PROJECT DESCRIPTION:	**Are band applications of P and K more efficient and profitable than broadcast?**
PROJECT NUMBER:	**R2020-N MN DEPT OF AGRICULTURE**
ANNUAL REPORT DUE DATE:	**On or before April 30, 2021**
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Introduction

Previous research in the Midwest has shown mixed results for varying placement of P and K fertilizers (Randall and Hoeft, 1988; Mallarino et al., 1999; Borges and Mallarino, 2000; Rehm and Lamb, 2004; Wolkowski, 2007; and Boomsma et al., 2007). In a review paper, Boomsma et al. (2007) explained several factors and situations where band applications are likely to be superior to broadcast. These include: low P and K soil test levels, soils with high fixation capacity, reduced tillage systems (resulting in cooler soils with smaller root systems), low subsoil P and K levels (partly due to nutrient stratification in reduced tillage systems), cultivar differences, using strip tillage, not using P and K starter fertilizers, and when using automatic guidance for multiple field operations (including controlled wheel traffic). Band applications (deep and starter bands) have lost favor for some farmers due to increased farm size, equipment size, equipment cost, and time savings. Broadcast P and K applications are easier, faster and cheaper on a cost per acre of application. Recent challenging economic times in agriculture have farmers looking for ways to reduce input costs and increase efficiency and profitability of fertilizer inputs while maintaining or increasing yields. Banding P and K at reduced rates may be a viable option for many. Additionally, subsurface banding of P fertilizer can reduce the risk of P runoff compared to broadcast application (Lewandowski et al., 2006). These reasons warrant continued research on P and K placement methods.

Minnesota fertilizer guidelines (Kaiser et al., 2018 online) have substantial reductions, up to 50% for very low and low testing soils, in P and K fertilizer rates for corn when banding compared to broadcasting. In soybean, no rate reductions for band placement are given as research has shown no response to banding or a slight advantage for broadcast application (Randall and Hoeft, 1988 and Wolkokski, 2007). The majority of Minnesota's deep band placement research was conducted by Rehm and colleagues in the late 1980's and 1990's in ridge-till. They found deep banded K occasionally increased corn yields in ridge-till but responses were influenced by corn hybrid selection. Ridge tillage is rarely used today and differences in response in those studies were due to repeated application in the ridge. The primary question is whether banding in conventional tillage systems is advantageous as most corn producing states do not suggest rate reductions when banding regardless of soil test level. Collecting "new" corn yield response to fertilizer placement data is crucial for validating fertilizer rate reductions for band applications in Minnesota, and for answering a common question. Are band applications of P and K more efficient and profitable than broadcast?

The goal of this research is to improve fertilizer recommendations for corn and soybean farmers in Minnesota. The primary objectives are: 1) to measure yield response, fertilizer use efficiency and nutrient removal in corn as affected by band and broadcast applications of P and K fertilizer; 2) correlate and calibrate crop yield response to STK using both dry (traditional ammonium acetate extractant) and moist (slurry) soil methods; 3) to measure yield response and nutrient removal in soybean as affected by soil test P and K levels (only in year 1); and 4) disseminate these results to farmers and their agricultural advisors via oral and written communications and social media.

Materials and Methods

Research sites were established for P in 2010 and for K in 2011 at SROC in Waseca (Nicollet–Webster clay loam) and near Rochester (Mt Carroll silt loam). These research sites had been used for long-term fertility studies since establishment. Currently, each site has a wide range in soil test levels due to previous management. The P sites contain 64 plots (16 treatments replicated four times) and the K sites contain 48 plots (12 treatments replicated four times). Individual plots are large enough in size (20 ft wide by 40–55 ft in length) to allow for a paired comparison study (two 10 ft wide plots) using a split-split plot design. Due to their size and range in soil test levels, these sites are ideal for conducting a paired comparison (band vs broadcast) research study.

All sites were corn in 2018 and were planted to soybean (Asgrow 20X9) at 135,000 seeds/ac on 15 May 2019 in Waseca and 26 May 2019 in Rochester. Weeds were controlled with a combination of post emerge herbicides. A fungicide (Trivapro 20.7 oz/ac with 25 gal/ac of water) was applied at the Waseca site on 30 July 2019. Soybean seed yields were combine harvested on 9 and 20 Oct 2019 at Waseca and Rochester, respectively. Corn was planted at 35,000 seeds/ac on 22 and 27 Apr 2020 at Waseca and Rochester, respectively (see Table A1 for hybrids and N-P-K-S application rates and dates). Ear leaves (10 per plot) were taken at R1-2 from all sites in 2020. Corn grain was combine harvested with a research plot combine on 5 and 13-14 Oct 2020 at Waseca and Rochester, respectively. Yields were calculated and are reported at 13% and 15.5% moisture for soybean and corn, respectively.

A grain sample was collected at harvest, dried at 145°F, ground and submitted to a commercial lab to determine nutrient (P or K) concentration. Grain tissue samples were analyzed by Brookside Lab using a wet ash extraction with nitric acid and hydrogen peroxide in a closed Teflon vessel in a CEM microwave. Each sample (extractant) was analyzed on a Thermo 6500 Duo ICP. Nutrient removal in grain was calculated by multiplying nutrient concentration by grain yield (dry matter yield).

Soil samples were taken in June at 0- to 6- and 6- to 12--inch depths on both P and K studies and again in October at a 0- to 6- and 6- to 12-inch depths in the K studies. Eight 0.75-inch diameter soil cores per plot were taken from each plot. Two sets of four samples were taken perpendicular to the crop row (fertilizer band on banded treatments). These four samples were taken 0, 7.5, 15 and 22.5 inches from the crop row (band). These cores were mixed and composited together into one sample per plot. The 0- to 6-inch depth K samples were kept cool and moist after collection and later delivered to Solum Lab (Ames, Iowa) where they were mixed and analyzed using their field moist procedure (Mehlich III extractant) in 2019. Due to Solum closing, moist sample extraction and K analyses were conducted on St Paul campus (Kaiser lab for extraction and RAL for analyses). The remaining sample was dried on a paper plate at 100° F for 12-14 hours in a forced air oven, returned to the paper bags and left at room temperature until they were ground, and sent to the University of Minnesota (RAL) soil testing lab for ammonium acetate K extraction and analysis. The P study soil samples were air dried, ground and submitted to RAL for Bray P1 extraction and analysis. These samples were analyzed using techniques described in Recommended Chemical Soil Test Procedures for the North Central Region (2015).

In the first year of the study (2019), treatment effects on soybean yield, seed nutrient concentration and nutrient removal were primarily due to inherent variability in soil test P and K as only two treatments in the K study actually received K fertilizer for the 2019 crop. These two treatments (#'s 6 and 11) received the same broadcast fertilizer rate (60 and 120 lb K_2O/ac) in spring of 2019 that they had received during the previous 4 years. No P fertilizer was applied (spring or previous fall) to any treatment for the 2019 soybean crop in the P study.

A custom applicator mistakenly applied additional N-P-K-S fertilizer to reps 1 & 2 at Waseca in Apr of 2020. This error was very unfortunate. The 2020 data from these reps are not presented in this report.

The data were analyzed using ANOVA with treatment as a fixed effect and block and interactions with block as random effects. All data were statistically analyzed using SAS® Proc Mixed (SAS 9.4, SAS Institute Inc., 2012. Cary, North Carolina). A 0.10 level of significance is used unless otherwise stated.

2019 Results and Discussion

Weather data characterizing the 2019 growing season at Waseca are presented in Table 1. Abundant rainfall especially in May, Jul and Sep and a cold spring that delayed planting. About 4.5 inches of rainfall were recorded in the last two weeks of May at Waseca and daily high temperatures only reached the upper 50's and low 60's on many days during this period. These cool and wet conditions slowed crop development. Growing season (May-Sep) rainfall exceeded 28 inches or about 7 inches more than normal at both sites. Growing degree units (GDUs) for the year totaled 2,528 (102% of normal); however, GDUs lagged below normal throughout most of the growing season.

Potassium Study

<u>Waseca</u>

Soybean yields were least (51.7 bu/ac) in the control (treatment # 1) which hasn't received K fertilizer for more than 15 years and were maximized in treatment #'s 4, 8 and 12 which all received 180 lb K_2O/ac for the 2016 through 2018 crop years (Table 2). Interestingly, treatment #'s 4, 8 and 12 had statistically greater yields than treatment # 6 which received 60 lb K_2O/ac in Apr of 2019 and during the 2013 through 2018 crop years. Analysis (ANOVA) of treatment means showed soybean yields were optimized at STK ≥122 ppm with Jun dry test and >81 ppm with Jun moist test (Table 2); whereas, regression analysis showed relative soybean yields were >98% when STK ≥ 155 and 98 ppm with the Jun dry and moist tests, respectively (Figure 1). Seed K concentration ranged from 1.33 to 1.69% and were greatest with treatment # 11 which received 120 lb K_2O/ac in Apr of 2019 and from 2013 through 2018. Seed K removal ranged from 35.9 lb K/ac (44.0 lb K_2O) in the control to 52.6 lb K/ac (64.2 lb K_2O) in treatment # 11.

Soil test K in the 0- to 6-inch depth varied greatly among treatments primarily due to the varied rates of fertilizer K that were applied previously (Table 2). Seasonal differences in STK (dry and moist) between Jun and Oct soil samplings were not observed or minimal in 2019 which is unlike previous years at this site where Oct STK was always greater than Jun STK. Soil test K in the 7- to 12-inch depth was not affected by treatments (data not shown) as treatment means ranged from 67 to 73 ppm (Jun dry) at Waseca.

<u>Rochester</u>

Soybean yields were least (58.1 bu/ac) in the control (treatment # 1), which has received no K fertilizer for 8 years (Table 3). Yields were also reduced with treatment #'s 2 (66.4 bu) and 5 (63.9 bu). All other treatments had statistically equal yields which ranged from 67.8 to 70.0 bu/ac. Several treatments had yields equal to treatment #'s 6 and 11 which received 60 and 120 lb K_2O/ac, respectively, in Apr of 2019 and during the 2016 through 2018 crop years. These data demonstrate the law of diminishing return to fertilizer K; moreover, if STK values are adequate for crop production applying additional K fertilizer did not increase yields but would have reduced return on investment in the application year. When analyzed with ANOVA, treatments that optimized soybean yield had STK ≥117 ppm with Jun dry test and ≥97 ppm with Jun moist test (Table 3); whereas, regression analysis showed relative soybean yields were >98% when STK ≥ 143 and 125 ppm with the Jun dry and moist tests, respectively (Figure 2). Seed K concentration ranged from 1.50 to 1.80% and was greatest with treatment # 11 which received 120 lb K_2O/ac in Apr of 2019 and during the 2016 through 2018. Seed K removal ranged from 45.4 lb K/ac (54.5 lb K_2O) in the control to 63.6 lb K/ac (76.3 lb K_2O) in treatment # 11.

