

# Variable Rate Starter Fertilization

*Does it affect corn yield and should it be based on soil attributes?*

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**Summary:** Some key observations. Plant populations were rarely affected by fertilizer P treatments. Generally, broadcast and starter fertilizer enhanced early growth of corn. Broadcast P applications increased yields at five of eight locations while starter applications increased yields at only two of eight locations. Our findings contradicted our experimental hypotheses that corn grain yield response would be affected by starter rate and starter rates should be varied based on soil attributes.



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 vary significantly by geographic region within these states and, more importantly, vary 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<sub>3</sub>) 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, such as ammonium polyphosphate

(APP) applied in-furrow, may be an efficient and economic 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, placement, 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? and 2) what soil attributes or landscape parameters can be used to make variable starter rate application recommendations? These questions will be addressed 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 starter rates will be applied within blocks-with and without broadcast P fertilizer. The with-and-without broadcast P blocks will allow us to compare the efficiency of starter P to broadcast P across the landscape.

## Objectives

The objectives of this study are:

- To measure the effect of the rate of application of APP on early growth of corn, grain yield, P removal in grain and fertilizer use efficiency (FUE)
- To determine if the optimum rate of APP varies within a field
- To develop and calibrate an algorithm for making variable rate starter applications based on soil attributes
- To compare and contrast the effects of broadcast P addition on the response(s) observed in objectives 1, 2, and 3.

## Methodology

**Design.** The 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 into 65-foot long segments with each treatment (rate of P fertilizer) randomly applied within each strip and replication using variable-rate controllers and GPS guidance. This design

allows for treatment randomization and replication, such as typical small plot studies. However, each research location had 16 replications, whereas traditional small plot studies have 4 replications. The advantage of this design over multiple traditional small plots was it allowed for comparisons across the landscape within the same experimental unit while it maintained independence between samples.

Sample independence is an issue when statistically analyzing traditional strip trials where a single treatment is applied to a strip the length of the experiment. This design also allowed differences in soil type and soil test P, pH, and other soil attributes to be tested as main effects in the statistical model. Individual replications were pooled together based on soil attributes prior to statistical analysis.

**Locations.** Research locations (Gaylord and Stewart in 2012; New Richland, Willmar, and Janesville in 2013; and Waseca, New Richland, and St. Charles in 2014) were established in the spring. Six locations were in south-central Minnesota, one (Willmar) was in west-central Minnesota, and one (St. Charles) in southeast Minnesota.

**Soil samples.** Prior to fertilizer application, one composite soil sample (0-6 inch depth) was taken from two neighboring plots or an area about 20 feet wide by 45 feet long. A total of 4 samples were taken from each of the 16 replications at each location. Each sample was analyzed for soil test P (both Bray P1 and Olsen), pH, CaCO<sub>3</sub> and exchangeable K. One composite (6-12 inches) soil sample for soil test P (both Bray P1 and Olsen) was taken from each of the 16 replications to characterize the subsoil at each site.

**Treatments.** Fertilizer treatments (eight) were a factorial combination of broadcast and starter applied P fertilizer at multiple rates. Two rates (0 and 120 lb P2O5/A) of triple super phosphate were broadcast-applied pre-plant and incorporated with tillage. Then four rates [0, 2.5, 5 and 7.5 gal/A (0, 9.9, 19.7, and 29.6 lb P2O5/A)] 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 randomized complete block design. Other essential crop nutrients [nitrogen (N), potassium (K), sulfur (S), and zinc (Zn)] were applied prior to spring tillage at rates to optimize corn production. The majority of these experimental sites were corn following soybeans; therefore the authors feel the effect of N in the starter treatments would be minimal.

**Conditions.** Extraordinarily cool and wet conditions occurred during the spring of 2013 and 2014, which delayed field operations and planting at some locations. Corn was planted on May 15 at New Richland, June 2 at Willmar, and June 2 at Janesville in 2013.

