PROJECT DESCRIPTION:	**Are band applications of P and K more efficient and profitable than broadcast?**
ANNUAL REPORT DATE:	**April 30, 2020**
PRINCIPAL INVESTIGATOR:	**Jeffrey Vetsch**
CO-INVESTIGATOR:	**Dr. Daniel Kaiser**
ORGANIZATION:	**University of Minnesota**

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 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. Soybean seed yields were combine harvested on 9 and 20 Oct 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. 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). 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.

The 2019 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.

Results and Discussion

Weather data characterizing the 2019 growing season at Waseca are presented in Table 2. 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

Waseca

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.

Rochester

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.

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.

Outreach and Extension for the period from April 2019 through March 2020

These data were presented to the AFREC council by the PI on December 10, 2019.

Acknowledgement

Funding for this project in 2019 was provided by Minnesota’s Agriculture Fertilizer Research and Education Council (AFREC). The authors greatly appreciate the support from this organization.

References

Boomsma, C.R., M. Canepa, and T.J. Vyn. 2007. Factors affecting the relative benefit of deep-banding versus broadcast application of phosphorus and potassium for corn and soybean. Proc. North Central Extension-Industry Soil Fertility Conference. Des Moines, Iowa. Vol. 23 p. 55-63.

Borges, R and A.P. Mallarino. 2000. Grain yield, early growth, and nutrient uptake of no-till soybean as affected by phosphorus and potassium placement. Agron. J. 92:380-388.

Kaiser, D.E., J.A. Lamb and R. Eliason. 2011. Fertilizer guidelines for agronomic crops in Minnesota. Ext. Publ. 06240-S Univ. of Minnesota.

Kaiser, D.E. and J.A. Vetsch. 2017. Soil potassium availability to corn and soybean in Minnesota assessed using field moist soil samples. 2017 ASA–CSSA–SSSA Annual Meetings. Tampa, FL, Oct. 22-25. Online: https://www.acsmeetings.org/future-past-meetings

Lewandowski, A., J. Moncrief, and M. Drewitz. 2006. The Minnesota phosphorus index assessing risk of phosphorus loss from cropland. Univ. of Minnesota Extension. St. Paul. AG-BU-08423.

Mallarino, A.P., J.M. Bordoli, and R. Borges. 1999. Phosphorus and potassium placement effects on early growth and nutrient uptake of no-till corn and relationships with grain yield. Agron. J. 91:37-45.

Randall, G.W. and R.G. Hoeft. 1988. Placement methods for improved efficiency of P and K fertilizer: A review. J. of Prod. Agric. 1:70-79.

Rehm, G.W. and J.A. Lamb. 2004. Impact of banded potassium on crop yield and soil potassium in ridge-till planting. Soil Sci. Soc. Am. J. 68:629-636.

SAS Institute Inc. 2008. SAS 9.2 Users guide. SAS Institute Inc., Cary, North Carolina

Warncke, D. and J.R. Brown. 2015. Potassium and Other Basic Cations. In: M. Nathan and R Gelderman, editors. Recommended chemical soil test procedures for the North Central Region. North Central Region Publication No. 221 (Revised). SB 1001. Missouri Agri. Exp. Stn. Columbia, MO. p. 36-44.

Wolkowski, R.P. 2007. Is fall deep banded fertilizer placement superior? Proc. Of the 2007 Wisconsin Fertilizer, aglime, and pest management conference. Volume 46 p. 133-139.Gavlak, R., D. Horneck, and R.O. Miller. 2005. Soil, Plant, and Water Reference Methods for the Western Region. Western Region Extension Publication 125 (3rd edition).

Table 1. Growing Season Precipitation at Waseca and Rochester.

		Air Temperature		Precipitation			
		Waseca		Waseca		Rochester	
Month	Year	2019	Normal†	Precip.	Normal†	Precip.	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

† 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^	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.