Soil test K in the 0- to 6-inch depth varied greatly among treatments primarily due to the varied rates of fertilizer K that were applied previously (Table 3). Soil test K from Oct samples was consistently less than from Jun samples for both dry and moist tests. Previous year results showed no consistent pattern in seasonal STK variability at Rochester, some years STK was greater in Oct and others it was less in Oct than in Jun. Treatment # 11, which received 120 lb K_2O/ac per year since 2016 had much greater STK than did treatment # 6. This difference was not observed at Waseca. These data demonstrate how different the STK response to applied fertilizer K is between these two soil types. Soil test K in the 7- to 12-inch depth was not affected by treatments (data not shown) as treatment means ranged from 60 to 66 ppm (Jun dry) at Rochester.

Phosphorus Study
Waseca
Soybean yields were least (48.6 bu/ac) in the control (treatment # 1) which has received no P fertilizer for 10 years (Table 4). Yields were also reduced with treatment #'s 2 (56.6 bu), 4 (55.9 bu), 5 (54.8 bu) and 9 (57.2 bu). All other treatments had statistically equal yields which ranged from 58.0 to 61.0 bu/ac. Using ANOVA of treatment means, soybean yields were optimized at Bray P1 ≥9 ppm (Table 4); whereas, regression analysis showed relative soybean yields were >98% when Bray P1 ≥16.8 ppm (Figure 3). These two methods result in quite different optimum or "critical" STP levels for soybean production at Waseca. However, the regression method is greatly influenced by the yield level (percent) one chooses as a "desired" optimum relative yield. At 95% relative soybean yield the Bray P critical level is 7.8 ppm. Seed P concentration ranged from 0.39 to 0.59% and was greatest with treatment # 14 which had the greatest STP value (32 ppm). Seed P removal ranged from 9.7 lb P/ac (21.3 lb P_2O_5) in the control to 18.6 lb P/ac (40.0 lb P_2O_5) in treatment # 14.

Soil test P in the 0- to 6-inch depth varied greatly among treatments primarily due to the varied rates of fertilizer P that were applied previously (Table 4). Bray P in the 7- to 12-inch depth also varied both by treatment (previous P fertilizer applied) and landscape position. Treatment means ranged from 3 to 8 ppm in the 7- to 12-inch depth (data not shown). Statistical analysis of these 7- to 12-inch depth data will be completed at the end of the research study.

Rochester
Soybean yields were not affected by previous treatments and STP at Rochester (Table 5 and Figure 4). All treatments had statistically equal yields which ranged from 62.1 to 66.0 bu/ac. These data are consistent with findings from the previous P study (ALPS) at this site which often showed no response to fertilizer P application or change in STP, even at the very low STP level (<6 ppm Bray P1). Seed P concentration and STP were affected by treatments (previous P fertilizer). However, seed P was ≥0.54% even when STP ranged from 5 to 9 ppm. Seed P removal ranged from 18.2 lb P/ac (40.0 lb P_2O_5) to 21.1 lb P/ac (46.4 lb P_2O_5) but like soybean yield it was not affected by past treatments.

Soil test P in the 0- to 6-inch depth varied greatly among treatments due to fertilizer P that was applied in previous years of the ALPS study (Table 5). Bray P in the 7- to 12-inch depth was not measurably different as it only ranged from 3.5 to 5.5 ppm.

2019 Summary

Research sites were established in 2010 and 2011 at Waseca and near Rochester. These research sites had been used for long-term fertility studies since establishment. Due to their size and range in soil test P and K levels, these sites are ideal for conducting a band vs broadcast research study. All sites were planted to soybean in 2019 and will be corn in 2020. Soil samples collected in 2019 showed a wide range (from very low to very high levels) in soil test P or K at all sites. Soybean yields responded to changes in STK and K fertilizer treatments at both sites (Waseca and Rochester) in 2019; whereas, soybean yields only responded to changes in STP at Waseca. Band and broadcast treatments were applied to both P and K studies at Waseca in the fall of 2019 for the 2020 corn crop. These treatments will be applied in April at Rochester.

2020 Results and Discussion

Weather data characterizing the 2020 growing season at Waseca are presented in Table 1. A warmer than normal summer (Jun through Aug) with slightly greater than normal precipitation describes the growing season at Waseca. This weather was ideal for crop growth and corn production. Growing season (May-Sep) rainfall was 24.63 inches or about 3.2 inches more than normal. Growing degree units for the year totaled 2,602 (104% of normal).

In 2020, the data from each study site (P and K) were analyzed with two separate ANOVA. The first compares corn production parameters across all treatments (old residual effects of treatments and fertilizer applied for 2020 corn); whereas, the second ANOVA summarizes the split treatments (band vs broadcast) applied for corn in 2020. The loss of two reps in the K study at Waseca resulted in lack of statistical power and thus fewer significant differences. At the end of the study, a combined ANOVA across sites will also be conducted.

Potassium Study

Waseca

An ANOVA of all 12 treatments showed only a few corn production parameters were affected by past (varied STK) and present (2020 fertilizer rates) treatments at Waseca (Table 6a). Corn grain yields ranged from 219 to 247 bu/ac among treatments but were not statistically different (only two reps analyzed). Generally, corn grain moisture was about 1.0 to 1.5 percentage points greater in treatments that received K fertilizer for corn in 2020 compared with treatments that did not receive K fertilizer in 2020. Potassium fertilization can enhance late season plant health (stay green), which may result in greater grain moisture at harvest. Ear leaf K concentrations were generally quite low <1.11% among most treatments. However, ear leaf K was much greater in treatment #11 (1.66%) which has received 120 lb K_2O/ac per year over the last eight growing seasons and in treatment #12 (1.41%) which has also received high rates of K fertilizer in previous years. Interestingly, ear leaf K concentrations in all 12 treatments were less than the reported critical range of 1.7 to 2.5% (Univ. of Minnesota Extension website). Grain K concentration, K removal in grain and final plant population were not affected by treatments. Grain K removal ranged from 33.3 to 40.3 lb K/ac and averaged 36.8 lb K/ac or 44.3 lb K_2O/ac.

Soil test K from 2019 samples in the 0- to 6-inch depth varied greatly among treatments primarily due to the varied rates of fertilizer K that were applied in previous years (Table 6a). The 2020 moist K analyses had not been completed at the time of writing this report (early March); therefore, the 2020 soil K data will be added and discussed at a later time. The 2019 soil data included in table 6a and 6b are from reps 3 and 4, not all reps, as reported in table 2 of this report. However the interpretation is very similar and won't be redone here.

An ANOVA of the four split (band vs broadcast) treatments showed a few corn production parameters were affected by fertilizer treatments (rate or placement) at Waseca (Table 6b). Corn grain yields ranged from 219 to 249 bu/ac among treatments but were not statistically different. Corn grain moisture was about 1.7 percentage points greater in broadcast treatments than in band treatments. This likely was a result of greater early growth/development in the band treatments or delayed growth/maturation in broadcast treatments. This was clearly evident throughout Jun and Jul at Waseca (Figure. 5). There were no significant treatment differences for ear leaf K and grain K concentrations. Grain K removal was slightly less with treatment #2 than with other treatments. This difference was a result of numerically lower yields and grain K concentration with treatment #2. A significant treatment × placement interaction for plant population (P>F = 0.006) was observed; however, it's unlikely it had any effect on corn yield.

An ANOVA of the four split (band vs broadcast) treatments found very few significant differences in 2019 soil data (Table 6b). This would be expected as these paired (split band vs broadcast) plots had very similar STK due to previous fertilization practices. Furthermore, the treatments chosen for 2020 all had relatively low (most <100 ppm) STK and should have responded to fertilizer K addition. More split treatments will be added in 2021and the treatments will have a greater range in STK. Moist K values were considerably less than dry K as has been observed and reported previously.

Rochester

An ANOVA of all 12 treatments showed corn grain moisture and ear leaf K concentration were affected by past (varied STK) and present (2020 fertilizer rates) treatments at Rochester (Table 7a). Corn grain yields ranged from 228 to 236 bu/ac among treatments but were not statistically different. Like Waseca, corn grain moisture at Rochester was greater (wetter) in treatments that received K fertilizer for corn in 2020 compared with treatments that did not receive K fertilizer. Ear leaf K concentration was greatest in treatment #11 (2.07%) which has received 120 lb K_2O/ac per year over the last eight growing seasons, intermediate in treatment #'s 4, 6, 8 and 12, all of which had Jun (dry) STK>150 ppm and/or received greater amounts of K fertilizer historically (treatment # 6). Except for treatment # 11, all treatments had ear leaf K concentrations less than the reported critical range of 1.7 to 2.5% which is similar to Waseca. Grain K removal ranged from 38.5 to 41.6 lb K/ac and averaged 39.7 lb K/ac or 47.9 lb K_2O/ac.

Soil test K from 2019 samples in the 0- to 6-inch depth varied greatly among treatments primarily due to the varied rates of fertilizer K that were applied in previous years (Table 7a). The 2020 moist K analyses had not been completed at the time of writing this report (early March); therefore, the 2020 soil K data will be added and discussed at a later time.

An ANOVA of the four split (band vs broadcast) treatments showed corn grain yields were greater with band application than with broadcast, when averaged across K fertilizer treatments/rates (Table 7b). Grain yields were not affected by the main effect of treatment/rate (varied STK levels), when averaged across placements. This is an important finding as it shows when adequately fertilized, yield level (potential) was not greater in treatments with greater STK (initial fertility). These data support the use of the sufficiency approach for K fertilization of corn. Corn grain moisture was 1.4 percentage points greater in broadcast treatments than in band treatments. This was likely a result of greater early growth in the band treatments and delayed maturation in broadcast treatments (Figure. 6). When averaged across placement (sub plots), ear leaf K concentrations were greatest in treatment #'s 2 and 3, intermediate in #9 and least in #1. Grain K concentration, grain K removal and plant populations were not affected by treatment main effects and there were no significant interactions for any parameter.

