On Farm Assessment of Critical Soil Test Phosphorus and Potassium Values in Minnesota

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Introduction

Proper phosphorus (P) and potassium (K) management is essential to maintain higher yields in crop rotations. Soils in Minnesota can contain large amounts of P and K. However, only a fraction of the total amount contained in the soil is readily available for plant uptake. To assess this availability, soil tests were developed that provided an index of crop response. These soil tests are generally divided into multiple categories (Very Low to Very High) to indicate the relative potential for a yield response following application of fertilizer. Of these categories there exists a point where fertilizer application produces little or no measurable or profitable yield increase. Generally, this point is referred to as the critical soil test level. To determine the critical point, a large amount of data is needed across years and locations. The use of strip trials can be beneficial at increasing the amount of information and to capture differences in soil test data across the landscape.

Soil test P and K levels can vary significantly across Minnesota. Most differences are related to soil forming factors such as climate and parent material. As you move from east to west in the state, soil pH generally increases which greatly affect P availability. In these soils free calcium can form compounds with phosphate with varying solubility and crop availability. While this P may eventually become available, it can be problematic and should be taken into account in management decisions. In other parts of the state, significant variability in soil pH can exist within grower's fields. This makes some areas within field low in soil test P in spite of previous fertilizer application while other areas will have high soil test P. This type of variability can make management of fertilizers difficult since some areas may be highly responsive while others are not. Variable rate application of fertilizers may be used in these circumstances to manage nutrients better within fields

Potassium chemistry in the soil is different than P due to the fact that K exists as a positive cation (K^+) in the soil while P is present as orthophosphate ions (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, and $H_3PO_4^0$) that have a negative charge. Since K in the soil has a positive charge it is attracted to negative charge surfaces of clay and is held within the soil which limits movement. In addition, K ions can be trapped between clay layers (fixed K). Soils in the state tends to vary in their ability to hold K because of differences in cation exchange capacity (ability of the soil to attract positive ions) due to differences in the amount and types of clay and also in the amount of K in the parent material for soils. In addition, recent research has noted that drying soil samples can have a significant effect on the amount of K extracted. This is not a new problem but drying the samples to consistent moisture was done in order to make analysis in labs easier. Knowing the effects of drying on soils can be important in order to determine the effect on soil test K. While drying a soil may affect the amount of K extracted, soil pH has no significant effect on K as it can have on P.

In Minnesota, the Bray-P1 and Olsen soil tests are recommended for P while the ammonium acetate test is recommended for potassium. The Bray-P1 test uses a strong acid to extract phosphorus. In soils with high levels of calcium carbonate, the carbonate can neutralize the acid in the Bray solution which can cause an underestimation of the amount of P available to crops. In circumstances when the soil pH is greater than 7.4 the Olsen extraction is recommended since it is less susceptible to being affected by soil carbonates. A third test, the Mehlich-3 extraction is being used in the corn belt as a substitute for both tests and has an advantage that it is used to extract multiple elements such as P, K, and micronutrients. The Mehlich-3 test is buffered at a neutral pH which is supposed to allow it to work better in high pH soils. Previous work has shown that this test does not work well in soils in Western Minnesota. However, comparisons can be easily made with the other tests for P and K in order to see if it can be used in acid or neutral soils as a substitute for either the Bray-P1 or Olsen P tests or the ammonium acetate test for K.

Since global positioning systems have become commercially available, researchers have been utilizing these technologies to conduct field-scale nutrient management projects. Most research has been done with technologies currently available to farmers. Many prominent researchers in the Corn Belt have conducted these types of studies with varying results. Since soil tests represent an index of crop response work needs to be done to continually evaluate whether the current P or K classifications fit with current practices. These types of studies are usually easy to set up since they only involve a single high application rate of a nutrient compared with no fertilizer.

Meetings of soil fertility researchers at the University of Minnesota established a set of priorities for fertilizer P and K management within the state. In order to maintain high yield levels, the group decided that there was a need for more research on the establishment of critical soil test P and K values across the state. Specific objectives of this proposed project are to:

1. 1) Evaluate corn yield response to P and K based on initial soil test level on irrigated and rain-fed fields
2. Assess the potential impacts on soil P and K below 6” on response to P or K fertilizer
3. Evaluate the potential of luxury uptake of P and K in corn grain
4. Compare soil test P and K values according to the Mehlich-3 test and commonly used tests for P or K
5. Determine if extracting K on field moist samples better correlates to yield than dried samples

Methods

Phosphorus studies were established beginning in 2010 through 2011 while potassium studies were first established in 2011. Table 1 summarizes soil data from the P studies while the K studies are summarized in Table 2. Studies consisted of two treatments, either no P or K (depending on the study) and a either 200 lbs P_2O_5 or 200 lbs K_20 broadcast and incorporated prior to planting. All yes/no treatment combinations were replicated 4 times. Any additional nitrogen, P, K, sulfur, or zinc fertilizer was applied based on needs for the individual locations to keep these elements non-limiting when they were not specifically being studied. Six P sites (Table 3) and two K sites were continued on sites previously used. At second year sites, 150 lbs P_2O_5 or K_2O/ac were applied to half of the old rate strips to give four separate treatments; no P or K both years, P or K year 1 and none year 2, no P or K year 1 and P or K year 2, and P or K applied both years. This was done to study the carryover effect of fertilizer from a single years’ application to a second years’ crop.

Table 1. Soil series information, planted crop at each location, and initial potassium soil test data from phosphorus studies conducted from 2010 to 2013. Soil test data was collected in the spring and represents a field average for the 2 acre study areas.

			Soil Test†		Texture‡	Soil Series	
Location	Year	Crop	K	CCE		Major	Minor
			ppm	%			
Blomkest	2010	Corn	190	12.4	ClL	Harps-Okaboji	Canisteo-Seaforth
Foxhome	2010	Soybean	136	3.4	FSL	Elmville	Wyndmere
Lamberton	2010	Corn	143	0.0	L	Ves-Storden	--
New Richland	2010	Corn	279	5.4	ClL	Canisteo-Glencoe	Glencoe
Rochester	2010	Corn	158	0.4	SilL	Port Byron	Mount Carroll
Grand Meadow	2011	Soybean	139	0.0	SCL	Clyde	Protavin
Stewart	2011	Soybean	187	0.8	ClL	Canisteo-Glencoe	Crippin
Staples	2012	Corn	100	0.1	SL	Verndale	--
New Richland	2013	Corn	216	1.7	ClL	Canisteo-Glencoe	Crippin-Nicollet

† K, Soil test potassium (K-ammonium acetate); CCE, calcium carbonate equivalency.
‡Soil Texture: ClL, clay loam; FSL, fine sandy loam; L, loam; SCL, silty clay loam; SilL, silt loam.

Table 2. Soil series information, planted crop at each location, and initial Olsen phosphorus soil test data from potassium studies conducted in 2011 through 2013. Soil test data was collected in the spring and represents a field average for the 2 acre study areas.

			Soil Test†			Texture‡	Soil Series	
Location	Year	Crop	P	pH	CEC		Major	Minor
			ppm		Meq/100g			
Grand Meadow	2011	Soybean	11	6.1	33.6	SCL	Clyde	Protavin
Preston	2011	Corn	12	6.4	17.4	SiL	Rockton	Chaseburg
Staples ‘11	2011	Corn	16	6.8	8.9	SL	Verndale	--
Staples ‘12	2012	Soybean	17	7.5	11.9	SL	Verndale	--
New Richland	2013	Corn	10	4.8	31.7	L	Clarion	Nicollet

† P, Soil test phosphorus (Olsen extraction); pH, soil pH; CEC, cation exchange capacity.
‡Soil Texture: SL, Sandy loam; L, loam; SCL, silty clay loam; SilL, silt loam.

Soil samples were collected prior to treatment application. Soil samples were collected every 40 feet from the center of each paired yes/no strip. A total of 16 samples were taken from each strip making the total strip length 640 feet at each location. An additional 20’ was added to the end of each strip to allow space for application equipment to reach optimum speed prior to entering the research plot area. Strip width varied from 15 to 20’ wide at each location. Considering both the yes and no strips each soil sample would represent a 30 to 40’ wide by 40’ long area (0.0275 to 0.0367 ac) within the field. This small of an area was chosen in order to limit random variability in yield between each yes/no area. For the P studies, if the site was carried over for a second year each grid cell from the treated and untreated area was sampled prior to fertilizer application in year 2 to assess the increase in soil P following fertilizer application and crop removal the previous year (Table 3). This data also was used to double the total amount of yes/no comparisons at each location which was an advantage at low testing high pH sites which did not have enough high testing areas for the soil test correlation. To assess subsoil availability, prior to the first year treatment application at both P and K sites, samples were collected from the 6-12” depths and analyzed for only one P or K test. The subsoil P and K levels were used as a covariate in the statistical analysis of the data. For the second year studies 0-6" samples only were collected from treated and untreated areas.

Table 3. Planted crop and soil test data for second year studies conducted on locations in 2011 and 2012 that were previously used in 2010 and 2011 (Table 1), respectively. Soil test data are from samples collected from the 0-6" soil depths prior to treatment application that represent soil test values following treatment application and crop harvest in year 1.

			Bray-P1 Phosphorus†		Olsen Phosphorus†	
Location	Year	Crop	0 lb P_2O_5	200 lb P_2O_5	0 lb P_2O_5	200 lb P_2O_5
			--------ppm-------		-----------ppm---------	
Blomkest	2011	Soybean	2b	7a	4b	18a
Foxhome	2011	Sp Wheat	5b	9a	7b	13a
Lamberton	2011	Soybean	17b	40a	10b	17a
Grand Meadow	2012	Corn	42b	58a	17b	25a
Lamberton	2012	Corn	31	33	16	17
Stewart	2012	Corn	37b	47a	18b	25a
Staples	2013	Corn	33b	46a	16b	24a

† Lower case letters following numbers represent significance ($LSD \leq 0.10$) within each location for each soil test procedure.

