EVALUATION OF PHOSPHORUS RESPONSE TO FERTILIZER PLACEMENT AND HYBRID SELECTION

by

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Abstract

Two studies were conducted to evaluate phosphorus response. The first study focused on genetic improvements in corn (*Zea mays*) for water limited scenarios on phosphorus uptake. The object of the first study was to evaluate plant response to fertilizer and soil phosphorus for contrasting corn hybrids, including a drought tolerant (DT) and conventional hybrid. This study was established at seven locations for two years (2011 and 2012). Four locations were rain fed and three locations were under irrigation. Fertilizer treatments included phosphorus fertilizer at various rates and placements for the two different hybrids. The experimental design randomized complete block with factorial arrangement in four replications. Early growth biomass, early season whole plant tissue concentration (V6), ear leaf tissue concentration, and grain yield was measured throughout the season. Results showed differences in all measurements between hybrids. Differences in most measurements were also significant with fertilizer application. The DT hybrid had less early growth and P uptake but had higher ear leaf P concentration as well as higher yields. The second study focused on P placement, P stratification may be a concern for producers using reduced tillage systems. The objective of this study was to evaluate different placements and rates of P fertilizers in two crops, corn and soybean (*Glycine max*). This study is currently ongoing; however, here we are presenting data from three locations and four years (2009-2012). Two of the locations were rain fed and one was irrigated. There were four different fertilizer rates with three different placements as well as various combinations of those placements. The experimental design was randomized complete block with four replications at two locations and three replications at one location. Corn early growth biomass, whole plant tissue concentration, ear leaf tissue concentration, soybean uppermost fully open trifoliate P concentration, and yield for both crops were evaluated throughout the season. Results showed

response to the phosphorus treatments in all the measured parameters. Results also showed differences in all measured parameters except yield, were significantly affected by placement.

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Dedication

I dedicate my work to my family. To William, Sheri, Lucas, Alex, Kayla, and Conner, thanks for your endless support and love. My family has made me the way I am today, they are the reason I am able to succeed. I could not have asked for a better family.

To my grandparents, they have always supported me in whatever I wanted to do. To Lucas's wonderful family; Dorothy and their two amazing kids, Wallace and Thomas. To Alex's fiancé Abby, she will be a wonderful addition to the family.

"Whether you think you can, or you think you can't -- you're right" - Henry Ford

CHAPTER 1 - INTRODUCTION

Corn genetic improvements in recent years have generated hybrids intended for water limited conditions (drought tolerant). Some of these hybrids resulted from a conventional breeding selection process. These hybrids have characteristics that may be related to different genetic factors including growth habits and differences in root system. Companies that are developing drought tolerant (DT) corn generated with conventional breeding have indicated that these hybrids have deeper rooting systems with potentially higher capability for access to subsoil water. A selection process targeting different rooting system may also affect overall nutrient uptake particularly for immobile nutrients such as phosphorus. A hybrid with higher root growth, root biomass nitrogen and phosphorus uptake can be expected to show different response to starter fertilizer. With more roots per unit area, there will be more roots for nutrient uptake. Therefore, response to starter fertilizers may be expected to be different for a hybrid with a slow rate of root growth and/or low nutrient uptake rate (Rhoads and Wright, 1998). Differences in nitrogen and phosphorus concentrations among hybrids were found in ear leaf tissue at VT (Gordon et al, 1998). Studies have suggested that differences in rooting system among corn hybrids may contribute to the significant differences in nutrient uptake from fertilizer and soil phosphorus (Gordon et al, 1998). The adoption of reduced tillage practices in more recent years has raised questions about fertility management issues, especially in phosphorus. With less tillage phosphorus stratification may become an issue over time. Nutrient stratification refers to the non-uniform distribution of nutrients within the soil. Phosphorus stratification concerns include potential impacts on crop yield and nutrient uptake due to inability of the crops to access the nutrients stratified in the soil. With the reduced tillage P stratification is the result of surface application and decreased mixing of the fertilizer with fewer tillage passes. Stratification also can result from uptake within the plants that then decompose on the surface that are not tilled into the soil (MacKay et al, 1987). Crop response to P fertilization is to be expected at low soils tests P (STP) (Liekam et al, 2003) and may be observed regardless of placement. The most consistent phosphorus response in reduced tillage systems tends to be starter fertilizer on low testing soils. High STP has shown yield responses to fertilizer P but many studies show conflicting results (Gordon et al, 1997; Mallarino et al, 1991). For high STP soils according to the Kansas State recommendation (STP greater than 20 mg kg^{-1} sufficiency and STP greater than 30 mg kg^{-1} build-maintenance) the recommendation would be no phosphorus necessary for the upcoming crop (Liekam et al, 2003). There is not one placement method proved to be overall superior over another placement method. The amount of soil contact that the fertilizer receives with each placement varies widely from broadcast to starter. The starter placement as well as the subsurface band placement concentrates the fertilizer into a zone coming into less contact per unit area when compared to a broadcast application. One advantage of having the concentrated zone would be more availability in that area.

There are many studies that suggest placement is not a factor as long as there is enough soil P for the crop's upcoming yield goal. Placement could become more important in moisture limiting environments due to limited access via crop roots and lack of diffusion of the phosphorus nutrient for the plant (Mengel 1995).

Thesis organization

This thesis is divided into four chapters. The first chapter is a general introduction. The second chapter "Corn hybrids with contrasting drought tolerance response to phosphorus" examines how advances in corn hybrids mainly the selection for drought tolerance and response to phosphorus fertilization, including starter, broadcast, or a combination of starter and broadcast phosphorus application, and aims to determine the effectiveness of current fertility recommendations and if they are compatible with the new drought tolerant hybrids. The third chapter “Crop response to phosphorus fertilization in reduced tillage systems” looks at different rates and placements of phosphorus fertilizer in reduced tillage cropping systems, and looks to see if phosphorus stratification is an issue in these reduced tillage systems. The fourth chapter is a general conclusion.