An ANOVA of the four split (band vs broadcast) treatments showed 2019 soil data were affected by the main effect of treatment/rate but not by placement (Table 7b). This would be expected as these paired (split band vs broadcast) plots received the same fertilizer rates in previous years. Generally, treatment 9 and 2 had greater STK than treatments 1 and 5. These STK differences were used when assigning K fertilizer rates for each treatment in 2020.

Phosphorus Study

Waseca

An ANOVA of all 16 treatments showed most corn production parameters, except for grain yield, were affected by past (varied STP) and present (2020 fertilizer rate) treatments (Table 8). Corn grain yields ranged from 209 to 229 bu/ac among treatments but were not statistically different (P>F = 0.291). Generally, grain moisture was greatest in treatments with low STP (Bray P1 ≤10 ppm) and did not receive P fertilizer for corn in 2020 compared with treatments that did receive P fertilizer or had Bray P1 >10 ppm. Inadequate P fertility can retard growth and development of corn and therefore lead to greater grain moisture at harvest. Ear leaf P and grain P concentrations were generally greatest in treatments with high STP (2019 Bray P >17 ppm, treatment #'s 13, 14 and 16); intermediate in treatments with medium STP or Low STP and received P fertilizer; and least in treatments with low STP that didn't receive P fertilizer (treatment # 4). Nearly all treatments had ear leaf P within the reported critical range of 0.2 to 0.4% (Univ. of Minnesota Extension website). Final plant populations were significantly different among treatments (P = 0.091); however, populations ranged from 33,000 to 33,900 plants/ac therefore it is unlikely these differences affected yields significantly. Grain P removal ranged from 18.8 to 29.3 lb

P/ac among treatments and averaged 24.3 lb P/ac or 55.6 lb P_2O_5/ac. Treatment differences in grain P removal generally paralleled the trends/differences observed in grain P concentration.

Soil test P in the 0- to 6-inch depth varied greatly among treatments due to the varied rates of fertilizer P that were previously applied at Waseca (Table 8). Bray P1 in 2019 soil samples ranged from 4.5 ppm in treatment #1 (zero lb P applied since 2010) to 31.9 ppm in treatment #14 (521 lb P_2O_5 applied since 2010). Bray P1 in 2020 soil samples ranged from 5.5 ppm in treatment #4 to 27.6 ppm in treatment #14. Soil test P increased from 1 to 5 ppm in 2020 compared with 2019 in treatments that received fertilizer P in 2020; whereas, STP decreased about 1 to 4 ppm in treatments that didn't receive P in 2020.

An ANOVA of the eight split (band vs broadcast) treatments showed corn grain yields were not affected by the main effects of treatment/rate (main plot) and placement (sub plot) at Waseca (Table 9). This is an important finding, as it shows when adequately fertilized, yield level (potential) was not greater in treatments with greater STP. These data support the use of the sufficiency approach for P fertilization of corn. It should be noted that all eight treatments in this comparison had Bray P1 <10 ppm in 2019; therefore, none of the 2020 split plot comparisons had High (Bray P1 of 16 to 20 ppm) or Very High (Bray P1 ≥21 ppm) STP levels. Corn grain moisture was slightly (0.3 percentage points) greater with broadcast application than with band. When averaged across placement (sub plots), ear leaf P concentration was least in treatment # 1 which hadn't received fertilizer P until the 2020 growing season (old control plot). A significant treatment/rate × placement interaction for ear leaf P concentration showed broadcast P application had greater ear leaf P than band application in treatment #1 (old control plot); whereas, band application had greater ear leaf P than broadcast in treatment #11. The authors have no explanation for this finding. Grain P concentration and grain P removal were affected by the main effect of treatment/rate but not by P fertilizer placement. Grain P concentration and P removal were least in treatment #1, intermediate in treatment #'s 2 and 5 (both had low STP in 2019), and were greater with other treatments. Final plant populations were not affected by treatments.

An ANOVA of the eight split (band vs broadcast) treatments showed STP in 2019 was different among P treatments/rates but was not affected by placement (Table 9). This would be expected as these paired (split band vs broadcast) plots received the same fertilizer rates in previous years; whereas, the individual treatments had varied rates of P applied in previous years. Interestingly, there were no significant differences observed in the 2020 STP data. Phosphorus fertilizer application increased 2020 STP in all treatments compared to 2019 levels and fertilization increased the lowest STP treatments (#'s 1, 2 and 5) more than other treatments resulting in less STP variation among these 8 treatments in 2020. Fertilizer rates, applied for corn in 2020, were great enough to obtain a yield response to fertilizer P, while being low enough to not dramatically reduce the probability of getting a yield response to fertilizer P addition in 2021.

Rochester

An ANOVA of all 16 treatments found only ear leaf P concentrations (*P*>F = 0.099) were affected by past (varied STP) and present (2020 fertilizer rate) treatments at Rochester (Table 10). This lack of response to fertilizer P and STP level at this site is consistent with what was observed in the previous research study (ALPS) at this location. Corn grain yields ranged from 221 to 229 bu/ac among treatments but were not statistically different (*P*>F = 0.832). Ear leaf P was quite variable and generally less in treatments with low STP and/or had no fertilizer P applied in 2020 (treatment #'s 3, 5 and 1). All treatments had ear leaf P within the reported critical range of 0.2 to 0.4%. Grain P removal ranged from 27.4 to 31.4 lb P/ac among treatments and averaged 30.0 lb P/ac or 68.8 lb P_2O_5/ac.

Soil test P in the 0- to 6-inch depth varied greatly among treatments due to the varied rates of fertilizer P that were previously applied at this site (Table 10). Bray P1 in 2019 ranged from 4.5 ppm in treatment #1 (zero lb P applied since 2010) to 20.5 ppm in treatment #14 (518 lb P_2O_5 applied since 2010). Bray P1 in 2020 ranged from 6.5 ppm in treatment #3 to 18.3 ppm in treatment #14. Phosphorus fertilization increased Bray P1 from 3 to 9 ppm in 2020 compared with 2019 values; moreover, the median increase was about 3 ppm. Bray P1 decreased about 1 to 2 ppm in treatments that did not receive P fertilizer in 2020.

An ANOVA of the seven split (band vs broadcast) treatments found corn grain yield, grain P concentration and grain P removal were not affected by the main effects of treatment/rate (main plot) and placement (sub plot) at Rochester (Table 11). Corn grain moisture was slightly (0.3 percentage points) less or drier with broadcast application than with band. When averaged across treatment/rate, ear leaf P concentration was greater with broadcast application than with band. Plant population was greater with band than with broadcast P fertilizer application, when averaged across the main effect of treatment/rate. The lack of a yield response to P fertilizer application observed at this site in 2020 and in the previous study (ALPS) nearly eliminates the ability to observe a yield response to fertilizer placement at this site.

An ANOVA of the seven split (band vs broadcast) treatments showed STP in 2019 was different among treatment/rate (effect of main plot) but was not affected by placement (Table 11). This would be expected as these paired (split band vs broadcast) plots received the same fertilizer rates in previous years; whereas, the individual treatments had varied rates of P applied in previous years. When averaged across the main effect of treatment/rate, STP in 2020 was 2.8 ppm greater with band application than with broadcast. This is a common problem with band applications of immobile nutrients in a conservation tillage system. It can be difficult to get a representative soil test result when sampling fields/plots with band applications. Further evidence of this was observed in greater variability in the 2020 soil data compared to the 2019 data.

2020 Summary

Corn grain yields were 6 bu/ac greater with band application of K than with broadcast at Rochester. At Waseca yields were numerically greater (4 bu/ac) with band K than with broadcast, but not statistically significant (P>F = 0.318). Dramatic visual differences in corn growth, height and color (K deficiency symptoms) were observed at both Waseca and Rochester. Broadcast application of K resulted in smaller plants and more K deficiency symptoms than band application. At Waseca, band application of P also resulted in greater early growth than with broadcast application, but no yield differences were observed. This study will be continued in 2021 and several more band vs broadcast comparison treatments (plots) will be added.

Outreach and Extension for the period from April 2019 through early March 2021

The PI presented/discussed the findings from this study on several occasions: 1) to the AFREC council on December 10, 2019; 2) at the SROC Agronomy Tour (online) on July 1, 2020; 3) in a written research update report to the AFREC council at their December 2020 meeting; 4) at the Strategic Farming panel discussion (online) on January 27, 2021; 5) on the Gopher Coffee Shop Podcast on January 29, 2021; 6) at the 2021 Nutrient Management Conference (online) on February 16, 2021; and 7) on the Soil Fertility Podcast on March 4, 2021. The Nutrient Management Conference, Strategic Farming panel discussion and the SROC Agronomy Tour had a combined attendance of 660.

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Table 1. Growing Season Precipitation at Waseca and Rochester.

		Air Temperature		Precipitation			
		Waseca		Waseca		Rochester	
Month	Year	Observed	Normal†	Observed	Normal†	Observed	Normal
		--- degrees F ---		----- inches -----		----- inches -----	
May	2019	53.6	58.7	6.33	3.93	7.23	3.66
Jun	2019	68.4	68.5	3.32	4.69	3.72	4.34
Jul	2019	72.6	72.0	6.43	4.42	8.53	4.53
Aug.	2019	67.4	69.8	5.34	4.75	2.57	4.66
Sep.	2019	64.8	61.3	6.69	3.67	6.76	3.66
May-Sep.	Total			28.11	21.46	28.81	20.85
May	2020	56.7	58.7	4.27	3.93		3.66
Jun	2020	72.2	68.5	5.83	4.69		4.34
Jul	2020	73.2	72.0	5.43	4.42		4.53
Aug.	2020	70.3	69.8	7.03	4.75		4.66
Sep.	2020	59.5	61.3	2.17	3.67		3.66
May-Sep.	Total			24.63	21.46		20.85

† 30-Yr normal, 1981-2010.

Table 2. Soybean production, K removal, and STK as affected by past and 2019 fertilizer K rates at Waseca.

