Evaluation of Potassium Fertilization Strategies for Corn and Soybean: the Buildup Phase

Jeffrey A. Vetsch and Daniel E. Kaiser
University of Minnesota
dekaiser@umn.edu

ABSTRACT

Potassium is a crop nutrient which can severely limit yield potential when deficient. Potassium fertilizer historically was low cost. Price increases have resulted in more questions as to the benefit from potassium applied for corn and soybean. The objective of this study was establish a set of trials which vary in soil test K level to be used to determine corn and soybean grain yield response to K based on initial soil test and to compare soil K analysis on moist versus air dried soil samples for determining crop response to K. Three locations were established in Minnesota on differing soil textures (sandy loam, silt loam, and clay loam soil). Two of the three sites were cropped for multiple years without K fertilizer to draw down soil test levels to low levels while the third site was managed using small rates of K applied in a band with the planter historically prior to trial establishment. Three treatments were applied at each site. Rates of 0, 60, and 120 lb K_2O were applied at two sites and 0, 40, and 80 lbs were applied at the third site. The crop grown was corn during 2012, 2013, and 2015 and soybean was grown in 2014. Soil samples were collected at a depth of six inches in Spring, early Summer (June), and fall post-harvest. Soil samples were extracted using 1 M ammonium acetate for samples which were air dried and ground or sieved and analyzed field moist. Data from this study was compiled with previous results to correlate crop response to soil test K concentration. Initial soil test K concentration was low to medium at all locations. Corn and soybean grain yield consistently responded to K application at all sits and years. The lowest rate of K applied to maintain a medium soil test K classification resulted in maximum grain yield 75% of the time while the rate to maintain a high soil K test resulted in greater yield only 25% of the time. Soil test K was increased when K was applied. Soil test K did vary based on sample timing. The three fertilizer rates resulted in K soil test values within the desired ranges mainly for the June sampling. When combined with past data the corn and soybean data analyzed together showed a wide range in soil test values between the soil test at maximum- and 95% of maximum yield and had a lower R^2 value indicating more yield variation. Analysis on moist tests improved the predictability of the test but the interpretation of critical levels was very different for the moist versus air dried test. The data indicated that a greater critical level is required for air dried soil samples for medium or fine textured soils while a lower critical level is required for very sandy soils. Overall, the data indicates some changes should be made to current K fertilizer guidelines in Minnesota.

INTRODUCTION

Until recently, research on potassium (K) fertilization of corn and soybean in Minnesota had not received a great deal of attention. Generally, resources had focused on nitrogen and phosphorus research, because of greater potential for economic return and greater environmental concerns related to these nutrients. In 2008, potash (0-0-60) price increased dramatically, it peaked at nearly $900 per metric ton (MT) in 2009 (potash.corp.com, Nov. 2014). In recent years the price of potash has ranged from $300 to $500 per MT. Commodity prices for corn and soybeans have also experienced considerable volatility during recent years. Price volatility of inputs and commodities increases financial risk for growers. These financial risks include the risk of yield loss from inadequate fertilizer application and risk of applying expensive fertilizer that may not be needed, especially on rented farmland. Applied research on corn and soybean yield responses to fertilizer K on various soils at various soil test K levels is critical for farmers managing fertilizer inputs and production risks.

Crop growth and yield response to soil and fertilizer K are affected by several soil, crop and management factors. The primary factors include: clay mineralogy, specifically K can be bound or released by soil clay particles; cycling of K from plant residues; and inconsistencies in K soil tests, usually due to soil moisture and/or drying of soil samples. Ultimately, these factors complicate K nutrition in crops and K fertilizer recommendations. Potassium is an essential nutrient of plants and it is taken up by plants in large quantities. High yielding corn and soybean crops can take up 170 and 200 lb K_2O/ac, respectively. However, crop removal of K in grain is considerably less than crop uptake. Vetsch and Kaiser (2013) found K removal in corn and soybean grain averaged 35 and 65 lb K_2O/ac, respectively.

