# 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; 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. 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 P1 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. 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. 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.

Extraordinary 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 and June 2 at Willmar and Janesville in 2013. 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. 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 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.

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

| | | | | | pH | | | | Olsen-P | |
|---|---|---|---|---|---|---|---|---|---|---|
| Location | Depth | Bray-P1 | K | Min | Avg. | Max | SOM | Min | Avg. | Max |
| | Inch | ------ppm------ | | | | | % | -----ppm ----- | | |
| 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 | 8.0 | 5.0 | 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 | 8.0 | 3.3 | 4 | 7 | 36 |
| | 6-12 | 4 | 138 | 6.0 | 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 | 7.0 | 8.0 | 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 | 4.0 | 2 | 4 | 6 |

†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 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.

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/ac) 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 34,500 seeds/ac were planted to achieve a final stand of 32-34,000 plants/ac; whereas, at New Richland-13, Janesville and Waseca 35,500 seeds/ac were planted to obtain a final population of 34-35,000 plants/ac. Final populations were greater than expected/desired (36,200 plants/ac) at Stewart but near desired at other locations. Waseca population data (file) was lost.

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/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 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-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.

Phosphorus 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 is 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 lb $P_2O_5$/ac) were much less than the broadcast rate (120 lb $P_2O_5$/ac). 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 both broadcast and in-furrow placed starter P fertilizer enhanced early growth of corn and increased P uptake, especially in cool and wet springs.

**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-12 | 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-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 | 5.70 | 6.01 | |
| New Rich.-13 | 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-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 | 7.70 | 6.69b |
| | 120 | 7.22 | 7.90 | 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 | 10.10 | 9.62a |
| | Average | 8.66b | 9.43a | 9.17b | 9.72a | |
| St. Charles-14 | 0 | 7.44 | 8.36 | 8.20 | 8.60 | 8.15b |
| | 120 | 8.53 | 8.73 | 8.84 | 9.00 | 8.78a |
| | Average | 7.99b | 8.55a | 8.52a | 8.80a | |
| Waseca-14 | 0 | 4.73 | 6.70 | 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.

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/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), when averaged across the main effect of broadcast P rate. Starter rate had minimal affect 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 × 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.

**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-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 | 0.50 | 0.50 |
| | 120 | 0.50 | 0.51 | 0.50 | 0.54 | 0.51 |
| | Average† | 0.51ab | 0.50b | 0.49b | 0.52a | |
| New Rich.-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 | 0.40 | 0.39b |
| | 120 | 0.40 | 0.40 | 0.41 | 0.42 | 0.41a |
| | Average† | 0.39 | 0.40 | 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 | 0.30 | 0.30 | 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 | 0.40 | 0.39 | 0.40 | 0.39b |
| | 120 | 0.42 | 0.42 | 0.44 | 0.44 | 0.43a |
| | Average | 0.40 | 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 | 0.30 | 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.

Relative yields as affected by treatment main effects and soil test levels across locations (Willmar excluded) are presented in Table 7 and Figures I, J and K. 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 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-12 | 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-12 | 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.-13 | 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-13 | 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-13 | 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 | |
| New Rich.-14 | 0 | 25.0 | 28.0 | 28.5 | 30.0 | 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 | 14.0 | 19.3 | 19.6 | 20.0 | 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.

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: 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 I) 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 J). This response to starter fertilizer occurred regardless of soil test P level (Figure K). 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 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-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.

Grain moisture at harvest varied among locations because of planting and harvesting date differences and 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 × 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.

**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 | 97.0 |
| Medium | 99.6 | 99.8 |
| High | 100.0 | 100.5 |
| Very High | 98.5 | 100.0 |
| *P* > ***F***: | 0.77 | 0.17 |
| **Broadcast Rate** | | |
| 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** | | |
| 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 |

Treatment effects on grain P concentration and removal are presented in Tables 9 and 10, respectively. Grain P 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.

**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-12 | 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-12 | 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.-13 | 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-13 | 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-13 | 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 | |
| New Rich.-14 | 0 | 16.9 | 16.6 | 16.6 | 16.9 | 16.8 |
| | 120 | 17.0 | 17.1 | 17.1 | 16.7 | 17.0 |
| | Average | 16.9 | 16.8 | 16.9 | 16.8 | |
| St. Charles-14 | 0 | 17.2 | 17.0 | 16.7 | 17.2 | 17.0 |
| | 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 | 22.0 | 21.4 | 22.2 |
| | 120 | 22.0 | 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.

## <u>Summary and Observations</u>

Research on the effects of starter (ammonium poly phosphate) fertilizer 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 the study include: 1) plant populations were rarely affected by fertilizer P treatments (broadcast or starter); 2) generally, broadcast and starter fertilizer enhanced early growth of corn (V5 whole plant mass) in 2013 and 2014, cool and wet springs, but had little effect in 2012 a warm spring; and 3) 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: 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.

**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-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 | 0.30 | 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.-13 | 0 | 0.21 | 0.20 | 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 | 0.20 | 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.

## Acknowledgements

The authors thank the Minnesota Corn Growers, Corn Research and Promotion Council and the Fluid Fertilizer Foundation for the funding this project and the FFF partnering labs for “in-kind” support. We also thank the field research crews at the Department of Soil, Water, and Climate and

Southern Research and Outreach Center for their assistance with the project. We also thank our farmer cooperators for their assistance and the use of land for this research project.

**Table 10. Phosphorus removal in corn grain 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- | -------------------------------lb $P_2O_5$/ac---------------------------- | | | | |
| Gaylord-12 | 0 | 54.5 | 55.6 | 56.8 | 56.5 | 55.8 |
| | 120 | 58.5 | 58.3 | 62.9 | 59.0 | 59.7 |
| | Average† | 56.5 | 57.0 | 59.8 | 57.8 | |
| Stewart-12 | 0 | 77.2 | 79.1 | 71.1 | 80.0 | 76.7b |
| | 120 | 82.4 | 79.1 | 88.4 | 82.1 | 83.0a |
| | Average† | 79.8 | 79.1 | 79.8 | 80.9 | |
| New Rich.-13 | 0 | 47.0 | 47.8 | 50.8 | 49.6 | 48.8b |
| | 120 | 57.4 | 62.3 | 59.8 | 59.1 | 59.7a |
| | Average† | 52.2 | 55.1 | 55.3 | 54.4 | |
| Willmar-13 | 0 | 30.2 | 35.3 | 31.6 | 32.2 | 32.3b |
| | 120 | 44.2 | 43.7 | 43.8 | 44.2 | 44.0a |
| | Average† | 37.2 | 39.5 | 37.7 | 38.2 | |
| Janesville-13 | 0 | 55.7 | 58.8 | 58.8 | 59.3 | 58.2 |
| | 120 | 57.6 | 58.2 | 59.7 | 59.6 | 58.8 |
| | Average† | 56.7 | 58.5 | 59.2 | 59.5 | |
| 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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## Appendix: Additional Tables and Figures