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CHAPTER 2 - CORN HYBRIDS WITH CONTRASTING DROUGHT TOLERANCE RESPONSE TO PHOSPHORUS

ABSTRACT

Current corn (*Zea mays*) genetic improvements focusing on water-limited scenarios, has made it necessary to understand how root system architecture and growth may affect overall nutrient uptake particularly for immobile nutrients. The objective of this study was to evaluate plant response to fertilizer and soil phosphorus for contrasting corn hybrids, including a drought tolerant (DT) and conventional. The study was established at seven locations during two years (2011 and 2012). Four locations were rain fed and three locations were irrigated. Fertilizer treatments included starter and broadcast phosphorus application, with 112 kg ha^{-1} P_2O_5 broadcast and 22 kg ha^{-1} P_2O_5 starter. The experimental design was a factorial and in a randomized complete block with four replications. The factors were four fertilizer treatments and two hybrid combinations for a total of eight treatments. Early growth biomass was evaluated at the V6 growth stage, including whole plant tissue phosphorus concentrations. Ear leaf tissue was also collected at the VT-R1 growth stage and analyzed for phosphorus concentration. Grain yield was evaluated at the end of the growing season. Results showed significant differences in early growth, ear leaf phosphorus concentration, and grain yield response between hybrids. Significant differences in early growth, phosphorus uptake, ear leaf phosphorus concentration, and grain yield were also found between fertilizer application methods. Across locations the DT hybrid had slower early growth and P uptake compared to the conventional hybrid but by mid-season the DT hybrid had a higher ear leaf P concentration and much higher yields.

Abbreviations: DT, drought tolerant; STP, soil-test P.

INTRODUCTION

Corn genetic improvements in recent years have included hybrids adapted for water limited conditions (drought tolerant). Initial DT hybrids were the products of a conventional breeding selection process. However, new transgenic drought tolerant corn hybrids are also becoming available to producers. A previous study demonstrated that corn response to starter fertilizer application can vary by hybrid (Gordon et al, 1997). These differences may be related to different genetic factors including growth habits and differences in root system. Commercially generated data has suggested that drought tolerant (DT) corn generated with conventional breeding should have a deeper rooting system with potentially higher capability for access to subsoil water. A selection process targeting different rooting patterns may also affect overall nutrient uptake particularly the uptake of immobile nutrients (Mengel, 1995). A hybrid with greater root growth, root biomass and ability to take up nitrogen and phosphorus may also show a different response to starter fertilizer (Mengel, 1995). A positive response to starter fertilizer may be expected of a hybrid having a slow rate of root growth and/or low nutrient uptake rate (Rhoads and Wright, 1998). Previous studies in Kansas evaluated the response of several corn hybrids to starter fertilizer application. Gordon et al (1998) evaluated the effects of starter fertilizer on six corn hybrids with maturities ranging from 2530 to 2850 growing degree units (GDD) grown under no-tillage and dryland conditions. Results showed significant differences in the amount of nitrogen and phosphorus uptake at the V6 growth stage. Differences in nitrogen and phosphorus concentrations among hybrids also were found in ear leaf tissue at VT (Gordon et al, 1998). They suggested that differences in rooting system among corn hybrids may contribute to the significant differences in nutrient uptake from fertilizer and soil phosphorus. However, the study evaluated specific commercial hybrids available at that time that were not categorized based on drought tolerance and perhaps not selected specifically for root characteristics. Therefore, results cannot be applied to general categories based on root system architecture particularly for drought tolerant corn with a deeper rooting system. The objective of this study was to evaluate corn response and phosphorus uptake for drought tolerant and conventional hybrids with contrasting root system.

MATERIALS AND METHODS

Treatments, Experiment Design, and Implementation

A total of seven locations were established in 2011 and 2012, including three irrigated locations and four under rain fed conditions (Table 2-1). The irrigated locations used supplemental irrigation to maintain adequate soil moisture limiting water stress throughout the whole growing season; these amounts ranged from 450-635mm ha^{-1} and varied by location. Soil test P (STP) levels varied by location from 15-59 mg kg^{-1}. Plot size was 15 m in length and 3 m in width (45 m^2). Row spacing was 76 cm at all locations. The experimental design was a factorial in a randomized complete block design with four replications. The fertilizer treatments consisted of a control, starter only, broadcast only, and broadcast plus starter. These four fertilizer treatments were combined with two hybrids for a total of eight treatments combinations. The two hybrids used were a drought tolerant hybrid (DuPont Pioneer AQUAmax brand P1151 HR, 111 day maturity group (2700 growing degree days, GDD, Nielsen and Thomison, 2003), with Roundup Ready® Corn2, Liberty Link®, Herculex® I corn borer protection, and a conventional hybrid (DuPont Pioneer brand 33P84 with the same traits as the DT hybrid). Both hybrids were treated with Poncho® insecticide seed treatment and Raxil® head smut seed treatment. Starter fertilizer rate was 22 kg ha^{-1} P_2O_5 dribble placed as ammonium polyphosphate (10-34-0, N-P_2O_5-K_2O respectively). Broadcast fertilizer was applied at 112 kg ha^{-1} P_2O_5 broadcast as mono-ammonium phosphate (11-52-0, N-P_2O_5-K_2O

respectively) just before planting (1-5 days) in the spring. The combination of broadcast and starter were applied at the same rates. Tillage operations ranged from no-till to conventional till and varied by location. Locations 4 and 5 used no-till operations. Locations 1, 3, and 7 used a ridge till operation without incorporating any of the fertilizer treatments. Locations 2 and 6 used conventional tillage with the treatments incorporated at location 2 but not at location 6.

Field Measurements and Statistical Analysis

Composite soil samples (10-15 cores, 1.9 cm in diameter) were collected from the 0-15 cm depth from each block prior to fertilization (Table 2-1). Soil samples were dried in an oven at 40^{o}C for a minimum of 4 days. After the samples were dry the soil was ground with a soil grinder to pass through a 2mm sieve, then were analyzed for pH (1:1 soil:water), soil test phosphorus by the Mehlich 3 colorimetric method (Frank et al., 1998), soil test potassium by ammonium acetate ICP Spectrometer (Warncke and Brown, 1998), and organic matter by Walkley-Black method (Combs and Nathan, 1998).

Tissue samples were collected at the V6 and at the VT growth stage (Abendroth et al., 2011). Early growth biomass samples consisted of 10 whole corn plants collected at the V6-V7 growth stage. The whole plant samples (V6-V7 plants) were weighed after drying to determine dry weight early biomass. Ear leaf samples consisted of 15 ear leaves collected from each plot. Plant samples were oven-dried at 60^{o}C for 3-5 days. After the samples were dry the plants were ground to pass 2mm screen, then digested using a sulfuric acid and hydrogen peroxide digest (Thomas et al, 1967). Then the samples were analyzed for phosphorus and potassium concentration by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The samples were also analyzed for nitrogen by an indophenol blue colorimetric procedure using the Rapid Flow Analyzer (Model RFA-300) from Alpkem Corporation (RFA Methodology No.

