Variable Rate Starter Fertilization Based on Soil Attributes

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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 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, 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 starter rates will be applied within blocks of 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.

The objectives of this study are: 1) to measure the effect of rate of application of APP on early growth of corn, grain yield, P removal in grain and fertilizer use efficiency; 2) to determine if the optimum rate of APP varies within a field; 3) to develop and calibrate an algorithm for making variable rate starter applications based on soil attributes; and 4) to compare and contrast the effects of broadcast P addition on the response(s) observed in objectives 1, 2 and 3.

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. This design allows for treatment randomization and replication, like typical small plot studies. Except, 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, 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.

Research locations, Gaylord and Stewart in 2012 and New Richland, Willmar, and Janesville in 2013, were established in the spring. Four locations were in south-central Minnesota and one (Willmar) was in west-central 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. 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 P_1 and Olsen), pH, $CaCO_3$ and exchangeable K. One composite (6-12 inch) soil sample for soil test P (both Bray P_1 and Olsen) was taken from each of the 16 replications to characterize the subsoil at each site. Fertilizer treatments (eight) were a factorial combination of broadcast and starter applied P fertilizer at multiple rates. First, two rates (0 and 120 lb P_2O_5/ac) of triple super phosphate were broadcast-applied preplant 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.

Extraordinary cool and wet conditions in the spring of 2013 delayed field operations and planting. Corn was planted on May 15 at New Richland and June 2 at Willmar and Janesville. 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 then analyzed for total P. Stand counts and NDVI readings were also taken at V5. Corn grain yields were measured by combine harvesting the center two rows of each four-row plot. Grain yields are reported at 15.5% moisture. 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 and Discussion

A summary of soil test data from initial soil samples taken at each location is presented in Table 1. Soil test P (Bray P1) and K (ammonium acetate) levels averaged High to Very High at most locations (0-6 inch samples). The location average pH was near neutral at Gaylord, New Richland and Willmar; 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 to Very High across locations except for New Richland (Medium) and Willmar (Low). Olsen P ranged from Low to Very High at all locations. Locations differed in their extent of low P testing areas. At the Willmar location, most of the field tested Low in Olsen P (Figure C); whereas, at Janesville most of the field tested High or Very High (Figure D). The New Richland location had nearly equal sizes of Low, Medium and High/Very High P testing areas (Figure E). 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 or classes. Generally, fields were selected that had considerable variability in soil test P and potential for response to fertilizer P.

Table 1. Summary of soil test values for samples collected, prior to treatment application, from the starter studies at Gaylord and Stewart in 2012 and New Richland, Willmar and Janesville in 2013.

				pH				Olsen-P		
Location	Depth	Bray-P1	K	Min	Avg.	Max	SOM	Min	Avg.	Max
	Inch	------ppm------					%	-----ppm -----		
Gaylord	0-6	25	209	5.9	6.8	7.8	5.8	4	14	27
Stewart	0-6	19	208	6.4	7.6	8.0	5.0	4	13	28
New Richland	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	0-6	12	176	6.1	7.2	8.0	3.3	4	7	36
	6-12	4	138	6.0	7.3	7.9	2.8	2	4	6
Janesville	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

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

Daily precipitation and average air and soil temperatures are presented in the Appendix (Figures A1-3 and B1-3). Early growing season conditions in 2012 were warm and relatively wet; whereas, very cool and wet conditions occurred in 2013 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. Research has shown early growth differences are still possible even in warm springs. All locations had a period late in 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 all 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 6 were discarded at Gaylord, 7 at Stewart, 2 at New Richland, 4 at Willmar and 5 at Janesville. 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.

Plant populations were not affected by broadcast P or starter fertilizer rate at any of the locations (Table 2). Final populations were greater than expected (36,200 plants/ac) at Stewart while as expected at Gaylord (33,700 plants/ac). Strangely, the Stewart and Gaylord locations were planted on the same day with the same planter and hybrid. The desired seeding rate at Gaylord, Stewart and Willmar was 35,500 seeds/ac to achieve a final stand of 32-34,000 plants/ac. At New Richland and Janesville, 35,500 seeds/ac were dropped to obtain a final population of 34-35,000 plants/ac.

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

	Broadcast	10-34-0 Starter Rate (gallons per acre)				
Location	P Rate	0	2.5	5.0	7.5	Average†
	-lb P_2O_5/ac-	----------------------------plants per acre-----------------------------				
Gaylord	0	33150	33850	33290	34430	33680
	120	33900	33250	32370	35130	33660
	Average†	33520	33550	32830	34780	
Stewart	0	36640	36900	36100	35650	36320
	120	36750	36265	35480	36140	36160
	Average†	36700	36580	35790	35890	
New Rich.	0	35730	35650	36150	35650	35790
	120	36190	35660	35490	35790	35780
	Average†	35960	35650	35820	35720	
Willmar	0	34380	35200	34910	35060	34890
	120	34140	34580	35580	34860	34790
	Average†	34260	34890	35240	34960	
Janesville	0	35190	35510	36300	35330	35580
	120	36240	35870	35390	34830	35580
	Average†	35720	35690	35840	35080	

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

Treatment effects on the total dry weight (mass) of small corn plants at the V5 stage are presented in Table 3. The mass of small corn plants was increased with starter P application at all of the 2013 locations (New Richland, Willmar and Janesville), when averaged across broadcast P rates. Generally, at these responsive locations the greatest mass occurred with 5 and 7.5 gal/ac rates, the 0 gal/ac control had the least mass and the 2.5 gal/ac treatment was intermediate. Starter rate did not affect V5 mass (early growth of corn) at Gaylord and Stewart (2012 locations). Broadcast P application increased V5 plant mass at Willmar and Janesville. Considerable variability in V5 plant mass was observed at Gaylord. A few plots at this location were affected by flooding or by water running across the plots early in the growing season. Plots receiving 120 lbs of broadcast P had numerically lower average mass due to lower values for the 7.5 gal/ac starter rate in the 120 lb broadcast strip.

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

	Broadcast	10-34-0 Starter Rate (gallons per acre)				
Location	P Rate	0	2.5	5.0	7.5	Average†
	-lb P_2O_5/ac-	----------------------------grams per plant-----------------------------				
Gaylord	0	7.96	8.54	7.54	7.89	7.98
	120	8.30	7.99	8.00	6.97	7.81
	Average†	8.13	8.26	7.77	7.43	
Stewart	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	5.70	6.01	
New Rich.	0	5.94	7.50	8.58	7.72	7.43
	120	6.63	7.60	8.08	8.58	7.72
	Average†	6.28c	7.55b	8.32a	8.15ab	
Willmar	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	0	5.39	6.37	7.29	7.70	6.69b
	120	7.22	7.90	8.29	8.19	7.90a
	Average†	6.31c	7.13b	7.79a	7.94a	

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

Whole plant P concentration was increased significantly with broadcast P fertilizer application at 2 of 5 locations (New Richland and Willmar); moreover, P concentrations were numerically greater with broadcast P at the Stewart and Janesville locations (Table 4). The greatest increase in plant P concentration occurred at New Richland, a high yielding location with the 2nd lowest average Olsen P soil test. These differences in plant P concentration also contributed to increased P uptake with broadcast P application at New Richland, Willmar and Janesville (Table 5). Starter fertilizer application increased plant P concentration only at Stewart, but it did not result in increased P uptake. The lack of consistent differences due to starter fertilizer in 2012 was somewhat surprising. The broadcast rate of 120 lb P_2O_5/ac is much greater than the needs of the corn early in the growing season. Therefore at these two locations in 2012, broadcast P was enough to ensure ample early plant growth and uptake of P at the V5 growth stage. Starter application did significantly increase P uptake at all three 2013 locations (New Richland, Willmar and Janesville). These data showed in the cool and wet spring of 2013, in-furrow placed starter fertilizer enhanced early growth of corn and increased P uptake.