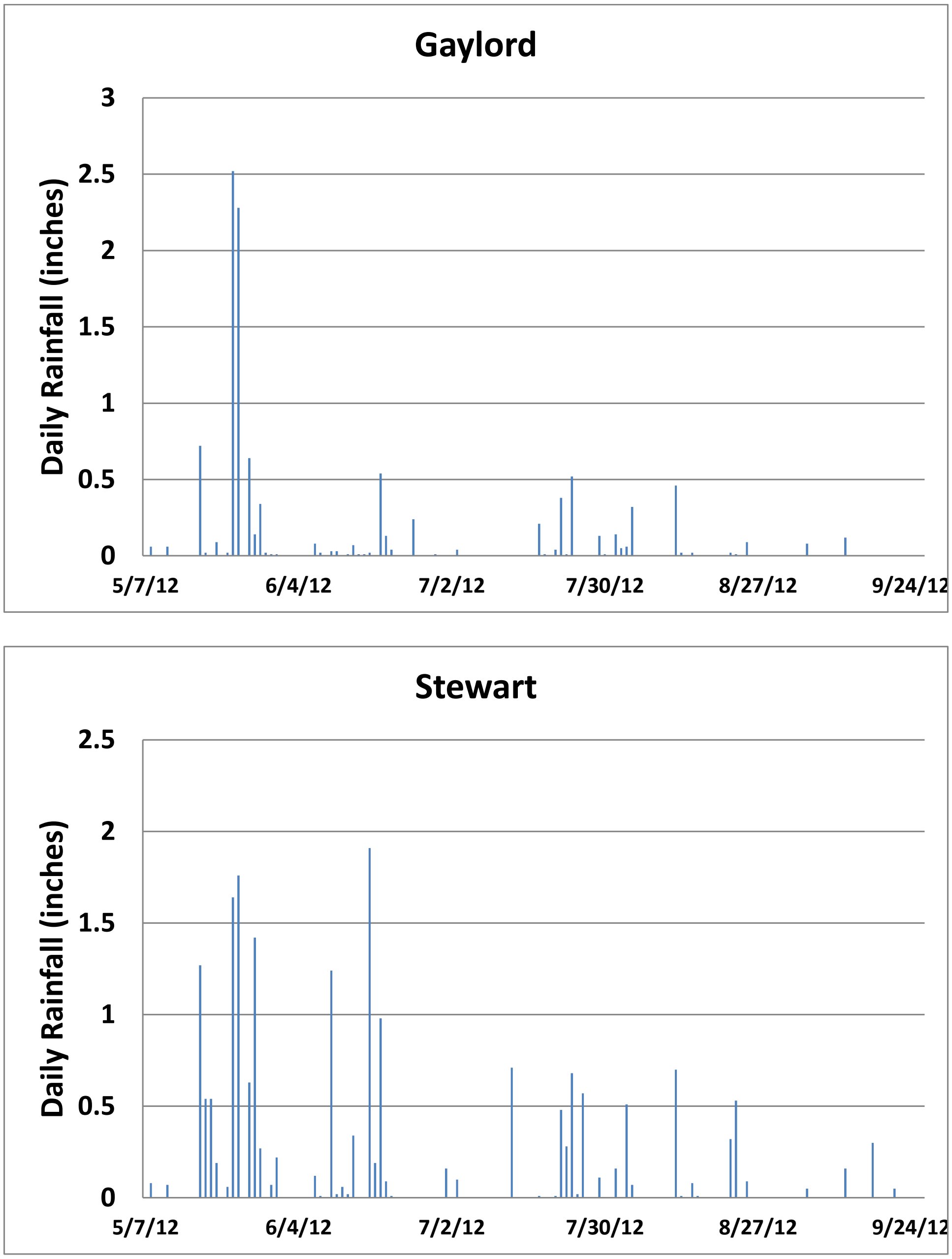
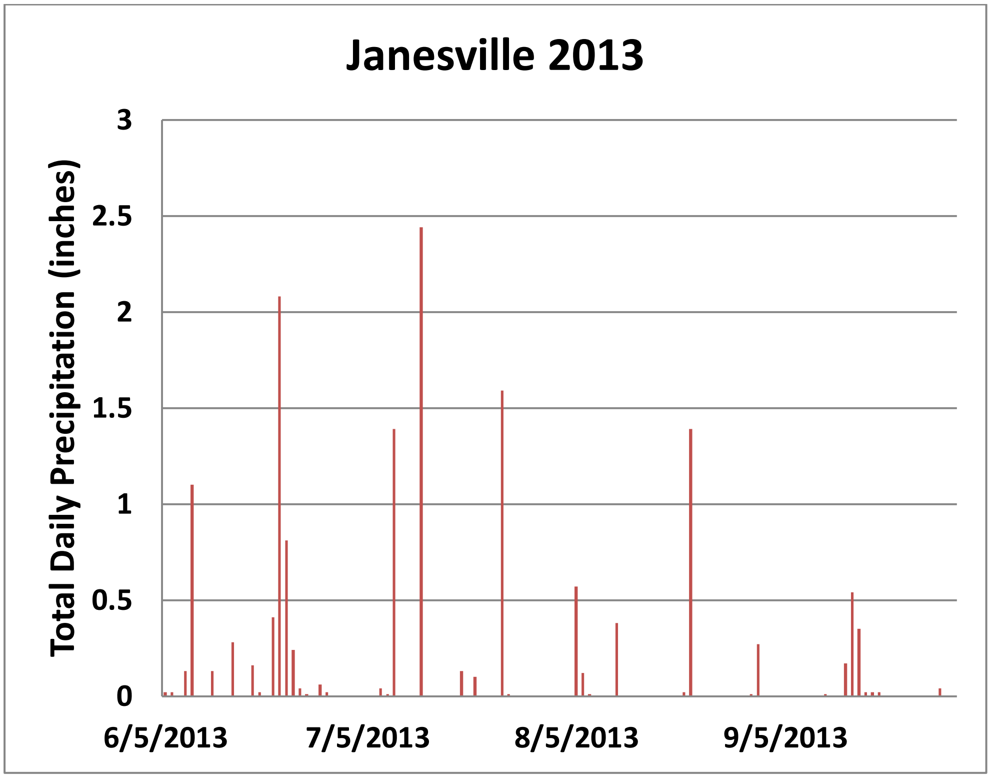



Figure A1. Summary of daily total precipitation data from Gaylord and Stewart beginning May 7 and ending at harvest in 2012. Total precipitation was 10.91 inches at Gaylord and 19.92 inches at Stewart. Data does not include all precipitation following fertilizer application.



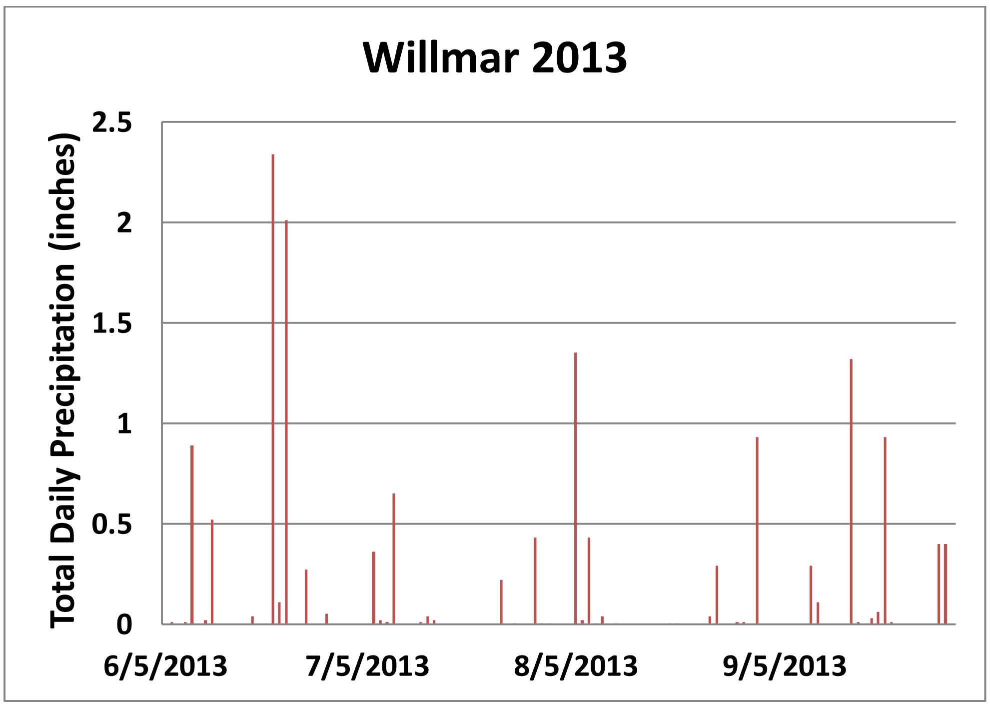




Figure A2. Summary of daily total precipitation data from Janesville and Willmar beginning June 6 and ending at harvest in 2013. Total precipitation was 17.60 inches at Janesville and 18.81 inches at Willmar. Data does not include all precipitation following fertilizer application.

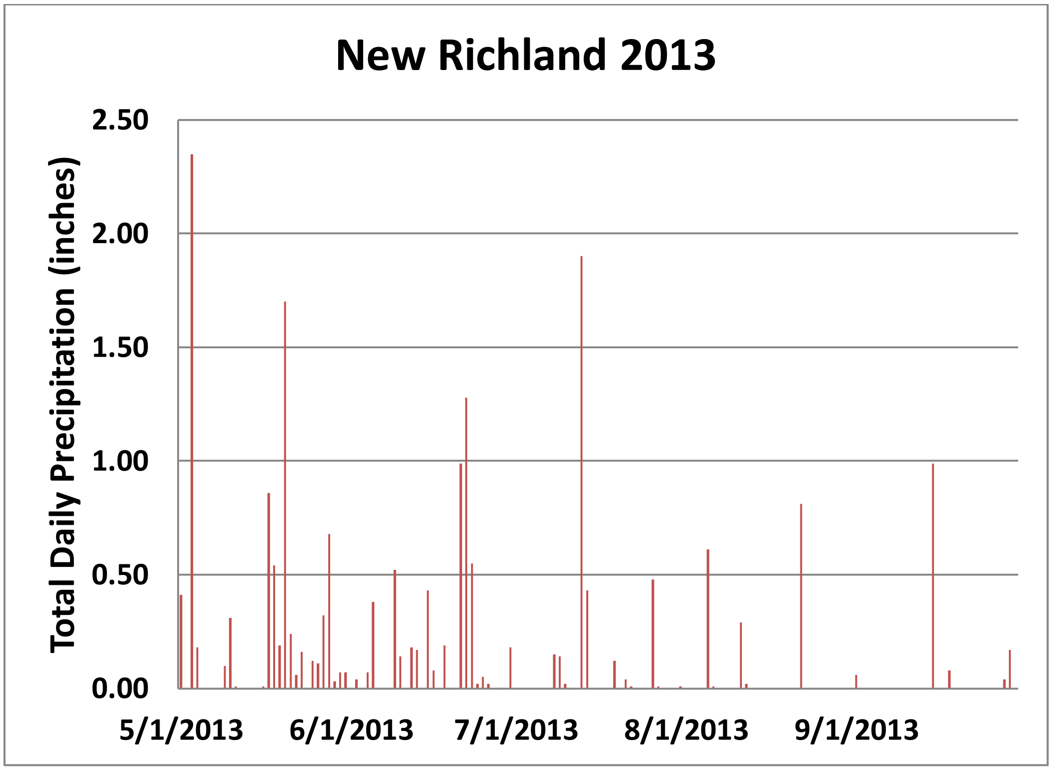
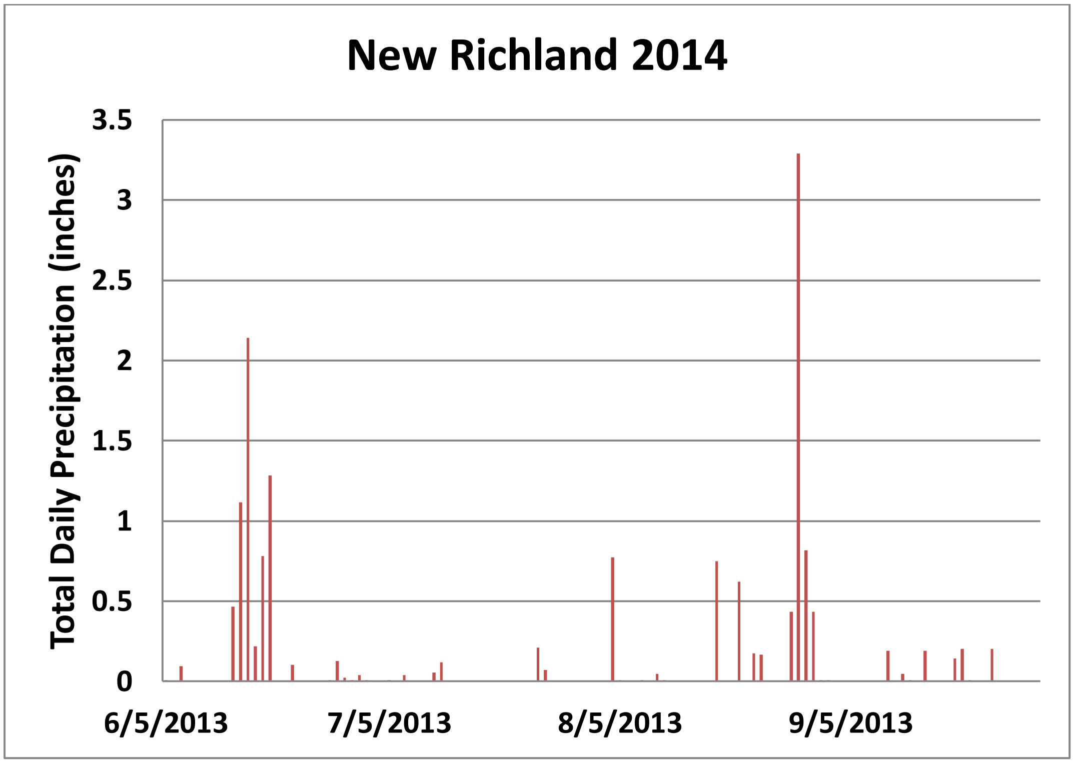