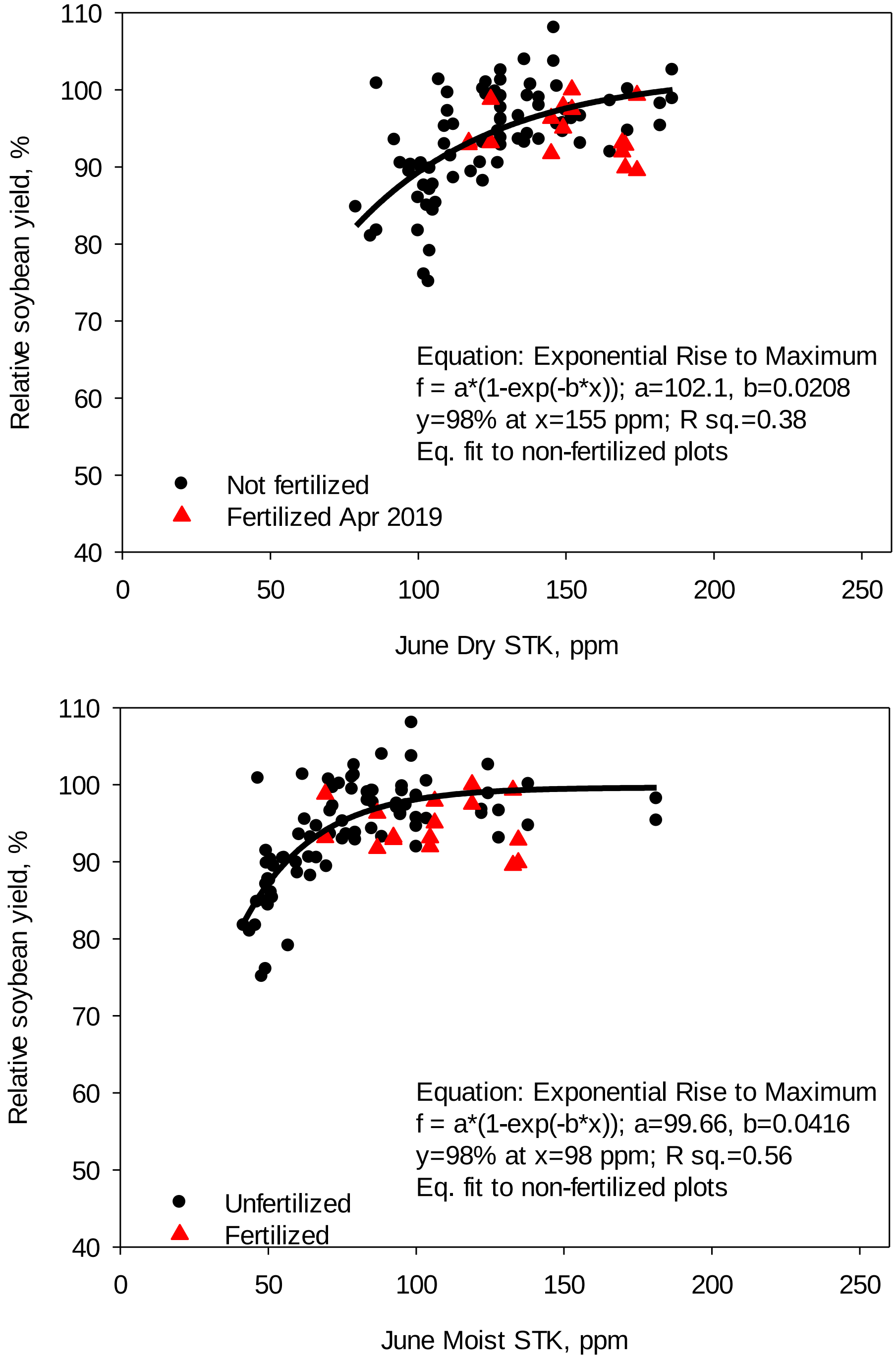

Figure 1. Relative soybean yield as affected by K fertilizer rate and soil test K in 2019 at Waseca.