Soil collected from the P study sites were dried at 65°F in a force air oven and ground to pass through a 2 mm sieve. Samples were analyzed for the Bray-P1, Olsen, and Mehlich-3 P soil test procedures using methods recommended for the North-central region analyzed colorimetrically. For potassium, the soil samples were collected and stored in plastic or lined bags in a refrigerator prior to mixing and sieving. The full sample was passed through a 5 mm sieve then split in half. One half of the sample was air dried on a bench at ambient air temperature while the other sample was place back in the refrigerator. The air dried sample was ground and analyzed with the ammonium acetate and Mehlich-3 test (same extraction method was used for Mehlich-3 P and K). For the moist samples, the amount of soil moisture was calculated by weighing soil samples before and after drying at 100°C. Two methods were used for extraction and analysis. For soils consisting of mainly sand, a 2 g dry weight equivalent of soil was weighed out and extracted with the ammonium acetate procedure only. For silty, clayey, and loamy soils a 100 g dry weight equivalent of soil was mixed with 200 g of water with a hand mixer into a soil-water slurry. A 2 g soil dry weight equivalent of soil was pipetted out of the slurry for extraction. This mixing method was needed in order to homogenize the soil sample to reduce sample to sample variability. At this time only the data for the air dry portion of the K samples is available. Soil samples collected from the 6-12" depth fraction were air dried only.

Statistical analysis was conducted using SAS. For both studies, the effects of P or K on yield, grain P uptake, and post-harvest soil test P was assessed using the mean of the 16 measurements within each strip. For studies conducted a second year at a location the analysis was further divided into responses from P applied the first or second year of the study as well as whether there was a significant interaction between P applied the first or second study year (a significant interaction would indicate that the effect of P for example in year 1 may vary by application year 2 or vice versa). To calculate critical soil test P or K values, yields were compared between strips with and without P within each sampling area. The yield of the strip where P was not applied was divided by where P was applied to determine a relative yield without P. This value was correlated with soil test P or K using several response functions. The response function used was that which resulted in the best correlation (R^2) between relative yield and soil test.

The probability of a significant response to fertilizer was calculated for the P studies and broken down into the current University of Minnesota soil test categories for corn and soybean data based on the Bray-P1 and Olsen soil tests. For the Bray-P1 test this is; 0-5 ppm (Very Low), 6-10 ppm (Low), 11-15 ppm (Medium), 16-20 ppm (High), and 21 ppm or greater (Very High). For the Olsen test the categories are 0-3 ppm (Very Low), 4-7 ppm (Low), 8-11 ppm (Medium), 12-15 ppm (High), and 16 ppm or greater (Very High). Four neighboring yes/no comparisons were used to determine the probability of yield response. These represented a 60 to 80' wide by 80' long area within the research study. These areas were analyzed like a four replication experiment and the initial soil test values were averaged and used to break the areas into classifications. When the analysis indicated a significant effect of fertilizer P the total number of significant areas was totaled and divided by the total number of areas within the particular soil P classification. All unique combinations of the 4 areas were considered at each location (areas were used for analysis more than once but never were analyzed with the same set of 3 neighboring plots more than once). Average yield increase represents a weighted average of the yield response for responsive and non-responsive areas. At this time there was not enough data from the K studies to accurately calculate probability of response.

Results and Discussion: Phosphorus Studies

Soil Test Variability

Average, minimum, maximum, and the standard deviation of individual soil samples taken from each location are given for the Bray-P1, Olsen, and Mehlich-3 P tests in Tables 4, 5, and 6, respectively. Locations varied in average initial soil test P categories from Low to Very High. Soil tests values across the trial areas were Low to Very Low at Blomkest, Foxhome, New Richland and Stewart. The low soil test values were attributed to high pH soil areas which encompassed some to all of the trial areas at all locations. According to past research there is a high probability of a large grain yield response at each of these locations from applied P fertilizer. Soil test values averaged High at Grand Meadow and Lamberton and Very High at Rochester and Staples. These locations along with Stewart had the highest variation in soil P across the trials as indicated by the larger standard deviations (Standard Dev.). The Stewart location had some low testing areas but also included higher testing areas with acid soil pH values. Soil test values ranged from Low to Very High within these three locations and represented larger variability within the small scale of these research trials. There was less variability at Blomkest, Foxhome, and New Richland locations. At the Blomkest, Foxhome, and New Richland sites soil test P for a majority of the trial area was Medium or less according to the Bray-P1 test (not shown).   Comparisons of the data from the Mehlich-3 test indicate some differences across locations in the assessment of soil test P at each location. Soil test P data from 2010 and 2011 has approximately the same range and variation in soil test values at the Bray-P1 test when looking at minimum and maximum soil P values for the Mehlich-3. The average Mehlich-3 soil test values compared to the Bray-P1 test seem to differ between some sites which likely are an indicator of possible correlation problems, especially in high pH soils with calcium carbonate present. Direct comparisons of all soil P values between tests separated by soil pH may better assess the use of the Mehlich-3 test in Minnesota.

Table 4. Summary of Bray-P1 phosphorus data collected before treatment application in Spring. Summary is of the average, minimum, and maximum values from 64 sampling areas within each location and their standard deviation.

		Bray-P1 Phosphorus			
	pH	Average	Min	Max	Standard Dev.
		ppm			
Blomkest	8.2	2.9	2	16	2.2
Foxhome	8.2	4.5	2	20	3.7
Grand Meadow	6.1	20.3	4	65	10.8
Lamberton	4.9	16.9	2	33	7.0
New Richland	7.5	5.6	2	13	3.2
Rochester	7.2	23.0	8	63	12.3
Stewart	7.1	24.5	2	64	14.1
Staples	7.2	34.3	18	103	15.6
New Richland	7.0	13.7	2	43	8.5

Table 5. Summary of Olsen phosphorus data collected before treatment application in Spring. Summary is of the average, minimum, and maximum values from 64 sampling areas within each location and their standard deviation.

		Olsen Phosphorus			
	pH	Average	Min	Max	Standard Dev.
		ppm			
Blomkest	8.2	7.1	3	23	2.7
Foxhome	8.2	4.8	2	13	2.3
Grand Meadow	6.1	11.2	2	33	5.7
Lamberton	4.9	12.5	5	24	4.2
New Richland	7.5	6.4	4	9	1.2
Rochester	7.2	12.1	3	26	5.4
Stewart	7.1	13.8	5	37	6.8
Staples	7.2	14.8	8	40	6.7
New Richland	7.0	7.5	3	22	4.1

A comparison of soil test P values measured by the individual tests is given in Figure 1 in the Appendix. In this comparison the data from sites was separated by soil pH. The separation point was either above or below 7.4. This was done based on past research found that Minnesota soils with a pH great than 7.4 tend to have free calcium carbonate in them that causes problems with the accurate of the Bray-P1 soil test. Since the Bray-P1 uses a strong acid to extract P, the carbonate can neutralize the acid and cause the test solution to extract less P thereby underestimating the amount of available P in the soil. The Mehlich-3 test has been offered as an alternative to the Bray-P1 since the extraction solution is buffered at a higher pH. Previous research in Minnesota has shown that the Melich-3 soil test may also fail at higher soil pH values. Field locations with pH values greater than 7.4 would confirm this by having a poor correlation between the Olsen P test and Bray-P1 or Mehlich-3 extracts, or between the Bray-P1 and Mehlich-3 extracts. The best correlation (as defined by curve fitting parameters) was between the Mehlich-3 and the Olsen test (R^2=0.53) when pH was greater than 7.4. This correlation is significant enough to say that the Mehlich-3 may be used. When soil pH was less than 7.4 the correlation of the Olsen and the Bray-P1 (R^2=0.84) and the Mehlich-3 (R^2=0.80) was similar. When the Bray-P1 and Mehlich-3 tests were compared they were highly correlated (R^2=0.89). This indicates that either soil test, Bray P1 or Melich-3, could be used when soil pH values are less than 7.4 and there still is some variability between the assessment of soil test P with those two tests and the Olsen. The comparison between the Bray-P1 and the Mehlich-3 test indicate that either soil test measures soil test P similarly because the slope of the line is near 1. This indicates that correlation and calibration data for the Bray P1 soil test could be used for the Mehich-3 soil test. Soil pH would have to be monitored to make sure the Olsen is used at high pH values.

Table 6. Summary of Mehlich-3 phosphorus data collected before treatment application in Spring. Summary is of the average, minimum, and maximum values from 64 sampling areas within each location and their standard deviation.

		Mehlich-3 Phosphorus			
	pH	Average	Min	Max	Standard Dev.
		----------	---------- ppm	----------	----------
Blomkest	8.2	11.3	2	43	6.3
Foxhome	8.2	13.8	2	31	6.9
Grand Meadow	6.1	18.4	4	58	8.8
Lamberton	4.9	15.3	4	29	6.0
New Richland	7.5	6.1	2	10	2.5
Rochester	7.2	20.0	7	55	10.6
Stewart	7.1	25.2	9	56	11.3
Staples	7.2	33.7	19	135	18.3
New Richland	7.0	15.8	9	33	4.7

Strip Mean Averages for Grain Yield, Grain Harvest Moisture, Grain P concentration, and Grain P removal

The analysis of data was run by comparing means of the 16 sampling areas within each yes/no strip. Grain yield and harvest grain moisture data are reported in Table 7. Across locations, grain yield significantly different ($P \leq 0.10$) between the no P and P application strips at three corn locations and one soybean. At Blomkest and New Richland, corn grain yield differences were the largest with a 20 bu./ac. advantage to the application of P. The second largest yield response was a 15 bu/ac yield increase at the New Richland location in 2013. Grain yields from the no P and P applied strips were also significantly different at the Lamberton location, but difference in grain yield was only 6 bu./ac. greater when P was applied. Grain yield differences at the Blomkest and New Richland sites were expected since both locations average Medium to Low in soil test P across the trial area. Initial soil test P values were slightly greater at the Lamberton location but this site did have soil test P values in areas of the trial that were Low. The only site where soybean yields were significantly was at Stewart which tested Very High according to the Olsen P test (Table 5) and produced a small yield increase to P (2 bu/ac). It appears that the low soil P areas had a large influence on the overall grain yield within the field within this site as well as the Lamberton Corn location. The Foxhome location tested low in soil test P, but there were no differences in soybean grain yields between where P was or was not applied. The lack of significance at this site could be a result of large variations in grain yield or other stresses such as iron deficiency chlorosis that may have had a greater impact on grain yield. The maximum soybean grain yields at Foxhome were upwards of 40 bu. per acre or greater in some areas of the research trial. Other areas at Foxhome either suffered from severe iron chlorosis or water logged soils and is the likely reason for the reduced soybean grain yield average. Grain yield levels were the greatest for corn at the Rochester and soybean at Grand Meadow, but no treatment differences were detected because these sites had some of the highest average soil test P test of all of the locations.