Trt	Old main plot STK level	Fertilizer Rate Old	Fertilizer Rate 2019	Seed Yield	Seed H_2O	Leaf [K]	Seed [K]	Seed K Removal	Soil Test K (0-6 inch) Jun Dry	Jun Moist	Oct Dry	Oct Moist
#		-- lb K_2O/ac --		bu/ac	%	%	%	lb K/ac	------------------- ppm			------------------
1	Low	0	0	51.7 f†	10.6 f		1.33 h	35.9 f	97 f	47 g	93 d	45 g
2	Low	60	0	58.4 d	10.8 ef		1.50 f	45.6 d	104 ef	56 fg	95 d	53 efg
3	Low	120	0	59.4 cd	10.9 cde		1.55 de	48.2 bcd	131 cd	76 e	125 c	69 cde
4	Low	180	0	62.8 a	11.2 ab		1.58 bcd	51.7 a	122 cd	81 de	130 c	84 bc
5	Medium	0	0	54.2 e	10.6 f		1.41 g	39.8 e	101 f	52 fg	110 cd	52 fg
6	Medium	60	60	59.0 d	11.1 abcd		1.62 bc	49.8 abc	139 bc	88 de	126 c	72 cd
7	Medium	120	0	60.3 bcd	11.1 abcd		1.57 cd	49.5 abc	136 cd	82 de	127 c	76 cd
8	Medium	180	0	61.8 ab	11.1 abc		1.60 bcd	51.4 ab	153 ab	108 bc	153 b	92 b
9	High	0	0	59.1 d	10.9 de		1.51 ef	46.4 cd	121 de	70 ef	109 cd	64 def
10	High	60	0	60.3 bcd	11.0 bcde		1.57 cd	49.5 abc	138 bcd	95 cd	118 c	83 bc
11	High	120	120	59.8 bcd	11.3 a		1.69 a	52.6 a	161 a	123 ab	176 a	139 a
12	High	180	0	61.4 abc	11.2 ab		1.63 b	52.2 a	167 a	135 a	170 ab	140 a
Old Treatment (level, old K rate, 2019 K rate)												
P > *F*:				<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

† Means seperated by letters show significance among the treatments.

Table 3. Soybean production, K removal, and STK as affected by past and 2019 fertilizer K rates at Rochester.

Trt	Old main plot STK level	Fertilizer Rate Old	Fertilizer Rate 2019	Seed Yield	Seed H_2O	Leaf [K]	Seed [K]	Seed K Removal	Soil Test K (0-6 inch) Jun Dry	Jun Moist	Oct Dry	Oct Moist
#		-- lb K_2O/ac --		bu/ac	%	%	%	lb K/ac	------------------- ppm			------------------
1	Low	0	0	58.1 d†	12.6		1.50 d	45.4 d	95 f	69 f	92 h	58 f
2	Low	60	0	66.4 b	12.9		1.68 bc	58.3 b	110 def	94 ef	98 gh	67 ef
3	Low	120	0	69.7 a	13.1		1.70 bc	61.9 ab	147 c	133 cd	128 ef	115 cd
4	Low	180	0	69.2 a	13.3		1.74 ab	62.6 ab	167 bc	170 b	146 cd	127 c
5	Medium	0	0	63.9 c	12.9		1.55 d	51.8 c	98 ef	86 ef	97 gh	71 ef
6	Medium	60	60	69.2 a	13.1		1.68 bc	60.7 ab	119 d	106 de	112 fg	91 de
7	Medium	120	0	68.1 ab	13.3		1.70 bc	60.6 ab	149 c	153 bc	138 de	120 cd
8	Medium	180	0	70.0 a	13.2		1.74 ab	63.6 a	176 b	164 b	160 bc	140 c
9	High	0	0	67.8 ab	13.2		1.64 c	58.2 b	117 de	97 e	103 gh	93 de
10	High	60	0	69.6 a	13.4		1.68 bc	60.9 ab	147 c	128 cd	133 de	114 cd
11	High	120	120	68.8 a	12.9		1.80 a	64.7 a	216 a	236 a	201 a	215 a
12	High	180	0	69.7 a	13.3		1.72 b	62.6 ab	176 b	173 b	165 b	173 b
Old Treatment (level, old K rate, 2019 K rate)												
P > *F*:				<0.001	0.18		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

† Means seperated by letters show significance of among the treatments.

Table 4. Soybean production, P removal as affected by Bray P1 in 2019 at Waseca.

Trt	Old main Bray P level	Fertilizer Rate Total^	Fertilizer Rate 2017-19	Seed Yield	Seed H_2O	Seed [P]	Seed P Removal	Bray P1
#		-- lb P_2O_5/ac --		bu/ac	%	%	lb P/ac	ppm
1	Low	0	0	48.6 f†	10.9	0.39 h	9.7 h	5 h
2	Low	150	0	56.6 cde	11.1	0.42 fgh	12.6 efg	7 fgh
3	Low	150	0	59.6 abc	11.1	0.50 bcd	15.4 bcd	8 efgh
4	Low	150	0	55.9 de	11.0	0.43 fgh	12.5 fg	7 fgh
5	Medium	143	0	54.8 e	11.0	0.41 gh	11.7 g	6 gh
6	Medium	240	0	58.0 abcd	11.0	0.45 efg	13.7 def	9 efg
7	Medium	233	0	58.3 abcd	11.0	0.46 def	14.1 cdef	9 efg
8	Medium	240	0	58.6 abcd	11.0	0.50 bcd	15.3 bcd	10 def
9	High	270	0	57.2 bcde	11.0	0.48 cde	14.2 cde	8 efg
10	High	353	0	59.3 abc	11.1	0.53 b	16.4 b	11 de
11	High	270	0	59.3 abc	11.3	0.51 bc	15.7 bc	9 efg
12	High	300	0	58.5 abcd	11.2	0.44 efg	13.5 def	10 def
13	V. high	401	0	60.1 ab	11.2	0.54 b	16.7 ab	17 bc
14	V. high	521	0	60.8 a	11.2	0.59 a	18.6 a	32 a
15	V. high	364	0	60.3 ab	11.1	0.51 bcd	16.1 b	14 cd
16	V. high	424	0	61.0 a	11.2	0.52 bc	16.6 ab	18 b
Old Treatment (level, total P applied and 2019 P rate)								
P > *F*:				<0.001	0.697	<0.001	<0.001	<0.001

^ Total P_2O_5 applied from 2010 through 2016 (average rate across replications).

† Means seperated by letters show significance of among the treatments.

Table 5. Soybean production, P removal as affected by Bray P1 in 2019 at Rochester.

Trt	Old main Bray P level	Fertilizer Rate Total^	Fertilizer Rate 2017-19	Seed Yield	Seed H_2O	Seed [P]	Seed P Removal	Bray P1
#		-- lb P_2O_5/ac --		bu/ac	%	%	lb P/ac	ppm
1	Low	0	0	65.2	12.3	0.54 f	18.4	5 h
2	Low	150	0	65.9	12.1	0.54 ef	18.7	7 efgh
3	Low	150	0	64.5	12.1	0.54 ef	18.2	9 defg
4	Low	150	0	64.0	12.4	0.59 bcd	19.6	7 fgh
5	Medium	135	0	65.2	12.6	0.56 cdef	19.2	6 gh
6	Medium	225	0	63.9	12.4	0.59 abcd	19.7	8 efg
7	Medium	221	0	64.5	12.4	0.57 cdef	19.1	10 de
8	Medium	229	0	66.0	12.3	0.59 bcd	20.2	8 defg
9	High	266	0	63.6	12.5	0.56 def	18.7	9 defg
10	High	349	0	64.7	12.3	0.60 abcd	20.4	14 b
11	High	263	0	62.1	12.2	0.58 bcde	18.8	9 def
12	High	293	0	64.3	12.1	0.59 abcd	19.9	11 cd
13	V. high	401	0	64.2	12.2	0.63 a	21.1	13 bc
14	V. high	518	0	63.1	12.3	0.59 abcd	19.5	21 a
15	V. high	356	0	64.4	12.6	0.61 ab	20.6	11 cd
16	V. high	435	0	64.2	12.2	0.61 abc	20.3	15 b
Old Treatment (level, total P applied and 2019 P rate)								
P > *F*:				0.323	0.620	0.013	0.182	<0.001

^ Total P_2O_5 applied from 2010 through 2016 (average rate across replications).

† Means seperated by letters show significance among the treatments.

Table 6a. Corn production, ear leaf K, K removal, and STK as affected by K fertilization at Waseca in 2020.

	Fertilizer Rate		Grain	Grain	Ear leaf	Grain	Grain K	Final Plant	2019 Soil Test K (0-6 inch)			
Trt	2019	2020	Yield	Moisture	[K]	[K]	Removal	Pop.	Jun Dry	Jun Moist	Oct Dry	Oct Moist
#	-- lb K_2O/ac --		bu/ac	%	%	%	lb K/ac	pl×10^3/ac	------------------ ppm ------------------			
1	0	60	232	22.8 a†	0.78 ef	0.353	38.8	33.8	93 e	46 f	89 e	46 d
2	0	45	219	22.5 ab	1.02 cd	0.323	33.3	33.3	100 e	57 def	106 de	54 cd
3	0	0	227	21.6 abcde	0.78 f	0.328	35.2	33.5	137 bcd	87 bcd	133 bcd	74 bcd
4	0	0	234	20.1 f	0.97 cdef	0.318	35.0	32.8	126 d	79 cde	131 bcd	78 bcd
5	0	60	234	22.2 abc	0.95 cdef	0.345	38.1	33.4	99 e	51 ef	103 de	53 cd
6	60	60	227	22.2 abc	0.99 cde	0.345	37.1	33.0	121 d	81 cde	125 cd	62 bcd
7	0	0	225	21.6 abcd	0.96 cdef	0.338	35.9	33.9	131 cd	78 cde	113 de	79 bcd
8	0	0	233	20.4 ef	1.11 c	0.328	36.1	34.0	151 b	116 b	146 bc	92 b
9	0	45	247	21.3 bcde	1.09 cd	0.345	40.3	33.8	119 d	70 def	106 de	68 bcd
10	0	0	242	21.7 abcd	0.91 def	0.323	36.9	34.0	147 bc	103 bc	121 cd	83 bc
11	120	120	238	21.1 cdef	1.66 a	0.335	37.7	33.6	151 b	113 b	161 ab	131 a
12	0	0	242	20.8 def	1.41 b	0.325	37.3	33.9	184 a	153 a	186 a	149 a
Treatment (2019 K rate, 2020 K rate)												
P > F:			0.656	0.046	<0.001	0.353	0.185	0.481	<0.001	0.002	0.006	0.004
Avg. LSD 0.10:			NS	1.2	0.20	NS	NS	NS	19	31	31	33

† Means with different letters within a column show significant differences among the treatments at alpha=0.10.

Table 6b. Corn production, ear leaf K, K removal, and STK as affected by rate and placement of K at Waseca in 2020.