Inconsistencies in crop responses to fertilizer K have been documented in the literature. Randall et al. (1997) found corn and soybean yield responses to K fertilization in only 3 of 24 site-years on clay loam soils at Morris and Waseca. However, corn yields averaged only 150 and 110 bu/ac at Waseca and Morris, respectively, during the study period (1974–1993). These yield levels are considerably less than those obtained today. An 18 site-year study in Iowa found K fertilization increased corn and soybean yields at 7 sites (Clover et al., 2007). All 7 responsive sites had STK in the optimum soil test category (131 to 170 ppm at that time in Iowa) the only low testing site did not respond.

Inconsistencies in crop response to fertilizer K may also be attributed to variability in the ammonium acetate soil test. Temporal variability in exchangeable K has been attributed to: soil moisture status at sampling, freezing and thawing cycles, soil types (clay mineralogy), and the time of year samples were taken (or the amount of time needed in the fall for K to leach from crop residues). Iowa's fertilizer K recommendations and relative STK categories were adjusted in 2005, because of STK uncertainty in the dry soil ammonium acetate test (Mallarino et al., 2005). Their research found economic corn yield responses on some soils at STK levels that traditionally did not respond to fertilizer K. In 2013, Iowa included recommendations for the field moist or slurry soil test because "research has indicated that the moist K test is more reliable than a test based on dried samples and is a better predictor of crop K fertilization need" (Mallarino and Sawyer, 2013). Variability in STK also makes calculating STK incline and decline rates difficult. Randall et al.

(1997) found no measureable decline in STK after a 12-yr period where no fertilizer K was applied. An annual application of 50 lb K_2O/ac generally maintained STK, while a 100 lb K_2O/ac rate increased STK about 4.4 ppm per year, however high variability in STK resulted in poor correlations and no significant differences. Reliable incline and decline rates would be very valuable to farmers and agricultural advisors who would like to know how STK might change if they choose not to apply fertilizer K when fertilizer prices increase significantly.

Cycling of K from plant residues can influence soil test K, especially when soil samples are taken in the fall. Adequate rainfall is needed to leach K from crop residues. Removing or harvesting crop residue (especially corn stover) prior to natural leaching of K from the residue can remove a significant amount of K that would otherwise be returned to the soil. Therefore, research on K uptake and removal in plant parts is important for proper management of K.

The effects of subsoil K on crop response to fertilizer K and the potential for movement of K on coarse textured soils are not well understood. Tillage practices, crop rotation, soil type (parent materials) and fertilizer placement can affect subsoil K and K stratification. Generally, research in Minnesota has not examined the effects of subsoil K on corn and soybean production. A 2013 revision of fertilizer K recommendations in Iowa removed the adjustment to K fertilizer recommendations based on subsoil K (Mallarino and Sawyer, 2013). Generally, K movement in sandy soils is not an environmental concern, but it has agronomic and economic ramifications. Frequently in a corn–soybean rotation, fertilizer P and K is applied in the fall prior to corn. Concern about K movement (leaching) in coarse textured, low CEC soils, has many farmers questioning biennial fall application of K fertilizer. Kaiser et al. (2011) showed the potential for K movement on coarse textured soils in Minnesota. Continued research is needed to determine the agronomic and economic impact of K movement in soils.

The primary goal of this research is to improve fertilizer K recommendations for corn and soybean farmers in Minnesota. The objectives of this study are 1) To establish long-term potassium fertilization experiments on highly productive K responsive soils in Minnesota, and; 2) To measure the effects of initial STK level and K fertilizer rate on yield, and; 3) To evaluate the field moist soil test as a predictor of crop response to STK levels and fertilizer K additions.