Figure A3. Summary of daily precipitation data from New Richland for the period from May 1 to September 30, 2013. Total precipitation was 20.20 inches.



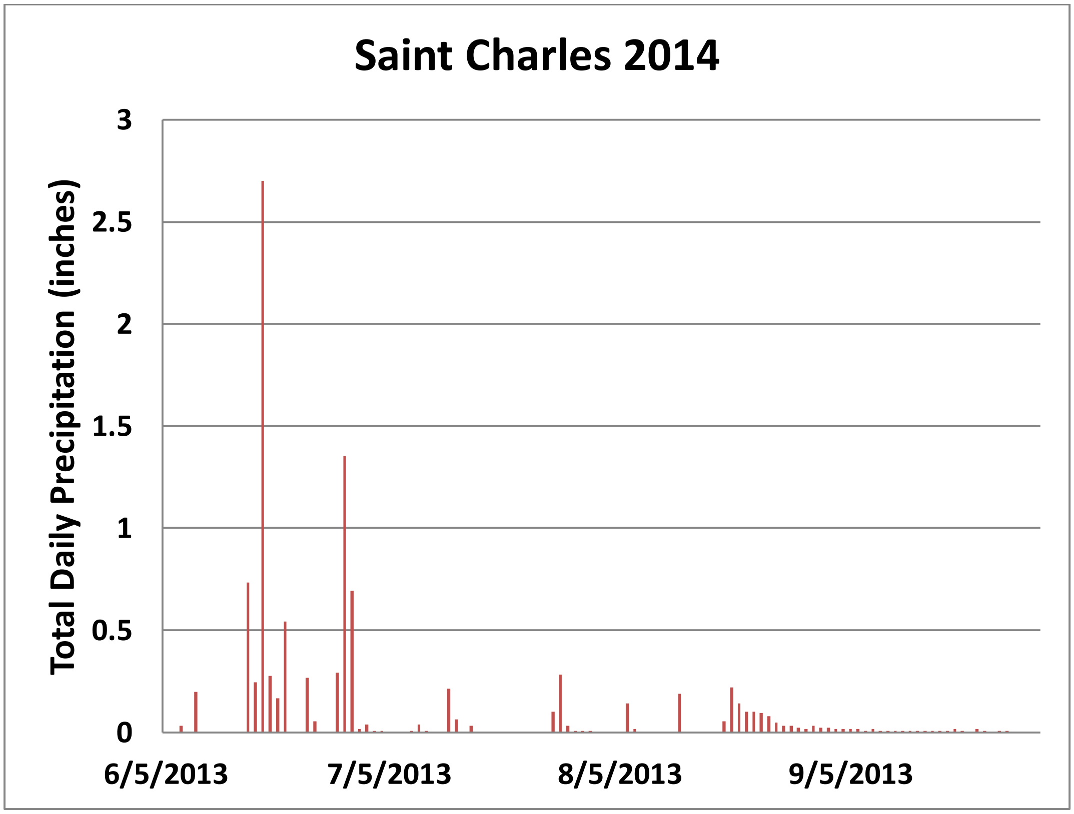




Figure A4. Summary of daily total precipitation data from New Richland and St. Charles beginning June 4 and ending at harvest in 2014.

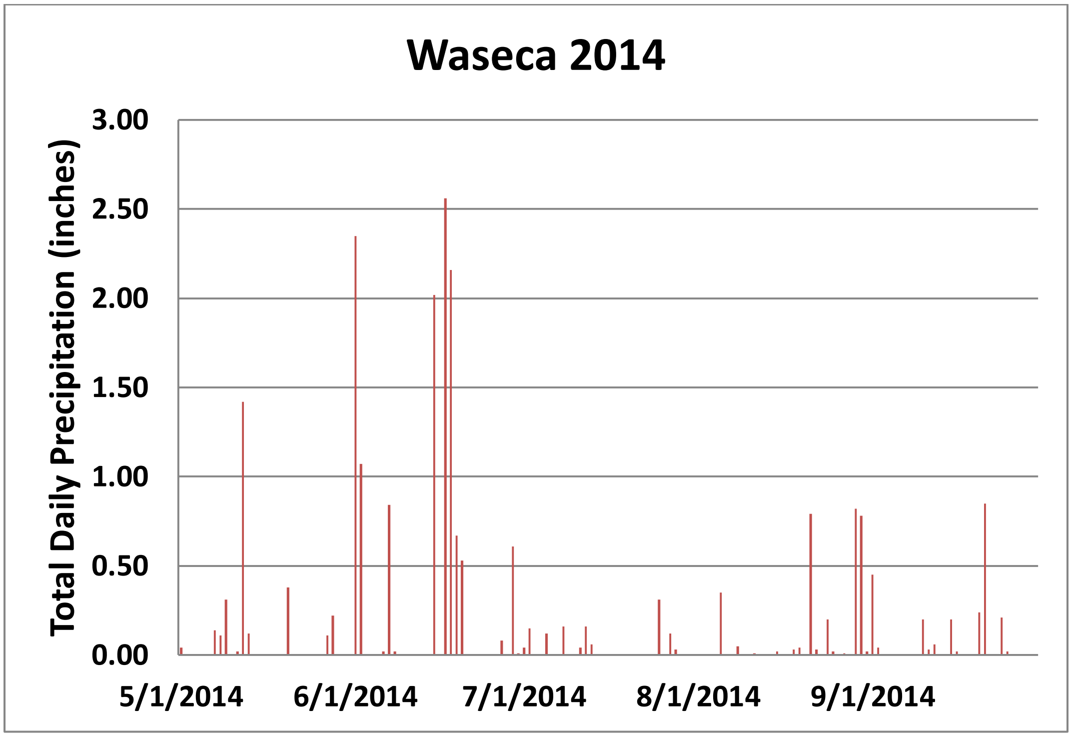
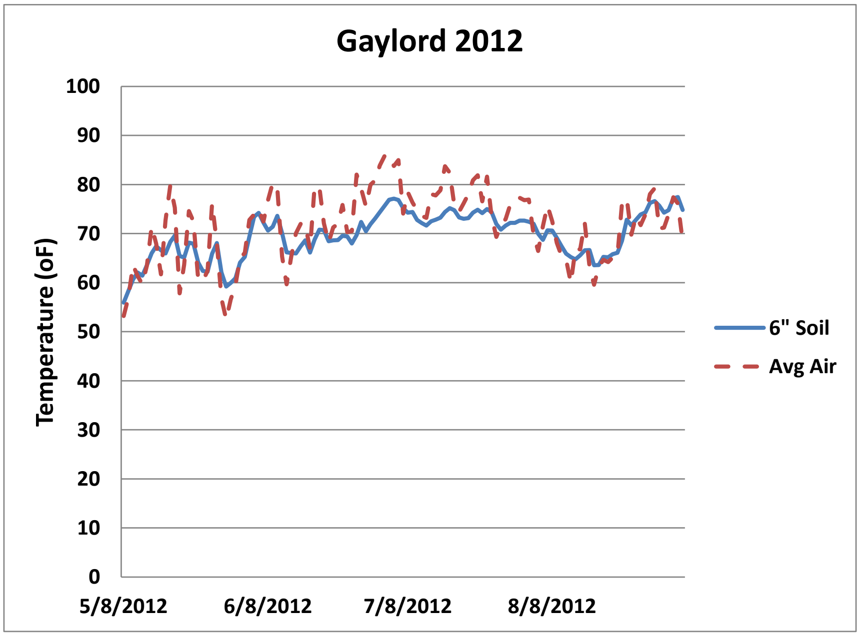



Figure A5. Summary of daily precipitation data from Waseca for the period from May 1 to September 30, 2014. Total precipitation was 22.49 inches.