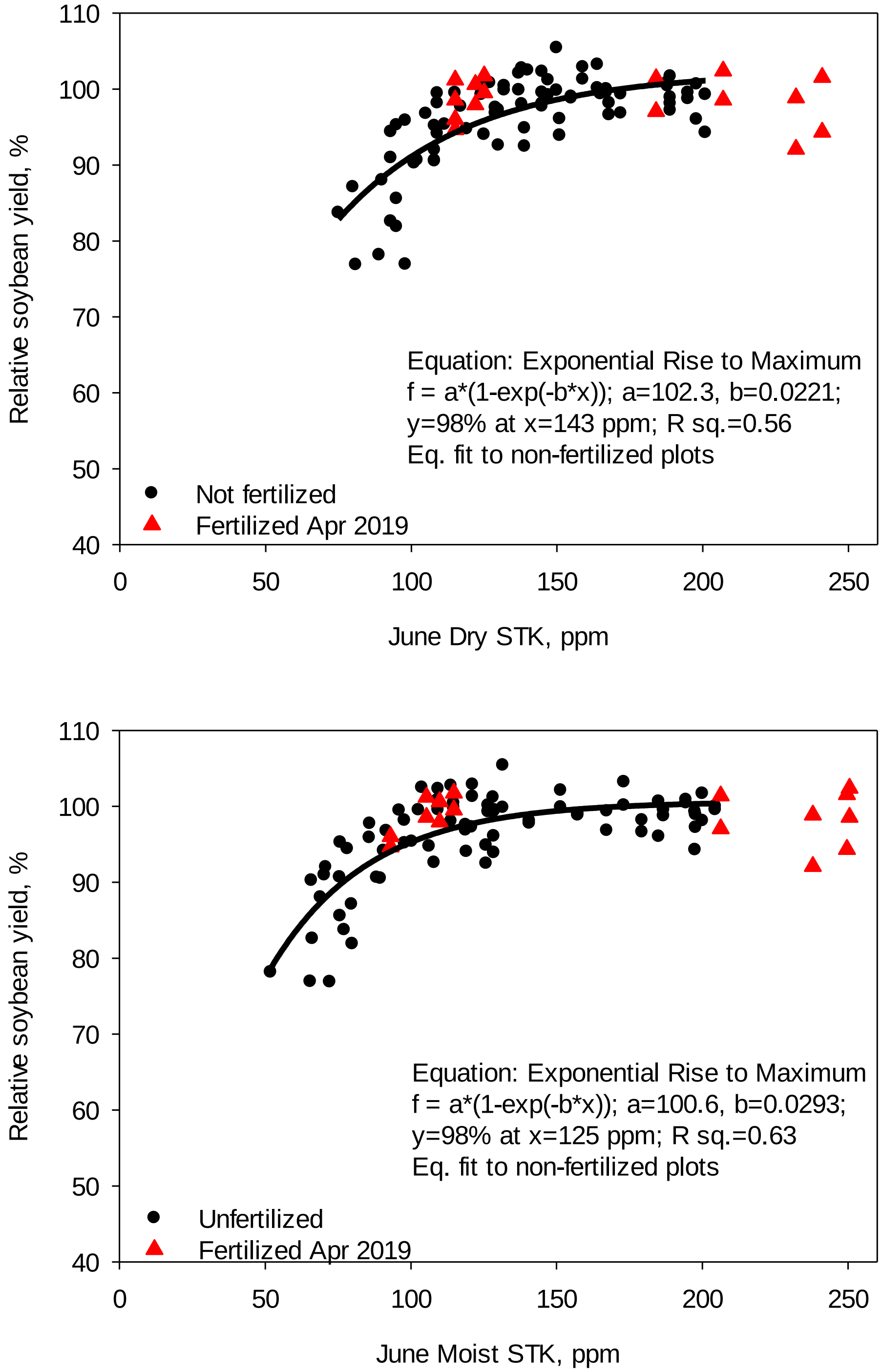

Figure 2. Relative soybean yield as affected by K fertilizer rate and soil test K in 2019 at Rochester.