MATERIALS AND METHODS

Experimental sites were established in April of 2011 at three locations in Minnesota. Sites at the Southern Research and Outreach Center in Waseca (Nicollet–Webster clay loam, glacial till) and the Sand Plain Research Farm in Becker (Hubbard loamy sand, outwash) had been mined to low levels of STK, with little or no fertilizer K application for several years. The Rochester site (Mt Carroll silt loam, loess) had received reduced "starter" rates of K fertilizer and infrequent beef manure. The previously grown crop at Waseca and Rochester was soybean and rye at Becker. All three sites will be cropped to a three-year rotation [corn (2011) – corn (2012) – soybean (2013)]. Twelve individual plots (20 ft wide by 50 ft in length) were replicated 4 times for a total of 48 plots per site. Plots were arranged in a split-plot design with the main plot being 3 rates (0, 60, and 120 lb K_2O/ac) of K as potash (0-0-60) broadcast-applied annually during the initial phase of the study (minimum of three years). At Rochester, where initial soil test K values were greater, fertilizer K rates of 0, 40, and 80 lb K_2O/ac were used. These fertilizer K treatments were applied for the first time in October of 2011.

Soil samples were taken in June of 2011, the initial year of the study, at 0-6, 6-12 and 12-24 inch depths and again in October at a 0-6 inch depth prior to fertilizer K application to characterize each site. In 2012 soil samples were taken in April and June at 0-6, 6-12 and 12-24 inch depths and in October at 0-6 inch depth (Table 1). Ten one-inch diameter soil cores per plot (6 cores per plot for 12-24 inch samples) were taken from each of the 48 plots. Samples were placed on a paper plate and dried at 100° F for 12-14 hours in a forced air oven. Then the samples were returned to the paper bags and left at room temperature until they were ground, processed and extracted with 1M ammonium acetate. The 0-6 inch samples from the June sampling date were mixed thoroughly in the field and split in half. One half of each sample was kept cool and moist, while the other half was placed in a paper bag at room temperature until later that day when they were dried.

Fertilizer N, P and S were applied at recommended rates (U of M) to meet crop needs at all sites. Corn and soybean were planted after pre-plant tillage, which differed at each location. Grain yield and moisture content were determined with a research plot combine each of the 48 plots. Corn grain yields were calculated at reported at 15.5% moisture and soybean at 13% moisture.

Beginning in 2012, the first year of treatment application, the data were analyzed as a split-plot experiment even though only the main-plot fertilizer rates were applied and the split-plot treatments won't be applied until later (2014 or 2015). This analysis allows us to evaluate the effects of the main-plots (fertilizer rates) and to look for significance in the sub-plots and interaction term (main plot × sub plot). If significant differences in the sub-plots and/or interaction terms exist, as it does in the Rochester location in 2012, we can and will adjust the fertilizer rates on specific plots as a way of correcting or minimizing the effects of these differences on future years of the study. All data were statistically analyzed using SAS® (SAS 9.2, SAS Institute Inc., 2008. Cary, North Carolina). Effects are considered significant at $P \leq 0.10$.

RESULTS AND DISCUSSION

Initial soil test data are summarized in Table 1. Current guidelines (Kaiser et al., 2011) outline categories for soil test K based on the ammonium acetate test as Very Low (0-40 ppm), Low (41-80 ppm), Medium (81-120 ppm), High (121-160 ppm), and Very High (161 ppm or more). Initial soil test values ranged from Medium to Very High at Rochester, Low to High at Waseca, and Low to Medium at Becker. Soil test values were obtained from soil depths greater than six inches and are summarized in Table 1.

Top soil (0-6") samples were collected post fertilization in spring (June) 2012. Figure 1 summarizes time series data for samples collected in April, June, and fall post-harvest from 2012 through 2014. Error bars were included in Figure 1 only when significant differences existed among the three treatments. All three fertilization rates could be easily detected with soil test starting in June 2012. While differences among treatments were evident, there was significant variation between samples in average soil test K across the treatments. Seasonal flux in soil test K was expected.