**Harvesting.** At the V5 growth stage of corn, eight whole corn plants were harvested from each plot, dried at 150° F, weighed to determine dry matter yield, ground, and analyzed for total P. Stand counts and NDVI readings were also taken at V5.

**Yield.** Corn grain yields were

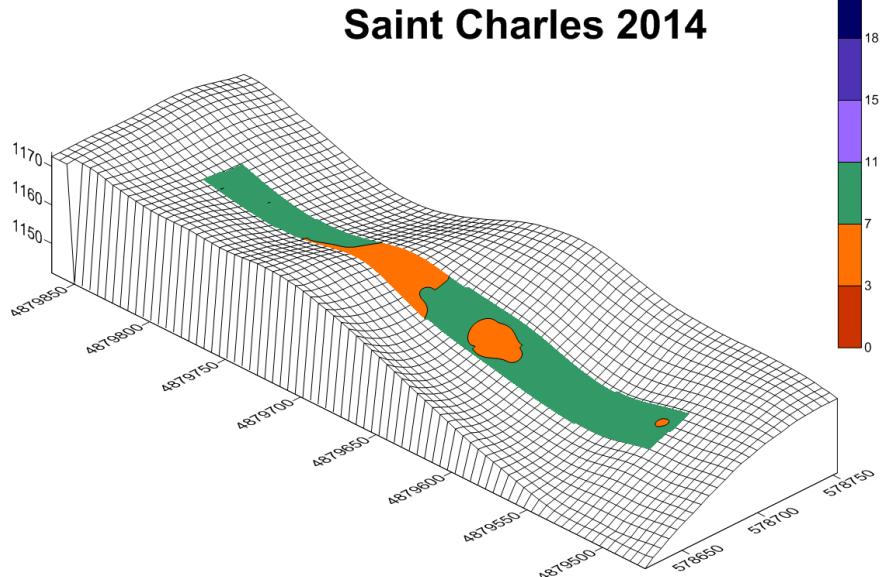


Figure 1. Inherent variability in soil test phosphorus (Olsen P) at St. Charles in 2014.

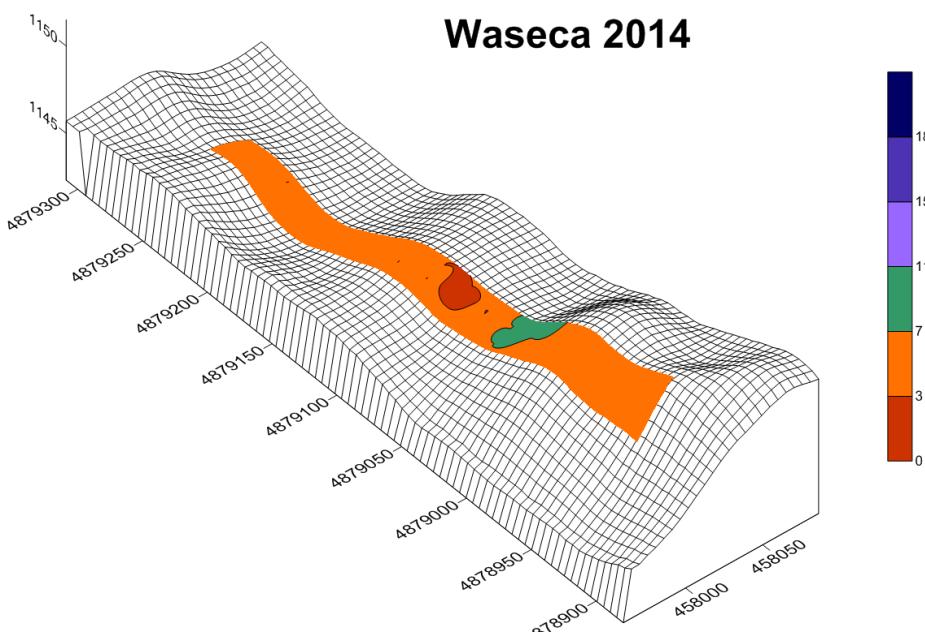


Figure 2. Inherent variability in soil test phosphorus (Olsen P) at Waseca in 2014.

measured by combine harvesting the center two rows of each four-row plot. Grain yields were reported at 15.5% moisture.