Table 7. Grain yield and harvest moisture summary for averages for the individual strip means within each replication from the 2010-2013 trial data.

	Grain Yield Average			Grain Moisture Average		
	No P	High P	Statistics†	No P	High P	Statistics†
	-------------bu/ac-----------		----*P>F*----	----------------%--------------		----*P>F*----
Blomkest	171b	195a	<0.01	15.1	15.1	0.84
Foxhome	23	28	0.26	8.7	8.7	0.98
Grand Meadow	54	54	0.68	9.7	9.7	1.00
Lamberton	199b	206a	0.09	15.2a	15.0b	<0.01
New Richland	168b	186a	<0.01	12.2b	13.0a	0.03
Rochester	191	193	0.60	22.1	21.8	0.19
Stewart	41b	43a	0.05	10.2a	9.9b	0.07
Staples	59	59	0.99	10.9	11.0	0.49
New Richland	206b	223a	0.07	26.4	26.4	0.91

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when $P \leq 0.10$.

Table 8. Effect of P fertilizer applied before year 1 and year 2 on crop yield. The Lamberton location had the same P rate applied over top the old strip therefore no analysis could be done comparing P carried over from year 1.

	No P YR 1		+ P YR 1		Statistics†		
	No P YR2	+P YR2	No P YR2	+P YR2	YR1 P	YR2 P	YR1 x YR2
	----------------------------bu/ac------------------------				-----------------*P>F*-----------------		
Blomkest	25.7	30.4	24.8	30.3	0.77	0.05	0.83
Foxhome	45.6	45.3	52.7	53.4	0.002	0.83	0.86
Lamberton	49.6	--	51.0	--	--	0.24	--
Grand Meadow	201	203	207	203	0.78	0.85	0.07
Lamberton	134ab	138ab	131b	143a	0.92	0.12	<0.01
Stewart	190	192	194	191	0.66	0.86	<0.01
Staples	174c	178b	172c	184a	0.43	<0.01	0.01

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when $P \leq 0.10$.

Table 8 summarizes the yield response data for studies conducted the second year at specific locations. As was noted in the methods, some of the locations had more than two treatments. At Blomkest the effect of P applied before corn could be assessed on soybean, spring wheat was studied at Foxhome, and corn was studied at Grand Meadow, Lamberton (2012), and Stewart. Phosphorus was applied over the same treatment strips at Lamberton (2011) so only the effect of the direct application could be studied. At that site there was no significant effect of P application on yield. At Blomkest yields were limited due to early season flooding, iron chlorosis, and two hail events during the growing season. However, there was a significant yield response of 5 bu/ac to P applied before the soybean crop planted the second year. This indicates that at this site for the soils studied there was little to no benefit from P applied before corn and not used during that year. Since corn yield was increased the previous year there is data that indicates that fresh P may be beneficial both years. The high pH of these soils does indicate a potential for fixation of any P not used by a crop. An unexpected response occurred at the Staples location where soil test P was Very High and corn grain yield was increased with the application in the spring before corn. In addition, the yield response was greater when P was applied both years.

At Foxhome, the yield data indicated the opposite effect. Spring wheat yield was higher in strips where P was applied before the previous soybean crop and there was no significant effect from P applied before the wheat crop. The protein was also tested and was 15.0% when no P was applied both years, 14.6% when P was only applied before the wheat crop, 13.7% when P was applied only before the soybean crop (year 1), and 13.5% when P was applied both years. There was again a significant effect of P applied before the first year on protein with the average values testing higher when P either no P was applied or P only applied before wheat. This was opposite of yield and not surprising due to the fact that any limitation of yield may result in an increase in protein due to any nitrogen taken up not being used for the production of starch due to a limitation of P being used for protein. This same effect has also been documented in corn when yield was limited by P. More studies are being planned at locations to look at these effects due to potential implications on when P should be recommended to be applied during crop rotations. At this time there is not enough data to draw a hard conclusion since only two studies were conducted. Past research has shown some flexibility in using a single application one year to supply the P needs of multiple cropping years.

There was little evidence of a yield increase at any of the two other corn locations studied in year 2. There was some slight evidence of a yield response to P applied year 2 at Lamberton. The P value for the effect of P year two was near the accepted significance level and yield trended higher for those treatments. A significant interaction was identified at all locations. The reason for the interaction is not clear. At Stewart, not treatment was significantly different from the control. There was no clear yield difference at the Grand Meadow location. With enough field areas the responses could be separated out by soil test classification. At this time this analysis has not been completed since there is not enough variation in soil test level.

Grain harvest moisture was significantly ($P \leq 0.10$) affected by P fertilizer at two locations, Lamberton and New Richland. At Lamberton, harvest moisture was 0.2% less when P fertilizer was applied. While this was statistically significant, the effect was very small compared to the grain yield impacts from P fertilizer at this location. At New Richland, the effect of P fertilizer on grain harvest moisture was the opposite of the effect at Lamberton. The grain harvest moisture was 0.8% greater when fertilizer P was applied. Effects on harvest moisture could be a result of changes in the plant growth development caused by the P fertilizer treatment. The data from Lamberton as well as other studies have demonstrated a small chance of decreased grain moisture from P fertilizer from effects on plant growth. Even though there may be a statistically significant effect on grain moisture, potential for yield reductions from insufficient P application should be a major concern for farmers with low soil test P areas being targeted in fields in order to maximize grain yield potential.

Grain phosphorus concentration was assessed to determine if luxury consumption (more P being taken up than needed) was occurring in the high P strips within each field. According to the International Plant Nutrition Institute, average grain P concentration is near 0.297% for corn and 0.612% for soybeans. These P concentration values are based on results from research conducted in the Corn Belt prior to 2005. In this study most of the grain P concentrations for corn were below both values (Table 9). The only exception was the grain P concentrations from the Rochester and Staples locations. The values were well above that for corn at 0.333 and 0.336% at Rochester and for soybeans at 0.654 and 0.679% at Staples. Applied P had a significant ($P \leq 0.10$) impact on grain P concentration at all locations except for Rochester and Grand Meadow. At the Blomkest, Lamberton, New Richland, and Stewart locations, the increase in grain P concentration can be attributed to the increased grain yields where P was applied. The greatest increase in grain P concentration was 36% at Blomkest and New Richland when P fertilizer was applied. There was also a 32% increase in grain P concentration at Foxhome where the soybean grain yield was not significantly increased by the application of P fertilizer. It is likely that grain P concentration is more sensitive to low P availability than soybean grain yield. For the second year locations, grain P concentration differed only for strips receiving P fertilizer the previous year (Table 10) at Foxhome. At Grand Meadow and Stewart, the P applied the second season increased P concentration in the grain. Grain P concentration also differed at Lamberton, but the P strips were applied to the same field areas therefore we could not compare P applied the previous year to freshly applied P. There was no difference at the Blomkest and Lamberton (2012) locations for the second year studied.

Table 9. Grain phosphorus concentration and estimated phosphorus removal based on averages of the individual strip means within each replication from the first year trial data.

	Grain P Concentration			Grain P_2O_5 Removal		
	No P	High P	Statistics†	No P	High P	Statistics†
	----------------%------------		----*P>F*----	-------------lb/ac-------------		----*P>F*----
Blomkest	0.172b	0.232a	<0.01	38b	58a	<0.01
Foxhome	0.445b	0.590a	<0.01	14b	23a	0.06
Grand Meadow	0.608	0.633	0.17	39	41	0.32
Lamberton	0.220b	0.244a	0.06	58b	66a	0.07
New Richland	0.168b	0.232a	<0.01	36b	56a	<0.01
Rochester	0.333	0.336	0.61	81	83	0.39
Stewart	0.521b	0.575a	0.02	24b	28a	<0.01
Staples	0.654b	0.679a	<0.01	46	48	0.28
New Richland	0.239b	0.286a	0.10	38b	58a	<0.01

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when $P \leq 0.10$.

Table 10 Grain phosphorus concentration as affected by P application before the previous year's or the current year's crop from year two studies.

	No P YR 1		+ P YR 1		Statistics†		
	No P YR2	+P YR2	No P YR2	+P YR2	YR1 P	YR2 P	YR1 x YR2
	-------------------------------%---------------------------				-----------------*P>F*-----------------		
Blomkest	0.571	0.588	0.571	0.576	0.53	0.22	0.51
Foxhome	0.422b	0.423b	0.457a	0.453a	0.05	0.83	0.77
Lamberton '11	0.544b	--	0.571a	--	--	0.04	--
Grand Meadow	0.227b	0.245a	0.241a	0.246a	0.23	<0.001	<0.01
Lamberton '12	0.214	0.229	0.220	0.244	0.54	0.27	0.38
Stewart	0.253	0.261	0.265	0.276	0.24	0.06	0.59
Staples	0.290c	0.312ab	0.311ab	0.326a	0.19	<0.001	0.24

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when $P \leq 0.10$.

Table 11 Phosphorus removal by grain as affected by P application before the previous year's or the current year's crop from year two studies.

	No P YR 1		+ P YR 1		Statistics†		
	No P YR2	+P YR2	No P YR2	+P YR2	YR1 P	YR2 P	YR1 x YR2
	--------------------------lb P_2O_5/ac------------------------				-----------------*P>F*-----------------		
Blomkest	18bc	21a	17c	20ab	0.66	0.05	0.99
Foxhome	23b	23b	30a	30a	<0.01	0.64	0.96
Lamberton '11	32b	--	35a	--	--	<0.01	--
Grand Meadow	57	62	62	62	0.41	0.17	0.04
Lamberton '12	34	37	34	41	0.18	0.22	0.06
Stewart	58	60	62	62	0.28	0.01	0.59
Staples	62b	68a	65b	73a	0.48	<0.001	0.75

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when $P \leq 0.10$.