A303-S072). Dry weight biomass at V6-V7 and phosphorus concentration in corn samples were used to determine phosphorus uptake. Grain yield was determined at the end of the season harvesting the center two rows with a plot combine.

Statistical analysis was completed using the GLIMMIX procedure in SAS 9.2 (Institute, 2010). Locations and blocks within locations were considered random factors for the analysis across locations. Statistical significance was established at the 0.05 probability level.

RESULTS AND DISCUSSION

Early Growth Biomass

The hybrid and fertilizer treatments showed a significant interaction with the early growth biomass at location 4 (Tables 2-2 and 2-3). Location 4 had very low rainfall amount (Table 2-1), high temperature, with high stress conditions for plant growth. There was a statistically significant effect of hybrid on early growth biomass for locations 1, 3 and across locations (Table 2-2). The average early growth biomass for the DT hybrid was significantly lower at these locations and across locations compared to the conventional hybrid (Table 2-4). Other locations also showed a tendency for lower average early growth biomass with the DT hybrid.

The fertilizer treatments also had a statically significant effect on early growth biomass (Table 2-2). Locations 1, 2, and 6 statistically increased early growth biomass with all fertilizer treatments, location 4 showed increases in the early growth biomass with the broadcast treatment as well as the starter plus broadcast treatment (Table 2-4). Locations 3, 5, and 7 did not have significant increases in early growth biomass with the additions of phosphorus fertilizer in the treatments; there is a slight tendency for added early growth biomass with the added phosphorus fertilizer with the treatments (Table 2-4). Location 3 had high STP levels and optimum growing conditions (Table 2-1). Location 5 had medium STP levels (Liekam et al, 2003) and good growing conditions with irrigation (Table 2-1). Location 7 had low STP (Liekam et al, 2003) and good growing conditions and added irrigation (Table 2-1). Across locations all of the fertilizer treatments increased early growth biomass when compared to the control treatment (Table 2-4). Across locations there was a significant increase in early growth biomass with the starter plus broadcast treatment over all other treatments (Table 2-4). The increase in early growth biomass can be contributed to the added phosphorus fertilizer (Mallarino et al, 1999). The early growth starter effect is common with P and N application; however, K and other nutrients usually don't show this effect on early growth (Mallarino et al, 2011).

Phosphorus Uptake

The analysis of variance showed no interaction effect between hybrid and fertilizer treatments for phosphorus uptake (Tables 2-2 and 2-5). There is a statistically significant effect of hybrid at locations 1, 3, and 7 (Table 2-2). Locations 1 and 3 show a statically significant increase in phosphorus uptake for the conventional hybrid (Table 2-6). Location 7 is showing a statistically significant increase in phosphorus uptake in the DT hybrid (Table 2-6). All other locations showed a slight tendency for higher phosphorus uptake with the conventional hybrid. Analysis across locations showed no effect of hybrid on phosphorus plant uptake (Table 2-2).

Fertilizer treatment showed a significant effect at all locations except for locations 3 and 5 (Table 2-2). All locations except for location 3 showed the most phosphorus uptake in the starter plus broadcast with significantly higher phosphorus uptake over the control treatment (Table 2-6). The analysis across locations showed a statistically higher phosphorus uptake for the treatment with the starter plus broadcast, followed by the broadcast only and the starter treatment. All the treatments with some phosphorus application showed a statistically higher uptake when compared to the control (Table 2-6).

Ear Leaf Phosphorus Concentration

The analysis of variance showed no significant interaction effect between hybrid and fertilizer on ear leaf phosphorus concentration (Tables 2-2 and 2-7). There is a statistically significant difference between hybrids in ear leaf phosphorus concentration at locations 5 and 7 (Table 2-2). At these two locations the DT hybrid had higher phosphorus concentrations in the ear leaf when compared to the conventional hybrid (Table 2-8). Other locations also show similar tendency in ear leaf phosphorus concentration with higher values for the DT hybrid (Table 2-8). Analysis across locations showed a statistically significant effect of hybrid selection on ear leaf phosphorus concentration with higher value for the DT hybrid (Tables 2-2 and 2-8). Differences in plant analysis by hybrid have been verified before, concentrations often differ across hybrids and should be considered when comparing two different hybrids (Sawyer and Mallarino, 2012).

The fertilizer treatments showed a statistically significant effect on ear leaf phosphorus concentration for locations 3, 4, 5, 6, and 7 (Table 2-2). At these locations the starter plus broadcast treatment and the broadcast treatment showed the highest ear leaf phosphorus concentration. At location 3 the starter and the control showed the lowest ear leaf phosphorus concentration compared to the broadcast and broadcast plus starter treatments. At locations 4 and 5 the starter plus broadcast treatment and the broadcast treatment showed the higher ear leaf phosphorus concentrations when compared to the control. The starter treatment did not have statistical differences in ear leaf phosphorus concentration when compared to the other fertilizer treatments at these two locations. At locations 6 and 7 the starter plus broadcast treatment and the broadcast treatment showed the higher ear leaf phosphorus concentrations when compared to the starter and control treatments. Analysis across locations showed statistically significant increase in ear leaf phosphorus concentrations in the starter plus broadcast and broadcast treatments over the starter and control treatments.

Grain Yield

Hybrid and fertilizer treatment showed no interaction effect on grain yield (Tables 2-2 and 2-9). There is a statistically significant hybrid effect on grain yield at all locations except for location 6 (Table 2-2). At these locations the DT hybrid showed a higher grain yield when compared to the conventional hybrid (Table 2-10). Analysis across locations showed similar results with significant effect of hybrid selection on grain yield (Table 2-2). The DT hybrid showed an increased grain yield by 1.12 Mg ha^{-1} across locations when compared to the conventional hybrid (Table 2-10). Although we did see an increase in grain yield when comparing the two hybrids, both hybrids did respond similar to the fertilizer treatments (Roth et al, 2013).