One challenge for the study was assessing whether the desired ranges in classifications were achieved. The average soil test K across treatments at Rochester and Waseca was generally least with June sampling than with fall sampling but was greater at Becker. In most cases the ranges for the June sampling more consistently fit with the desired build ranges of Low, Medium, and High for Waseca. Average soil test values tended to be greater at Rochester and less at Becker compared to the Waseca site. The consistently greater soil test at Rochester could be explained by past manure and fertilizer history. The sandy soil at Becker has a lower CEC compared to the other locations (not shown) and would have a greater tendency to leach K.

Yield data for the irrigated Becker location are summarized in Table 2. Potassium treatments affected corn or soybean grain yield during all years studied. Grain yield always differed between the 0 and 60 lb K_2O treatments but never differed between the 60 and 120 lb K_2O treatments. Potassium supplied in the irrigation water has been measured but is not reported as it ranged from 0-5 lbs K_2O per acre which would not have resulted in a major impact on treatments. The 120 lb K_2O treatment did result in significantly greater soil test K (Figure 1) but 60 lb K_2O was sufficient to maintain maximum yield potential.

Potassium application increased corn or soybean grain yield at Rochester during all four years even though soil test K concentration tended to be greater at Rochester (Table 3 and Figure 1). All K treatments increased yield compared to the non-fertilized treatment all years of the study. However, grain yield for the 40 and 80 lb treatments only differed in 2013 and 2014 which correspond to years where there were greater differences in April soil test K between the same two treatments. The lack of a difference between the 40 and 80 lb treatment in 2015 was not expected since the two treatments differed the previous two years.

At Waseca, the 60 and 120 lb treatments only differed in 2013, and there was no difference among treatments in 2012 (Table 4). Yield levels were depressed in 2012 and 2014 at Waseca due to drought in 2012 and a record wet June followed by abnormally dry summer in 2014. These conditions likely caused the lack of response in these years. Greater variability at Waseca resulted in larger LSD (no shown) values and a general inability to detect differences among treatments, especially in 2012.

Grain yield responses to fertilizer K application were relatively large at the Becker and Waseca locations but much less at Rochester. These large yield increases for both crops resulted in a sizable return on investment for annual fertilizer application at Becker and Waseca. At Rochester, differences in grain yield between the fertilized and non-fertilized grew larger over time. Relative differences in soil test values among treatments were somewhat similar between Waseca and Rochester, while yield differences between these sites were much different. However, this could be attributed to greater concentration of K for the non-fertilized treatment at Rochester. The fact that there was no difference in grain yield between the two K fertilizer rates at eight out of twelve site-years is interesting and points to modest annual K applications being sufficient to produce maximum yield potential for soils Low-Medium in K.

Yield data from these sites were converted to relative yield (% of maximum yield) and combined with data collected from other sites across Minnesota. The correlation of relative yield to soil test K data are presented in Figure 2. Current K fertilizer guidelines in Minnesota do not separate soils by cation exchange capacities (CEC) or soil texture. When combined with other data, the data suggest a lower critical level for soils with very sandy surface textures. Sandy soil has a lower CEC than medium and fine textured soils making it difficult to hold K in the soil. Data in Figure 1 point to the lower K holding capacity as soil test values were more difficult to build at the Becker location than the other two sites. Soils in Minnesota like the one at Becker have sand concentrations 90% or greater and very little clay; therefore, the CEC can be comprised of a greater percentage of variable charge CEC on the soil organic matter.

The lack of clay in the sandy soil impacted the relative difference between soil test K for the moist versus air dried soil analysis (not shown). Table 5 summarizes the difference between the moist and air-dried soil tests based on 95% yield level and the soil test at the relative yield plateau value. While only a 5% difference in yield, the different in soil test K for the air dried test on medium and fine textured sites was 100 ppm. Analysis on field moist samples narrowed the gap between soil test K values for the 95% and plateau yield data for the medium and fine textured sites and also resulted in a lower critical value. There were slight interpretation differences for the coarse textured site (Becker data), but the difference between the air dry and moist soils was minor. It also should be noted the r-squared values were poorer for the air dried test indicated greater variability within the dataset.