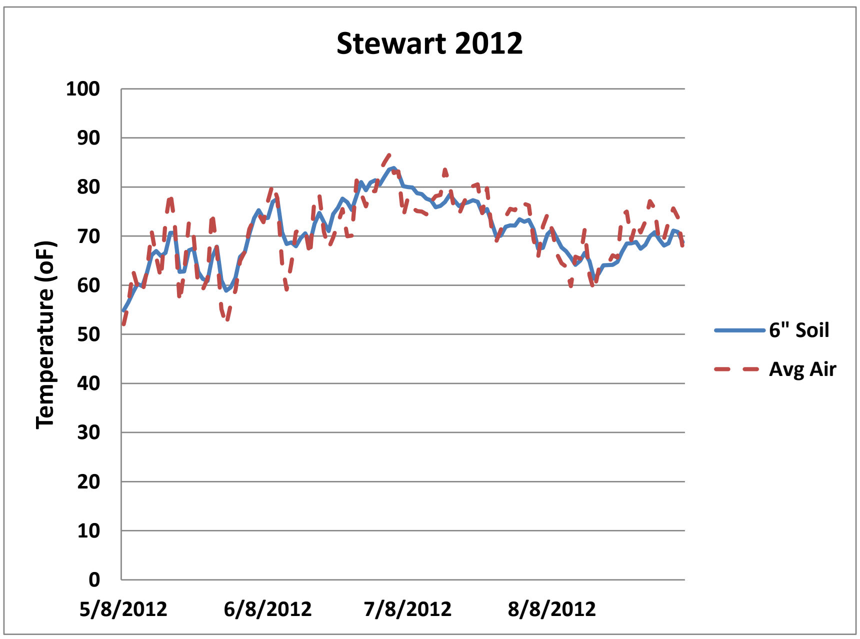
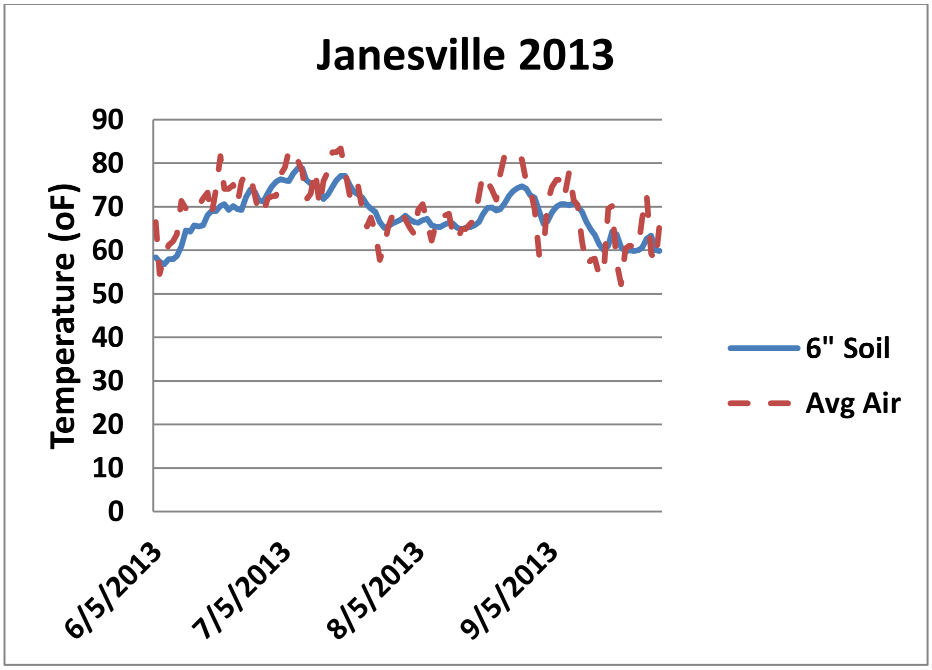




Figure B1. Summary of daily average 6” soil and air temperature from two field locations studied in 2012.



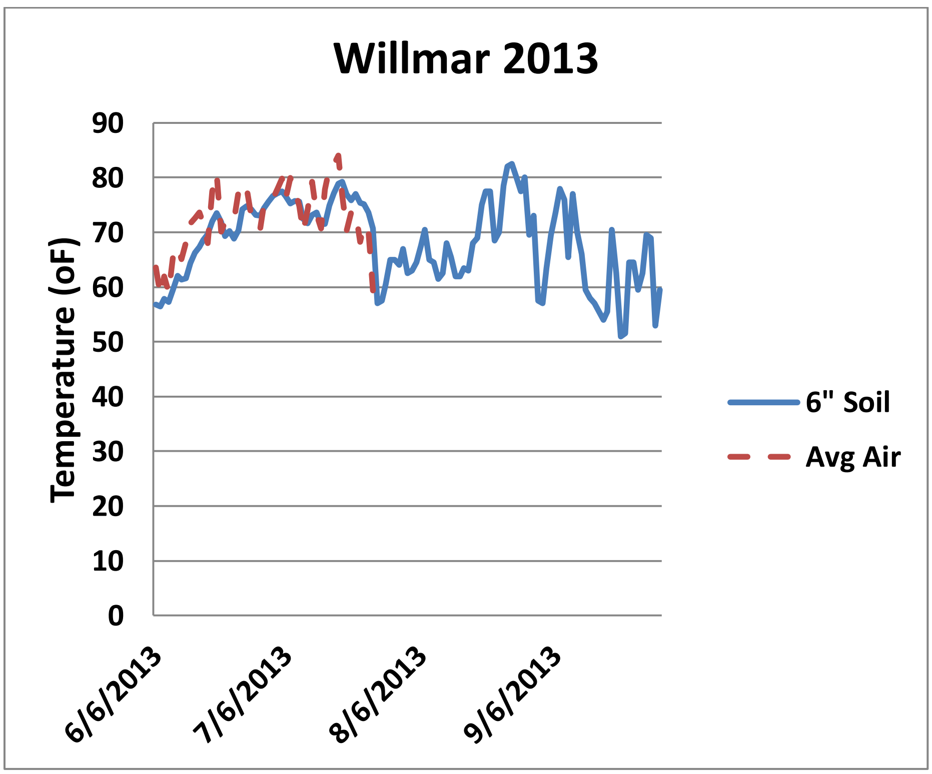




Figure B2. Summary of daily average 6” soil and air temperature at Janesville and Willmar in 2013.

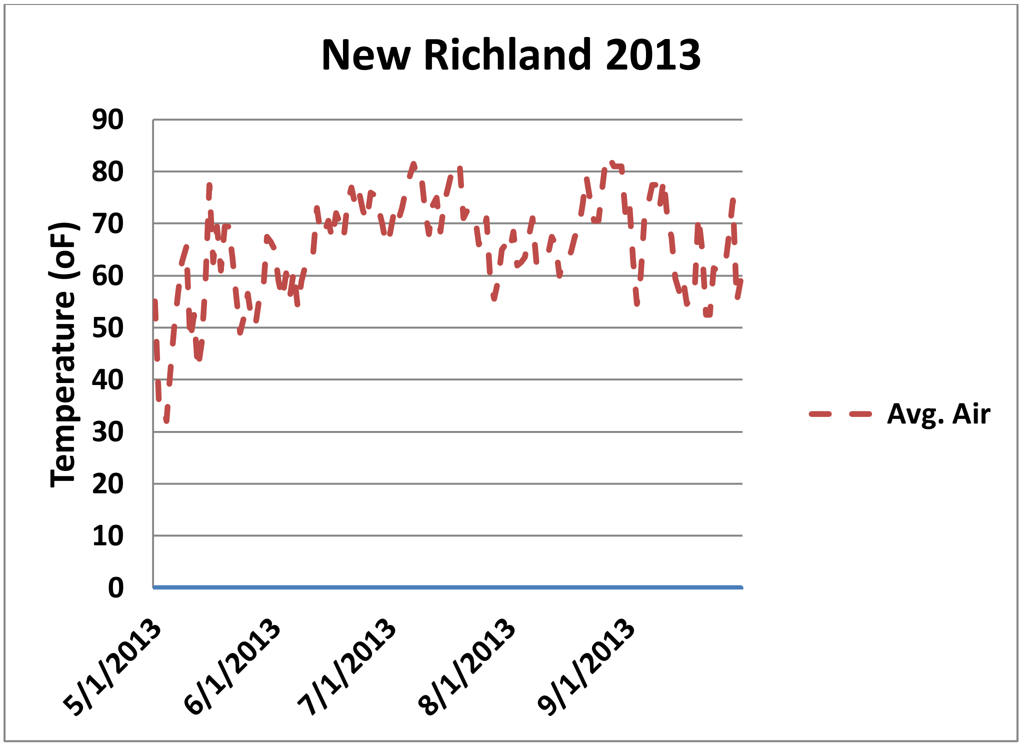
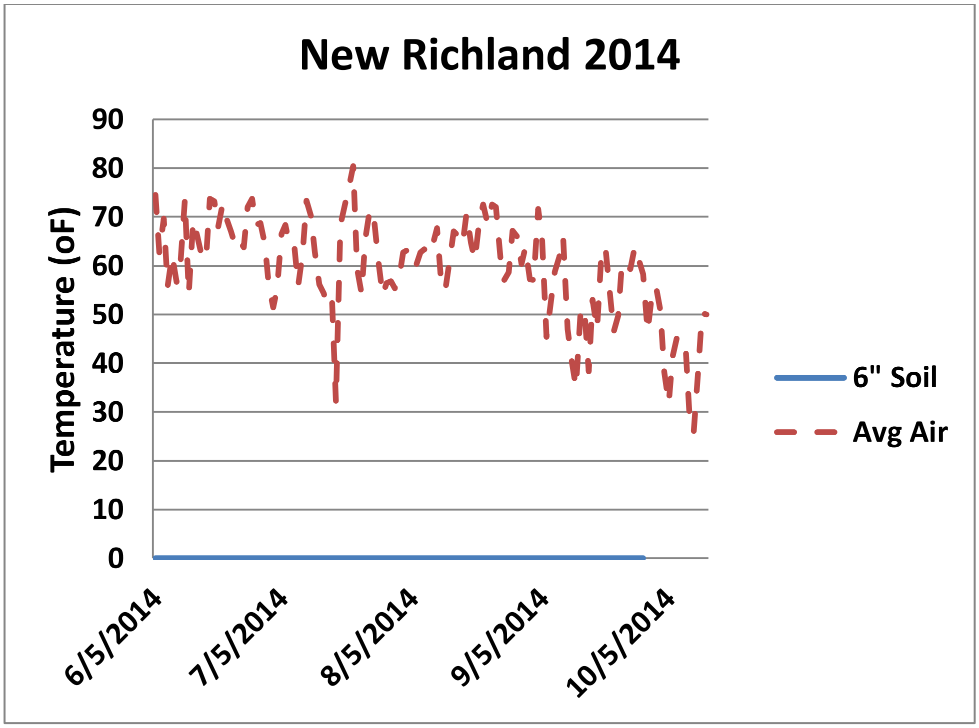