**Grain sample.** A grain sample was collected from each plot, dried at 150°F, ground, and then analyzed for total P. Phosphorus removal in the grain was calculated from the yield and grain P concentration data.

## Results

**Soil tests.** 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 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 St. Charles and Waseca locations (Figures 1 and 2) most of the fields tested low to medium in Olsen P. At Janesville, however, most of the field tested high or very high. The New Richland locations had nearly equal sizes of low, medium, and high/very high P testing areas (Figure 3).

This type of variability allowed us to look not only at response to broadcast and starter P 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.

**Weather.** Daily 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. 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.

**Analysis.** 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

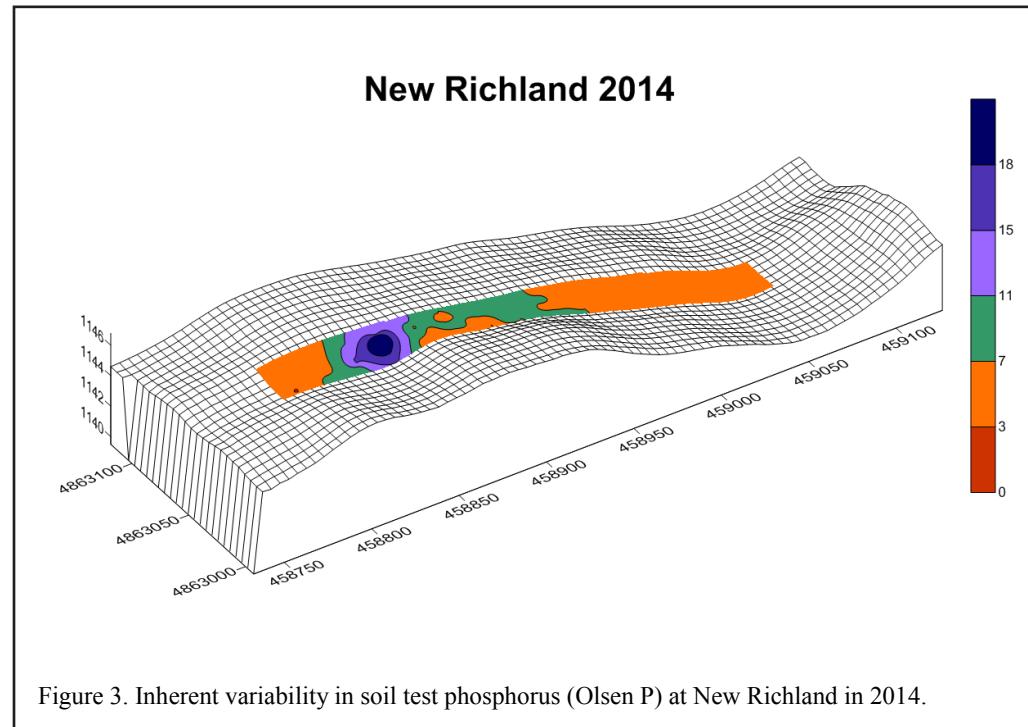


Figure 3. Inherent variability in soil test phosphorus (Olsen P) at New Richland in 2014.