Table 4. Corn plant (V5) phosphorus concentration as affected by broadcast and starter fertilizer P rates.						
	Broadcast	10-34-0 Starter Rate (gallons per acre)				
Location	P Rate	0	2.5	5.0	7.5	Average†
	-lb P_2O_5/ac-	----------------------------%----------------------------				
Gaylord	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	0	0.51	0.49	0.48	0.50	0.50
	120	0.50	0.51	0.50	0.54	0.51
	Average†	0.51ab	0.50b	0.49b	0.52a	
New Rich.	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	0	0.38	0.39	0.37	0.40	0.39b
	120	0.40	0.40	0.41	0.42	0.41a
	Average†	0.39	0.40	0.39	0.41	
Janesville	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	
†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.						
	Broadcast	10-34-0 Starter Rate (gallons per acre)				
Location	P Rate	0	2.5	5.0	7.5	Average†
	-lb P_2O_5/ac-	----------------------------milligrams/plant----------------------------				
Gaylord	0	35.8	39.8	36.3	37.6	37.4
	120	38.0	36.7	38.3	32.7	36.4
	Average†	36.9	38.3	37.3	35.2	
Stewart	0	29.0	29.7	25.2	30.8	28.7
	120	30.1	29.4	30.9	31.6	30.5
	Average†	29.5	29.5	28.0	31.2	
New Rich.	0	24.6	31.7	35.9	31.4	30.9b
	120	32.0	34.9	38.4	38.9	36.0a
	Average†	28.3c	33.3b	37.1a	35.2ab	
Willmar	0	17.4	20.1	19.9	20.3	19.4b
	120	20.0	21.0	22.8	23.1	21.7a
	Average†	18.7b	20.6ab	21.3a	21.7a	
Janesville	0	25.5	28.8	30.5	34.4	29.8b
	120	33.7	35.8	38.0	39.1	36.7a
	Average†	29.6c	32.3bc	34.2ab	36.8a	
†Within each row or column, small letters following numbers indicate treatment significance at $P<0.05$. Numbers followed by different letters are significantly different.						

Treatment effects on corn grain yield at each location are summarized in Table 6. Broadcast P application increased corn yields 7, 9, and 25 bu/ac at Stewart, New Richland and Willmar, respectively. At New Richland, the 5 gal/ac rate of 10-34-0 increased corn yields 10 bu/ac compared with the control (0 gal/ac), when averaged across the main effect of broadcast P rate. Yields with the 2.5 and 7.5 gal/ac rates were intermediate at New Richland. Grain yields were not affected by the main effect of starter application at the other four locations. However, a significant broadcast P × starter interaction at Gaylord showed starter fertilizer increased yields when no broadcast P was applied. Grain yields trended higher with starter fertilizer at Stewart but the differences were not significant at the α=0.05 level of significance. The observed yield differences, response to broadcast P and no response to starter, at Willmar were concerning; therefore, Willmar data were excluded from the across location analyses.

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

	Broadcast	10-34-0 Starter Rate (gallons per acre)				
Location	P Rate	0	2.5	5.0	7.5	Average†
	-lb P_2O_5/ac-	----------------------------bushels per acre------------------------------				
Gaylord	0	180*	187*	189*	190*	187
	120	191	188	190	189	189
	Average†	186	188	190	189	
Stewart	0	222	229	226	227	226b
	120	231	233	235	234	233a
	Average†	227	231	230	230	
New Rich.	0	206	216	220	217	215b
	120	222	222	227	222	224a
	Average†	214b	219ab	224a	220ab	
Willmar	0	139	147	144	150	145b
	120	173	172	169	167	170a
	Average†	156	160	156	158	
Janesville	0	190	191	193	198	193
	120	198	192	194	194	195
	Average†	194	191	194	196	

†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.

Treatment effects on relative corn grain yield across locations (Willmar excluded) are presented in Table 7. For this analysis the plot areas were divided into zones based on soil test classifications or levels. Initially we included all 5 levels (Very Low, Low, Medium, High and Very High) used in the University of Minnesota fertilizer recommendations bulletin. After preliminary analysis we reduced the number of levels to 3 (Low, Medium and High). Because there were very few Very Low areas in these fields, the Very Low areas were pooled into the Low level group. Likewise, to better balance the amount of data in each level the Very High level was pooled in with the High level group.

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	98.0 a	97.9 a
Medium	98.8 a	97.9 a
High/Very High	99.4 a	99.5 a
P > ***F***:	0.300	*0.074*
Broadcast Rate		
0 lb P_2O_5/ac	97.5 b	97.1 b
120 lb	99.9 a	99.8 a
P > ***F***:	**<0.001**	**<0.001**
Starter (10-34-0) Rate		
0 gal/ac	97.4 b	97.1 b
2.5 gal	98.6 ab	98.4 ab
5.0 gal	99.7 a	99.3 a
7.5 gal	99.3 a	99.0 a
P > ***F***:	**0.009**	**0.041**
Interactions, (*P* > *F*)		
Level*Broadcast Rate	0.489	0.295
Level*Starter Rate	0.810	0.900
Broadcast Rate*Starter Rate	**0.013**	0.110
Level*Broadcast*Starter	0.581	0.735

Relative yields were not significantly affected by Olsen or Bray soil test P level and there were no significant interactions with soil test P level (Table 7). These data showed the response to broadcast and starter P fertilization was fairly consistent across soil test P levels (soil test P variability in the field) and locations. This finding is contrary to our initial hypothesis that Low P (calcareous) areas of the field would require a greater starter rate. This may change as we add more data in future years. Relative yields increased about 2.5 percentage points with broadcast P application, when averaged across the main effects of soil test P levels and starter application. Relative yields were greater with 5 and 7.5 gal/ac rates of starter fertilizer than with a 0 gal/ac rate, when averaged across the main effects of broadcast P application and soil test P levels. Remarkably the results described above were quite similar between the Olsen and Bray P soil tests. One would expect 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 rate*starter rate interaction for Olsen P showed starter increased yields only when no broadcast P was applied (Figure F). This finding is logical considering the high rate of broadcast P (120 lb P_2O_5 per ac) used in this study. However, the by soil test P level analysis showed within the Low level, relative yields trended higher as starter rates increased even when 120-lb P_2O_5 was broadcast-applied (data not shown).