Figure B3. Summary of growing season (May – September) daily average air temperature at New Richland in 2013.



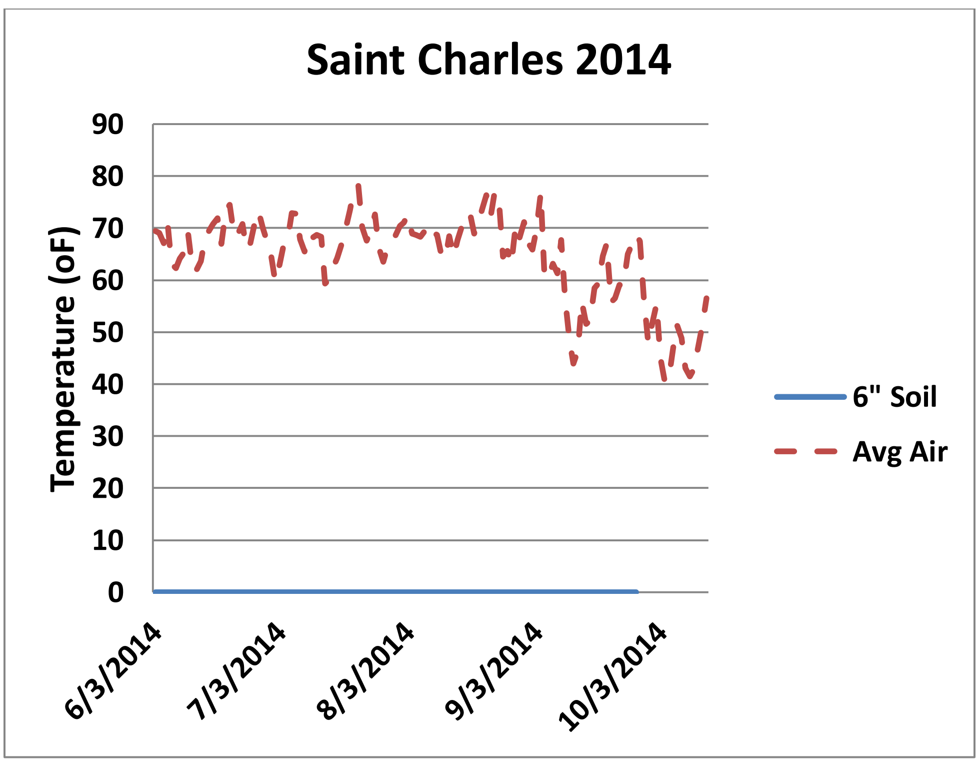




Figure B4. Summary of daily average 6” soil and air temperature at New Richland and St. Charles in 2014.

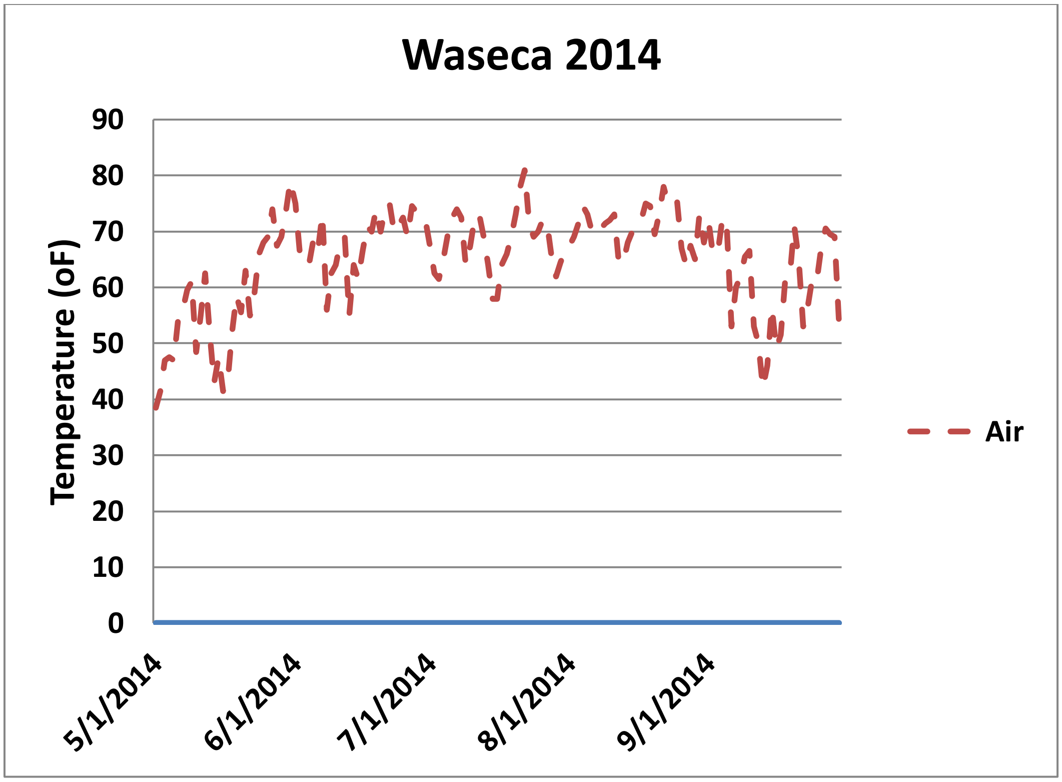



Figure B4. Summary of growing season (May – September) daily average air temperature at Waseca in 2014.