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

Location	Depth	Bray-P1			pH			Olsen-P		
		Inch	-----ppm-----	K	Min	Avg.	Max	SOM	Min	Avg.
Gaylord-12	0-6	25	209	5.9	6.8	7.8	5.8	4	14	27
Stewart-12	0-6	19	208	6.4	7.6	8	5	4	13	28
New Rich.-13	0-6	16	251	6.2	7.3	7.8	5.7	5	10	29
	6-12	6	165	7.2	7.6	7.7	4.5	5	8	11
Willmar-13	0-6	12	176	6.1	7.2	8	3.3	4	7	36
	6-12	4	138	6	7.3	7.9	2.8	2	4	6
Janesville-13	0-6	27	171	5.3	5.8	6.5	5.8	6	19	38
	6-12	24	164	5.3	5.8	6.9	5.4	6	17	36
New Richl.-14	0-6	13	135	5.8	7	8	4.7	3	8	24
	6-12	4	92	6.4	7.4	8.1	3.6	2	4	7
St. Charles-14	0-6	11	98	6.3	6.8	7.3	2.6	5	8	11
	6-12	11	91	6.3	6.7	7.1	2.1	5	8	12
Waseca-14	0-6	6	184	5.7	6.6	7.8	4.8	2	5	10
	6-12	5	116	5.7	6.9	7.9	4	2	4	6

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

Stewart, two at New Richland in both 2013 and 2014, four at Willmar, five at Janesville, and two at Waseca.

**Plant populations** were generally not affected by broadcast and/or starter fertilizer P rates except for New Richland-14 (2014) where populations were slightly greater (800 plants/A) when broadcast P was not applied (Table 2). Desired seeding rates varied somewhat among locations because two different planters were used in this study. At Gaylord, Stewart, Willmar, New Richland-14 and St. Charles approximately 14,500 seeds/A were planted to achieve a final stand of 32,000 to 34,000 plants/A; whereas, at New Richland-13, Janesville, and Waseca, 35,500 seeds/A were planted to obtain a final population of 34,000 to 35,000 plants/A. Final populations were greater than expected/ desired (36,200 plants/A) at Stewart but near desired at other locations.

**Effects.** Treatment effects on total dry weight (mass) of whole corn plants at the V5 stage are presented in Table 3. 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/A rates, the 0/gal/A control had the least mass and the 2.5 gal/A rate was intermediate. In 2014, plant mass was greater than the control (0 gal/A rate) with 2.5, 5.0, and 7.5 gal/A rates, but no differences among the 2.5, 5.0, and 7.5 gal/A 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/A 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<sub>2</sub>O<sub>5</sub>/A 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 x 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.

**P concentrations** in V5 plants were increased significantly by broadcast P application at five of eight locations [New Richland (both), Willmar, St. Charles, and Waseca] and concentrations were numerically greater at the Stewart and Janesville locations (Table 4). The greatest increase in plant P concentration with broadcast P application occurred at the New Richland (both) and Waseca locations, which had some of the lowest Olsen P levels. The differences in P concentration, along with increased plant mass, contributed to increased P uptake with broadcast P application at six of eight locations (Table 5). Phosphorus concentration of V5 corn plants was increased significantly (P<0.05) by starter P application only at Stewart in 2012 (Table 4). The lack of significant and consistent differences in P concentration are likely due to greater plant mass with these treatments, which results in dilution of P concentration in the plant. Another factor to consider is the rates of P applied in the starter (10, 20, and 30 lbs P2O5/A) were much less than the broadcast rate (120 lbs. P2O5/A). At these rates starter P was effective at increasing plant mass but did not significantly increase P concentration like broadcast P did, especially when broadcast P was not applied. Starter application did increase P uptake at all 2013 and 2014 locations, which were dominated by cool and wet conditions. However, starter application did not increase P uptake in 2012, a warm spring. These data showed that both in-furrow and broadcast starter P fertilizer enhanced early growth of corn and increased P uptake, especially in cool and wet springs.

**Yields.** Treatment effects on corn grain yield at each location are summarized in Table 6. When averaged across starter P rates, broadcast P application increased corn yields 7, 9, 25, 12, and 24 bu/A 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), when averaged across the main effect of

Table 2. Corn plant populations at V5 as affected by broadcast and starter fertilizer P rates.