Both corn and soybean data were combined in Figure 2 as there was no clear evidence of differences in response rates or critical levels by crop. These results have implications for K management. It is evident that our current (U of M) soil test ranges require adjustment. On medium and fine textured sites, soil test values for the low and high end range in the current classifications should be increased. As it appears a critical level closer to 200 ppm is needed for both corn and soybean. For sandy low CEC soils, it appears a lower critical level is needed and less K should be applied. Less K applied to sandy soils is a good idea as K is less likely to be held by the soil resulting in wasted fertilizer.

These data show no clear advantage for using moist soil analysis on sandy soils in Minnesota. The moist soil analysis may result in a greater ability to detect yield responsive sites on medium and fine textured soils; therefore, a separate calibration for moist soil is justified on medium and fine texture soils.

CONCLUSIONS

Application of K fertilizer can increase corn and soybean yield and overall productivity in Low and Medium K testing soils. Corn yield responses were large (up to 50%) in some site-years. In most cases, application of fertilizer K at a 2X rate with the intention of building soil test K to high or very high levels did not result in greater yield than applying 1X rate annually on medium K testing soils. Soil texture should be considered when making K fertilizer recommendations. Soils with a very sand surface texture do not hold on to K and have a lower critical level than medium or fine textured soils. Field moist analysis of K has greater potential for improving fertilizer guidelines and profitability on medium and fine textured soils versus soils with very sandy soil textures.

Table 1. Summary statistics for soil test K from samples taken in 2011 prior to treatment application.

Sampling		Waseca			Rochester			Becker		
Time	Depth	Range	Mean	Median	Range	Mean	Median	Range	Mean	Median
	Inch	ppm, exchangeable K								
Jun-11	0-6	80-147	102	99	111-232	145	138	56-86	70	71
	6-12	79-128	97	93	68-102	84	85	56-90	76	75
	12-24	74-134	103	102	52-97	73	73	31-65	43	42
Jun-11	Moist	30-62	43	43	48-163	92	88	27-59	42	42
Oct-11	0-6	96-144	114	111	102-172	127	122	41-77	56	56

Table 2. Yield response to K at Becker, MN for corn (2012, 2014, and 2015) and soybean (2016). Letters following numbers denote treatment significance at $P \leq 0.10$.

Annual K rate	2012	2013	2014	2015
--lb K_20/ac--	bushels per acre			
0	183b	48.6b	131b	151b
60	199a	56.8a	223a	237a
120	201a	55.7a	222a	240a
		Treatment Significance		
P>F	<0.001	<0.01	<0.001	<0.001

Table 3. Yield response to K at Rochester, MN for corn (2012, 2014, and 2015) and soybean (2016). Letters following numbers denote treatment significance at $P \leq 0.10$.

Annual K rate	2012	2013	2014	2015
--lb K_20/ac--	bushels per acre			
0	217b	53.8c	194c	224b
40	222a	55.4b	216b	235a
80	220ab	58.1a	230a	238a
		Treatment Significance		
P>F	0.06	<0.01	<0.001	<0.01

Table 4. Yield response to K at Waseca, MN for corn (2012, 2014, and 2015) and soybean (2016). Letters following numbers denote treatment significance at $P \leq 0.10$.

Annual K rate	2012	2013	2014	2015
--lb $K_2$0/ac--	-----------------------------bushels per acre-----------------------------			
0	134	48.3c	101b	154b
60	143	55.1b	159a	230a
120	151	60.7a	174a	232a
		Treatment Significance		
P>F	0.26	<0.01	<0.001	<0.01

Table 5. Summary of critical soil test K levels based on data presented in Figure 2 for air dry and field moist soil samples extracted with 1M ammonium acetate (AA).