Fertilizer treatments also had a statistically significant effect on grain yield (Table 2-2). Locations 1, 6, and 7 showed an increase in grain yield with phosphorus fertilization treatments when compared to the control (Table 2-10). At location 1 the broadcast treatment showed the highest yield increase (Table 2-10). At locations 6 and 7 the starter plus broadcast as well as the broadcast treatment showed equal increases on yield when compared to the control treatment (Table 2-10). At all locations the starter treatment did not have significant increases on grain yield when compared to the control although the starter showed some tendencies for slightly higher grain yield (Table 2-10). Across locations the added fertilizer treatments showed statistically significant grain yield responses (Table 2-2). The grain yield increase was highest with the starter plus broadcast and broadcast treatments (Table 2-10). This may be expected considering the overall higher P application rate. The starter treatment showed a slight increase in grain yield when compared to the control treatment although this was not statistically significant (Table 2-10). It is common to have grain yield increases with starter fertilizer applications especially with adequate soil moisture and a low initial soil test P in minimum tillage operations (Wortmann et al, 2006). Locations with supplemental irrigation showed significantly higher overall yield. However, under irrigation the DT hybrid keep the tendency for higher yield. Location 6 showed an average higher yield for the conventional hybrid; however, this was not statistically significant. Therefore, the DT hybrid seems to perform at least equality well under irrigation when compared to the conventional hybrid, with no yield penalty under more optimum conditions of irrigation.

CONCLUSIONS

The different hybrids showed different response throughout the growing season in every aspect except for phosphorus uptake. The conventional hybrid showed higher early growth biomass when compared to the DT hybrid although this did not translate into higher yields. In fact the conventional hybrid with more early growth produced less grain yield. The conventional hybrid also showed higher phosphorus uptake in the earlier growth stages (V6-V7) although this was not statistically significant. Later on in the season the DT hybrid showed higher ear leaf phosphorus concentration (VT-R1) when compared to the conventional hybrid. Yield also was different between the two hybrids with the DT hybrid having average higher yields.

Overall there were no interaction effects between hybrids and fertilizer phosphorus treatments. Therefore, these hybrids seem to show similar response to fertilizer P. This would suggest that there is no need to change the P fertility management for DT hybrids compared to conventional hybrids. However, fertilizer recommendations need to be adjusted to yield potential and P removal with the grain.

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TABLES

Table 2-1. Location description, soil types, and preliminary soil test results.

Location	County	Year	Envr. §	Predominant soil: Series	Predominant soil: Subgroup ‡	Precipitation: Average ¶	Precipitation: Actual	Soil test †: pH	Soil test †: O.M.	Soil test †: P #	Soil test †: K ††
						- - - - mm - - - -			$g\ kg^{-1}$	- - $mg\ kg^{-1}$ - -	
1	Republic	2011	Rain fed	Crete	P. Argiustolls	690	520	4.9	23	42	339
2	Shawnee	2011	Rain fed	Eudora Bismarckgrove	F. Hapludolls	920	650	6.7	9	23	220
3	Republic	2012	Rain fed	Crete	P. Argiustolls	690	410	5.3	26	53	458
4	Reno	2012	Rain fed	Farnum Funmar	P. Argiustolls	750	420	4.9	16	59	242
5	Reno	2012	Irrigated	Nalim	U. Argiustolls	750	420	6.6	26	23	277
6	Shawnee	2012	Irrigated	Eudora	F. Hapludolls	920	550	6.4	18	15	189
7	Republic	2012	Irrigated	Crete	P. Argiustolls	690	410	6.4	34	15	615

† Mean values collected from each block at the 0- to 15-cm soil sampling depth.
§ Envr, Environment.
‡ P, Pachic; F, Fluventic; U, Udic.
¶ Mean rainfall from 30-yr from weather station within 20 km of each study location.
# P, Mehlich-3 test.
†† K, Ammonium-acetate.

Table 2-2. Significance of F values for the fixed effects of corn hybrid and fertilizer treatment on plant early growth, P uptake, ear leaf P concentration and grain yield.

	Fixed effects		
Location	Hybrid (H)	Fertilizer (F)	H × F
	- - - - - - - - - - - - - - - - - - p > F - - - - - - - - - - - - - - - - - -		
		Early Growth	
1	0.011	< 0.001	0.228
2	0.363	0.001	0.754
3	0.041	0.860	0.884
4	0.871	0.001	0.013
5	0.192	0.197	0.205
6	0.243	< 0.001	0.520
7	0.561	0.245	0.169
All locations	0.020	< 0.001	0.914
		Phosphorus Uptake	
1	0.013	< 0.001	0.713
2	0.361	0.001	0.735
3	0.016	0.873	0.612
4	0.882	0.020	0.460
5	0.912	0.118	0.141
6	0.637	< 0.001	0.394
7	0.008	< 0.001	0.295
All locations	0.576	< 0.001	0.662
		Ear Leaf Phosphorus Concentration	
1	0.305	0.171	0.171
2	0.791	0.801	0.972
3	0.134	0.021	0.234
4	0.109	0.023	0.700
5	0.002	0.001	0.631
6	0.543	0.045	0.600
7	0.003	0.001	0.643
All locations	< 0.001	< 0.001	0.516
		Grain Yield	
1	0.001	0.027	0.188
2	0.003	0.573	0.599
3	< 0.001	0.203	0.076
4	< 0.001	0.193	0.395
5	0.022	0.993	0.577
6	0.123	0.002	0.964
7	< 0.001	0.013	0.096
All locations	< 0.001	0.002	0.415

Table 2-3. Interaction effects of hybrid and fertilizer treatments on plant early growth biomass by location and across locations.

Location	Drought Tolerant				Conventional			
	Control‡	Starter	Broadcast	S + B	Control	Starter	Broadcast	S + B
	g plant^{-1}							
1	2.43	3.81	2.69	4.35	2.81	4.10	3.44	4.34
2	7.15	10.06	10.32	10.31	7.36	9.77	11.06	11.47
3	7.28	7.79	7.38	7.52	8.53	8.34	7.92	8.74
4	7.49 c†	7.71 c	10.27 a	9.13 ab	8.25 bc	8.25 bc	8.49 bc	9.78 a
5	8.62	8.31	7.36	10.21	8.64	10.43	9.03	9.29
6	4.42	7.00	8.54	9.24	4.66	7.25	8.71	11.74
7	8.63	8.52	8.82	9.91	7.61	9.60	9.15	8.59
All Locations	6.57	7.60	7.87	8.67	6.84	8.25	8.28	9.20

† Numbers in each row followed by different letters are statistically significant at the 0.05 probability level.

‡ Fertilizer treatments applied for each hybrid.

Table 2-4. Plant early growth biomass at the V6 growth stage as affected by the main effect of hybrid and fertilizer treatments.