Location	Broadcast	10-34-0 Starter Rate (gallons per acre)				Average†
	P Rate	0	2.5	5	7.5	
	-lb P <sub>2</sub> O <sub>5</sub> /ac-	plants per acre				
Gaylord-12	0	33150	33850	33290	34430	33680
	120	33900	33250	32370	35130	33660
	Average†	33520	33550	32830	34780	
Stewart-12	0	36640	36900	36100	35650	36320
	120	36750	36265	35480	36140	36160
	Average	36700	36580	35790	35890	
New Rich.-13	0	35730	35650	36150	35650	35790
	120	36190	35660	35490	35790	35780
	Average	35960	35650	35820	35720	
Willmar-13	0	34380	35200	34910	35060	34890
	120	34140	34580	35580	34860	34790
	Average	34260	34890	35240	34960	
Janesville-13	0	35190	35510	36300	35330	35580
	120	36240	35870	35390	34830	35580
	Average	35720	35690	35840	35080	
New Rich.-14	0	33030	32690	32930	33420	33020a
	120	31940	32540	32090	32300	32220b
	Average	32490	32610	32510	32860	
St. Charles-14	0	33610	33390	34090	33120	33550
	120	33780	33610	33460	33340	33550
	Average	33700	33500	33770	33230	
Waseca-14	0	no data	no data	no data	no data	--
	120	no data	no data	no data	no data	--
	Average	--	--	--	--	

†Within each row or column, small letters following numbers indicate treatment significance at P<0.05. Numbers followed by different letters are significantly different.

Table 3. Mass of V5 corn plants as affected by broadcast and starter fertilizer P rates.

Location	Broadcast	10-34-0 Starter Rate (gallons per acre)				Average†
	P Rate	0	2.5	5	7.5	
-lb P <sub>2</sub> O <sub>5</sub> /ac-		grams per plant-				
Gaylord-12	0	7.96	8.54	7.54	7.89	7.98
	120	8.3	7.99	8	6.97	7.81
	Average†	8.13	8.26	7.77	7.43	
Stewart-12	0	5.73	6.05	5.23	6.14	5.79
	120	5.98	5.88	6.17	5.88	5.98
	Average†	5.85	5.96	5.7	6.01	
New Rich.-13	0	5.94	7.5	8.58	7.72	7.43
	120	6.63	7.6	8.08	8.58	7.72
	Average†	6.28c	7.55b	8.32a	8.15ab	
Willmar-13	0	4.49	5.08	5.29	5.09	4.99b
	120	5.02	5.23	5.52	5.47	5.31a
	Average†	4.76b	5.15ab	5.40a	5.28a	
Janesville-13	0	5.39	6.37	7.29	7.7	6.69b
	120	7.22	7.9	8.29	8.19	7.90a
	Average†	6.31c	7.13b	7.79a	7.94a	
New Rich.-14	0	8.09	9.18	8.91	9.34	8.88b
	120	9.24	9.69	9.44	10.1	9.62a
	Average	8.66b	9.43a	9.17b	9.72a	
St. Charles-14	0	7.44	8.36	8.2	8.6	8.15b
	120	8.53	8.73	8.84	9	8.78a
	Average	7.99b	8.55a	8.52a	8.80a	
Waseca-14	0	4.73	6.7	6.71	6.93	6.27b
	120	5.45	7.96	8.18	8.91	7.62a
	Average	5.09b	7.33a	7.45a	7.92a	

†Within each row or column, small letters following numbers indicate treatment significance at P<0.05. Numbers followed by different letters are significantly different.

Table 4. Corn plant (V5) phosphorus concentration as affected by broadcast and starter fertilizer P rates.