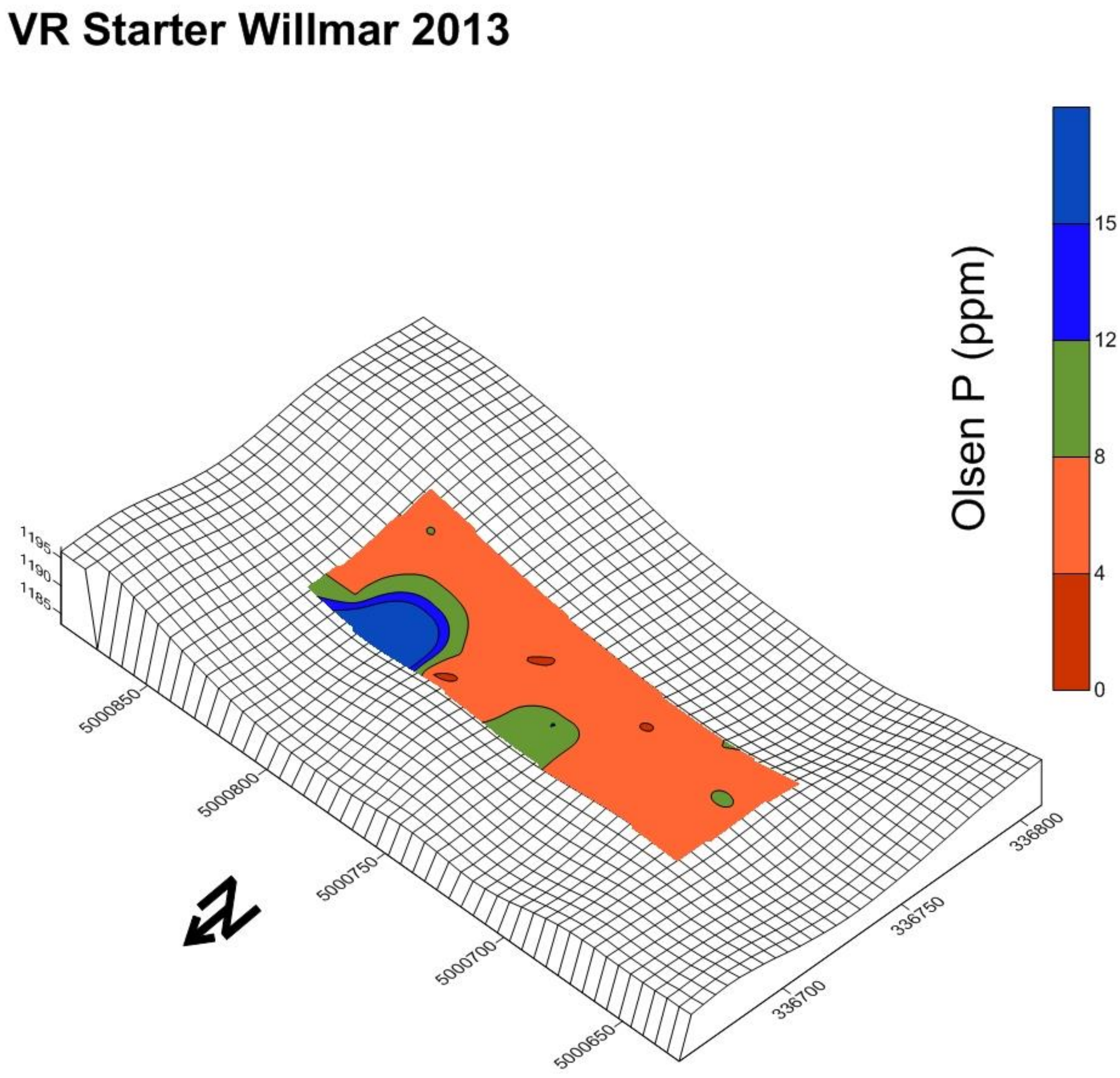



Figure C. Inherent variability in soil test phosphorus (Olsen P) at Willmar in 2013.

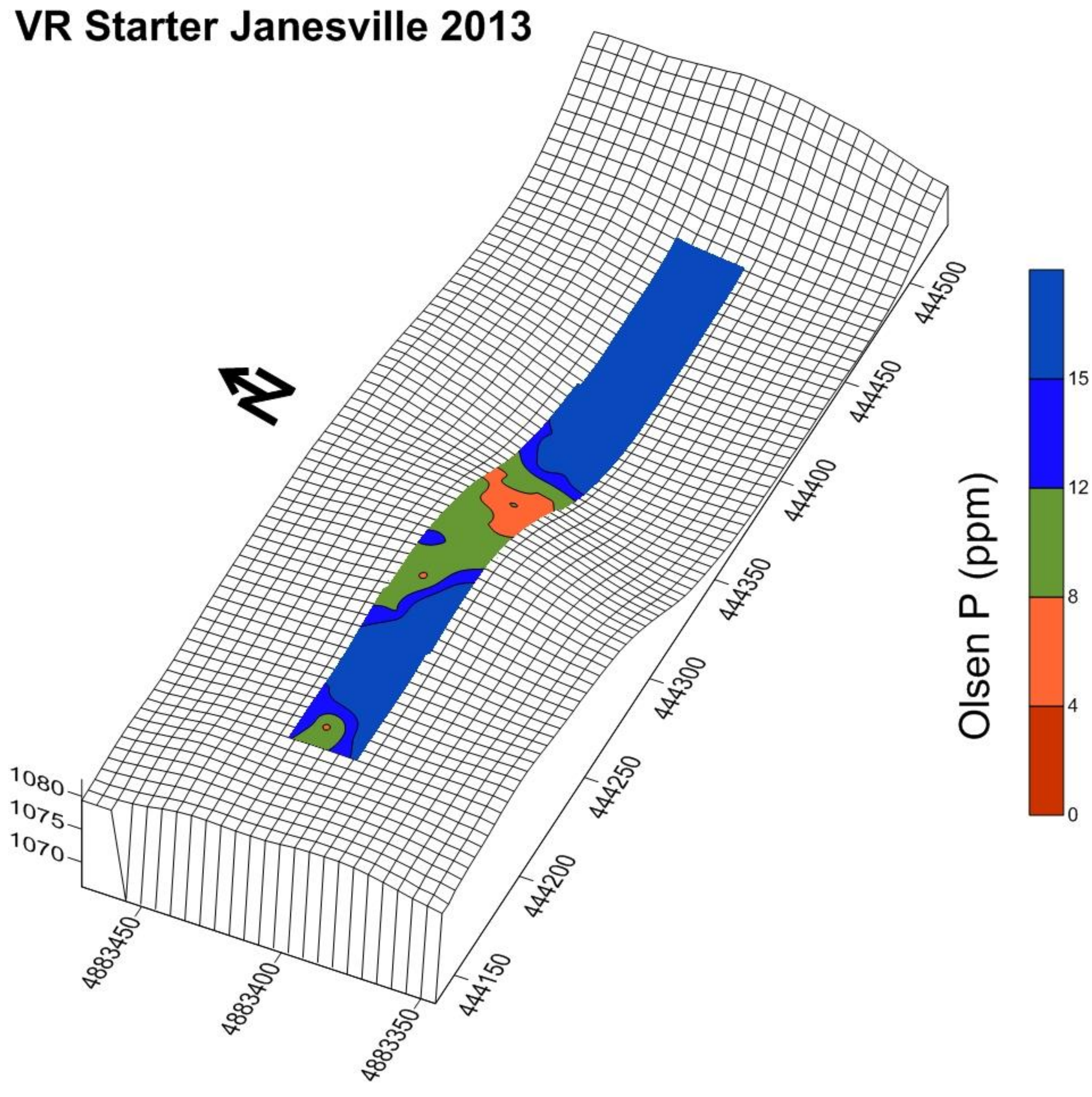



Figure D. Inherent variability in soil test phosphorus (Olsen P) at Janesville in 2013.

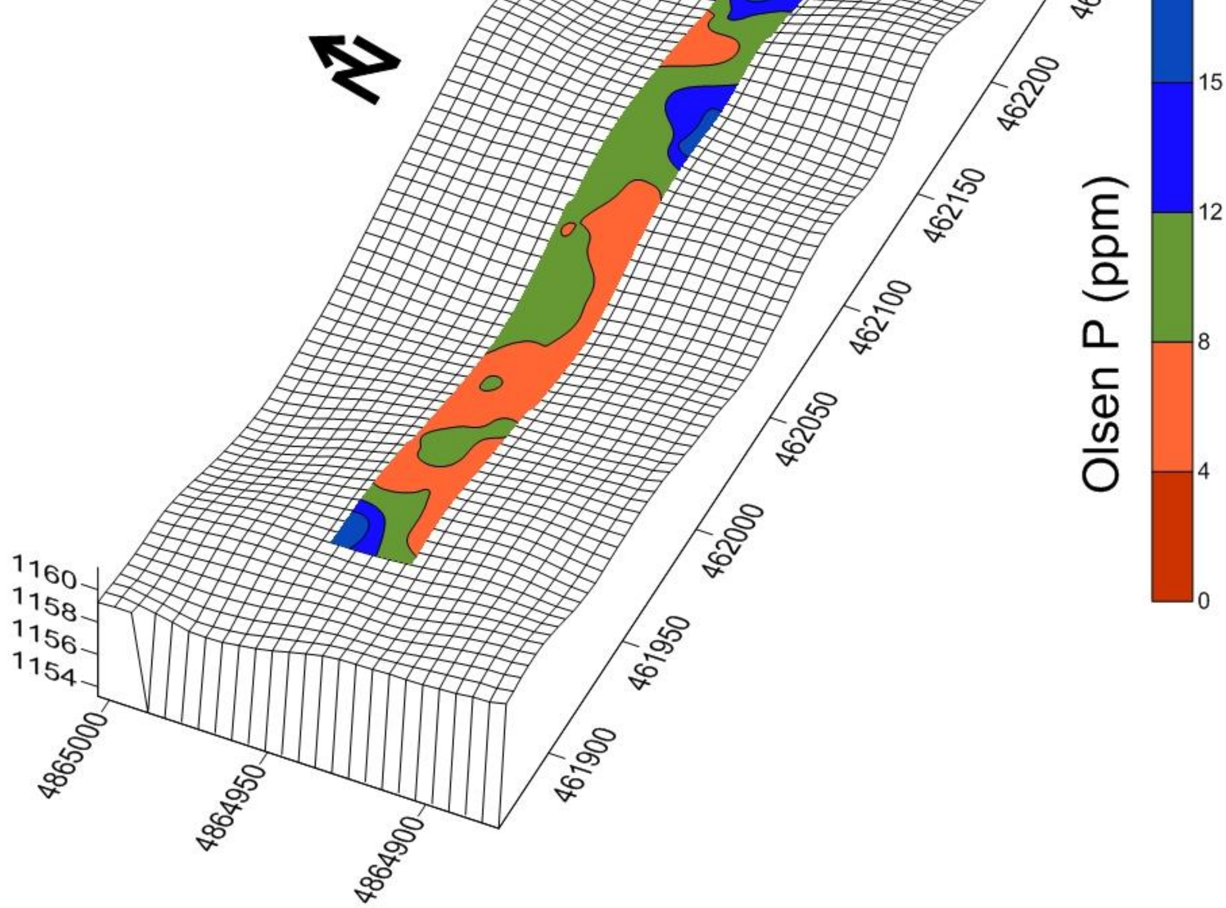



Figure E. Inherent variability in soil test phosphorus (Olsen P) at New Richland in 2013.