Grain P removal (reported as P_2O_5) was estimated by multiplying grain yield (weight per acre) by the grain P concentration. Grain P removal significantly ($P \leq 0.10$) increased by P fertilizer application at the same locations where differences from P fertilizer application were seen in grain P concentration (Table 9). At the sites where grain P removal differed, an apparent uptake efficiency of the P fertilizer could be measured using differences between when P fertilizer was and was not applied. The apparent grain P uptake efficiency was 10% at Blomkest, 4.5% at Foxhome, 4% at Lamberton, 13.3% at New Richland, and 2% for Stewart. This indicates that very little of the applied P was assimilated into the grain. It is important to note that the rates applied were not meant to measure the P utilization efficiency and in fact with the high fertilizer P application rates, the efficiency values would be low because the P fertilizer rate was much greater than current soil test recommendations or expected crop removal. We did not measure uptake into the plant but based on previous research there is little excess uptake of P into plant tissue while there may be some luxury uptake into grain. At some locations, P not used by the crop may still be available in the following cropping year. The question in high pH soils affected by calcium carbonate is how much P fertilizer will be sequestered and will not be available for plant use in subsequent crop years. These studies indicate no direct evidence of lower P availability when soil pH levels were high. The highest soil pH levels for studied carried to a second year were at Blomkest and Foxhome. At Blomkest yield benefitted from the fresh application of P while at Foxhome it did not. These were two sites with two different results; more data are needed to form a definitive conclusion on the frequency of P application in these types of soils. P removal in grain was increased at Foxhome but not at Blomkest during the second year. An increase was also seen at the Lamberton location. The differences at both of the significant locations was only 3 lbs P_2O_5 per are more P taken up when P was applied at Lamberton and when it was applied before the previous crop at Foxhome.

Yield Response to P and Critical Soil Test Values and Probability of Yield Response to P

One of the primary purposes of this study was to compare the grain yields with and without P to determine relative grain yield and relate that to the soil test value measured from the area encompassing the yes/no comparison. This comparison was used to determine the critical soil test P level or the value at which crops do not respond to applications of fertilizer P. Since routine phosphorus soil tests do not measure the total amount of nutrients within the depth sampled, values can vary between soil test methods. The different soil test methods do not measure the same pool of nutrients in the soil. For instance the Bray-P1 and Olsen tests may measure the same pool of easily extractable P in the soil, but since the Bray-P1 test is acidic it may also extract some calcium bound P that is not measured with the Olsen test. Since the soil tests extract different amounts of nutrients, the critical soil test levels will be different. For instance, the critical soil test P levels for the current University of Minnesota guidelines can be defined as, for corn, 15 ppm for the Bray-P1 and 11 ppm for the Olsen. In the case of soybeans, the critical level is near 10 ppm for the Bray-P1 and 7 ppm for the Olsen.

Table 12. Critical soil test P levels summarized by relative yield level for all corn data

	Critical soil test P level at selected relative corn grain yield levels		
Soil Test	95%	98%	100%
	--	ppm	--
Bray-P1	12	19	24
Olsen	8	11	13
Mehlich-3	13	19	22

Table 13. Critical soil test P levels summarized by relative yield level for all soybean data

	Critical soil test P level at selected relative corn grain yield levels		
Soil Test	95%	98%	100%
	--	ppm	--
Bray-P1	14	19	25
Olsen	10	12	16

Critical soil test P values for corn are summarized by relative yield level in Table 12 for each individual soil test method. Figures 2, 3, and 4 summarize relative yield (yield with no P as a percentage of yield with P) for the Bray-P1, Olsen, and Mehlich-3 P tests, respectively. Critical soil test P has been defined in the past in terms of 100, 98, or 95% of maximum grain yield. The official definition of the critical soil test level is the level at 95% maximum yield. According to the data from, 100% corn grain yield was achieved at 24 ppm for the Bray-P1, 13 ppm for the Olsen, and 22 ppm for the Mehlich-3 P tests. The values for the Bray-P1 and Olsen tests are close to those where 100% yield should be achieved under most circumstances based on current Minnesota recommendations. In general most states that use the Mehlich-3 test have similar critical P levels for both. The previous model using only 2010 corn data found that the Mehlich-3 critical levels were much higher than the Bray. It is likely that some of the sites with calcareous soils are influencing the Mehlich-3 soil test more than the others. This was noted earlier in this report in that the relationship between the Bray-P1 and Mehlich-3 tests was better in sites where soil pH values were the lower. Adding in the 2012 data improved the correlation of the Mehlich-3 soil test. However, it still would not be recommended for use for calcareous soils. Data from the Olsen P test was less variable (Figure 3) than the Bray-P1 (Figure 2) and Mehlich-3 (Figure 4). Soil test P results from the Blomkest and New Richland sites dominated the majority of the Low and Very Low soil tests observations, while the soil test results from the Lamberton and Rochester sites tended to dominate the observations for higher soil test P values. More data is needed to establish more low and high soil test P values for both the calcareous or non-calcareous soils. The increase number of observation will help to determine more accurately if the probability of yield response or critical soil test P levels change based on different soils. It was surprising that for all soil test P methods, a reduction in soil test P by 50% from the critical soil test level only resulted in a 5% reduction in grain yield. The largest difference in grain yield was only 30% when fertilizer was not applied. This indicates that a significant portion of the overall grain yield can be obtained in area of a field with low soil test P values. However, the value of the crop yield increase from the application of P fertilizer will more than cover the cost of fertilizer when soil tests are Low. Therefore, fertilizer P would be recommended when soil test P values are Low.

Critical soil test P data for soybean are given in Table 13. Only data from the Bray-P1 and Olsen extracts were used. There was much more variability in the results for the Mehlich-3 test which prevented the analysis from determining a significant statistical model to fit to the data. Due to this we could not accurately calculate a critical soil test level for that test. For the Bray-P1 test, the critical soil test value at 100% max yield was 25 ppm (Figure 5). This is much higher than that of corn and likely is being influenced by high pH, calcareous soils. Data from the Olsen test was about exactly the same for corn (Figure 6). While this number is surprising in a corn soybean rotation many growers are going to fertilize for the corn and if they are targeting at specific soil test level then there should be no negative impacts on soybean yields. The other consideration is that most of the data for soybeans was collected in 2011. Other research noted that some areas tended to respond more to P than other areas of the state. It could be that conditions were favorable for P response in 2011 causing critical levels to shift. Also, there were many outlier points in the data sets which likely affected results. While we are confident in the data collected, more points over more years would be highly beneficial for the development of the critical soil test levels. From the data we have it does not appear that of the soils studied there were any that would necessitate separation to have a different critical soil test levels. There were differences in calcareous and non-calcareous soils but they tended to fit the same relationship and the evidence suggests that the same correlation can be used for each soil type across the state.

Table 14. Probability of a significant yield response to corn based on current break points for the Bray-P1 and Olsen P tests and the average magnitude of response to P within a given soil test range. n= number of samples within each classification.

		Bray-P1 Test				Olsen-P Test		
		Probability of Response	Magnitude of Response†			Probability of Response	Magnitude of Response†	
Class	n		Sig.	All	n		Sig.	All
		--------------------%--------------------				--------------------%--------------------		
VL	16	100	13.0	13.0	48	88	16.4	14.3
L	133	72	12.7	9.2	50	80	11.9	9.5
M	59	25	7.9	2.0	75	29	9.3	2.7
H	59	10	2.2	0.2	114	18	7.5	1.4
VH	133	5	11.4	0.6	113	13	7.4	1.0

†Percent increase in yield considering (Sig.) only field areas where P significantly increased yield and (All) all zones for the given soil test classification

The probability of a significant yield response was calculated for both corn (Table 14) and soybean (Table 15) and broken down into the current P classifications for the Bray-P1 and Olsen P tests. For corn, the probability of a significant yield response was 100% when soils tested Very Low, 72% when Low, 25% when Medium, 10% when High, and 5% when Very High. The probabilities were different when using the Olsen test especially when the soils tested medium or higher. When comparing the number of field areas within each given class to use for the analysis the Olsen test had a better distribution of sites which would make for a more robust analysis. This may be one of the reasons for the shift in the probabilities. Some data points were excluded from the analysis but more work needs to be done to look over the points to see why the probability of response was so high in the Very High classification for the Olsen test. Most past work has found that there is a small probability in this classification (1-2% of the time) that there will be a significant yield increase. In general the trend did follow what was expected as the probability of response decreased with increasing soil test P. The magnitude of the response also decreased at soil test P increased. For the Bray-P1 test in the Very Low category we found that there was an average increase of 13.0% in yield for all points in that category. For the Olsen test there was an 88% probability response and the average increase in yield was 16.4%. This data shows that as soil test decreases there is a high probability of a larger increase in yield. For the Olsen P test there was a 13.0% chance of response when soil tested Very High in p, but the average response was only 1.0%, or about 2.0 bu/ac for a 200 bu. yield potential. This type of information can be critical when deciding where to apply fertilizer especially in cash short situations. When in a rental situations if growers have to make a choice the best option is to target Very Low or Low testing areas and potentially Medium testing areas due to the higher probabilities of response and the magnitude of the potential response. If money to cover fertilizer cost is not a problem then building and maintaining in the High category around the critical level poses less of a risk, and there does not appear to be convincing evidence that maintaining a Very High soil test is needed or economical unless a grower is using a inexpensive source of fertilizer P.

Table 15. Probability of a significant yield response to soybean based on current break points for the Bray-P1 and Olsen P tests and the average magnitude of response to P within a given soil test range. n= number of samples within each classification.

		Bray-P1 Test				Olsen-P Test		
		Probability of	Magnitude of Response†			Probability of	Magnitude of Response†	
Class	n	Response	Sig.	All	n	Response	Sig.	All
		--------------------%--------------------				--------------------%--------------------		
VL	76	26	37.2	9.8		39	45.1	17.3
L	14	50	17.5	8.7		32	23.3	7.4
M	25	36	10.6	3.8		22	4.8	1.0
H	33	27	4.8	1.3		21	6.4	1.3
VH	122	17	4.2	0.7		11	0.3	0.0

†Percent increase in yield considering (Sig.) only field areas where P significantly increased yield and (All) all zones for the given soil test classification

For soybean, there was some variability in the Bray-P1 tests assessment of the probability in the Low classification. This is likely a result of most of the Low testing areas being on calcareous soils and their effect on the Bray-P1 extraction of P. The Olsen soil test follows a more consistent pattern and was likely a better option in the locations studied to determine the probability of response. It should be noted that the Foxhome site from 2010 was not included due to issues with other factors affecting yield other than P. There were similar issues at the Blomkest site in 2011 so areas of the plot were also excluded. Comparing responses for the Olsen test between corn and soybeans there is a lower probability of a response to P of soybean within a given class. However, the magnitude of the response was larger.