Location	Broadcast	10-34-0 Starter Rate (gallons per acre)				Average†
	P Rate	0	2.5	5	7.5	
-lb P <sub>2</sub> O <sub>5</sub> /ac-		%				
Gaylord-12	0	0.45	0.45	0.44	0.47	0.45
	120	0.46	0.46	0.46	0.47	0.46
	Average†	0.46	0.46	0.45	0.47	
Stewart-12	0	0.51	0.49	0.48	0.5	0.5
	120	0.5	0.51	0.5	0.54	0.51
	Average†	0.51ab	0.50b	0.49b	0.52a	
New Rich.-13	0	0.42	0.43	0.42	0.41	0.42b
	120	0.48	0.46	0.47	0.45	0.47a
	Average†	0.45	0.45	0.45	0.43	
Willmar-13	0	0.38	0.39	0.37	0.4	0.39b
	120	0.4	0.4	0.41	0.42	0.41a
	Average†	0.39	0.4	0.39	0.41	
Janesville-13	0	0.47	0.45	0.42	0.45	0.45
	120	0.46	0.46	0.46	0.48	0.46
	Average†	0.47	0.45	0.44	0.46	
New Rich.-14	0	0.3	0.3	0.31	0.31	0.30b
	120	0.34	0.36	0.34	0.36	0.35a
	Average	0.32	0.33	0.32	0.34	
St. Charles-14	0	0.38	0.4	0.39	0.4	0.39b
	120	0.42	0.42	0.44	0.44	0.43a
	Average	0.4	0.41	0.41	0.42	
Waseca-14	0	0.28	0.28	0.28	0.28	0.28b
	120	0.33	0.33	0.33	0.34	0.33a
	Average	0.31	0.3	0.31	0.31	

†Within each row or column, small letters following numbers indicate treatment significance at P<0.05. Numbers followed by different letters are significantly different.

Table 5. Whole plant phosphorus uptake at V5 as affected by broadcast and starter fertilizer P rates.

Location	Broadcast	10-34-0 Starter Rate (gallons per acre)				Average†
	P Rate	0	2.5	5	7.5	
	-lb P2O5/ac-	milligrams/plant				
Gaylord-12	0	35.8	39.8	36.3	37.6	37.4
	120	38	36.7	38.3	32.7	36.4
	Average†	36.9	38.3	37.3	35.2	
Stewart-12	0	29	29.7	25.2	30.8	28.7
	120	30.1	29.4	30.9	31.6	30.5
	Average†	29.5	29.5	28	31.2	
New Rich.-13	0	24.6	31.7	35.9	31.4	30.9b
	120	32	34.9	38.4	38.9	36.0a
	Average†	28.3c	33.3b	37.1a	35.2ab	
Willmar-13	0	17.4	20.1	19.9	20.3	19.4b
	120	20	21	22.8	23.1	21.7a
	Average†	18.7b	20.6ab	21.3a	21.7a	
Janesville-13	0	25.5	28.8	30.5	34.4	29.8b
	120	33.7	35.8	38	39.1	36.7a
	Average†	29.6c	32.3bc	34.2ab	36.8a	
New Rich.-14	0	25	28	28.5	30	27.9b
	120	32.2	36.1	33.9	37.4	34.9a
	Average	28.6b	32.1a	31.2ab	33.7a	
St. Charles-14	0	28.4	33.2	31.7	34.7	32.0b
	120	36.2	36.9	38.7	39.5	37.8a
	Average	32.3c	35.1b	35.2ab	37.1a	
Waseca-14	0	14	19.3	19.6	20	18.2b
	120	18.4	26.7	27.6	30.3	25.8a
	Average	16.2b	23.0a	23.6a	25.2a	

†Within each row or column, small letters following numbers indicate treatment significance at P<0.05. Numbers followed by different letters are significantly different.

Table 6. Corn grain yield as affected by broadcast and starter fertilizer P rates.