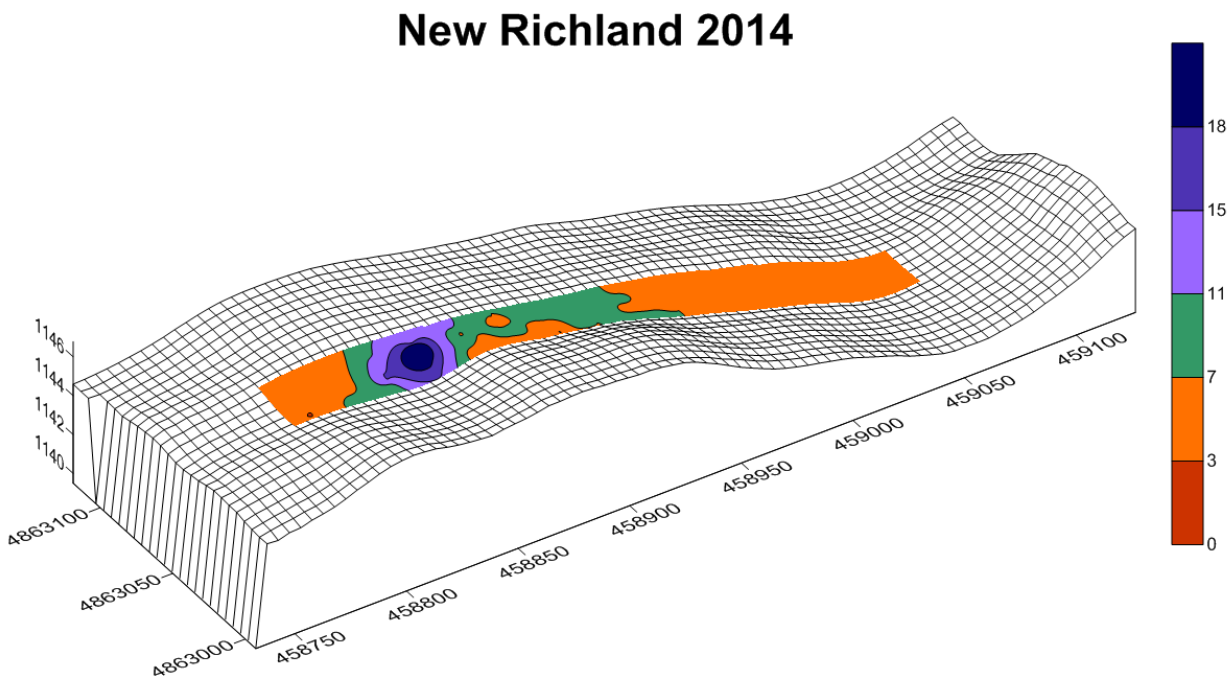



Figure F. Inherent variability in soil test phosphorus (Olsen P) at New Richland in 2014.

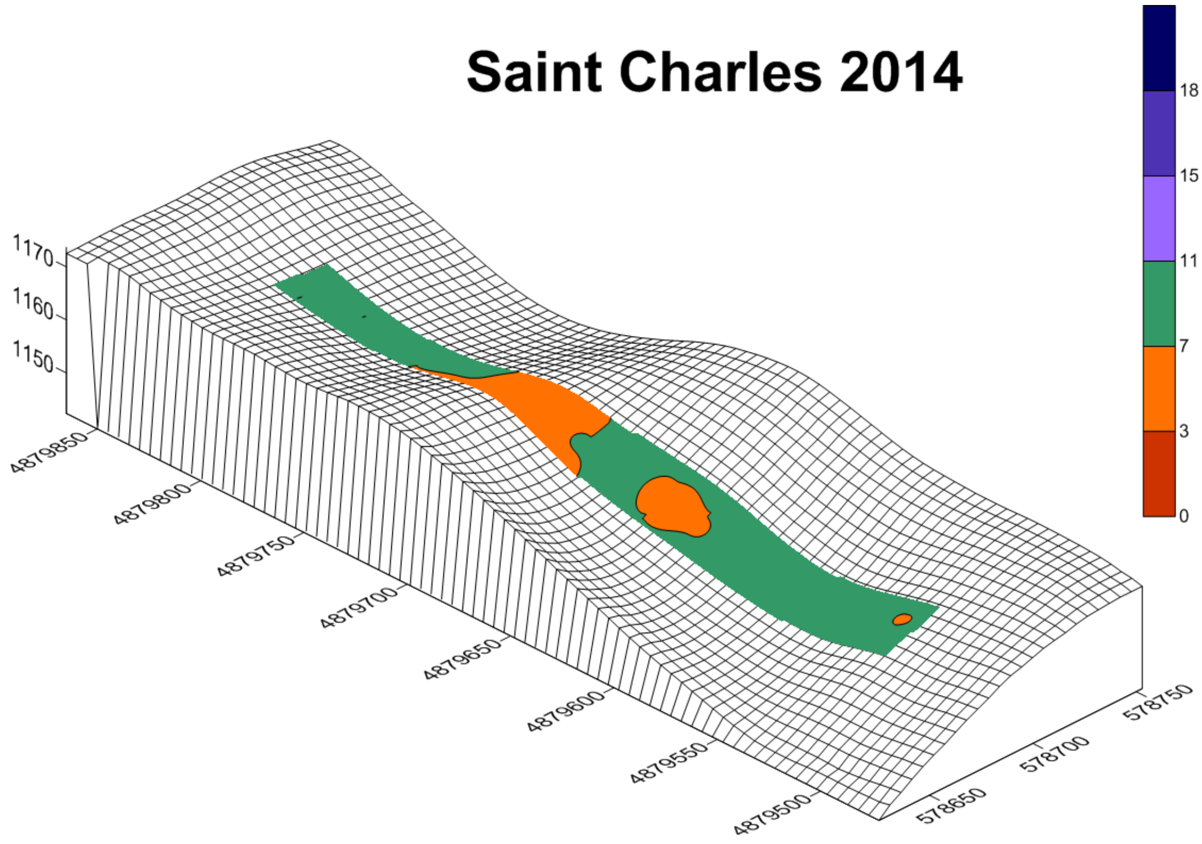



Figure G. Inherent variability in soil test phosphorus (Olsen P) at St. Charles in 2014.

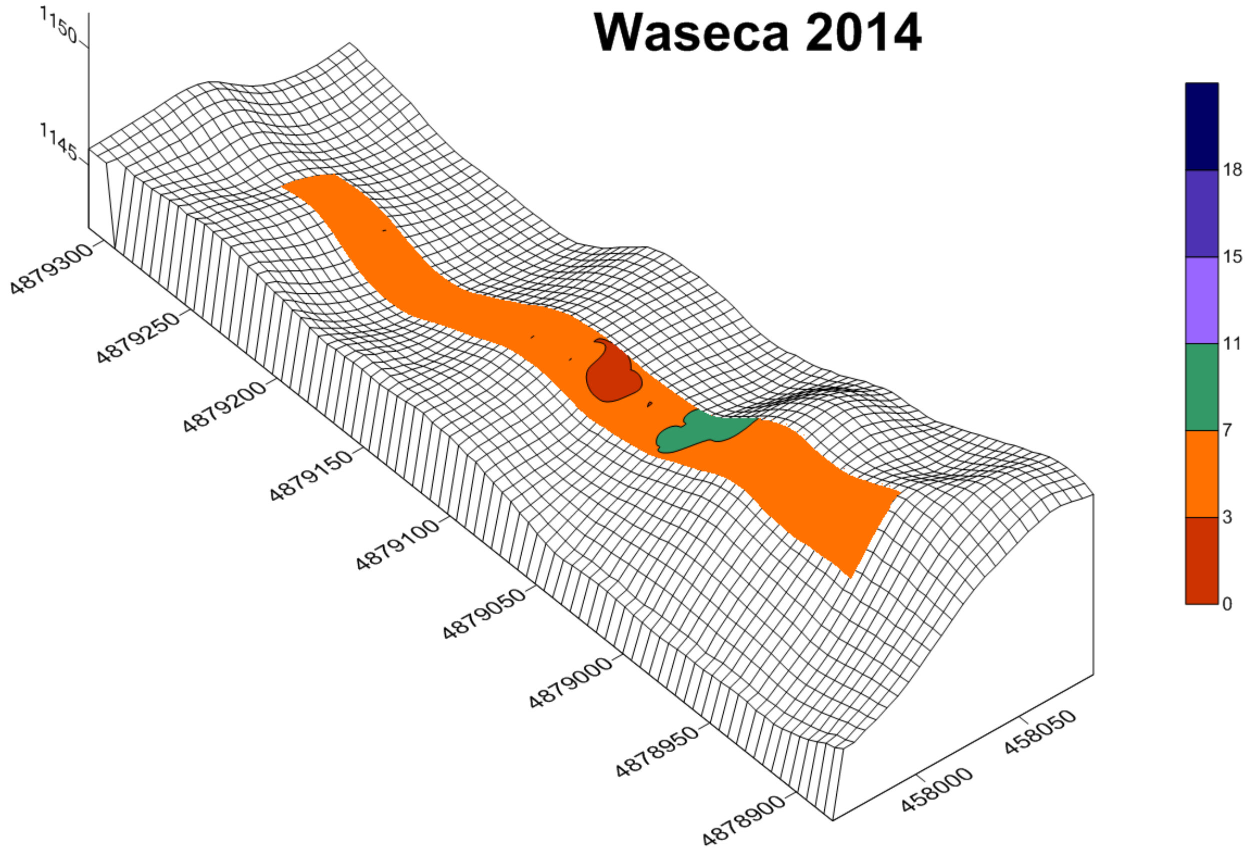



Figure H. Inherent variability in soil test phosphorus (Olsen P) at Waseca in 2014.