Grain moisture at harvest was considerably drier in 2012 than in 2013, primarily due to a cool wet spring that delayed planting in 2013 (Table 8). No significant differences in grain moisture were observed in 2012. In 2013, grain moisture was reduced slightly with both broadcast and starter P application at Janesville. However, a significant broadcast rate*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. 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.

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

	Broadcast	10-34-0 Starter Rate (gallons per acre)				
Location	P Rate	0	2.5	5.0	7.5	Average†
	-lb P_2O_5/ac-	-------------------%			-------------------	
Gaylord	0	16.8	16.5	17.0	17.1	16.9
	120	17.0	16.1	16.5	16.9	16.6
	Average†	16.9	16.3	16.8	17.0	
Stewart	0	14.7	14.4	14.5	14.6	14.6
	120	14.2	14.7	14.5	14.5	14.5
	Average†	14.5	14.5	14.5	14.6	
New Rich.	0	26.9	26.5	26.1	25.9	26.4
	120	26.6	26.1	25.7	25.9	26.1
	Average†	26.8a	26.3ab	25.9b	25.9b	
Willmar	0	22.4	23.3	22.2	23.0	22.7
	120	24.0	24.8	24.2	24.5	24.4
	Average†	23.2	24.0	23.2	23.7	
Janesville	0	25.5*	24.6*	24.6*	24.3*	24.7a
	120	24.3	24.3	24.0	24.1	24.2b
	Average†	24.9a	24.4b	24.3b	24.2b	

†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.

Treatment effects on Grain P concentration from the 2012 locations are presented in Table 9. No differences in grain P concentration were observed in the 2012 data. Grain P data from 2013 locations were not reported by the lab at the time of this report.

<u>Forthcoming Work and Summary</u>

This research study is scheduled to continue through the 2015 growing season. Two or three locations are planned for 2014 with an additional one or two in 2015. At the time of writing this report, some data had not yet returned from the lab while other data have not been completely analyzed. Therefore, no definitive conclusions can be drawn from these incomplete data. Some key observations from the first two years of the study include: 1) plant populations were not affected by fertilizer P treatments (broadcast or starter); 2) both broadcast and starter fertilizer enhanced early growth of corn in 2013 a cool and wet spring, but had little effect in 2012 a warm spring; and 3) corn grain yields were increased by broadcast P application at 3 of 5 locations, while starter application increased yields at only 2 of 5 locations (significant interaction between broadcast P and starter at Gaylord).

Table 9. Corn grain phosphorus concentration as affected by broadcast and starter fertilizer P rates.

	Broadcast	10-34-0 Starter Rate (gallons per acre)				
Location	P Rate	0	2.5	5.0	7.5	Average†
	-lb P_2O_5/ac-	------%------				
Gaylord	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	0	0.32	0.32	0.30	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.	0	--	--	--	--	--
	120	--	--	--	--	--
	Average†	--	--	--	--	--
Willmar	0	--	--	--	--	--
	120	--	--	--	--	--
	Average†	--	--	--	--	--
Janesville	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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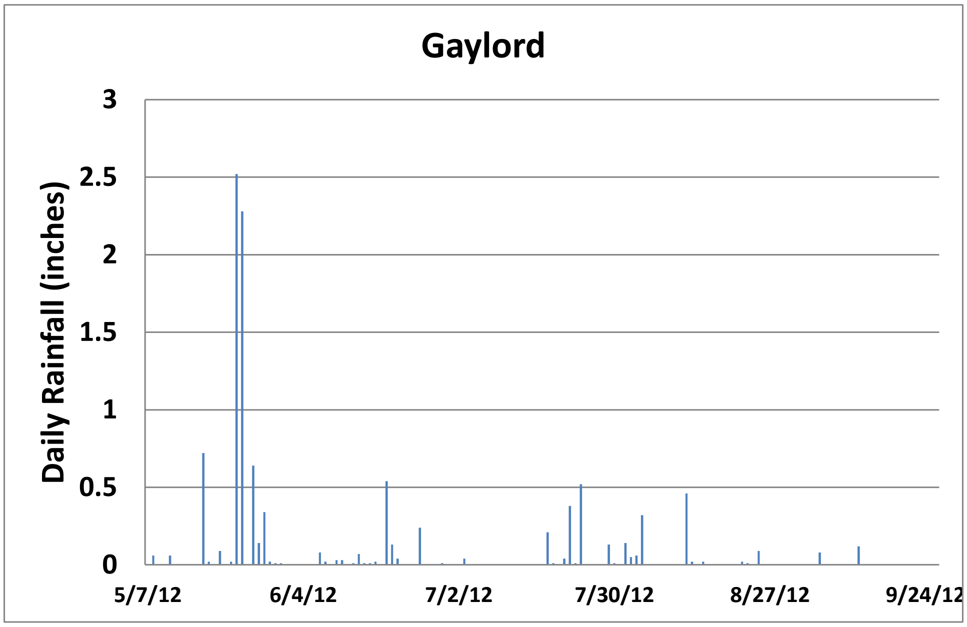
Appendix: Tables and Figures