Results and Discussion: Potassium Studies

This summary is for the third year of a multi-year study focusing on potassium management. Since few locations have been studied we do not have a strong data set for corn and soybean to calibrate the current soil test. Some correlation and calibration work is included but more data in future years from additional locations will aid in better determining the critical level of K for different soil tests. This report focuses on strip mean data by site to study K response.

Soil Test Variability

A summary of the soil test data for the ammonium acetate and Mehlich-3 soil tests is given in Tables 16 and 17, respectively. Soil test K averaged in the Very High classification at three locations (Grand Meadow, Preston, and New Richland) and Medium at both Staples locations. However, individual sampling points measured from Medium to Very High at Grand Meadow, Preston, and New Richland and Low to High at Staples. The variability in soil test values was the greatest at Preston as indicated by the larger standard deviation. Data in Figure 8 shows the relationship between the traditional test for K used in Minnesota, the ammonium acetate, and the Mechlich-3. In this case the tests were almost identical in their assessment of soil test K. Since soil test K is not affected by pH there is much more flexibility in the extraction methods across a number of soils than for P.

Table 16. Summary of air dried ammonium acetate potassium soil test for samples collected in spring prior to K application from the 0-6" soil depth. Summary is of the average, minimum, and maximum values from 64 sampling areas within each location and their standard deviation.

	Air Dry Ammonium Acetate Potassium			
	Average	Min	Max	Standard Dev.
	------------------------------------	ppm	------------------------------------	
Grand Meadow	147	104	207	21
Preston	150	94	311	58
Staples '11	99	67	130	13
Staples '12	113	62	323	46
New Richland	161	117	227	19

Table 17. Summary of air dried Mehlich-3 potassium soil test for samples collected in spring prior to K application from the 0-6" soil depth. Summary is of the average, minimum, and maximum values from 64 sampling areas within each location and their standard deviation.

	Air Dry Mehlich-3 Potassium			
	Average	Min	Max	Standard Dev.
	------------------------------------	ppm	------------------------------------	
Grand Meadow	134	97	181	20
Preston	142	91	337	60
Staples '11	105	79	133	12
Staples '12	122	76	294	45
New Richland	144	107	195	18

Table 18. Summary of slurry/moist ammonium acetate potassium soil test for samples collected in spring prior to K application from the 0-6" soil depth. Summary is of the average, minimum, and maximum values from 64 sampling areas within each location and their standard deviation.

	Slurry/Field Moist Ammonium Acetate Potassium			
	Average	Min	Max	Standard Dev.
	ppm			
Grand Meadow	145	72	241	35
Preston	152	72	479	88
Staples '11	95	54	126	15
Staples '12	137	63	486	78
New Richland	--	--	--	--

Table 19. Soil test K summary for averages for the individual strip means within each replication for the potassium locations for samples air dried prior to analysis and analyzed with the field moist or slurry methods.

	Air dry			Field Moist/Slurry		
	No K	High K	Statistics†	No K	High K	Statistics†
	ppm		----*P>F*----	ppm		----*P>F*----
Grand Meadow	141b	183a	0.09	151b	216a	0.07
Preston	98	120	0.11	81b	119a	0.05
Staples	108	141	0.25	--	--	

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when *P*≤0.10.

In addition to the air dried K test a moist/slurry method was used to directly analyze the field moist samples. This is done to prevent any fixation or release of K in the drying process used to prepare soil samples for routine analysis. Data from the year 1 locations is given in Table 18 and the second year location data is included in Table 19. There was no difference between the air dried and field moist/slurry test at any of the first year sites. Previous Iowa research has shown the moist/slurry test to be lower in heavier clay soils. We did not have any of those soil types in this study. The K test was higher at the Staples location in 2012 for the field moist test. At the Grand Meadow and Preston locations in year 2, both the air dried and slurry K tests measured a similar increase in soil test K. It did not appear that the moist/slurry K test would improve the prediction of the ammonium acetate K test at these sites. Only preliminary data are available for New Richland. However, values were much lower in some areas of the study indicating a greater difference due to drying samples at this location.

K effects on Corn Grain Yield and K removal in Grain

Table 20 summarizes the analysis for strip means for yield and grain moisture at harvest. Analysis across the trial area within each site indicated no significant effect on yield at two locations. Since most sites tested High no significant effect would be expected. However, factoring in the subsoil K level did show a significant effect of K on grain yield at the Preston location were corn yields were 3 bu/ac higher with K. Soybean yield was 2 bu/ac lower with K applied at Grand Meadow. The greatest increase in yield occurred at New Richland where corn yield was 9 bu/ac greater when K was applied. Harvest grain moisture was only affected at the Preston and Staples (2011) locations were the grain was wetter with K at both locations. Potassium has been noted to help plants with drought stress so the wetter grain could be due to the plant surviving longer into the season when rainfall amounts dropped off significantly at the end of the growing season at most locations in the state. Corn grain yield was only increased during the second growing season at Staples (Table 21). In this case, corn grain yield was increased only when K was applied before the corn crop grown in year 2.

Table 20. Grain yield and harvest moisture summary for averages for the individual strip means within each replication for the potassium locations.

	Grain Yield Average			Grain Moisture Average		
	No K	High K	Statistics†	No K	High K	Statistics†
	------------bu/ac------------		----*P>F*----	----------------%--------------		----*P>F*----
Grand Meadow	55a	53b	<0.001	10.3	10.4	0.81
Preston	170b	173a	0.06	13.1b	13.9a	0.004
Staples ‘11	178	177	0.68	12.8b	12.9a	0.07
Staples ‘12	58	57	0.23	10.1	9.9	0.23
New Richland	175b	184a	<0.01	23.9	24.1	0.26

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when $P \leq 0.10$.

Table 21 Grain yield as affected by K application before the previous year’s or the current year’s crop from year two studies.

	No K YR 1		+ K YR 1		Statistics†		
	No K YR2	+K YR2	No K YR2	+K YR2	YR1 K	YR2 K	YR1 x YR2
	----------------------------bu/ac-----------------------				-----------------*P>F*-----------------		
Preston	55.8	56.2	56.7	55.4	0.97	0.60	0.34
Grand Meadow	196	193	187	193	0.10	0.71	0.16
Staples	172b	176a	173b	182a	0.88	0.10	0.21

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when $P \leq 0.10$.

Table 22. Grain potassium concentration and estimated potassium removal based on averages of the individual strip means within each replication from the 2011-2012 trial data.

	Grain K Concentration			Grain K_2O Removal		
	No K	High K	Statistics†	No K	High K	Statistics†
	---------------%-------------		----*P>F*----	-------------lb/ac-------------		----*P>F*----
Grand Meadow	1.74b	1.79a	0.01	59.5	59.4	0.96
Preston	0.38	0.39	0.30	38.5	40.1	0.45
Staples ‘11	0.38b	0.40a	0.02	41.5	42.8	0.37
Staples ‘12	1.78	1.80	0.29	63.3	63.4	0.91
New Richland	0.33	0.33	0.93	36.3b	38.7a	<0.001

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when $P \leq 0.10$.

Potassium concentration in the grain was increased at 2 locations but the overall K removal was only affected at New Richland during the first growing cycle (Table 22) and at Staples during the second cropping year (Table 23). The lack of an effect on K removal is a result of the lack of significance in yield. At Grand Meadow and Staples (2011) the concentration of K in the grain was higher when K was applied. However this difference was very small at only 0.01 to 0.03 lbs of K_2O per bushel increase in K removal. While there may be an effect it does not appear to be significant enough to cause large economic loss through excess removal of K. Luxury uptake of K in the grain should be considered and important factor when deciding when K should be applied.

Table 23 Grain K removal as affected by K before the previous year's or the current year's crop from year two studies.

	No K YR 1		+ K YR 1		Statistics†		
	No K YR2	+K YR2	No K YR2	+K YR2	YR1 K	YR2 K	YR1 x YR2
	---------------------------lb K_2O/ac---------------------				-----------------*P>F*-----------------		
Preston	54c	56ab	57a	55bc	0.18	0.96	<0.01
Grand Meadow	37	37	36	37	0.76	0.94	0.69
Staples	47ab	48ab	46b	50a	0.82	<0.001	0.03

†Statistical analysis comparing strip mean averages within each location. Treatments are considered significantly different when $P \leq 0.10$.

Table 24 Critical soil test K levels for corn based on the trial data.

	Critical soil test K level at selected relative soybean grain yield levels		
Soil Test	95%	98%	100%
	--ppm--		
Am. Ac. K (air dry)	24	67	107
Am. Ac. K (moist)	35	82	85
Mehlich-3 K	29	89	106

Table 25 Critical soil test K levels for soybean based on the trial data.

	Critical soil test K level at selected relative soybean grain yield levels		
Soil Test	95%	98%	100%
	--ppm--		
Am. Ac. K (air dry)	52	82	192
Am. Ac. K (moist)	53	79	156
Mehlich-3 K	68	93	180

Critical soil test data could was determined for corn in-spite of poor R^2 values. The data for the air dry ammonium acetate test is shown in Figure 10, the field moist/slurry test is summarized in Figure 11, and Figure 12 summarizes the air dry test with the Mehlich-3 extraction. While the models were significant, there was very little change in relative yield among a wide range in soil test K values. For instance, 95% of the maximum yield was achieved on average with a soil test of 24 ppm with the air dried ammonium acetate test. Thus, the data should not be used until more low to very low soil test values can be studied. The field moist test did not perform better than the air dried test. Figures 13 through 15 summarize the data for soybean. Table 24 summarizes the critical soil test data. At 100% relative yield, the ammonium acetate dry and field moist/slurry tests gave slightly different results. Similar to the corn data, while we can determine a critical level from the data, more sites will be beneficial to increase the number of data points for the analysis.