	Fertilzer K		Grain	Grain	Ear leaf	Grain	Grain K	Final Plant	2019 Soil Test K (0-6 inch)			
Trt	Placement	Rate	Yield	Moisture	[K]	[K]	Removal	Pop.	Jun Dry	Jun Moist	Oct Dry	Oct Moist
#			bu/ac	%	%	%	lb K/ac	pl×10^3/ac	------------------ ppm ------------------			
1	Band	60	239	20.7	0.84	0.336	37.9	34.4 ab	99	49	86	43 de
1	Broadcast	60	225	24.7	0.73	0.371	41.1	33.2 cd	87	43	92	49 bc
2	Band	45	219	22.5	1.11	0.346	36.1	32.5 d	99	54	121	57 abcd
2	Broadcast	45	219	22.5	0.93	0.301	30.9	34.1 abc	101	59	91	52 bcd
5	Band	60	238	21.3	0.92	0.326	36.6	33.8 abc	99	52	88	49 ce
5	Broadcast	60	230	23.0	0.97	0.366	39.9	32.9 d	98	51	119	57 abd
9	Band	45	244	20.8	1.11	0.336	38.7	33.5 bd	121	79	96	65 bc
9	Broadcast	45	249	21.9	1.07	0.356	42.1	34.1 ac	118	62	117	71 a
Stats for Main Effects of RCB Design with a Split-plot Arrangement												
Main plot treatment and K rate												
1		60	232	22.7	0.79	0.354	39.5 A	33.8	93	46	89	46
2		45	219	22.5	1.02	0.324	33.5 B	33.3	100	57	106	54
5		60	234	22.2	0.95	0.346	38.2 A	33.4	99	51	103	53
9		45	247	21.3	1.09	0.346	40.4 A	33.8	119	70	106	68
P > F:			0.554	0.668	0.202	0.484	0.100	0.573	0.286	0.230	0.597	0.166
Sub plot (band vs broadcast application for 2020)												
Band			235	21.3 B	1.00	0.336	37.3	33.6	104	59	98	53 B
Broadcast			231	23.0 A	0.93	0.349	38.5	33.6	101	54	105	57 A
P > F:			0.318	0.096	0.465	0.471	0.528	1.000	0.499	0.136	0.554	0.029
Interaction												
Main plot × sub			0.470	0.491	0.818	0.570	0.485	0.006	0.797	0.131	0.476	0.100
Avg. LSD 0.10:			NS	NS	NS	NS	NS	1.0	NS	NS	NS	15

Table 7a. Corn production, ear leaf K, K removal, and STK as affected by K fertilization at Rochester in 2020.

Trt	Fertilizer Rate 2019	Fertilizer Rate 2020	Grain Yield	Grain Moisture	Ear leaf [K]	Grain [K]	Grain K Removal	Final Plant Pop.	2019 Soil Test K (0-6 inch) Jun Dry	Jun Moist	Oct Dry	Oct Moist
#	-- lb K_2O/ac --		bu/ac	%	%	%	lb K/ac	pl×10^3/ac	------------------- ppm		------------------	
1	0	60	228	19.2 a†	1.14 f	0.369	39.8	32.0	95 f	69 f	92 h	58 f
2	0	45	229	18.7 a	1.32 e	0.363	39.3	31.1	110 def	94 ef	98 gh	68 ef
3	0	0	232	17.5 bc	1.23 ef	0.356	39.1	32.5	147 c	133 cd	128 ef	115 cd
4	0	0	229	17.3 c	1.47 d	0.364	39.4	31.5	167 bc	171 b	146 cd	128 c
5	0	60	230	19.3 a	1.29 e	0.360	39.2	32.0	98 ef	86 ef	97 gh	71 ef
6	60	60	230	18.8 a	1.52 cd	0.373	40.6	31.9	119 d	106 de	112 fg	91 de
7	0	0	230	17.5 bc	1.26 ef	0.354	38.5	31.9	149 c	153 bc	138 de	120 cd
8	0	0	228	17.3 c	1.62 bc	0.363	39.1	31.8	176 b	164 b	160 bc	140 c
9	0	45	234	19.2 a	1.24 ef	0.358	39.6	31.9	117 de	97 e	103 gh	93 de
10	0	0	231	18.1 b	1.22 ef	0.364	39.8	31.2	147 c	128 cd	133 de	114 cd
11	120	120	232	18.0 b	2.07 a	0.380	41.6	31.7	216 a	236 a	201 a	215 a
12	0	0	236	17.1 c	1.67 b	0.366	41.0	31.6	176 b	173 b	165 b	173 b
Treatment (2019 K rate, 2020 K rate)												
P > F:			0.806	<0.001	<0.001	0.657	0.573	0.403	<0.001	<0.001	<0.001	<0.001
Avg. LSD 0.10:			NS	0.6	0.14	NS	NS	NS	21	28	17	29

† Means with different letters within a column show significant differences among the treatments at alpha=0.10.

Table 7b. Corn production, ear leaf K, K removal, and STK as affected by rate and placement of K at Rochester in 2020.

Trt	Fertilzer K Placement	Fertilzer K Rate	Grain Yield	Grain Moisture	Ear leaf [K]	Grain [K]	Grain K Removal	Final Plant Pop.	2019 Soil Test K (0-6 inch) Jun Dry	Jun Moist	Oct Dry	Oct Moist
#			bu/ac	%	%	%	lb K/ac	pl×10^3/ac	------------------- ppm		------------------	
1	Band	60	233	17.9	1.21	0.359	39.5	31.8	91	70	95	57
1	Broadcast	60	224	20.4	1.07	0.378	40.0	32.1	99	68	89	60
2	Band	45	233	18.1	1.39	0.370	40.7	31.1	113	99	102	71
2	Broadcast	45	225	19.4	1.26	0.355	37.8	31.2	108	90	95	64
5	Band	60	230	18.7	1.27	0.351	38.2	32.0	97	82	92	69
5	Broadcast	60	229	19.9	1.30	0.369	40.1	32.0	99	91	102	74
9	Band	45	236	18.8	1.21	0.348	38.9	31.9	113	93	105	93
9	Broadcast	45	231	19.6	1.27	0.368	40.3	32.0	121	102	101	93
Stats for Main Effects of RCB Design with a Split-plot Arrangement												
Main plot treatment and K rate												
1		60	228	19.2	1.14 B	0.369	39.8	32.0	95 C	69 B	92	58 B
2		45	229	18.7	1.32 A	0.363	39.3	31.1	110 AB	94 A	98	68 B
5		60	230	19.3	1.29 A	0.360	39.2	32.0	98 BC	86 A	97	71 B
9		45	234	19.2	1.24 AB	0.358	39.6	31.9	117 A	97 A	103	93 A
P > F:			0.441	0.327	0.064	0.654	0.950	0.455	0.053	0.016	0.199	0.010
Sub plot (band vs broadcast application for 2020)												
Band			233 A	18.4 B	1.27	0.357	39.3	31.7	103	86	99	72
Broadcast			227 B	19.8 A	1.22	0.368	39.5	31.8	106	87	97	73
P > F:			0.044	<0.001	0.329	0.128	0.814	0.727	0.467	0.696	0.520	0.868
Interaction												
Main plot × sub			0.751	0.132	0.303	0.213	0.241	0.988	0.675	0.446	0.192	0.461
Avg. LSD 0.10:			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 8. Corn production, ear leaf P, grain P, P removal, and Bray P1 as affected by P fertilization at Waseca in 2020.

Trt	Fertilizer Rate Total^	Fertilizer Rate 2020	Grain Yield	Grain Moisture	Ear leaf [P]	Grain [P]	Grain P Removal	Final Plant Pop.	2019 Bray P1	2020 Bray P1
#	-- lb P_2O_5/ac --		bu/ac	%	%	%	lb K/ac	pl×10^3/ac	ppm	ppm
1	0	45	212	22.4 egh†	0.199 de	0.204 fg	20.5 fg	33.8 a	4.5 h	8.5 e
2	150	30	215	22.5 efgh	0.211 cde	0.209 efg	21.2 efg	33.4 abc	7.4 fgh	8.8 e
3	150	30	224	22.6 defgh	0.231 bcd	0.250 ab	26.5 ab	33.9 a	7.5 fgh	9.4 de
4	150	0	209	25.9 a	0.184 e	0.188 g	18.8 g	33.3 bc	7.0 fgh	5.5 f
5	143	45	219	22.4 gh	0.237 bc	0.217 def	22.4 def	33.5 abc	5.6 gh	9.4 de
6	240	30	223	22.5 efgh	0.249 b	0.229 bcdef	24.2 bcde	33.9 a	9.3 efg	10.8 cde
7	233	30	227	23.1 cdefg	0.241 bc	0.233 bcde	25.1 bcd	33.7 ab	8.8 efg	11.0 cde
8	240	0	223	24.2 b	0.214 cde	0.223 cdef	23.7 bcdef	33.2 bc	10.0 def	8.3 ef
9	270	30	218	22.3 h	0.231 bcd	0.232 bcde	23.9 bcde	33.5 abc	8.3 efg	13.4 c
10	353	0	219	22.7 defgh	0.228 bcd	0.239 bcd	24.8 bcd	33.8 a	11.3 de	10.1 de
11	270	30	226	22.9 cdefgh	0.239 bc	0.245 abc	26.2 ab	33.9 a	9.0 efg	11.8 cd
12	300	0	221	23.6 bc	0.231 bcd	0.216 defg	22.6 cdef	33.0 c	9.9 def	8.6 e
13	401	0	221	23.2 cde	0.256 ab	0.251 ab	26.2 ab	33.3 bc	17.3 bc	13.0 c
14	521	0	229	22.9 cdefgh	0.291 ab	0.269 a	29.3 a	33.5 abc	31.9 a	27.6 a
15	364	0	220	23.4 cd	0.233 bcd	0.249 abc	26.1 abc	33.9 a	13.6 cd	11.9 cd
16	424	0	227	23.2 cdef	0.263 ab	0.249 abc	26.8 ab	33.4 abc	17.9 b	16.6 b
Treatment (total P applied and 2020 rate)										
P > *F*:			0.291	<0.001	0.004	<0.001	<0.001	0.091	<0.001	<0.001
Avg. LSD (0.10):			NS	0.77	0.035	0.027	3.4	0.5	3.8	2.9

^ Total P_2O_5 applied from 2010 through 2017 (no fertilzer P applied for 2018 & 2019 crops).

† Means with different letters within a column show significant differences among the treatments at alpha=0.10.