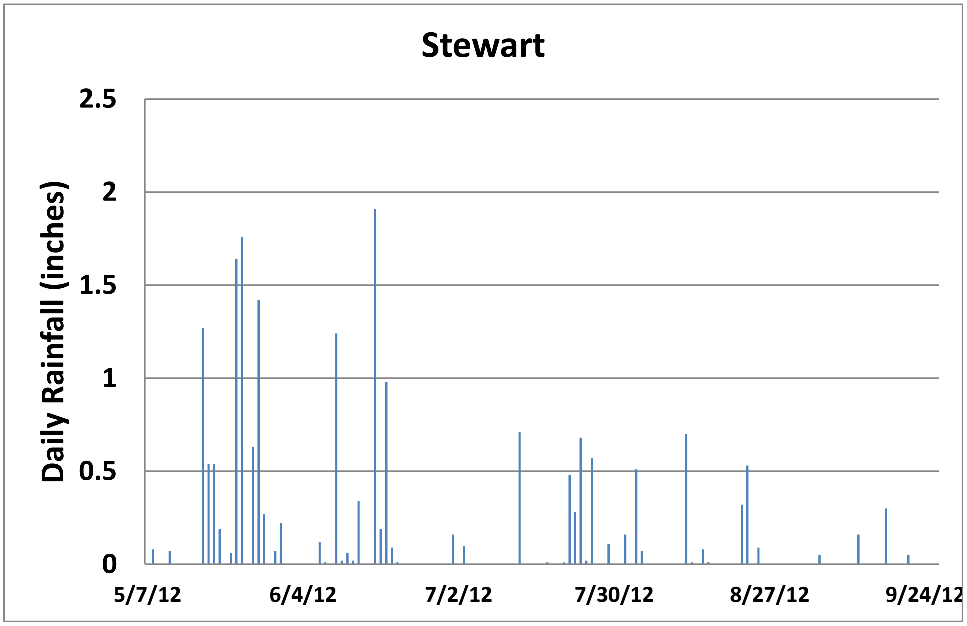
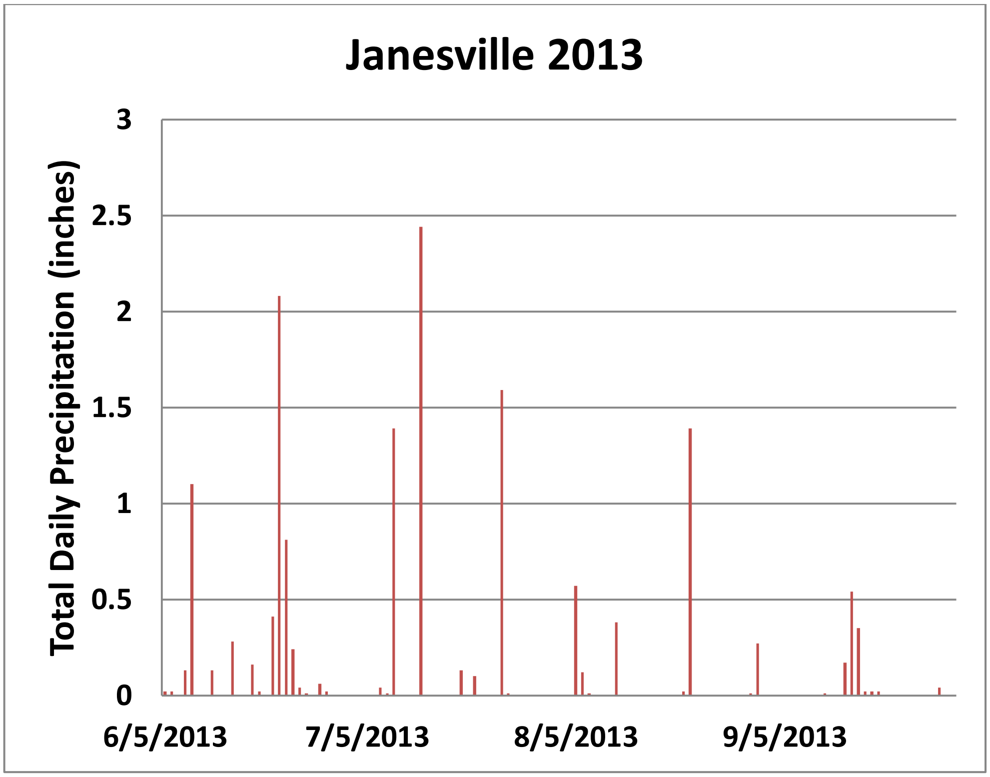


Figure A1. Summary of daily total precipitation data from Gaylord and Stewart beginning May 7 and ending at harvest in 2012. Total precipitation was 10.91 inches at Gaylord and 19.92 inches at Stewart. Data does not include all precipitation following fertilizer application.



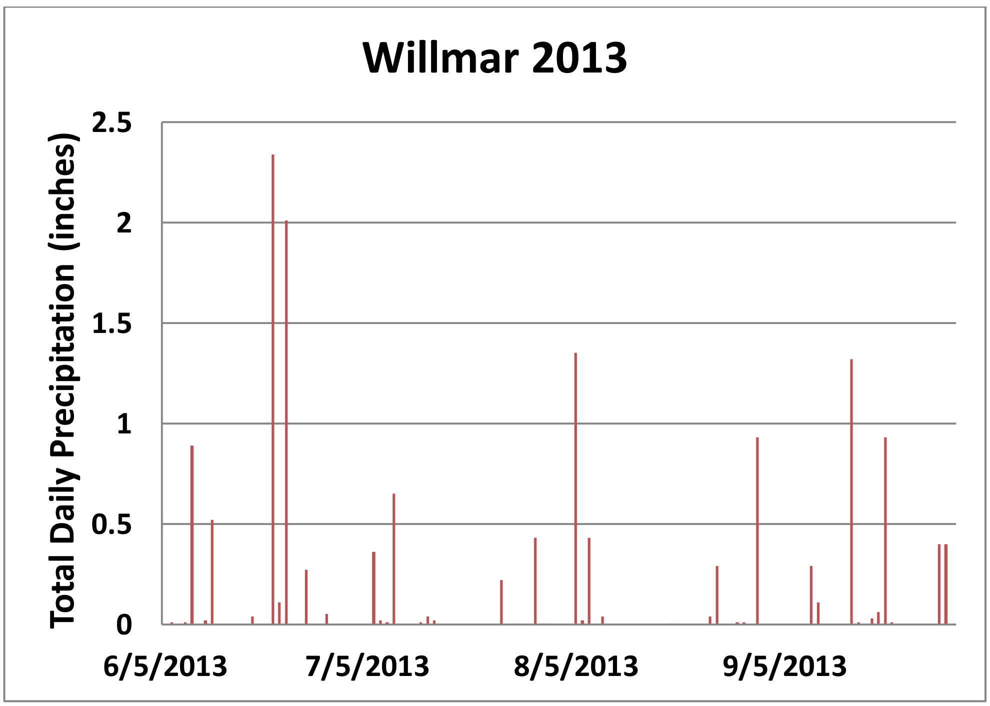


Figure A2. Summary of daily total precipitation data from Janesville and Willmar beginning June 6 and ending at harvest in 2013. Total precipitation was 17.60 inches at Janesville and 18.81 inches at Willmar. Data does not include all precipitation following fertilizer application.