Conclusions

The probability of response to phosphorus was greatest at when soil tested low. There was a high potential for a large increase in yield in Low testing corn and soybean fields and a moderate chance of a modest increase in yield in the Medium class. After two years of study the critical soil test level for P was found to be similar to current guidelines. However, more research sites would be beneficial to add to the data set. Critical soil test P levels were found to be higher than expected, however they were not different than for corn. If a grower were fertilizing based on a corn crop yield would not be reduced for soybean. At this time there is not enough data collected to determine critical soil test for K. Both P and K fertilizer application tended to increase P or K concentration in the grain. Phosphorus removal in the grain was significantly increased by P application and K removal was not. While removal can result in increased profit loss, the effect appears to be small and does not outweigh potential benefits for increases in profit potential due to higher yields.

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APPENDIX - Figures

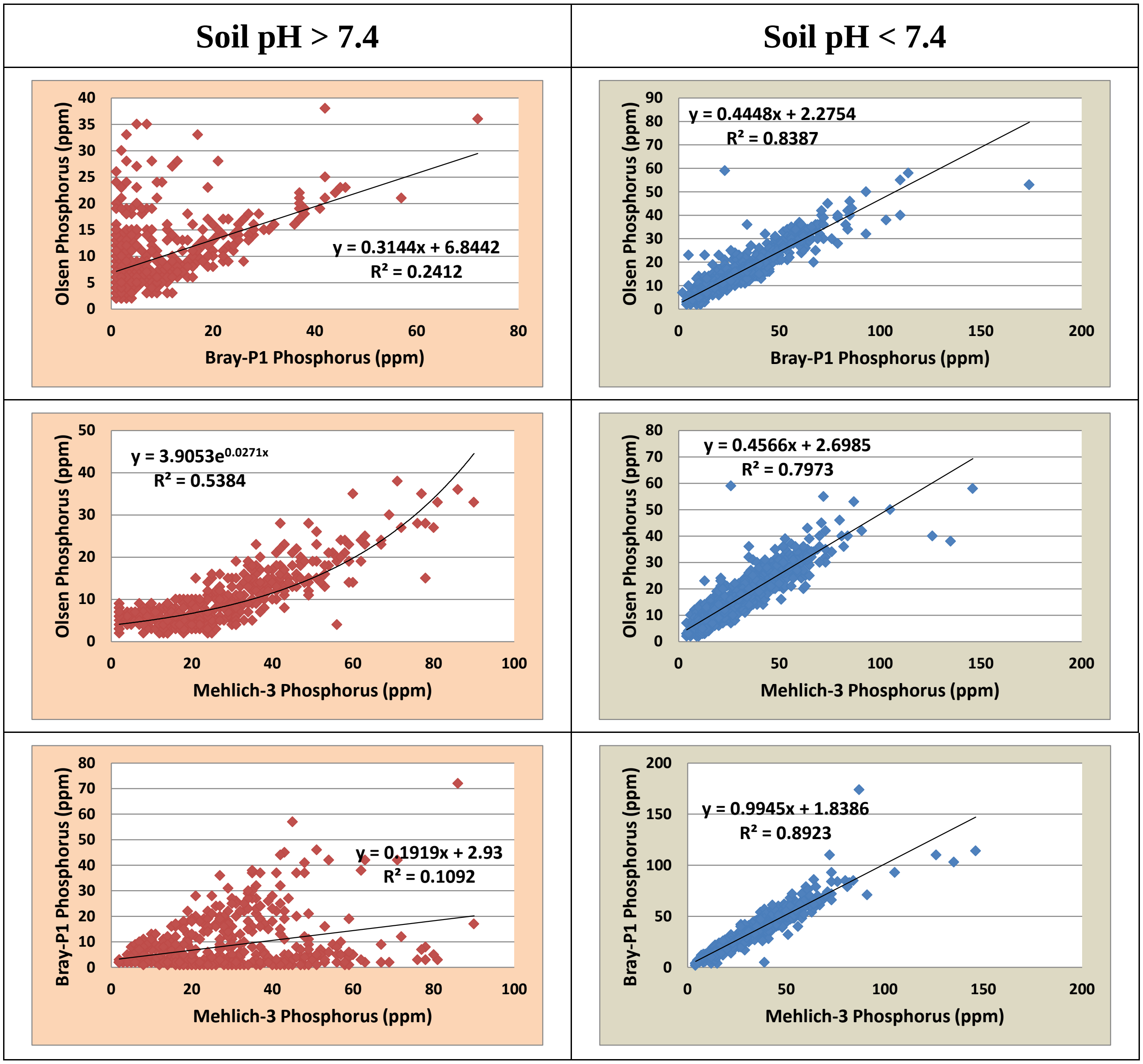

Figure 1. Comparisons of soil test methods for assessing soil P when soil pH is > 7.4 and pH<7.5.

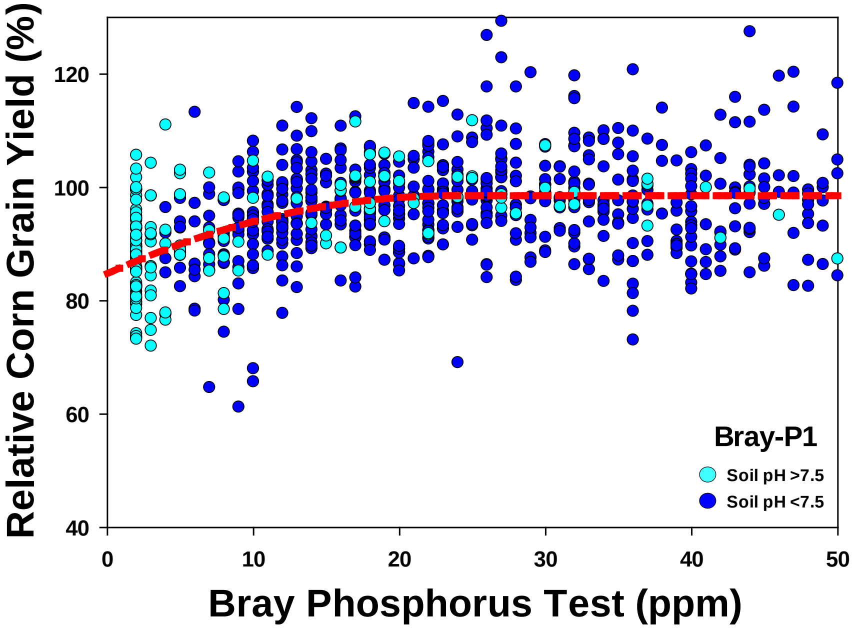

Figure 2. Relative yield of corn without phosphorus versus the Bray-P1 soil test collected prior to P fertilizer application from corn locations across Minnesota. The dashed line represents the best fit model for the corn site data (Quadratic Plateau) based on model fitting criteria. Dark blue circles represent field areas where soil pH < 7.6. Light blue circles are where pH was 7.6 or greater.

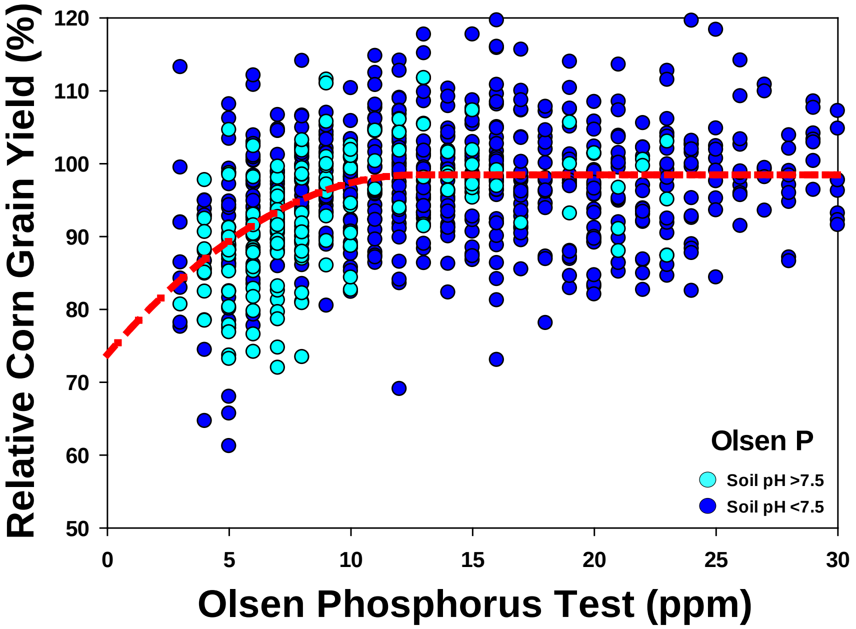

Figure 3 Relative yield of corn without phosphorus versus the Olsen soil test collected prior to P fertilizer application from corn locations across Minnesota. The dashed line represents the best fit model for the corn site data (Quadratic Plateau) based on model fitting criteria. Dark blue circles represent field areas where soil pH < 7.6. Light blue circles are where pH was 7.6 or greater.

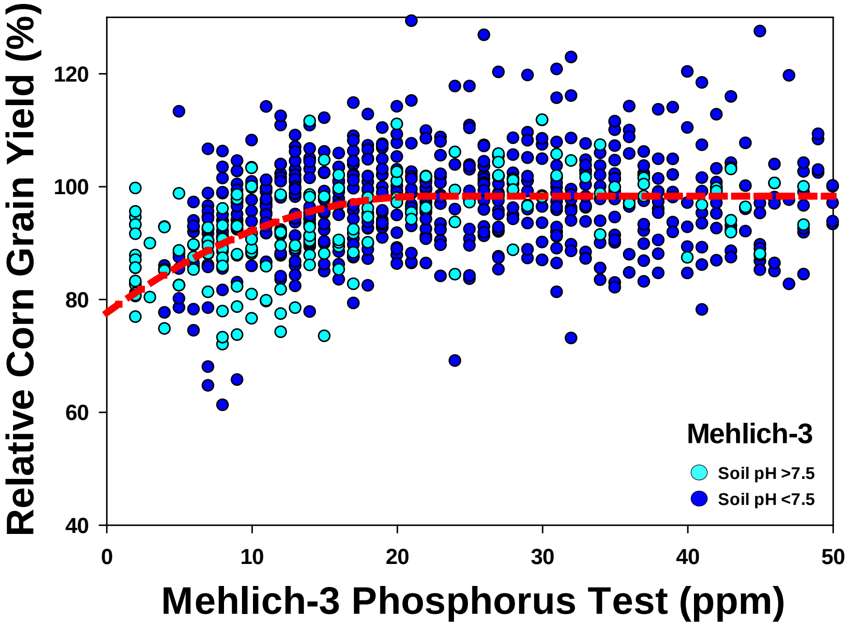

Figure 4 Relative yield of corn without phosphorus versus the Mehlich-3 soil test collected prior to P fertilizer application from corn locations across Minnesota. The dashed line represents the best fit model for the corn site data (Quadratic Plateau) based on model fitting criteria. Dark blue circles represent field areas where soil pH < 7.6. Light blue circles are where pH was 7.6 or greater.