Location	Hybrid		Fertilizer			
	Drought Tolerant	Conventional	Control	Starter (S)	Broadcast (B)	S + B
	g $plant^{-1}$					
1	3.32 b†	3.68 a	2.63 c	3.96 a	3.06 b	4.33 a
2	9.46	9.53	7.25 b	9.94 a	10.69 a	10.90 a
3	7.50 b	8.39 a	7.90	8.08	7.67	8.13
4	8.65	8.70	7.86 b	7.99 b	9.40 a	9.46 a
5	8.63	9.35	8.64	9.36	8.19	9.76
6	7.31	8.09	4.55 c	7.14 b	8.63 ab	10.50 a
7	8.97	8.73	8.11	9.06	8.98	9.23
All locations	7.68 b	8.14 a	6.71 c	7.93 b	8.08 b	8.93 a

† Numbers in each row followed by different letters within each main effect are statistically significant at the 0.05 probability level.

Table 2-5. Interaction effects of hybrid and fertilizer on phosphorus uptake of each treatment by location and across locations.

	Drought Tolerant				Conventional			
Location	Control†	Starter	Broadcast	S + B	Control	Starter	Broadcast	S + B
	mg plant^{-1}							
1	11.0	16.3	12.9	20.1	13.0	19.2	15.1	20.7
2	30.9	42.7	40.9	45.2	29.6	43.6	46.9	48.2
3	25.1	26.3	26.2	25.4	30.4	29.4	26.8	29.9
4	23.3	24.0	30.2	29.9	24.6	26.5	26.4	30.7
5	38.3	36.1	36.5	50.1	34.9	43.4	42.4	41.4
6	12.7	20.3	34.6	33.4	16.6	20.7	28.1	41.3
7	34.5	30.7	45.3	48.9	23.7	31.1	39.7	39.2
All Locations	25.1	28.1	32.2	36.3	24.7	30.6	32.4	36.1

† Fertilizer treatments applied for each hybrid.

Table 2-6. Phosphorus uptake of each treatment by location and across locations.

Location	Hybrid		Fertilizer			
	Drought Tolerant	Conventional	Control	Starter (S)	Broadcast (B)	S + B
	mg plant^{-1}					
1	15.1 b†	17.0 a	12.0 c	17.8 b	14.0 c	20.4 a
2	39.9	42.1	30.3 b	43.2 a	43.9 a	46.7 a
3	25.8 b	29.1 a	27.8	27.8	26.5	27.7
4	26.9	27.1	24.0 c	25.3 bc	28.3 ab	30.3 a
5	40.2	40.5	36.6	39.8	39.5	45.7
6	25.3	26.7	14.7 b	20.5 b	31.4 a	37.4 a
7	39.9 a	33.4 b	29.1 b	30.9 b	42.5 a	44.1 a
All locations	30.4	30.9	24.9 d	29.3 c	32.3 b	36.2 a

† Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.

Table 2-7. Interaction effect of hybrid and fertilizer on ear leaf phosphorus concentration of each treatment by location and across locations.

	Drought Tolerant				Conventional			
Location	Control†	Starter	Broadcast	S + B	Control	Starter	Broadcast	S + B
	- P Concentration g kg^{-1} -							
1	4.0	4.3	4.5	4.3	4.0	4.5	4.0	4.0
2	4.8	4.8	4.9	5.1	4.8	4.8	4.9	4.9
3	3.0	2.5	3.1	3.0	2.5	2.5	2.8	3.1
4	2.5	2.5	3.0	3.0	2.0	2.5	2.8	2.7
5	2.8	2.8	3.0	3.6	2.0	2.3	2.8	3.0
6	2.8	3.0	3.8	3.5	3.0	2.8	3.3	3.5
7	2.8	2.5	3.7	3.4	2.0	2.3	3.0	3.0
All Locations	3.2	3.2	3.7	3.7	2.9	3.1	3.4	3.4

† Fertilizer treatments applied for each hybrid.

Table 2-8. Ear leaf concentration of each treatment by location and across locations.

Location	Hybrid		Fertilizer			
	Drought Tolerant	Conventional	Control	Starter (S)	Broadcast (B)	S + B
	P Concentration g kg^{-1}					
1	4.3	4.1	4.0	4.4	4.3	4.1
2	4.9	4.8	4.8	4.8	4.9	5.0
3	2.9	2.7	2.8 ab†	2.5 b	2.9 a	3.0 a
4	2.8	2.5	2.3 b	2.5 ab	2.9 a	2.8 a
5	3.0 a	2.5 b	2.4 c	2.5 bc	2.9 ab	3.3 a
6	3.3	3.1	2.9 b	2.9 b	3.5 a	3.5 a
7	3.1 a	2.6 b	2.4 b	2.4 b	3.3 a	3.2 a
All locations	3.5 a	3.2 b	3.1 b	3.1 b	3.5 a	3.6 a

† Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.

Table 2-9. Interaction effect of hybrid and fertilizer on average grain yield of each treatment by location and across locations.

Location	Drought Tolerant				Conventional			
	Control†	Starter	Broadcast	S + B	Control	Starter	Broadcast	S + B
	- Mg ha^{-1} -							
1	12.68	12.90	14.13	12.75	11.31	12.13	12.28	12.46
2	6.78	6.83	8.23	7.42	5.19	6.22	5.95	5.58
3	6.04	5.76	5.82	6.11	3.27	4.37	4.33	1.81
4	1.80	2.05	1.70	2.01	0.91	0.60	0.52	0.94
5	9.27	9.39	9.93	9.50	8.99	8.87	8.52	8.74
6	11.71	12.26	13.22	13.35	12.00	12.82	13.95	13.78
7	13.28	13.22	13.66	14.09	11.33	12.35	13.20	12.21
All Locations	8.79	8.92	9.53	9.34	7.57	8.20	8.32	8.03

† Fertilizer treatments applied for each hybrid.

Table 2-10.Average grain yield of each treatment by location and across locations.