Location	Broadcast	10-34-0 Starter Rate (gallons per acre)				Average†
	P Rate	0	2.5	5	7.5	
	-lb P2O5/ac-	bushels per acre				
Gaylord-12	0	180*	187*	189*	190*	187
	120	191	188	190	189	189
	Average†	186	188	190	189	
Stewart-12	0	222	229	226	227	226b
	120	231	233	235	234	233a
	Average†	227	231	230	230	
New Rich.-13	0	206	216	220	217	215b
	120	222	222	227	222	224a
	Average†	214b	219ab	224a	220ab	
Willmar-13	0	139	147	144	150	145b
	120	173	172	169	167	170a
	Average†	156	160	156	158	
Janesville-13	0	190	191	193	198	193
	120	198	192	194	194	195
	Average†	194	191	194	196	
New Rich.-14	0	149	156	159	158	155b
	120	165	169	165	168	167a
	Average	157	162	162	163	
St. Charles-14	0	175	173	172	178	175
	120	176	180	180	173	177
	Average	175	177	176	175	
Waseca-14	0	109	138	138	137	131b
	120	147	152	164	156	155a
	Average	128b	145a	151a	146a	

†Within each row or column, small letters following numbers indicate treatment significance at P<0.05. Numbers followed by different letters are significantly different. \* Notes significant interaction, starter yields different only without broadcast P.

broadcast P rate. Starter rate had minimal effect on corn yields 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 x 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/A) response to broadcast P but no response to starter, were concerning; therefore, Willmar data were excluded from the across-location analyses.

Relative yields, as affected by treatment main effects and soil test levels across locations (Willmar excluded), are presented in Table 7. 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 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 to better balance the amount of data in each group. Relative yields were 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:

- About 3 percentage points with the 5 and 7.5 gal/A rates of starter fertilizer when compared with the control (0 gal/A rate) for the Olsen test
- About 2-3.5 percentage points with the 2.5, 5 and 7.5 gal/A rates of starter fertilizer when compared with the control (0 gal/A rate) for the Bray test, and averaged across the main effects of soil test P levels and broadcast P application.

The differences 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 x soil test P class/level interaction 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

Table 7. 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	
Medium	99.6	99.8	
High	100	100.5	
Very High	98.5	100	
P > F:	0.77	0.17	
Broadcast Rate			
0 lb P2O5/ac	97.4b	97.4b	
120 lb	101.0a	101.3a	
P > F:	<0.01	<0.001	
Starter (10-34-0) Rate			
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	0.5	0.29	
Broadcast Rate*Starter Rate	0.09	0.1	
Level*Broadcast*Starter	0.96	0.84	

Table 8. Corn grain moisture at harvest as affected by broadcast and starter fertilizer P rates.

Location	Broadcast P Rate	10-34-0 Starter Rate (gallons per acre)				Averaget
		0	2.5	5	7.5	
	-lb P2O5/ac-	%				
Gaylord-12	0	16.8	16.5	17	17.1	16.9
	120	17	16.1	16.5	16.9	16.6
	Averaget†	16.9	16.3	16.8	17	
Stewart-12	0	14.7	14.4	14.5	14.6	14.6
	120	14.2	14.7	14.5	14.5	14.5
	Averaget†	14.5	14.5	14.5	14.6	
New Rich.-13	0	26.9	26.5	26.1	25.9	26.4
	120	26.6	26.1	25.7	25.9	26.1
	Averaget†	26.8a	26.3ab	25.9b	25.9b	
Willmar-13	0	22.4	23.3	22.2	23	22.7
	120	24	24.8	24.2	24.5	24.4
	Averaget†	23.2	24	23.2	23.7	
Janesville-13	0	25.5*	24.6*	24.6*	24.3*	24.7a
	120	24.3	24.3	24	24.1	24.2b
	Averaget†	24.9a	24.4b	24.3b	24.2b	
New Rich.-14	0	16.9	16.6	16.6	16.9	16.8
	120	17	17.1	17.1	16.7	17
	Average	16.9	16.8	16.9	16.8	
St. Charles-14	0	17.2	17	16.7	17.2	17
	120	16.9	16.5	16.6	17.4	16.8
	Average	17.1	16.7	16.6	17.3	
Waseca-14	0	23.1	22.2	22	21.4	22.2
	120	22	21.5	21.8	21.7	21.8
	Average	22.5a	21.9b	21.9b	21.5b	

†Within each row or column, small letters following numbers indicate treatment significance at P<0.05. Numbers followed by different letters are significantly different. \* Significant broadcast P rate\*starter P rate interaction.