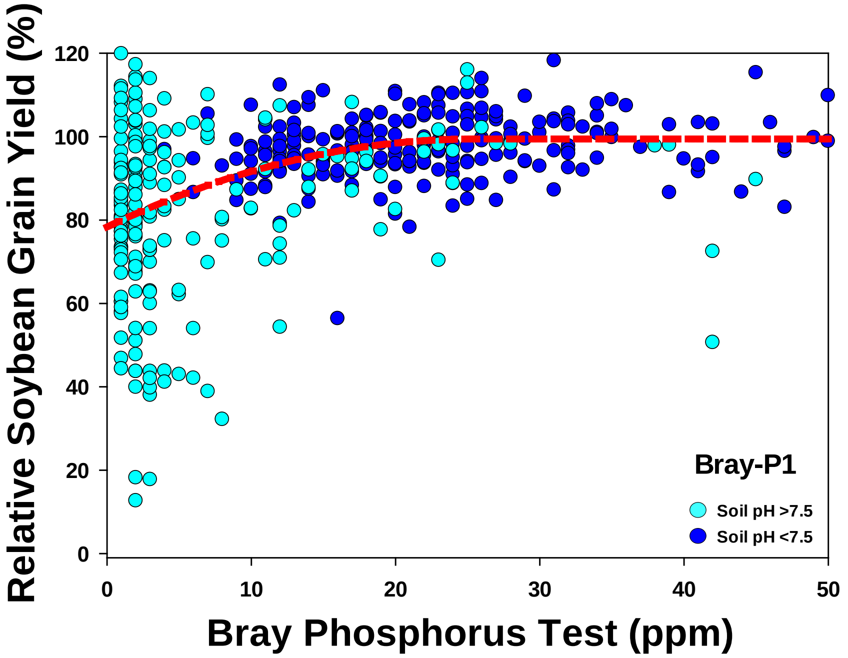

Figure 5. Relative yield of soybean without phosphorus versus the Bray-P1 soil test collected prior to P fertilizer application at locations across Minnesota. The dashed line represents the best fit model for the corn site data (Linear Plateau) based on model fitting criteria. Dark blue circles represent field areas where soil pH < 7.6. Light blue circles are where pH was 7.6 or greater.

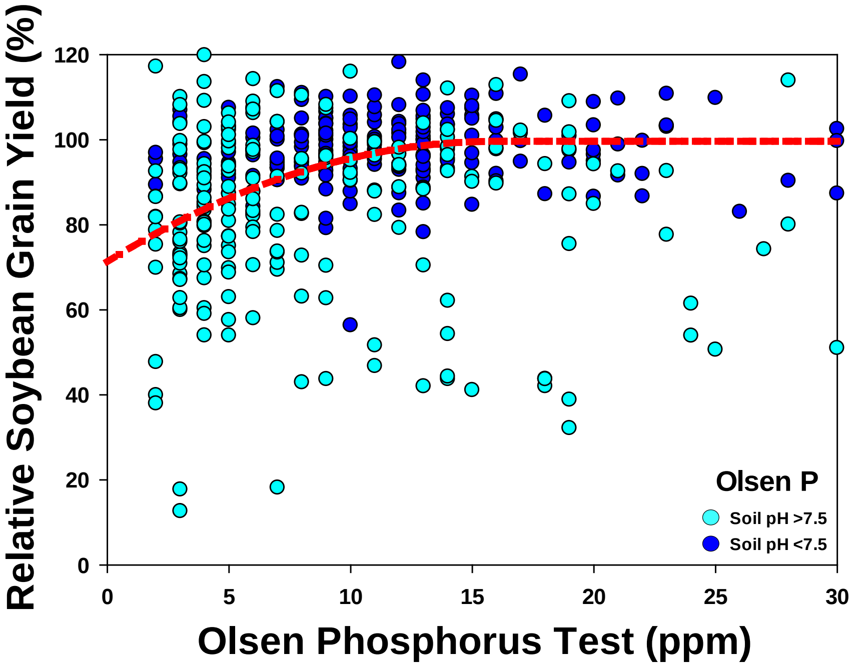

Figure 6. Relative yield of soybean without phosphorus versus the Olsen P soil test collected prior to P fertilizer application at locations across Minnesota. The dashed line represents the best fit model for the corn site data (Quadratic Plateau) based on model fitting criteria. Dark blue circles represent field areas where soil pH < 7.6. Light blue circles are where pH was 7.6 or greater.

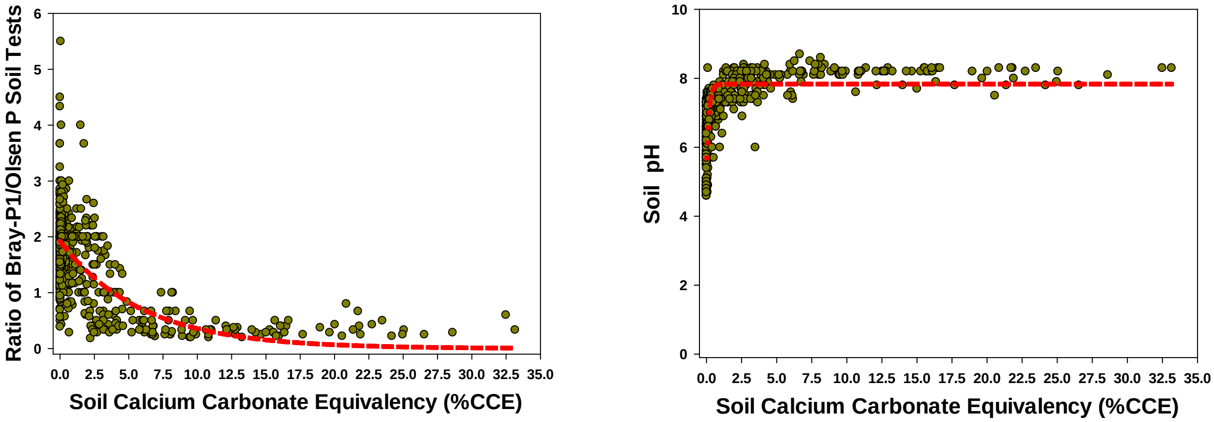

Figure 7. Relationship between calcium carbonate equivalency (%CCE) of soil samples and the ratio of P extracted by the Bray-P1 and Olsen P tests and soil pH from the year 1 sites.

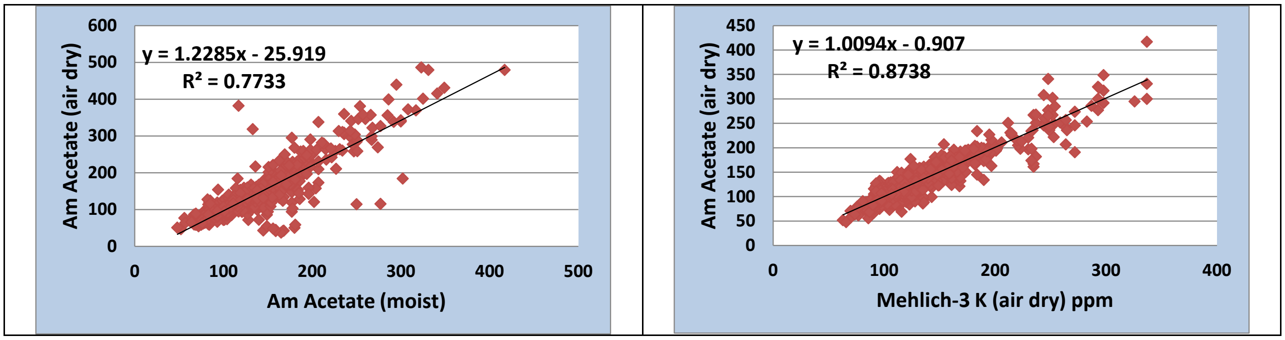

Figure 8. Relationship between the air dry ammonium acetate K soil test and the Mehlich-3 soil test for K. The diagonal line represents the significant linear relationship between the two K soil tests.

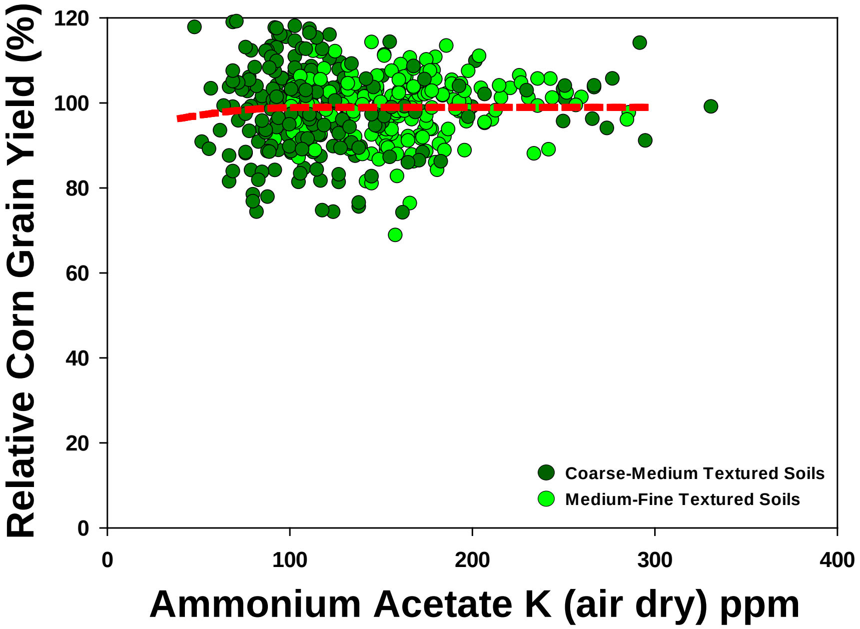

Figure 10. Relationship between relative corn yield and the air dried ammonium acetate K test. The dashed line represents the best fit curve.