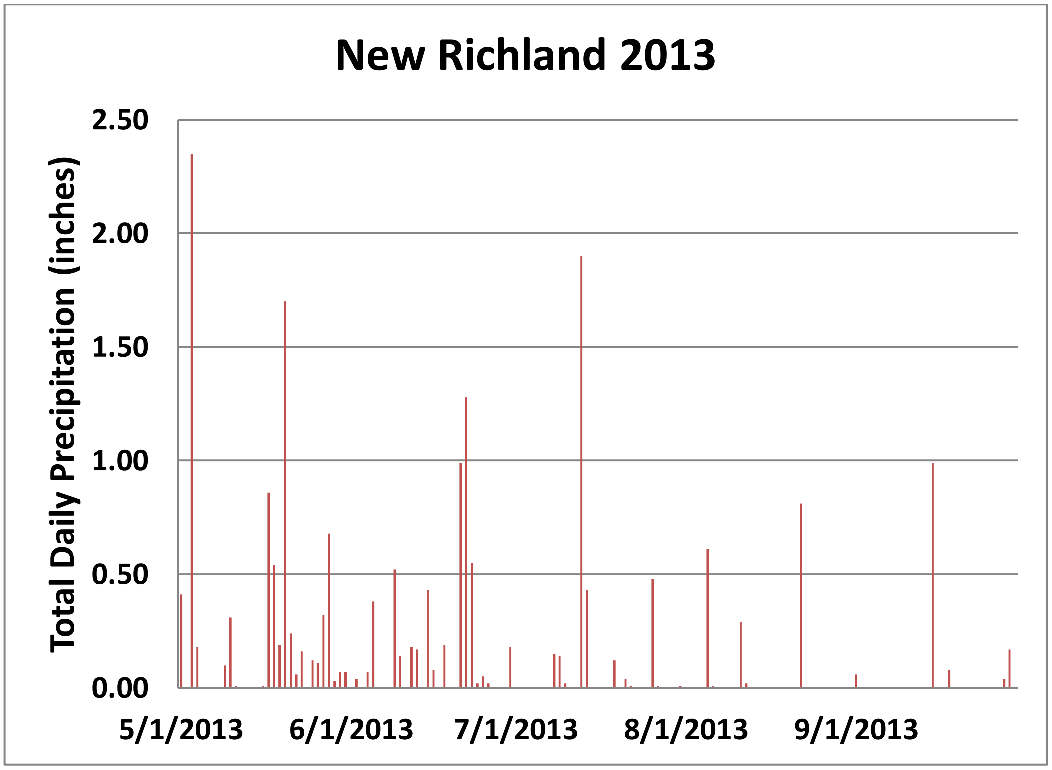
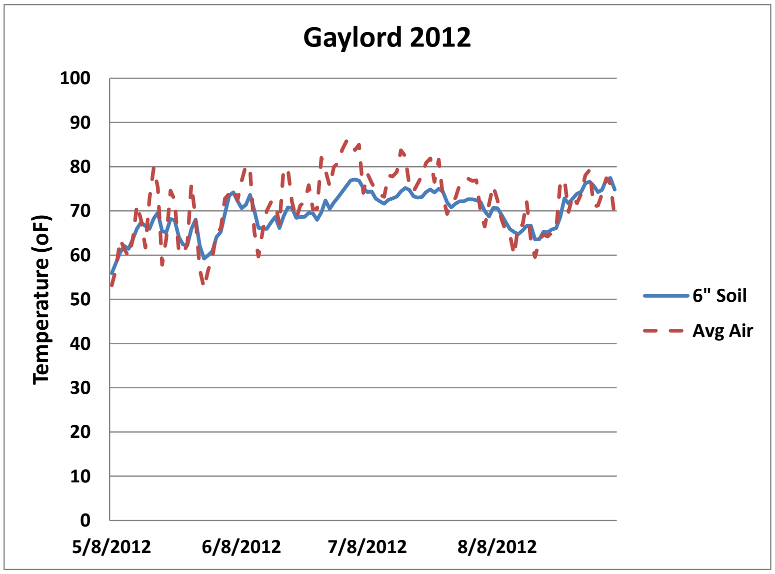


Figure A3. Summary of daily precipitation data from New Richland for the period from May 1 to September 30, 2013. Total precipitation was 20.20 inches.



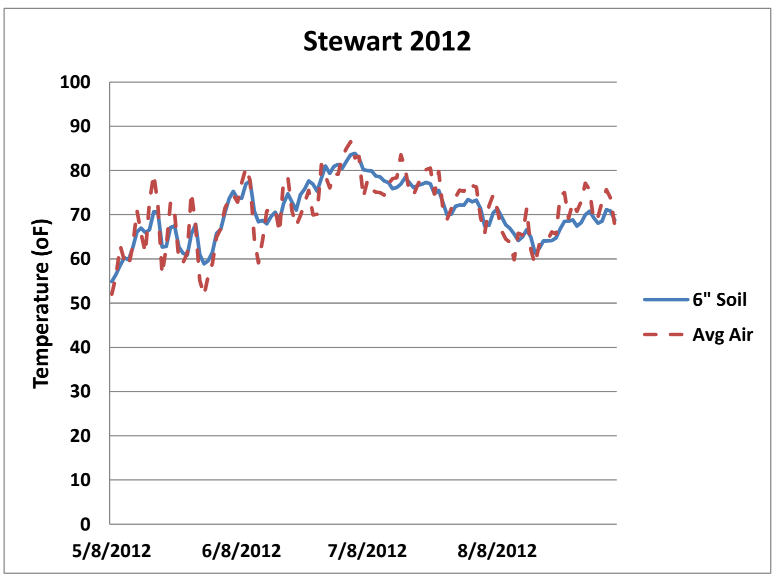
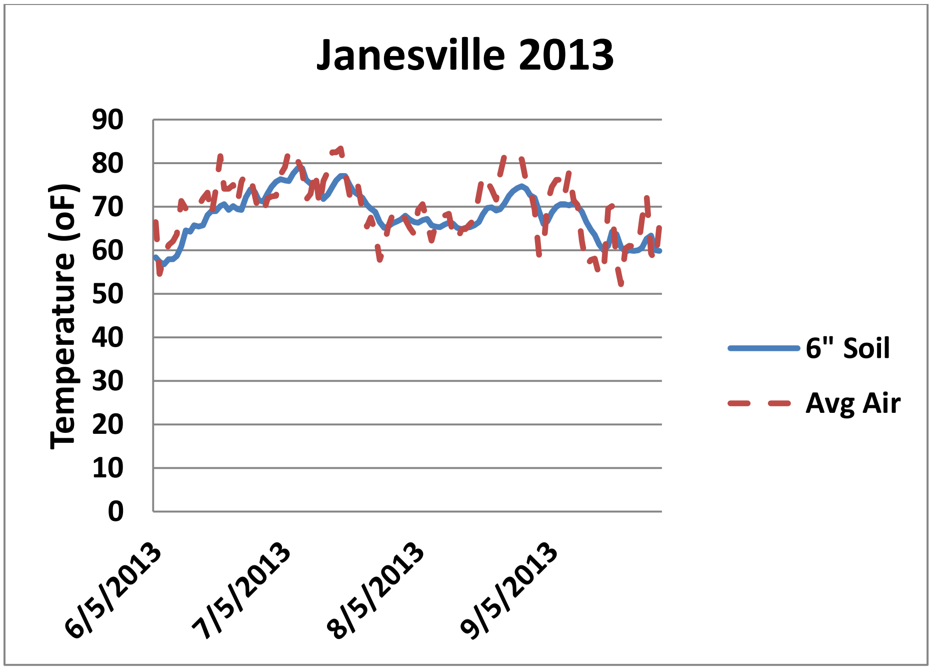


Figure B1. Summary of daily average 6” soil and air temperature from two field locations studied in 2012.



