reduced grain moisture at New Richland-13 and Waseca. The 5 and 7.5 gal/ac rates of starter P reduced grain moisture about one percentage point compared with the 0 gal/ac control at New Richland-13. These data showed fertilizer application occasionally reduced grain moisture at harvest thereby saving farmers money in grain drying costs which increases the likelihood of getting a positive economic return from the cost of the fertilizer.

CONCLUSIONS

When averaged across sites: 1) a significant broadcast P × soil test P level interaction showed the yield response to broadcast P application only occurred at Low and Medium soil test P levels; and 2) a significant broadcast P × starter P interaction showed starter fertilizer application increased relative corn yields only when broadcast P was not applied; interestingly, this response to starter fertilizer occurred regardless of soil test P level and the rate of starter did not significantly affect yield response. These findings contradict our experimental hypotheses that corn grain yield response would be affected by starter rate and starter rates should be varied based on soil attributes.

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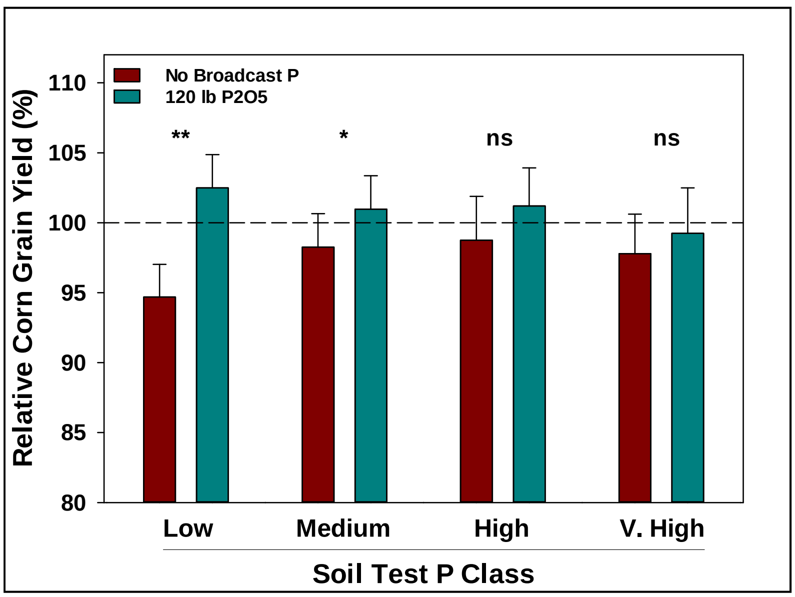

Figure 1. Relative corn grain yield as affected by broadcast rates of fertilizer P and soil test P classes (Olsen P), when averaged across starter P rates and locations (** and * denotes significance at α=0.05 and α=0.10, respectively).

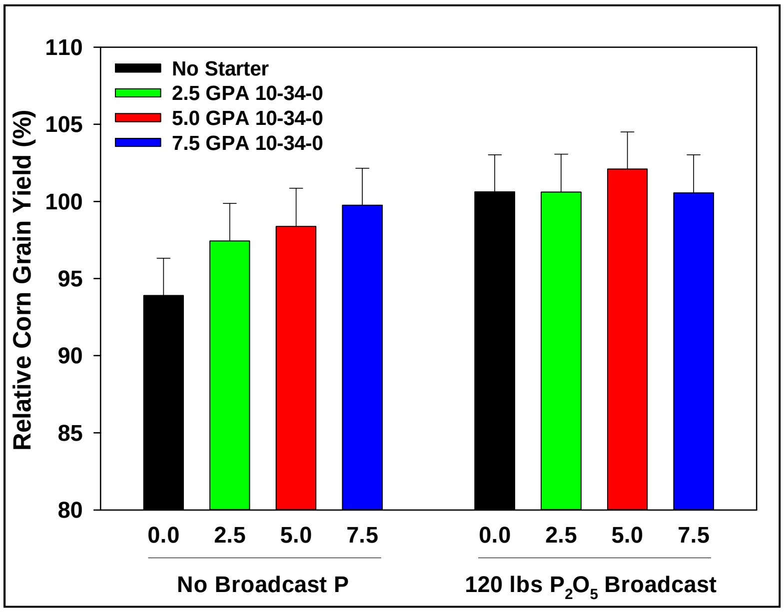

Figure 2. Relative corn grain yield as affected by the interaction between broadcast and starter (APP, ammonium poly phosphate) rates of fertilizer P, when averaged across locations and soil test P levels (error bar denotes significance at α=0.05).

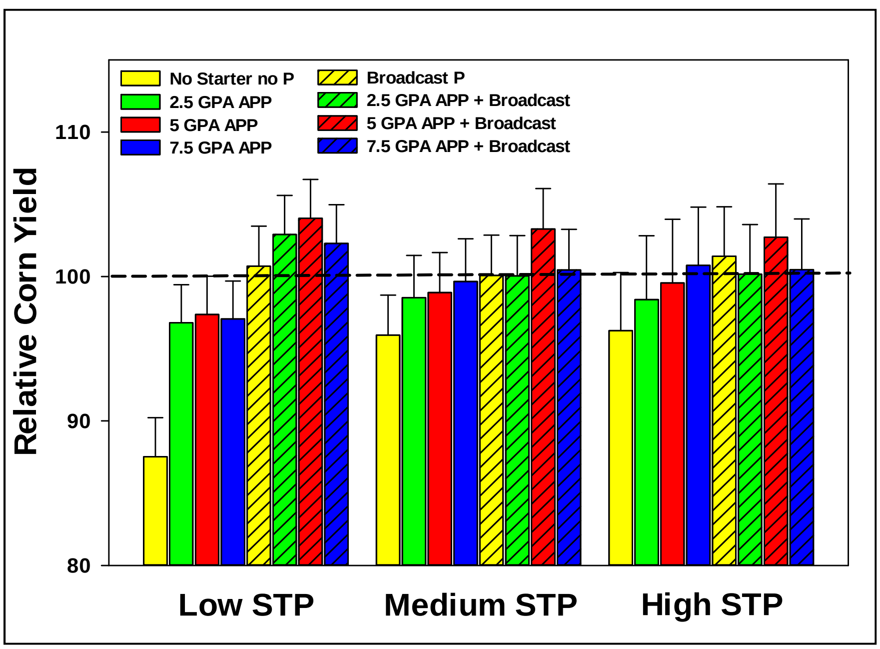

Figure 3. Relative corn grain yield at various soil test levels (Olsen P) as affected by broadcast and starter rates of fertilizer P, when averaged across locations (error bar denotes significance at α=0.05).

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