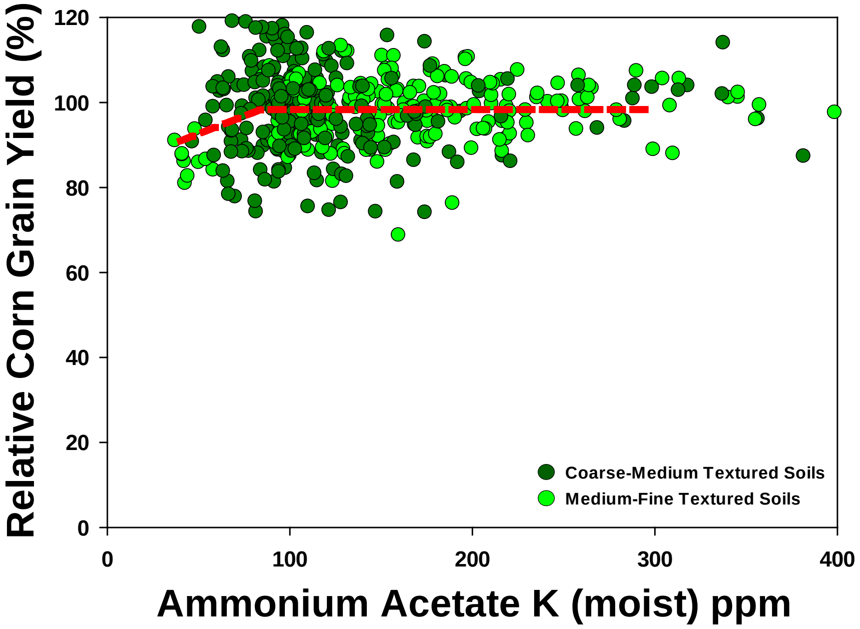

Figure 11. Relationship between relative corn yield and the ammonium acetate K test for field moist samples. The dashed line represents the best fit curve.

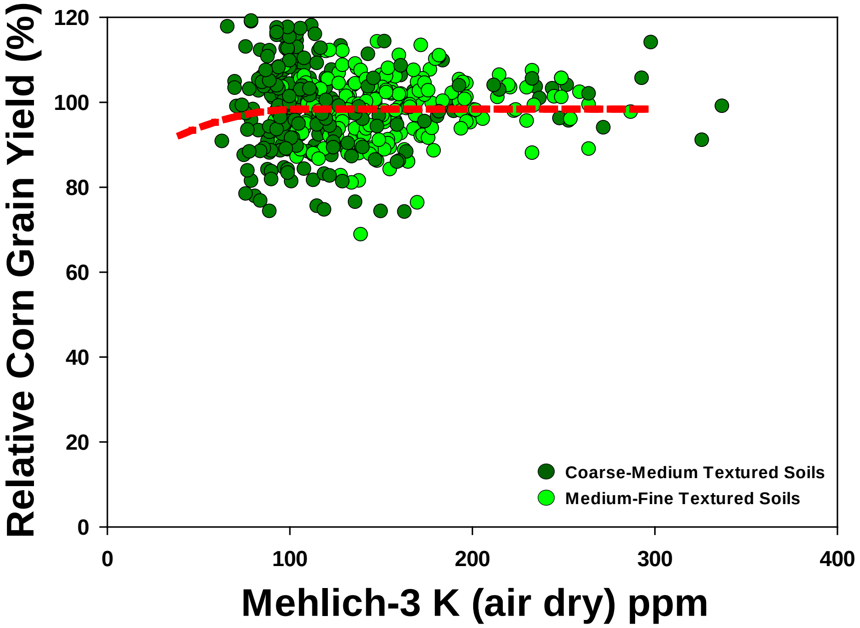

Figure 12. Relationship between relative corn yield and the air dried Mehlich-3 K test. The dashed line represents the best fit curve.

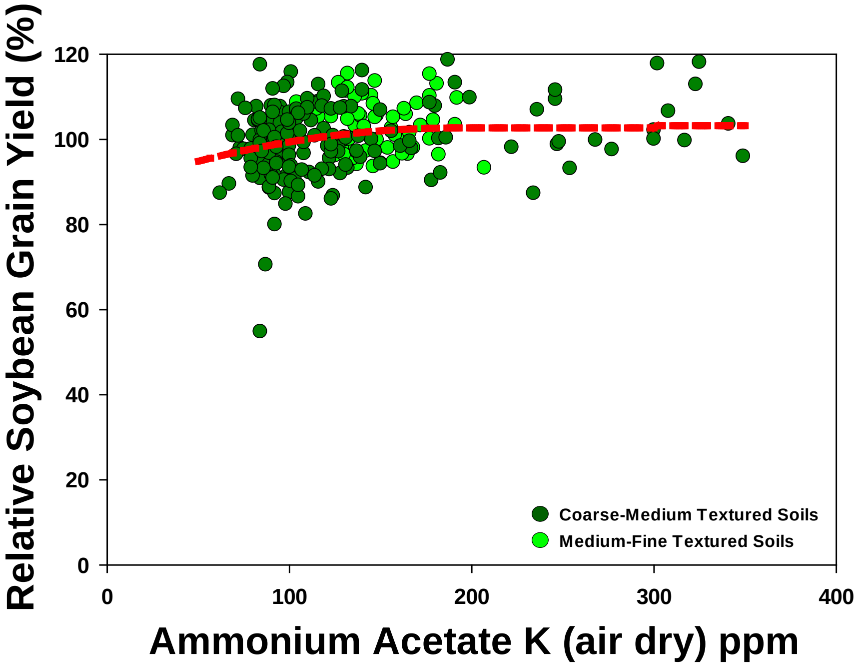

Figure 13. Relationship between relative soybean yield and the air dried ammonium acetate K test. The dashed line represents the best fit curve.

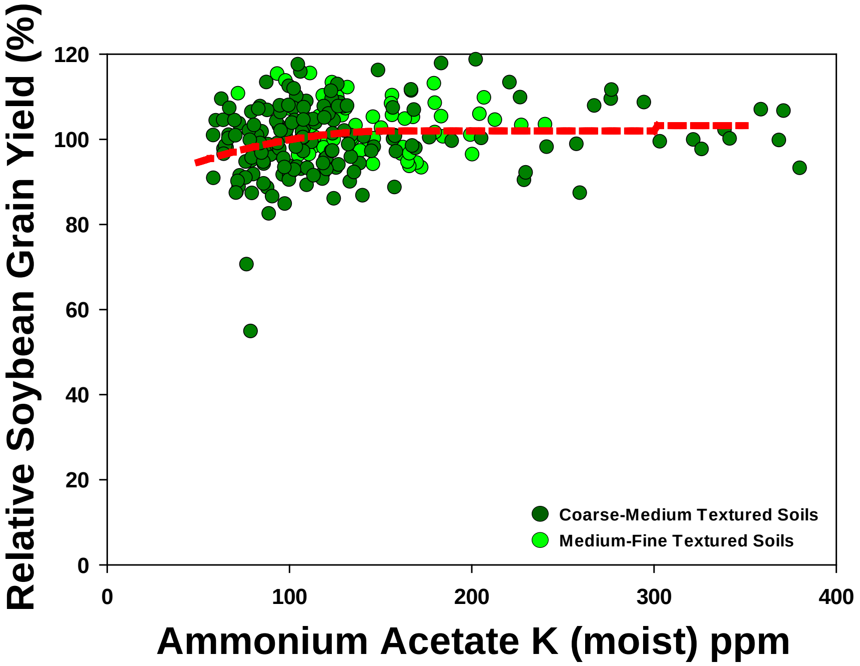

Figure 14. Relationship between relative soybean yield and the field moist/slurry ammonium acetate K test. The dashed line represents the best fit curve.

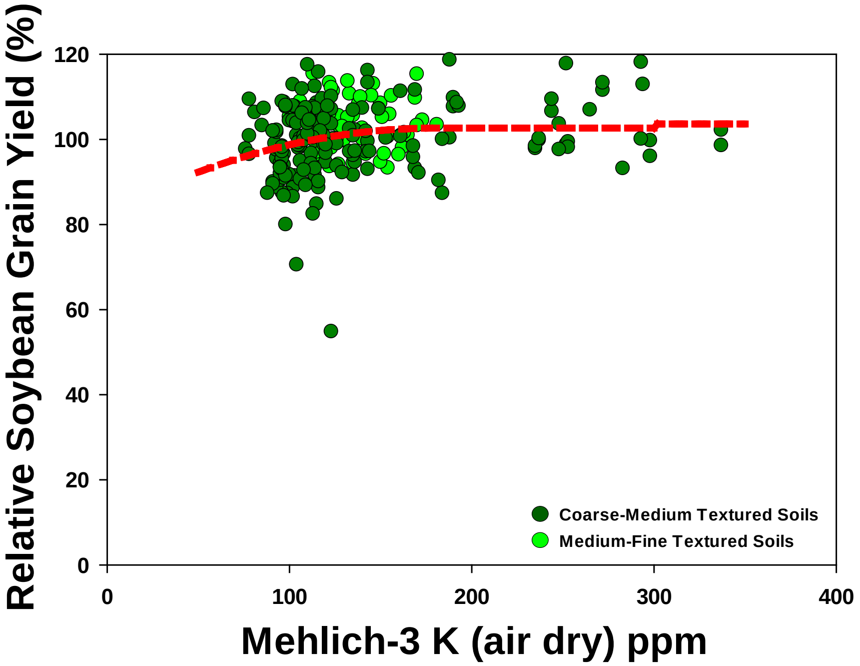

Figure 15. Relationship between relative soybean yield and the air dried Mehlich-3 K test. The dashed line represents the best fit curve.