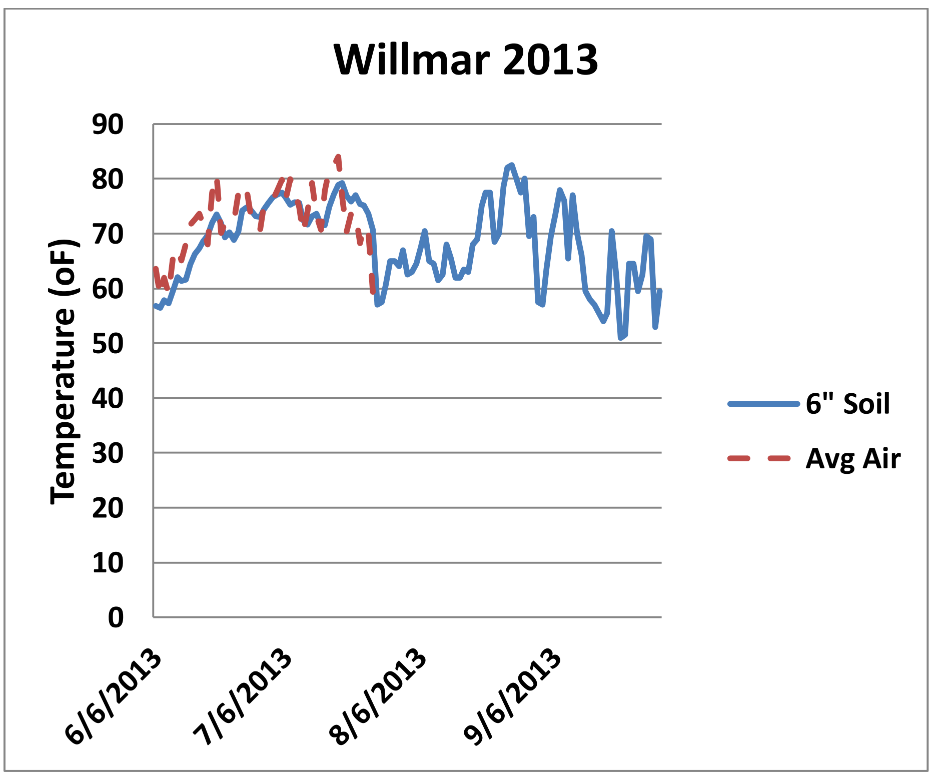


Figure B2. Summary of daily average 6” soil and air temperature at Janesville and Willmar in 2013.

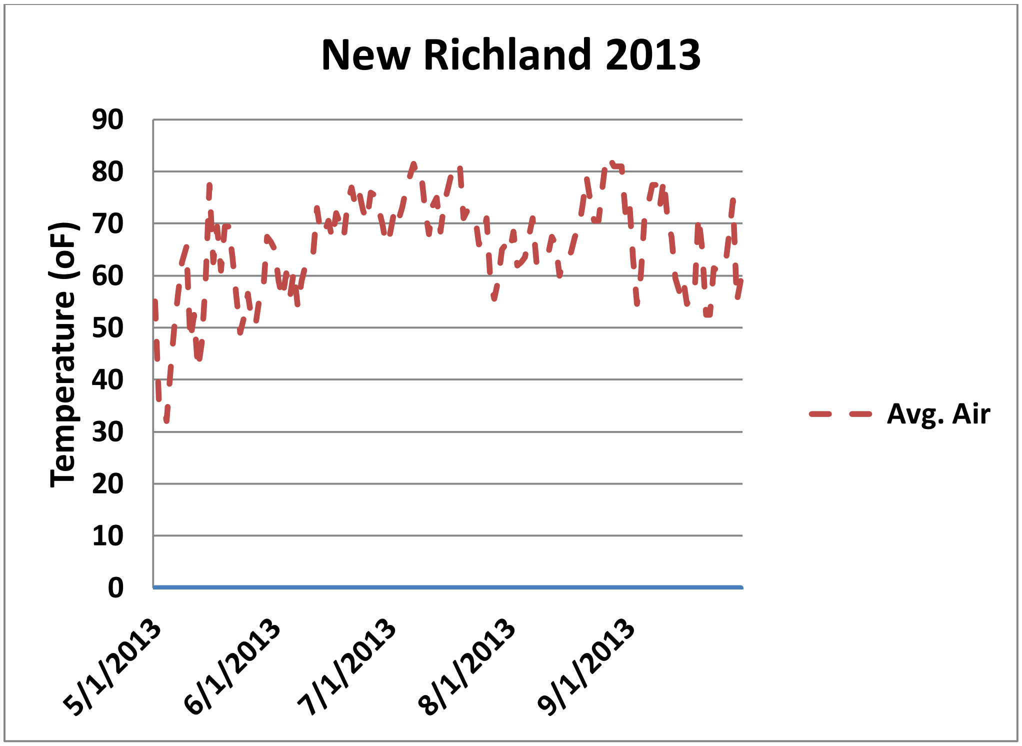


Figure B3. Summary of growing season (May – September) daily average air temperature at New Richland in 2013.