Location	Hybrid		Fertilizer			
	Drought Tolerant	Conventional	Control	Starter (S)	Broadcast (B)	S + B
	- - - - - - - - - - - - - - - - Mg ha^{-1} - - - - - - - - - - - - - - - -					
1	13.11 a†	12.04 b	11.99 b	12.51 ab	13.20 a	12.60 ab
2	7.31 a	5.66 b	5.96	6.51	6.95	6.51
3	5.93 a	3.45 b	4.66	5.06	5.09	3.97
4	1.88 a	0.74 b	1.35	1.33	1.10	1.47
5	9.51 a	8.77 b	9.13	9.11	9.22	9.11
6	12.62	13.12	11.84 b	12.53 b	13.56 a	13.55 a
7	13.56 a	12.26 b	12.30 b	12.78 ab	13.44 a	13.14 a
All locations	9.14 a	8.02 b	8.18 b	8.55 ab	8.92 a	8.68 a

† Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.

CHAPTER 3 - CROP RESPONSE TO PHOSPHORUS FERTILIZATION IN REDUCED TILLAGE SYSTEMS

ABSTRACT

Phosphorus stratification in reduced tillage systems is often a concern for producers, and questions remain regarding the need for alternative fertilizer placement methods. The objective of this study was to evaluate the effects of different placements and rates of phosphorus fertilizers in corn (*Zea mays*) and soybean (*Glycine max*). The study was established at 4 locations and set for a ten year period (spring of 2005-fall of 2014). One of the locations was dropped after the 2009 season. This paper will focus on three locations and four years of this study (2009-2012). Of the three locations, two were rain fed and one was irrigated. Fertilizer placements included: starter, broadcast, deep band, and various combinations of starter with broadcast or starter with deep band. Total fertilizer rates included: 0, 22, 45, and 90 kg P_2O_5 ha^{-1}. The experimental design was randomized complete block with four replications in two location and three replications in one location. Corn early growth biomass was evaluated at the V6 growth stage, including whole plant tissue phosphorus concentrations. Corn ear leaf tissue samples were collected at the VT-R1 growth stage and analyzed for phosphorus concentration. Soybean uppermost fully open trifoliate tissue were also collected at the R1-R2 growth stage and analyzed for phosphorus concentration. Corn grain yield and soybean seed yield were evaluated at the end of the growing season. Results showed significant differences in corn early growth, early season P concentration and uptake, ear leaf P concentration, soybean leaf P concentration, as well as corn and soybean yield response to phosphorus fertilization. Differences in corn early growth, P uptake, ear leaf P concentration, and soybean tissue P concentration were also significantly affected by fertilizer placement.

Abbreviations: STP, soil-test phosphorus.

INTRODUCTION

The adoption of reduced tillage practices in recent years has raised questions about fertility management issues especially in phosphorus. With less tillage phosphorus stratification may become an issue over time. Nutrient stratification refers to the non-uniform distribution of nutrients within the soil. Phosphorus stratification concerns include potential impacts on crop yield and nutrient uptake due to inability of the crops to access the nutrients stratified in the soil (Mallarino and Borges, 2006). In reduced tillage system, P stratification is the result of surface application and decreased mixing of the fertilizer with fewer tillage passes (Robbins and Voss, 1991). Stratification also can result from uptake by plants that then decompose on the surface that are not tilled into the soil (MacKay et al, 1987).

Crop response to P fertilization is to be expected at low soils tests P (STP) (Liekam et al, 2003). Previus studies have indicated that placemnt method may not be as relevant as soil test P levels (Bordoli and Mallarino, 1998). The most consistent phosphorus response in reduced tillage systems tends to be starter fertilizer on low testing soils. High STP has shown yield responses to fertilizer P but many studies show conflicting results (Gordon et al, 1997; Mallarino et al, 1991). For high STP soils (STP greater than 20 mg kg^{-1}) fertilizer P is usually not recommended (Liekam et al, 2003). No single placement method has been proven to be superior over all other options. Placement can change the amount of soil contact that the fertilizer receives. The starter placement as well as the subsurface band placement concentrates the fertilizer into a zone with less volume of soil fertilized compared to a broadcast application. One advantage of the concentrated zone is more fertilizer available in that area. Starter fertilizer has a concentrated zone showing an advantage in that high availability in the area of early crop growth does provide more early growth in corn with P_2O_5 fertilizer.

There are many studies suggesting that P placement is not a critical factor as long as there is enough soil P to meet the crop's nutrient demands. Placement could become more important in moisture limiting environments due to limited access via crop roots and lack of diffusion of phosphorus for the plant (Mengel, 1995). The objectives of this study was (i) to evaluate if fertilizer phosphorus placement has an effect on crop uptake and yield with long term effects in reduced tillage systems; and (ii) overall response to the phosphorus fertility over a long period of time.

MATERIALS AND METHODS

Treatment Design, Experiment Design, and Implementation

A total of four locations were established in 2005. Of those four locations three of them were continued for the 2009 through the 2012 growing seasons. These locations include Manhattan, Ottawa, and Scandia (Table 3-1). Manhattan and Ottawa were rainfed and Scandia received supplemental irrigation via an overhead linear irrigation system. All locations were in reduced tillage production practices for over five years prior to initiation of the study.