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 x starter P interaction showed that starter fertilizer application increased relative corn yields only when broadcast P was not applied. This response to starter fertilizer occurred regardless of soil test P level. 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 greater starter rate.

**Moisture.** Grain moisture at harvest varied among locations because of planting and harvesting date differences. It was considerably drier in 2012 than other years (Table 8). 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 x 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/A rates of starter P reduced grain moisture about one percentage point compared with the 0 gal/A control at New Richland-13. These data showed starter 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 fertilizer.

**Concentration.** Treatment effects on grain P concentration and removal are presented in Table 9. Grain concentrations were not affected by treatment main effects at either location in 2012. However, grain P was increased by broadcast P application at New Richland and Willmar in 2013. Broadcast P application increased grain P removal at three of five locations in 2012 and 2013, when averaged across starter P rates. Starter P rate had no affect on grain P concentration and removal, and

there were no significant interactions. Grain P data from 2014 locations had not returned from the lab at the time of writing this report.

### Summing up

Research on the effects of starter fertilizer (APP) rates with and without broadcast P application continued in 2014 and two new locations are planned in 2015. Some key observations from the first three years (eight total locations) of this study include:

- Plant populations were rarely affected by fertilizer P treatments (broadcast or starter)
- Generally, broadcast and starter enhanced early growth of corn (V5 whole plant mass) in 2013 and 2014 during cool and wet springs, but had little effect in 2012 during a warm spring
- Corn grain yields were increased by broadcast P application at five of eight locations, while starter application increased yields at only two of eight locations.

When averaged across sites:

- A significant broadcast P x soil test P level interaction showed the yield response to broadcast P application only occurred at low and medium soil test P levels.
- A significant broadcast P x 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.

Location	Broadcast P Rate -lb P <sub>2</sub> O <sub>5</sub> /ac-	10-34-0 Starter Rate (gallons per acre)				Average†
		0	2.5	5	7.5	
Gaylord-12	0	0.28	0.27	0.28	0.27	0.27
	120	0.28	0.29	0.31	0.29	0.29
	Average†	0.28	0.28	0.29	0.28	
Stewart-12	0	0.32	0.32	0.3	0.32	0.32
	120	0.33	0.31	0.35	0.32	0.33
	Average†	0.32	0.32	0.32	0.32	
New Rich.-13	0	0.21	0.2	0.21	0.21	0.21b
	120	0.24	0.26	0.24	0.24	0.25a
	Average†	0.22	0.23	0.23	0.23	
Willmar-13	0	0.19	0.22	0.2	0.19	0.20b
	120	0.24	0.23	0.24	0.25	0.24a
	Average†	0.22	0.23	0.22	0.22	
Janesville-13	0	0.27	0.28	0.28	0.28	0.28
	120	0.27	0.28	0.28	0.28	0.28
	Average†	0.27	0.28	0.28	0.28	
New Rich.-14	0	--	--	--	--	--
	120	--	--	--	--	--
	Average	--	--	--	--	--
St. Charles-14	0	--	--	--	--	--
	120	--	--	--	--	--
	Average	--	--	--	--	--
Waseca-14	0	--	--	--	--	--
	120	--	--	--	--	--
	Average	--	--	--	--	--

†Within each row or column, small letters following numbers indicate treatment significance at P<0.05. Numbers followed by different letters are significantly different.

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