VR Starter Willmar 2013

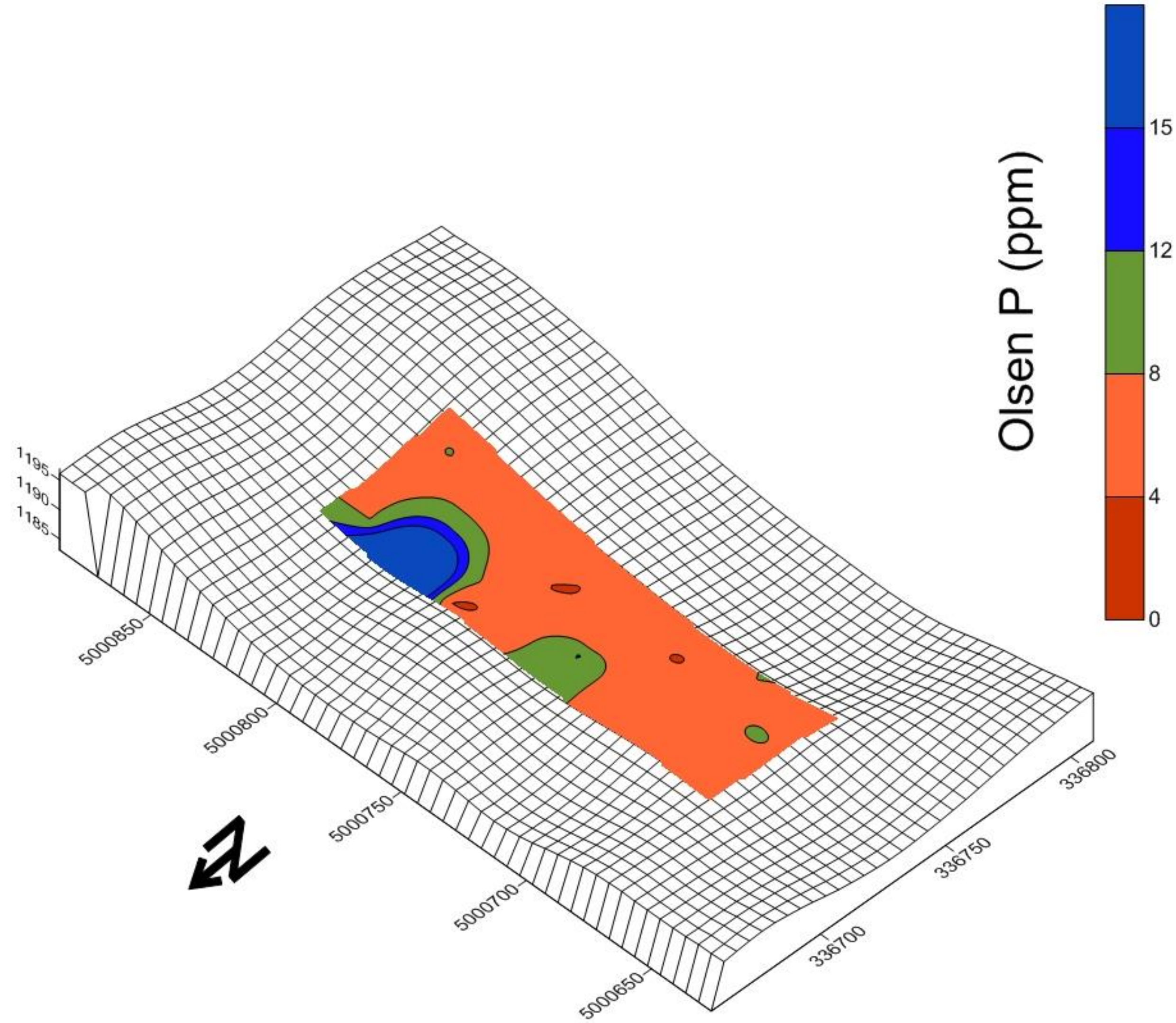


Figure C. Inherent variability in soil test phosphorus (Olsen P) at Willmar in 2013.

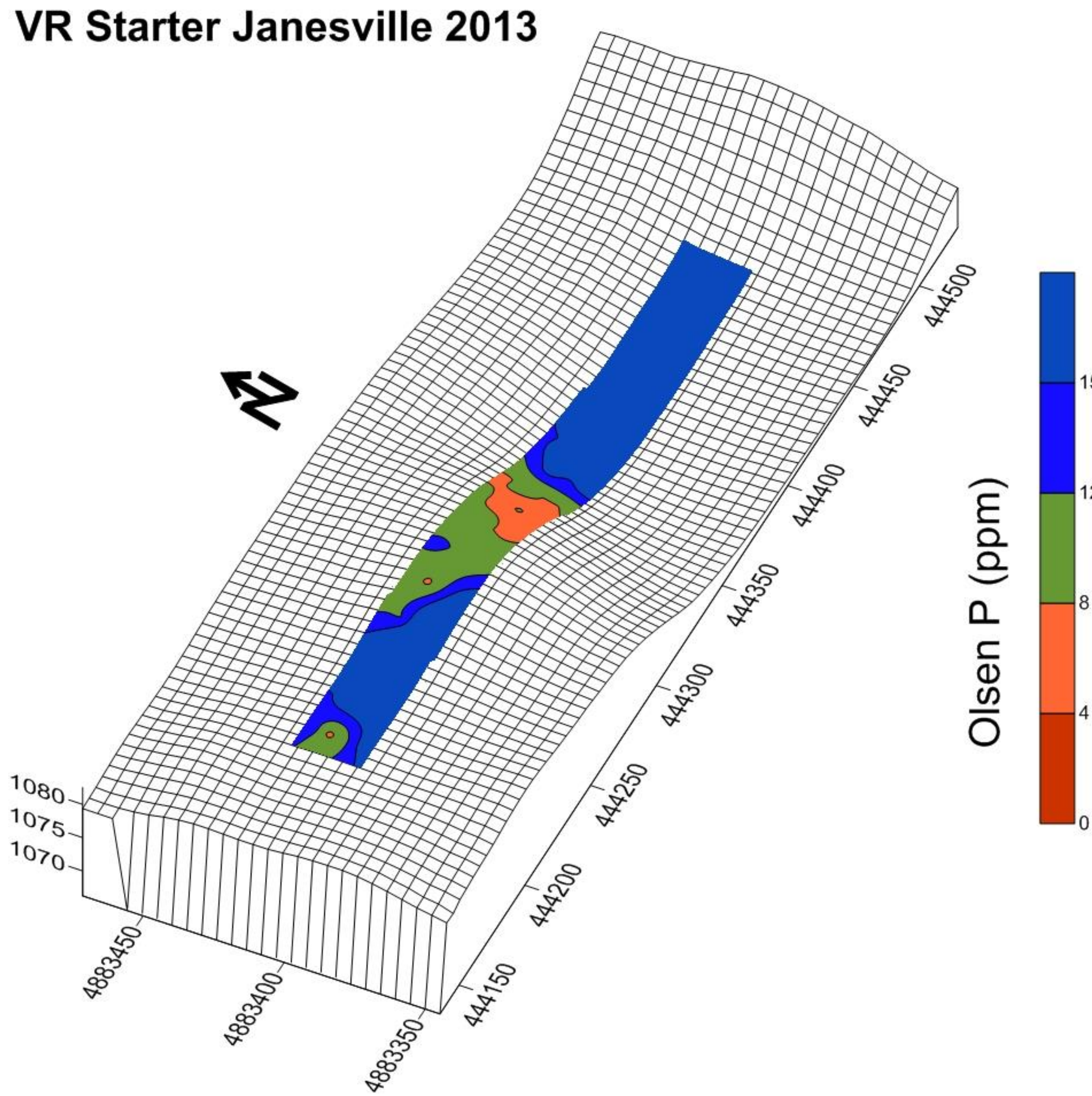


Figure D. Inherent variability in soil test phosphorus (Olsen P) at Janesville in 2013.