Common crop rotations for the region were used at each location with each crop present every year. Corn and soybean rotations were used for the Ottawa and Scandia location while a wheat (*Triticum Aestivum)*, corn, and soybean rotation was used at the Manhattan location. Soil test P (STP) levels varied by location, ranging from 8 to 38 mg ha^{-1}. Plot size was 12 m in length and 3 m in width (36 m^2) at the Ottawa and Scandia locations. Plot size was 24 m in length and 3 m in width (72 m^2) at the Manhattan location. Row spacing was 76 cm at all locations. The experimental design was a randomized complete block design with four replications at the Ottawa and Scandia locations; three replications at the Manhattan location. The fertilizer treatments applied to the corn crop consisted of a control, 22 kg P_2O_5 ha^{-1} (starter), 45 kg P_2O_5 ha^{-1} (broadcast), 22 kg P_2O_5 ha^{-1} and 22 kg P_2O_5 ha^{-1} (starter-broadcast), 45 kg P_2O_5 ha^{-1} (deep band), 22 kg P_2O_5 ha^{-1} and 22 kg P_2O_5 ha^{-1} (starter-deep band), 90 kg P_2O_5 ha^{-1} (broadcast), 22 kg P_2O_5 ha^{-1} and 67 kg P_2O_5 ha^{-1} (starter-deep band), 22 kg P_2O_5 ha^{-1} and 22 kg P_2O_5 ha^{-1} (starter-broadcast), 22 kg P_2O_5 ha^{-1} and 67 kg P_2O_5 ha^{-1} (starter-broadcast), and 90 kg P_2O_5 ha^{-1} (deep band). The Ottawa location also contained a treatment that consisted of 45 kg P_2O_5 ha^{-1} (broadcast) that was combined with a tillage operation. The fertilizer treatments applied to the soybean crop were two separate broadcast treatments of 45 kg P_2O_5 ha^{-1}. The fertilizer treatments applied the wheat crop in Manhattan consisted of a control, 22 kg P_2O_5 ha^{-1} (starter), 45 kg P_2O_5 ha^{-1} (broadcast), 22 kg P_2O_5 ha^{-1} and 22 kg P_2O_5 ha^{-1} (starter-broadcast), 45 kg P_2O_5 ha^{-1} (deep band), 22 kg P_2O_5 ha^{-1} and 22 kg P_2O_5 ha^{-1} (starter-deep band), 90 kg P_2O_5 ha^{-1} (broadcast), 22 kg P_2O_5 ha^{-1} and 67 kg P_2O_5 ha^{-1} (starter-deep band), 22 kg P_2O_5 ha^{-1} and 22 kg P_2O_5 ha^{-1} (starter-broadcast), 22 kg P_2O_5 ha^{-1} and 67 kg P_2O_5 ha^{-1} (starter-broadcast), and 90 kg P_2O_5 ha^{-1} (deep band). The starter treatment was applied at planting with the planter using a 5 × 5 cm placement using ammonium polyphosphate, 10-34-0 (N-P_2O_5-K_2O respectively). The broadcast treatment was applied prior to planting by hand evenly across the plot area using triple superphosphate, 0-46-0 (N-P_2O_5-K_2O respectively) at the Manhattan and Scandia locations. At the Ottawa location the broadcast treatments were applied with a backpack sprayer with 3 m boom and nozzles spaced 76 cm apart using ammonium polyphosphate, 10-34-0 (N-P_2O_5-K_2O respectively). The deep band treatments were applied 10 to 20 days prior to planting in the spring 15 cm directly below the row where the corn was to be planted using ammonium polyphosphate, 10-34-0 (N-P_2O_5-K_2O respectively) at the Ottawa and Scandia locations; the same deep band treatments were applied in the late fall at the Manhattan location. Nitrogen applied with the deep band application was balanced for all treatments using urea ammonium nitrate (UAN) (28-0-0; N- P_2O_5, K_2O respectively).

Field Measurements and Statistical Analysis

Plant tissue samples and yield were taken during the growing season each year. During the early season corn vegetative growth samples were taken at the V6 growth stage (Abendroth et al, 2011). The vegetative growth samples were obtained by collecting 10 corn plants at random from non-harvest rows in the plot area. Tissue samples were dried at $60^{o}C$ for a minimum of 4 days; samples were then weighed for dry weight. Ear leaf in corn was collected at the VT growth stage and the uppermost fully developed trifoliate in soybean at the R2 growth stage (Pedersen, 2009). Fifteen corn leaves and 30 soybean trifoliates were collected from each plot. After the samples were dry the plants were ground to pass a 2 mm screen with a Wiley mill (Model 4 Wiley Mill) from Thomas Scientific, Swedesboro, NJ. Plant tissue samples were digested using a sulfuric acid and hydrogen peroxide digest (Thomas et al, 1967). Then the samples were analyzed for phosphorus and potassium concentration by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The samples were also analyzed for nitrogen by an indophenol blue colorimetric procedure using the Rapid Flow Analyzer (Model RFA-300) from Alpkem Corporation using the RFA Methodology No. A303-S072. The dry weight and early season phosphorus concentration were used to calculate phosphorus uptake. Grain yield was obtained by machine harvest the center two rows; the Manhattan location was hand harvested. Grain weight was recorded and adjusted for 155 g kg^{-1} for corn and 130 g kg^{-1} for soybean.

Statistical analysis was completed using the GLIMMIX procedure in SAS 9.2 (SAS Institute, 2010). Statistical significance established at the ≤ 0.05 probability level.

RESULTS AND DISCUSSION

Corn Early Growth

There were significant differences in the phosphorus treatments at all locations in 2011 and at Scandia in 2012 when comparing corn early growth (Table 3-2). Each location showed a different response to the phosphorus treatments (Tables 3-3). The treatment applied as 22 kg ha^{-1} starter and 67 kg ha^{-1} deep band generally had the higher corn early growth biomass (Table 3-3). In 2011 the treatment applied as 22 kg ha^{-1} starter and 67 kg ha^{-1} broadcast had generally higher early growth biomass (Table 3-3). Overall, the treatments with highest early growth biomass had a starter fertilizer treatment except for the 90 kg ha^{-1} deep band treatment at the Scandia location. These results are similar to previous studies that show consistent early growth response with starter P application (Hergert et al, 2012). A benefit of the starter fertilizer could be an increase in early growth and uniformity. Corn commonly responds to starter fertilizer with increased early growth which results in larger plants of more uniform size (Hergert et al, 2012). When compared to broadcast or deep-band treatments, phosphorus fertilizers as starter with the planter have the tendency to show increased early growth (Mallarino et al, 1999).

Corn Early Season Phosphorus Concentration and Phosphorus Uptake

There were differences in the phosphorus treatments when looking at corn early season phosphorus concentration at all locations in all years (Table 3-2). The treatment applied as 22 kg ha^{-1} starter and 67 kg ha^{-1} deep band generally had the higher corn early season phosphorus concentration at all locations in all years (Table 3-4). The treatment applied as 22 kg ha^{-1} starter and 67 kg ha^{-1} broadcast also tended to be high in phosphorus concentration except for at Scandia in 2009. A possible explanation for this could be due to dilution effect (Kaiser et al, 2005). A plant with more biomass could have more total phosphorus yet a lower concentration when compared to smaller plants. With a few exceptions the treatments that had a starter placement tended to increase the early season phosphorus concentrations in the corn plants. Starter fertilizers may be used to overcome slow root growth and the potential for reduced nutrient uptake (Zublena and Anderson, 1994). In general the treatments with higher phosphorus application rate also tended to have higher early season phosphorus concentration in the corn plants. Corn removal is estimated at 6 kg ha^{-1} P_2O_5 per Mg ha^{-1} of corn harvested (Liekam et al, 2003). Based on this information and yield data we estimate that in many years the 90 kg ha^{-1} application rate exceeds the removal amount (Tables 3-9, 3-10, and 3-11), and this can contribute to increase in soil test P levels. As soil test phosphorus increases, the crop's response to fertilizer phosphorus generally decreases (Minor and Stecker, 1993).