	Air Dry AA-K		Field Moist AA-K	
Soil Texture	95% Rel. YLD	Plateau YLD	95% Rel. YLD	Plateau YLD
	---ppm---			
Coarse	64	79	51	59
Medium/Fine	100	200	75	85

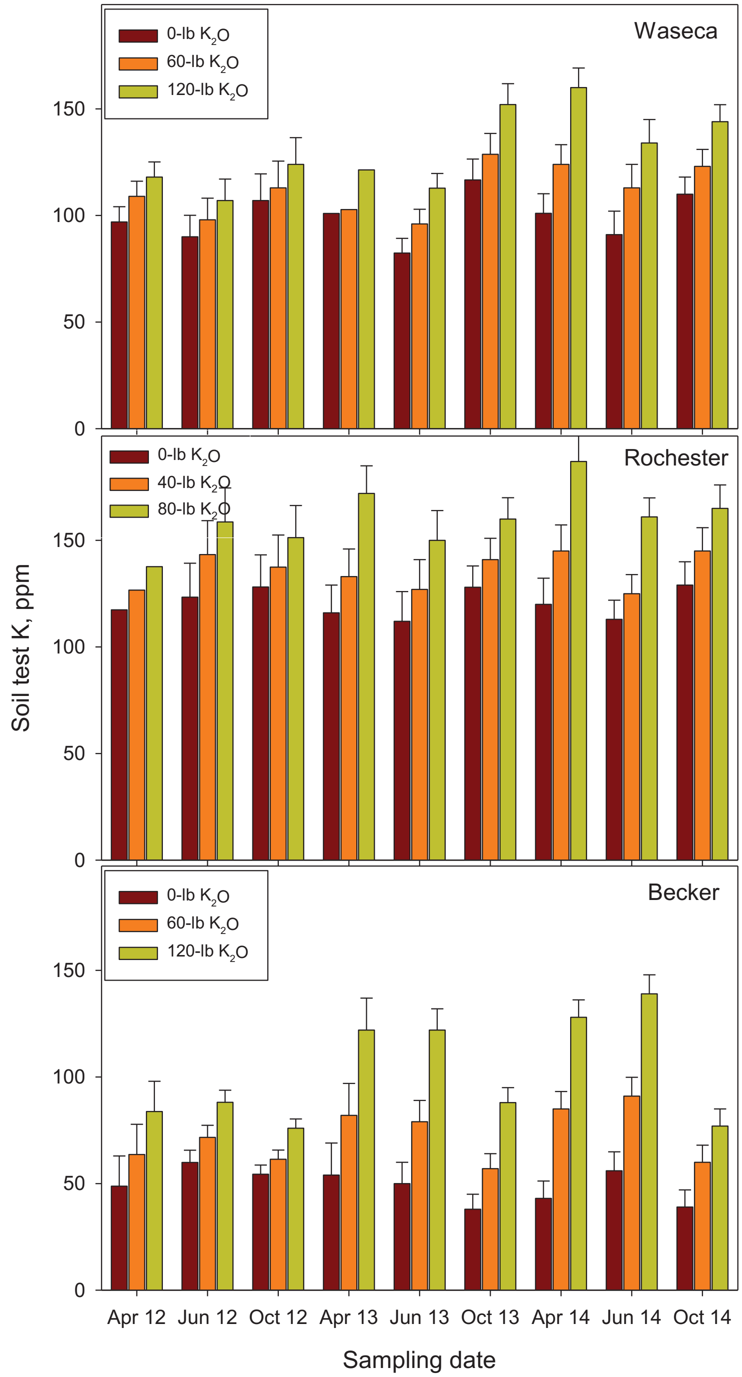

Figure 1. Mean soil test K (0-6 inch depth) in April, June and October of 2012 through 2014 as affected by K_2O rate at Waseca, Rochester and Becker [error bars denote LSD (0.10)].