| Table 11. 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 |
| | New Richland | **0.034** | 0.771 | 0.548 |
| | St. Charles | 0.994 | 0.354 | 0.134 |
| | Waseca | no data | no data | no data |
| 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 |
| | New Richland | **0.001** | **0.017** | 0.583 |
| | St. Charles | **0.007** | **0.002** | 0.271 |
| | Waseca | **0.016** | **<0.001** | 0.578 |
| 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 |
| | New Richland | **<0.001** | 0.382 | 0.526 |
| | St. Charles | **<0.001** | 0.092 | 0.314 |
| | Waseca | **<0.001** | 0.916 | 0.925 |
| 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 |
| | New Richland | **<0.001** | **0.029** | 0.873 |
| | St. Charles | **<0.001** | **<0.001** | 0.110 |
| | Waseca | **0.001** | **<0.001** | 0.390 |
| 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 |
| | New Richland | **0.002** | 0.158 | 0.247 |
| | St. Charles | 0.348 | 0.972 | 0.125 |
| | Waseca | **0.005** | **0.032** | 0.279 |

| Table 11. Summary of statistical significance of treatment main effects by location (cont.) | | | | |
|---|---|---|---|---|
| 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** |
| | New Richland | 0.250 | 0.932 | 0.560 |
| | St. Charles | 0.353 | 0.086 | 0.586 |
| | Waseca | 0.089 | **0.012** | 0.072 |
| Grain P Conc. | Gaylord | 0.212 | 0.709 | 0.762 |
| | Stewart | 0.237 | 0.785 | 0.093 |
| | New Richland 13 | **<0.001** | 0.923 | 0.439 |
| | Willmar | **0.005** | 0.821 | 0.448 |
| | Janesville | 0.917 | 0.617 | 0.942 |
| | New Richland 14 | -- | -- | -- |
| | St. Charles | -- | -- | -- |
| | Waseca | -- | -- | -- |
| Grain P Removal | Gaylord | 0.170 | 0.590 | 0.880 |
| | Stewart | **0.050** | 0.970 | 0.070 |
| | New Richland | **<0.001** | 0.717 | 0.610 |
| | Willmar | **0.004** | 0.838 | 0.748 |
| | Janesville | 0.734 | 0.656 | 0.962 |
| | New Richland | -- | -- | -- |
| | St. Charles | -- | -- | -- |
| | Waseca | -- | -- | -- |

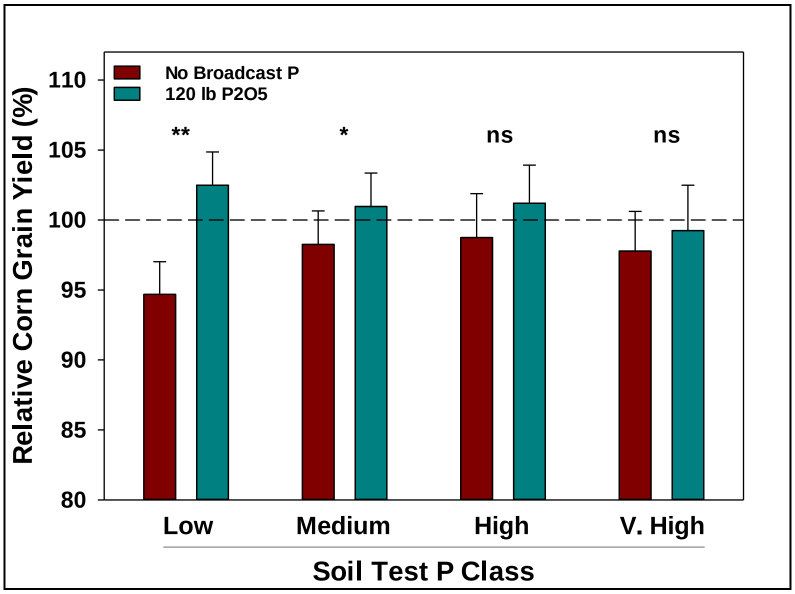



Figure I. Relative corn grain yield as affected by broadcast rates of fertilizer P and soil test P classes (Olsen P), when averaged across starter P rates and locations (** and * denotes significance at α=0.05 and α=0.10, respectively).

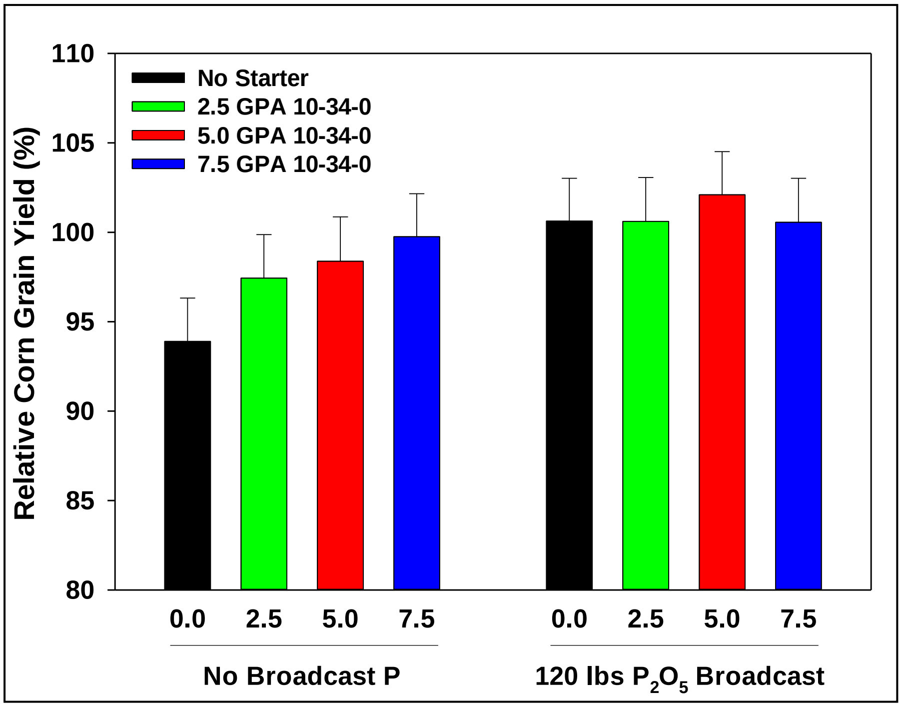



Figure J. Relative corn grain yield as affected by the interaction between broadcast and starter (APP, ammonium poly phosphate) rates of fertilizer P, when averaged across locations and soil test P levels (error bar denotes significance at α=0.05).

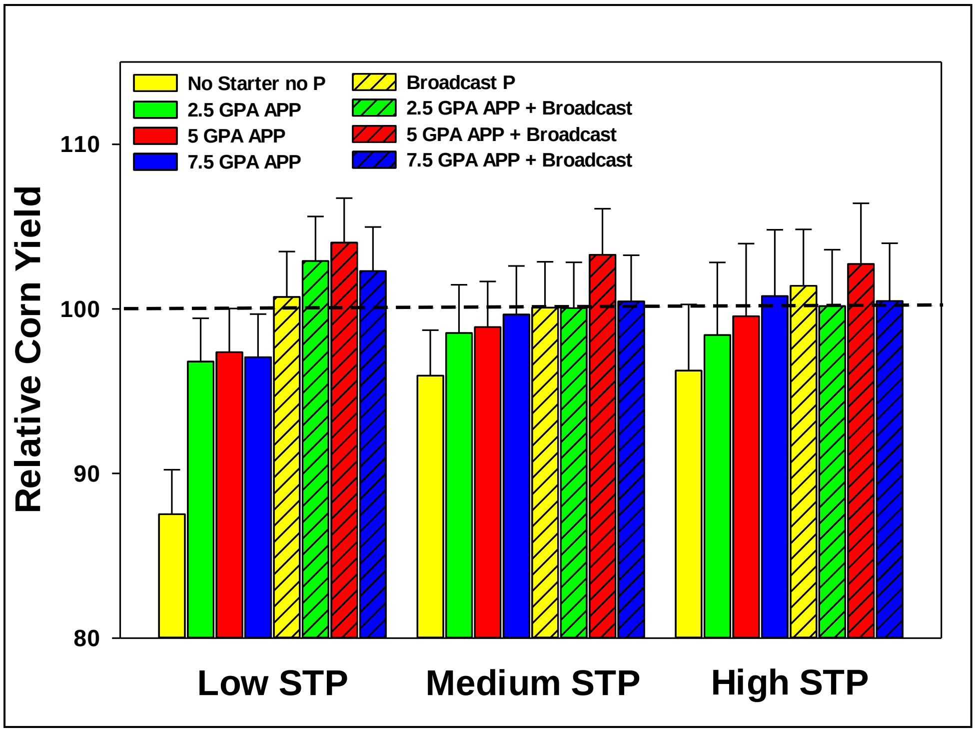



Figure K. Relative corn grain yield at various soil test levels (Olsen P) as affected by broadcast and starter rates of fertilizer P, when averaged across locations (error bar denotes significance at α=0.05).