Table 9. Corn production, ear leaf P, grain P, P removal, and Bray P1 as affected by rate and placement of P at Waseca in 2020.

Trt	Fertilizer Rate Total^	Fertilizer Rate 2020	Fertilizer Placement	Grain Yield	Grain Moisture	Ear leaf [P]	Grain [P]	Grain P Removal	Final Plant Pop.	2019 Bray P1	2020 Bray P1
#	-- lb P_2O_5/ac --			bu/ac	%	%	%	lb K/ac	pl×10^3/ac	ppm	ppm
1	0	45	Band	211	22.1	0.180 f	0.192	19.4	33.9	4.6	10.7
1	0	45	Broadcast	212	22.7	0.217 cde	0.215	21.7	33.8	4.4	6.4
2	150	30	Band	219	22.5	0.203 ef	0.207	21.4	33.4	7.2	9.2
2	150	30	Broadcast	211	22.5	0.219 cde	0.210	21.1	33.5	7.5	8.3
3	150	30	Band	224	22.5	0.237 abcd	0.253	26.7	34.0	8.0	8.0
3	150	30	Broadcast	225	22.7	0.225 bcde	0.247	26.3	33.8	7.0	10.8
5	143	45	Band	219	22.2	0.231 bcde	0.217	22.5	33.4	5.8	10.3
5	143	45	Broadcast	218	22.6	0.242 abcd	0.217	22.3	33.6	5.5	8.5
6	240	30	Band	225	22.3	0.242 abcd	0.227	24.1	34.1	9.3	10.0
6	240	30	Broadcast	221	22.7	0.255 ab	0.232	24.2	33.6	9.3	11.5
7	233	30	Band	227	23.0	0.238 abcd	0.228	24.5	33.6	8.3	11.6
7	233	30	Broadcast	228	23.1	0.245 abc	0.238	25.7	33.8	9.2	10.4
9	270	30	Band	216	22.1	0.231 bcde	0.244	25.0	33.7	8.5	15.2
9	270	30	Broadcast	220	22.5	0.231 bcde	0.219	22.7	33.3	8.0	11.6
11	270	30	Band	227	22.7	0.269 a	0.254	27.3	33.9	9.8	12.5
11	270	30	Broadcast	225	23.1	0.209 def	0.235	25.1	33.8	8.3	11.0
Stats for Main Effects of RCB Design with a Split-plot Arrangement											
Treatment/rate (main plot)											
1		45		212	22.4	0.199 C	0.204 C	20.5 D	33.8	4.5 C	8.5
2		30		215	22.5	0.211 BC	0.209 BC	21.2 CD	33.4	7.4 B	8.8
3		30		224	22.6	0.231 AB	0.250 A	26.5 A	33.9	7.5 B	9.4
5		45		219	22.4	0.237 AB	0.217 BC	22.4 BCD	33.5	5.6 C	9.4
6		30		223	22.5	0.249 A	0.229 AB	24.2 ABC	33.9	9.3 A	10.8
7		30		227	23.1	0.241 A	0.233 AB	25.1 AB	33.7	8.8 AB	11.0
9		30		218	22.3	0.231 AB	0.232 AB	23.9 ABCD	33.5	8.3 AB	13.4
11		30		226	22.9	0.239 A	0.245 A	26.2 A	33.9	9.0 A	11.8
P > F:				0.404	0.524	0.082	0.051	0.061	0.428	<0.001	0.221
Placement (sub plot)											
Band				221	22.4 B	0.229	0.228	23.9	33.7	7.7	10.9
Broadcast				220	22.7 A	0.230	0.227	23.6	33.6	7.4	9.8
P > F:				0.433	0.078	0.798	0.836	0.592	0.391	0.413	0.262
Interactions (P > F)											
Main plot x placement				0.514	0.991	0.020	0.157	0.182	0.863	0.645	0.647
Average LSD (0.10):				NS	NS	0.034	NS	NS	NS	NS	NS

^ Total P_2O_5 applied from 2010 through 2017 (no fertilzer P applied for 2018 & 2019 crops).

† Means with different letters within a column show significant differences among the treatments at alpha=0.10.

Table 10. Corn production, ear leaf P, grain P, P removal, and Bray P1 as affected by P fertilization at Rochester in 2020.

Trt	Fertilizer Rate Total^	Fertilizer Rate 2020	Grain Yield	Grain Moisture	Ear leaf [P]	Grain [P]	Grain P Removal	Final Plant Pop.	2019 Bray P1	2020 Bray P1
#	- lb P_2O_5/ac -		bu/ac	%	%	%	lb K/ac	pl×10^3/ac	ppm	ppm
1	0	45	226	18.0	0.318 cde†	0.290	31.1	31.2	4.5 h	7.3 ef
2	150	30	227	18.0	0.329 bcde	0.280	30.2	31.5	6.9 efgh	9.5 cdef
3	150	0	224	18.5	0.306 e	0.286	30.3	31.3	8.5 defg	6.5 f
4	150	30	226	18.5	0.324 bcde	0.271	28.9	31.4	6.6 fgh	15.5 ab
5	135	30	229	18.0	0.313 de	0.283	30.5	30.8	6.4 gh	9.1 cdef
6	225	30	226	18.4	0.339 bcde	0.278	29.7	31.1	8.0 efg	12.3 bc
7	221	0	224	17.9	0.324 bcde	0.284	30.1	31.2	9.5 de	7.3 ef
8	229	30	227	17.8	0.343 bcde	0.274	29.3	31.1	8.4 defg	11.0 cd
9	266	30	223	17.7	0.353 bc	0.289	30.4	31.1	8.6 defg	11.5 cd
10	349	0	222	17.9	0.360 ab	0.295	31.1	31.7	14.3 b	10.4 cde
11	263	0	221	18.5	0.338 bcde	0.279	29.2	31.7	9.3 def	8.0 def
12	293	0	224	18.1	0.347 bcd	0.281	29.8	31.2	11.0 cd	9.9 cdef
13	401	0	223	17.7	0.340 bcde	0.259	27.4	31.9	13.0 bc	11.3 cd
14	518	0	225	18.0	0.392 a	0.295	31.4	31.1	20.5 a	18.3 a
15	356	0	225	17.7	0.355 abc	0.293	31.1	31.2	10.8 cd	8.6 cdef
16	435	0	223	17.4	0.340 bcde	0.287	30.2	31.4	14.8 b	12.3 bc
Treatment (total P applied and 2020 rate)										
P > *F*:			0.832	0.655	0.099	0.609	0.692	0.961	<0.001	<0.001
Avg. LSD (0.10):			NS	NS	0.039	NS	NS	NS	2.6	3.9

^ Total P_2O_5 applied from 2010 through 2017 (no fertilzer P applied for 2018 & 2019 crops).

† Means with different letters within a column show significant differences among the treatments at alpha=0.10.

Table 11. Corn production, ear leaf P, grain P, P removal, and Bray P1 as affected by rate and placement of P at Rochester in 2020.

Trt	Fertilizer Rate Total^	Fertilizer Rate 2020	Fertilizer Placement	Grain Yield	Grain Moisture	Ear leaf [P]	Grain [P]	Grain P Removal	Final Plant Pop.	2019 Bray P1	2020 Bray P1
#	-- lb P_2O_5/ac --			bu/ac	%	%	%	lb K/ac	pl×10^3/ac	ppm	ppm
1	0	45	Band	224	18.3	0.299	0.274	29.0	31.4	4.5	5.8
1	0	45	Broadcast	228	17.8	0.336	0.308	33.1	31.0	4.5	8.7
2	150	30	Band	229	17.6	0.331	0.278	29.9	31.5	7.0	11.7
2	150	30	Broadcast	226	18.3	0.327	0.284	30.4	31.5	6.8	7.3
4	150	30	Band	229	18.8	0.300	0.258	27.6	31.7	7.3	21.8
4	150	30	Broadcast	224	18.1	0.348	0.288	30.3	31.2	6.0	9.3
5	135	30	Band	229	18.4	0.303	0.295	31.4	31.4	6.5	8.3
5	135	30	Broadcast	228	17.6	0.323	0.273	29.6	30.1	6.3	10.0
6	225	30	Band	224	18.2	0.328	0.280	29.7	31.4	7.5	15.3
6	225	30	Broadcast	228	18.7	0.353	0.275	29.6	30.8	8.5	9.3
8	229	30	Band	226	18.0	0.318	0.268	28.6	31.6	8.3	9.8
8	229	30	Broadcast	228	17.5	0.368	0.280	30.1	30.6	8.5	12.3
9	266	30	Band	226	18.1	0.345	0.283	30.1	32.0	8.8	13.3
9	266	30	Broadcast	219	17.4	0.363	0.298	30.7	30.3	8.5	9.8
Stats for Main Effects of RCB Design with a Split-plot Arrangement											
Treatment/rate (main plot)											
1		45		226	18.0	0.318	0.291	31.1	31.2	4.5 e	7.3
2		30		227	18.0	0.329	0.281	30.2	31.5	6.9 bcd	9.5
4		30		226	18.5	0.324	0.273	28.9	31.4	6.6 cd	15.5
5		30		229	18.0	0.313	0.284	30.5	30.8	6.4 d	9.1
6		30		226	18.4	0.340	0.278	29.7	31.1	8.0 abc	12.3
8		30		227	17.8	0.343	0.274	29.3	31.1	8.4 ab	11.0
9		30		223	17.7	0.354	0.290	30.4	31.1	8.6 a	11.5
P > F:				0.744	0.680	0.398	0.658	0.707	0.836	0.002	0.188
Placement (sub plot)											
Band				227	18.2 A	0.318 B	0.276	29.5	31.6 A	7.1	12.3 A
Broadcast				226	17.9 B	0.345 A	0.286	30.6	30.8 B	7.0	9.5 B
P > F:				0.673	0.080	<0.001	0.138	0.141	0.012	0.673	0.076
Interactions (P > F)											
Treatment x placement				0.592	0.165	0.167	0.300	0.411	0.758	0.435	0.107
Average LSD (0.10):				NS	NS	NS	NS	NS	NS	NS	NS

^ Total P_2O_5 applied from 2010 through 2017 (no fertilzer P applied for 2018 & 2019 crops).

† Means with different letters within a column show significant differences among the treatments at alpha=0.10.