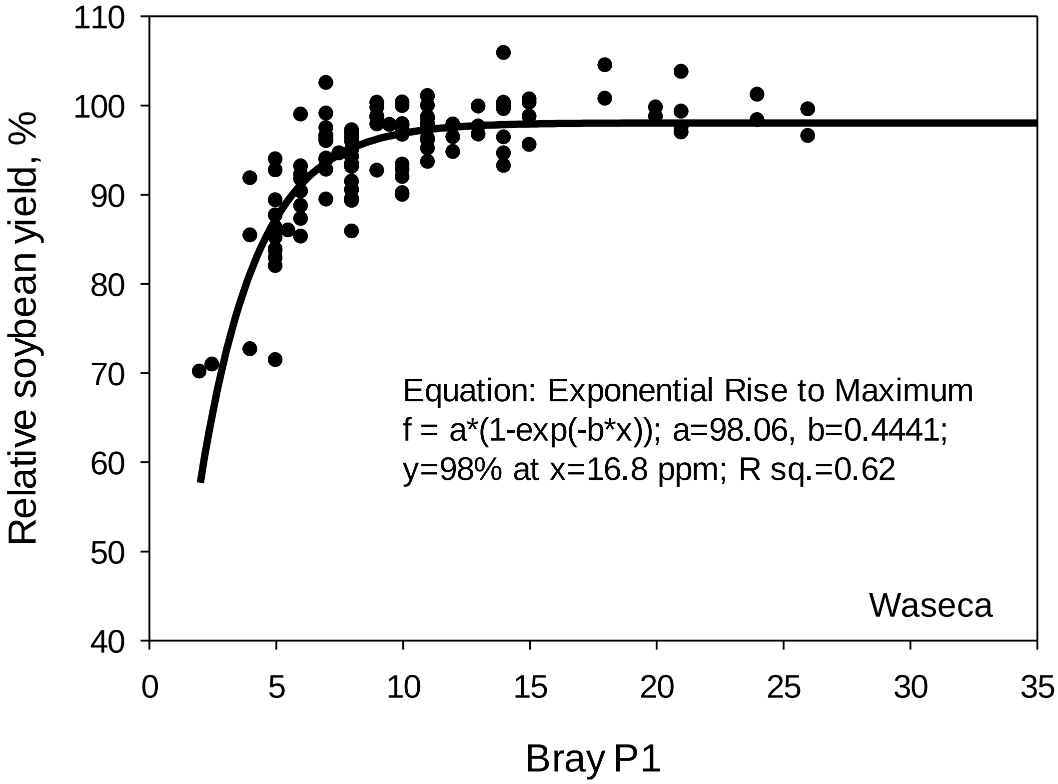

Figure 3. Relative soybean yield as affected by soil test P in 2019 at Waseca.

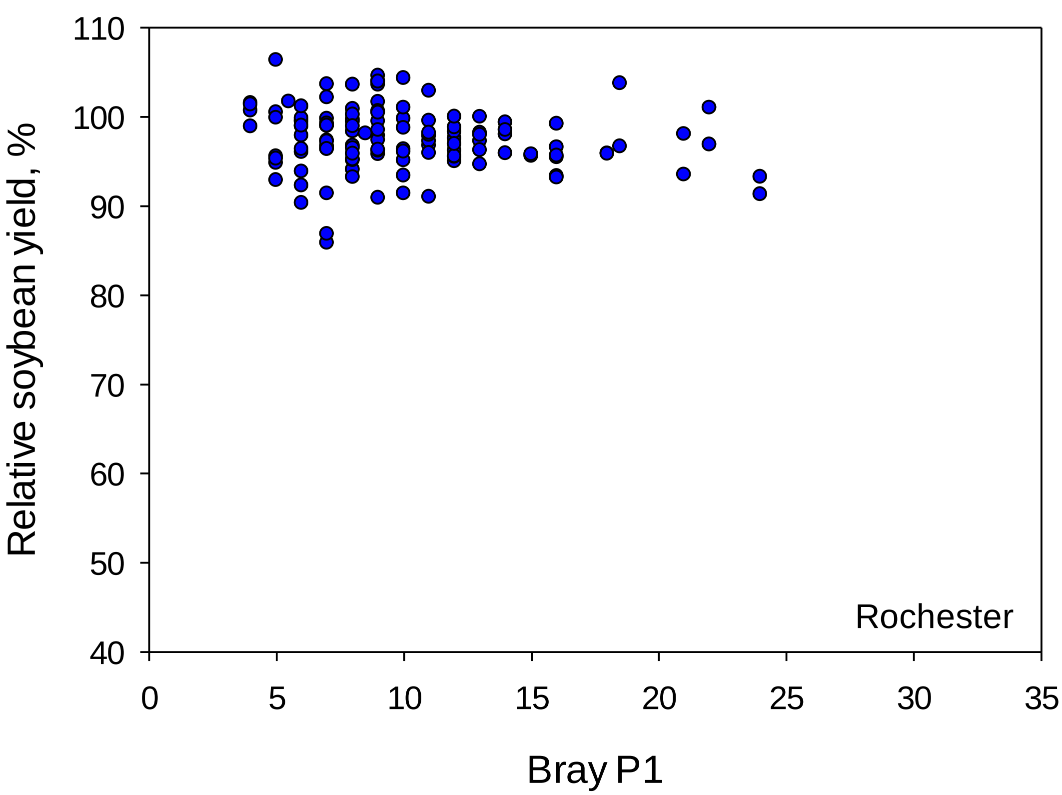

Figure 4. Relative soybean yield as affected by soil test P in 2019 at Rochester.

Appendix

Table A1. Experimental procedure details for each site in 2019.

Procedure	Units	Experimental site/location	
		Waseca	Rochester
Previous 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/Hybrid 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 treatment application to K study		28 Oct	---
Fertilizer treatment application to P study		30 Oct	---
Fall tillage type		Disk	None
Fall tillage date		30 Oct	NA