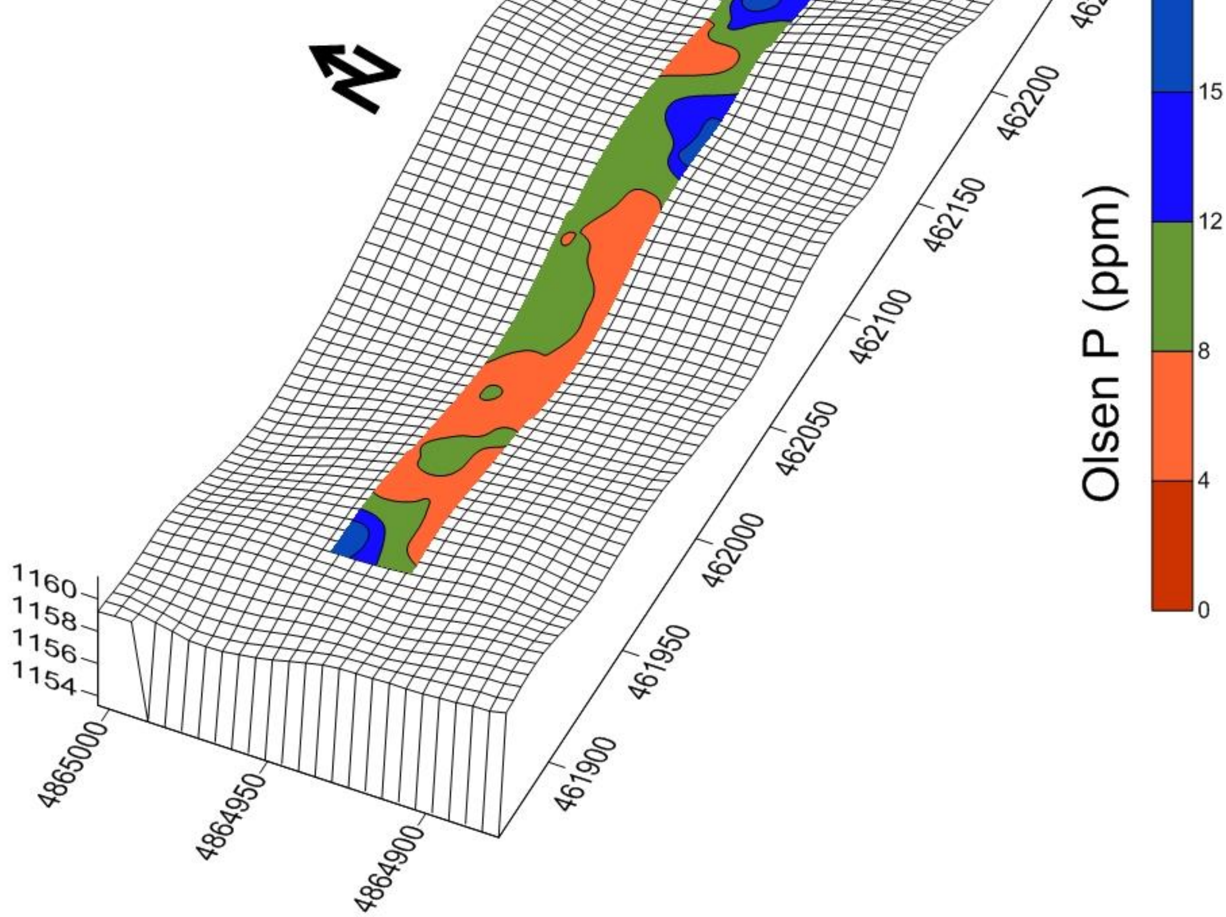


Figure E. Inherent variability in soil test phosphorus (Olsen P) at New Richland in 2013.

Table 10. Summary of statistical significance of treatment main effects by location.				
Parameter	Location	Broadcast P	Starter P	Broadcast*Starter
		--------------------P > F--------------------		
Plant Population	Gaylord	0.981	0.184	0.688
	Stewart	0.824	0.481	0.735
	New Richland	0.950	0.480	0.056
	Willmar	0.781	0.562	0.374
	Janesville	0.998	0.423	0.217
V5 Plant Wt.	Gaylord	0.474	0.160	0.101
	Stewart	0.356	0.781	0.161
	New Richland	0.460	**<0.001**	0.211
	Willmar	**0.045**	**0.015**	0.783
	Janesville	**0.004**	**<0.001**	0.079
V5 Plant P Conc.	Gaylord	0.371	0.314	0.531
	Stewart	0.071	**0.015**	0.138
	New Richland	**<0.001**	0.051	0.335
	Willmar	**0.028**	**0.450**	0.562
	Janesville	0.066	0.092	0.234
V5 Plant P Uptake	Gaylord	0.532	0.507	0.234
	Stewart	0.126	0.310	0.217
	New Richland	**0.007**	**<0.001**	0.214
	Willmar	**0.011**	**0.043**	0.783
	Janesville	**0.001**	**<0.001**	0.623
Corn Grain Yield	Gaylord	0.090	0.433	**0.050**
	Stewart	**0.050**	0.689	0.916
	New Richland	**0.004**	**0.029**	0.123
	Willmar	**<0.001**	0.922	0.608
	Janesville	0.427	0.386	0.118
Grain Moisture	Gaylord	0.329	0.051	0.508
	Stewart	0.622	0.966	0.259
	New Richland	0.197	**0.007**	0.869
	Willmar	0.053	0.490	0.969
	Janesville	**0.031**	**0.003**	**0.049**
Grain P Conc.	Gaylord	0.212	0.709	0.762
	Stewart	0.237	0.785	0.093
	New Richland	--	--	--
	Willmar	--	--	--
	Janesville	--	--	--
Grain P Removal	Gaylord	--	--	--
	Stewart	--	--	--
	New Richland	--	--	--
	Willmar	--	--	--
	Janesville	--	--	--

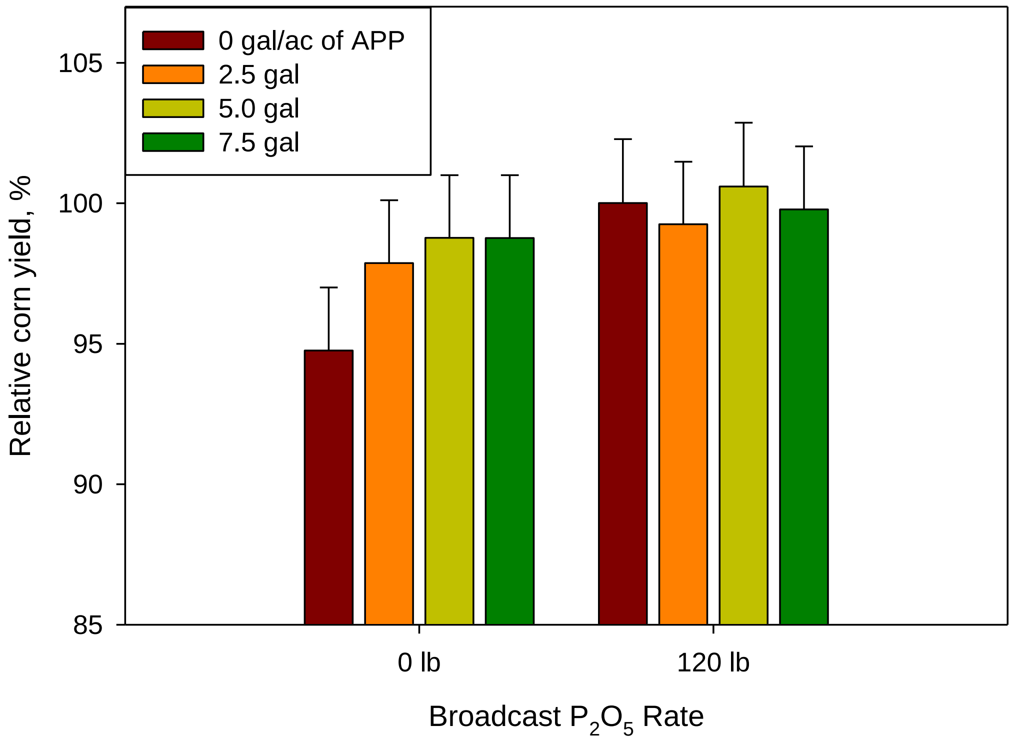


Figure F. Relative corn grain yield as affected by the interaction between broadcast and starter (APP, ammonium poly phosphate) rates of fertilizer P, when averaged across locations and three soil test P (Olsen P) levels (error bar denotes significance at α=0.05).