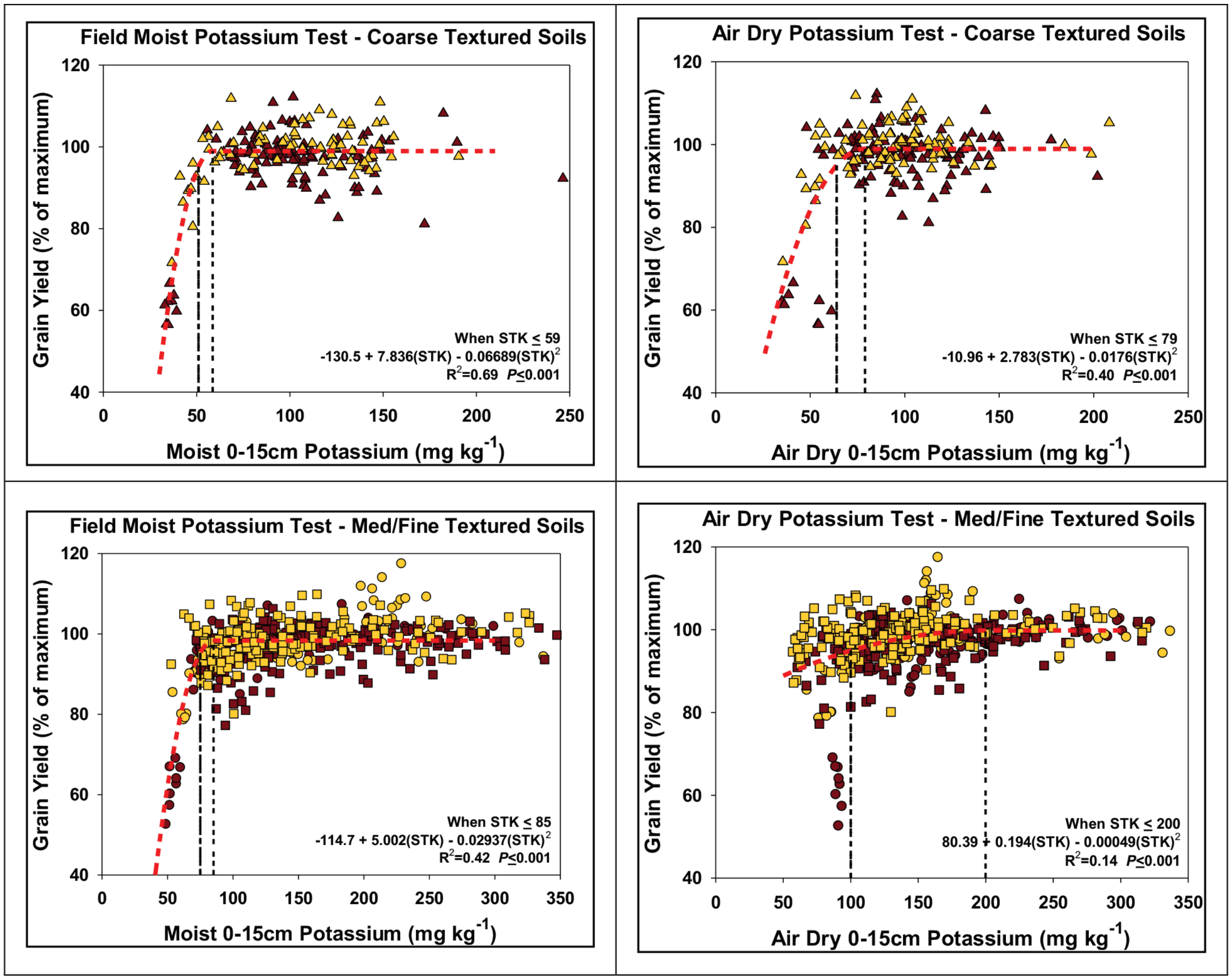

Figure 2. Summary of the relationship between relative yield produced by a non-fertilized control and soil test potassium for air dried and field moist samples collected at 0-15 cm (0-6”) and extracted by 1M ammonium acetate. For soil test potassium, 1 mg kg^{-1} measurement equals 1 ppm. Darker shading represents corn data points while lighter shaded shapes represent soybean.