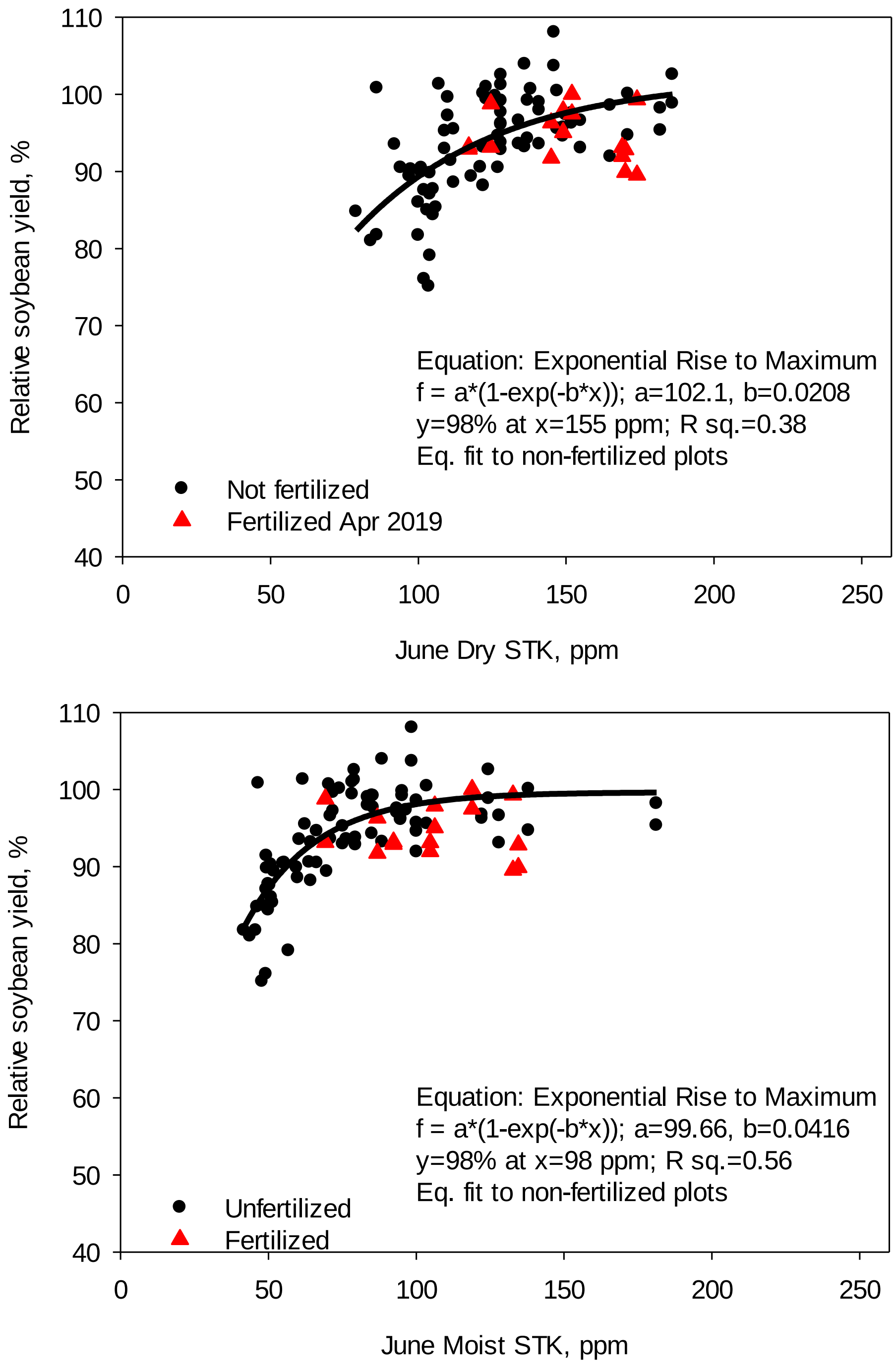

Figure 1. Relative soybean yield as affected by K fertilizer rate and soil test K in 2019 at Waseca.

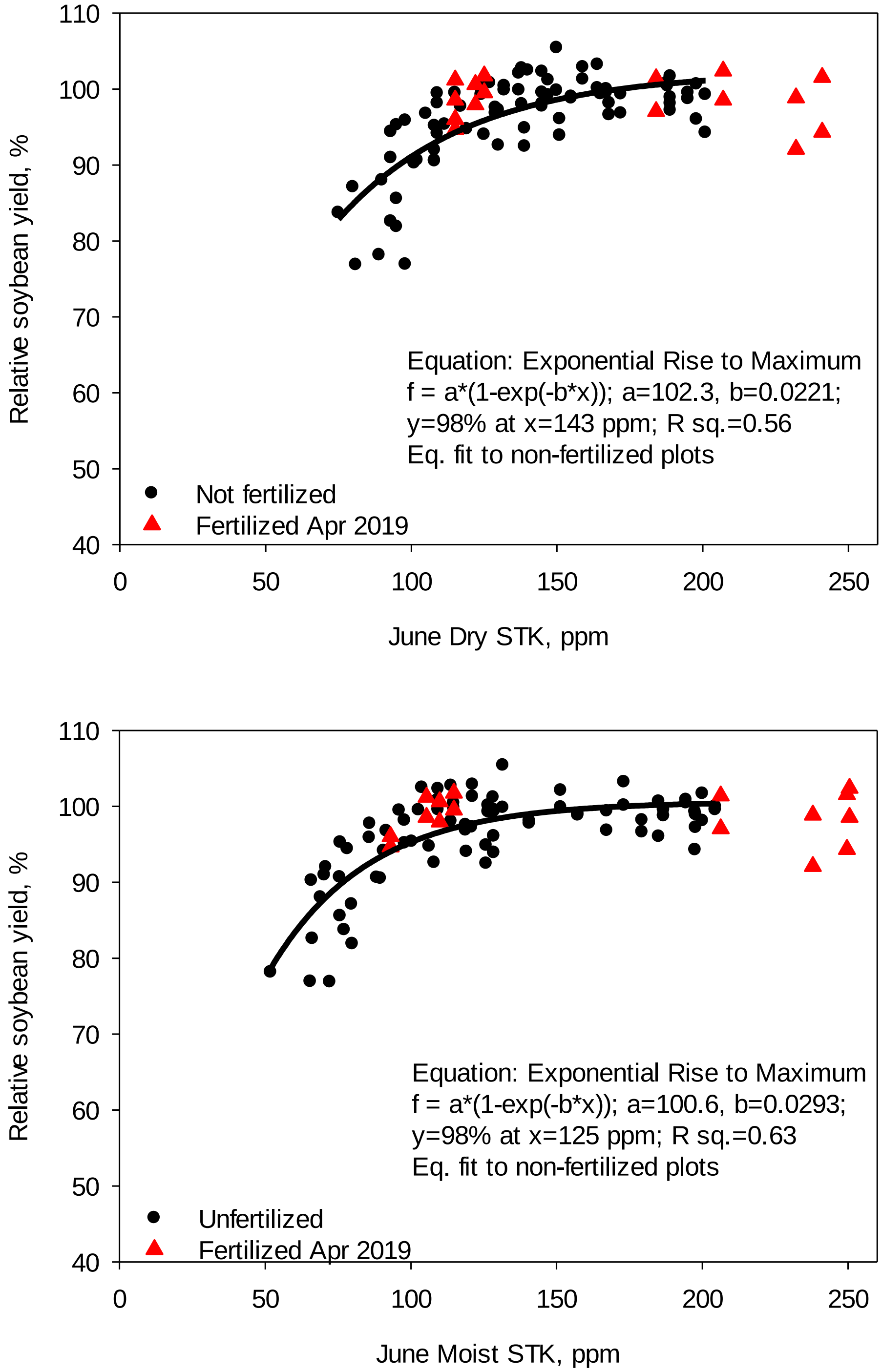

Figure 2. Relative soybean yield as affected by K fertilizer rate and soil test K in 2019 at Rochester.

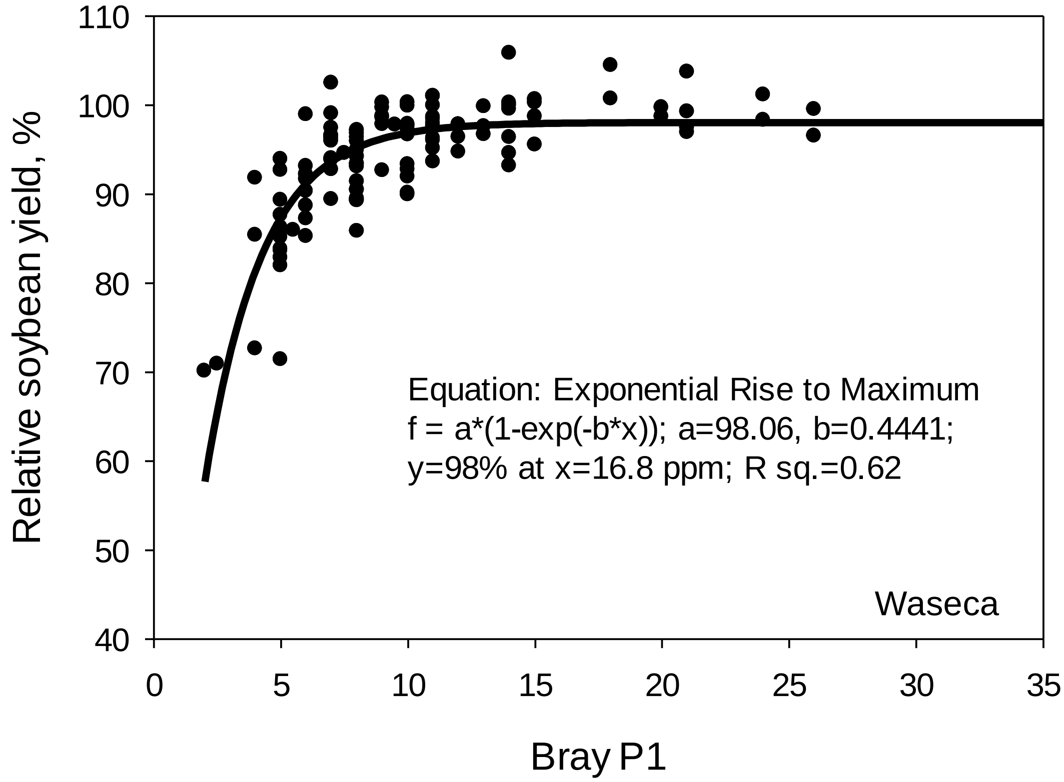

Figure 3. Relative soybean yield as affected by soil test P in 2019 at Waseca.

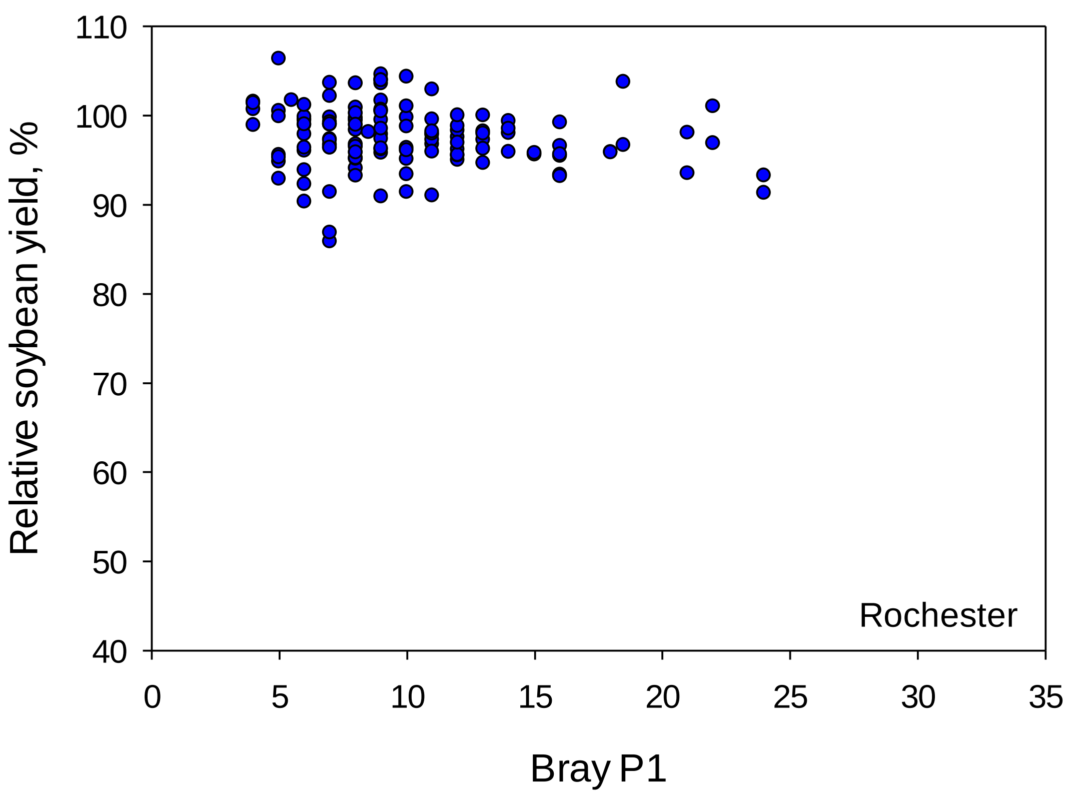

Figure 4. Relative soybean yield as affected by soil test P in 2019 at Rochester.

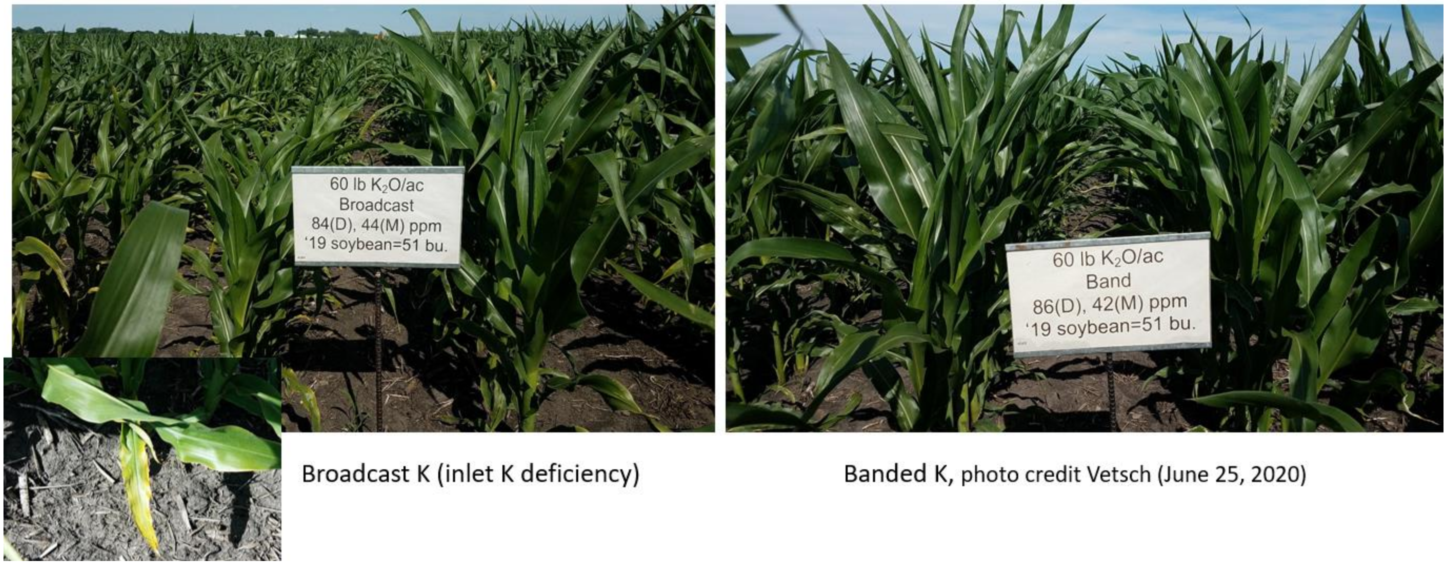

Figure 5. Band (right) application of K fertilizer enhanced early growth and development of corn in 2020 at Waseca. The broadcast treatments (left and inlet) displayed K deficiency symptoms that were not found in band treatments.

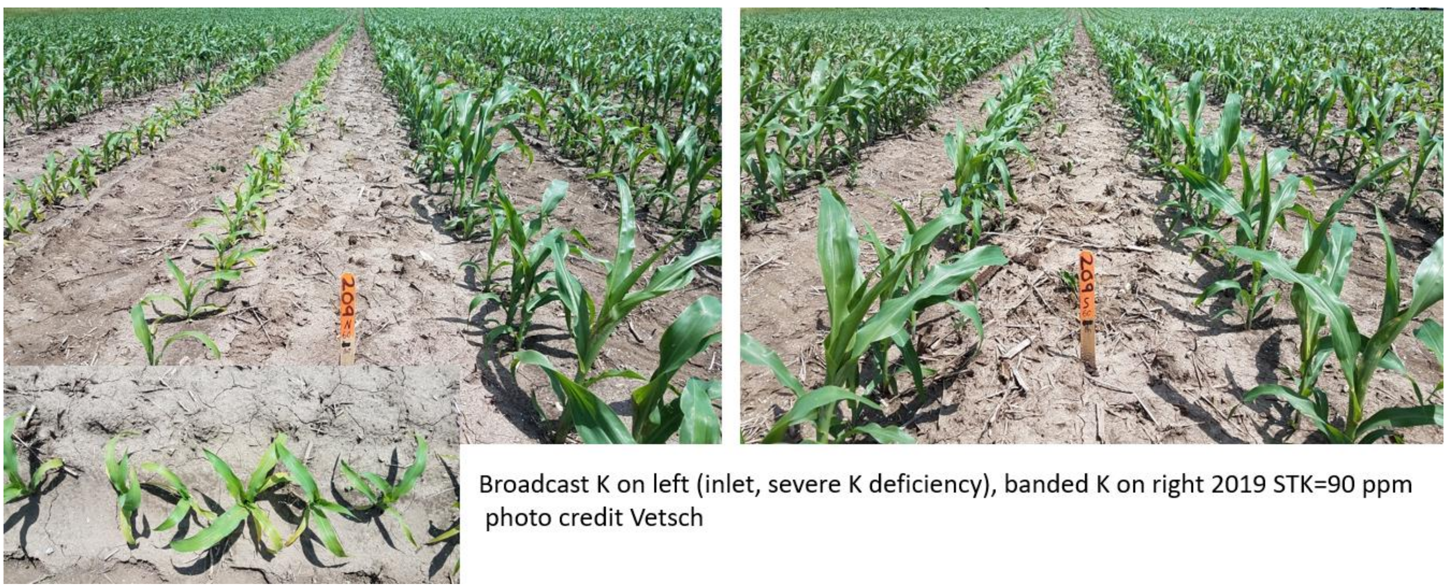

Figure 6. Band (right) application of K fertilizer enhanced early growth and development of corn in 2020 at Rochester. The broadcast treatments (left and inlet) displayed K deficiency symptoms that were not found in band treatments.

Appendix

Table A1. Experimental procedure details for each site.

Procedure	Units	Experimental site/location	
		Waseca	Rochester
2018 crop		Corn	Corn
2019 crop		Soybean	Soybean
2019 K fertilizer treatments applied		29 Apr	16 May
2019 P fertilizer treatments applied		None	None
Preplant tillage		7 & 14 May	26 May
Planting date		15 May	26 May
Variety planted		Asgrow 20X9	Asgrow 20X9
June soil sampling of P and K studies		20 Jun	13 Jun
Combine harvest		20 Oct	9 Oct
Fall soil sampling (only K study)		28 Oct	15 Oct
Fertilizer treatments applied to K study		28 Oct	---
Fertilizer treatments applied to P study		30 Oct	---
Fall tillage type		Disk	None
Fall tillage date		30 Oct	NA
2019 crop		Soybean	Soybean
2020 crop		Corn	Corn
2020 band and broadcast treatments applied		---	23 Apr
N & S application, 100-0-0-15, urea/AMS		20 Apr	23 Apr
Preplant tillage		21 Apr	23 Apr
Planting date		22 Apr	27 Apr
Hybrid planted, DeKalb GENSS		DKC 54-64RIB	DKC 50-08RIB
V4-5 N application, 50 lb N/ac urea w/NBPT		8 Jun	12 Jun
June soil sampling of P and K studies		9 Jun	16 Jun
Ear leaf sampling at V1-2		28-29 Jul	30 Jul
Combine grain harvest		5 Oct	13-14 Oct
Fall soil sampling (only K study)		9 Oct	28 Oct
2021 Broadcast fertilizer treatments applied		3 Nov	---
Fall tillage completed (disk-rip ~ 8” deep)		5 Nov	7 Nov
2021 Band fertilizer treatments applied		20 Nov	---