Early season phosphorus uptake showed similar result to that of early growth. There were significant differences in the phosphorus treatments at all locations in 2011 and at Scandia in 2012 when comparing corn early season phosphorus uptake (Table 3-2). Each location responded differently to the phosphorus treatments (Tables 3-5). The treatment applied as 22 kg ha^{-1} starter and 67 kg ha^{-1} deep band generally had a higher corn early season phosphorus uptake (Table 3-5). In 2011 the treatment applied as 22 kg ha^{-1} starter and 67 kg ha^{-1} broadcast tended to have higher early growth biomass (Table 3-5). Like early growth, the starter placement treatments tended to have higher P uptake. We would expect to see similar results when comparing early growth and P uptake in corn, if the plants are larger in size we would expect more P uptake as long as there is adequate fertility.

Corn Ear Leaf and Soybean Uppermost Trifoliate Phosphorus Concentration

Each location as well as each year showed different response to the phosphorus treatments when comparing the corn ear leaf phosphorus concentration. Treatments differences were found at all locations and all years except Manhattan 2010 when comparing corn ear leaf phosphorus concentration (Tables 3-2). The Manhattan location did not have a treatment that was consistent throughout the three years when evaluating corn ear leaf phosphorus concentration (Table 3-6). The Ottawa and Scandia locations had a few treatments that followed a consistent trend over time. The Ottawa location tended to show the greatest increases in corn ear leaf phosphorus concentration with the addition of the treatment applied as 22 kg ha^{-1} starter and 67 kg ha^{-1} deep band (Table 3-7). The Scandia location tended to show the greatest increases in corn ear leaf phosphorus concentration with the addition of the treatment applied as 22 kg ha^{-1} starter and 22 kg ha^{-1} broadcast as well as the treatment applied as 22 kg ha^{-1} starter and 67 kg ha^{-1} broadcast (Table 3-8). Overall the treatments containing the starter fertilizer placement tended to have higher corn ear leaf phosphorus concentration. There can be many factors that affect the tissue results. The nutrient concentration can change depending on amount of growth or size of the ear leaves being sampled, as well as the environment (moisture and temperature) that the corn plant has been exposed to (Sawyer and Mallarino, 2012).

Similar to the corn each location as well as each year showed different response to the phosphorus treatments when comparing soybean uppermost trifoliate tissue concentrations. Phosphorus treatments at the Ottawa and Scandia locations showed a statistically significant increase in soybean uppermost fully open trifoliate phosphorus concentration when compared to the control (Table 3-2). The soybean trifoliate phosphorus concentration showed no statistical differences at Manhattan with the added phosphorus treatments (Table 3-2). At Ottawa the treatment applied as 22 kg ha^{-1} starter and 67 kg ha^{-1} broadcast to the corn with another 45 kg ha^{-1} broadcast applied directly to the soybeans statistically had the highest overall soybean trifoliate phosphorus concentration throughout all years (Table 3-7). The treatment applied as 22 kg ha^{-1}

starter and 67 kg ha^{-1} broadcast to the corn with another 45 kg ha^{-1} broadcast applied directly to the soybeans had the most consistent increase in soybean trifoliate phosphorus concentration (Table 3-8). There is a trend to have higher plant tissue phosphorus concentrations with direct fertilization of phosphorus to the soybean.

Corn Grain Yield and Soybean Seed Yield

The Manhattan location had no differences in the treatments for corn grain yield (Table 3-2). The Ottawa showed difference in treatments for the 2009, 2010, and 2011 seasons when evaluating corn grain yield (Table 3-2). The treatments at the Scandia location showed differences corn grain yield for all years (Table 3-2). The Manhattan location showed no increases in yield which may be expected as this location was the one with highest soil test P (Tables 3-1 and 3-9). For the Ottawa location in 2009 there was a difference between treatments when comparing corn grain yield, there was no placement or rate effect. However, in 2010 and 2011 this location showed increases in yield over the control with all of the added phosphorus rates especially with the increased rate of phosphorus applied (Table 3-10). The Scandia location responded similar to Ottawa for all years. This location repeatedly has the control with no added phosphorus as the lowest yielding treatment (Table 3-11). Both Ottawa and Scandia show no differences in corn grain yield when looking at different placements within the same rate of the phosphorus fertilizer. These results would suggest that placement is not relevant as long as the phosphorus is added to meet the plant's requirement (Mallarino et al, 2005).

Like corn grain yield we showed statistical difference in treatments when focusing on soybeans at the Ottawa and Scandia locations and none at the Manhattan location (Table 3-2). The Ottawa location had differences in treatments in 2009, 2010, and 2012 and the Scandia location showed difference in all years (Table 3-2). Similar to corn grain yield in Ottawa and

Scandia we found increases in soybean seed yield with the added phosphorus treatments when compared to the control for both locations and all years (Tables 3-10 and 3-11). The treatments that contain direct fertilization to the soybean crop have a tendency for higher yield at the Ottawa and Scandia locations, although this was not statistically significant. Minnesota studies have found yield increases with direct fertilization of P to soybeans (Rehm et al, 2001). It seems that as long as there is adequate phosphorus provided by added fertilizer and soil contributions to meet the needs, yield will not be limited (Mallarino et al, 2005).

CONCLUSIONS

Throughout locations and years of this experiment there were certain advantages to some of the fertilizer placements for early season growth in corn, but these advantages did not translate into increased yield. There were statistical differences in all measured parameters when comparing treatments at Ottawa and Scandia which had low initial soil test phosphorus. The Manhattan location had soil test phosphorus above the critical level of 20 mg kg-1 and was the least responsive to the phosphorus treatments in all measurements especially yield. The Scandia location had the highest yield potential and was the most responsive to the phosphorus treatments. We did see an increase in early growth with starter phosphorus fertilizer except in Manhattan and Ottawa 2012 which had extremely droughty and poor conditions (Table 3-1). The starter placement in corn also tended to have higher phosphorus concentrations in the early season measurement as well as in the ear leaf measurement. However, this advantage in early growth and higher tissue phosphorus did not translate into an increase in grain yield. There was also an increase in tissue concentration in soybeans with the direct fertilization to the soybean crop. However, this increase did not translate into higher soybean yields.

Our results suggest that phosphorus stratification in reduced tillage is not an issue that would require a different fertilizer placement or different management. Placement also doesn't show an increased plant response under conditions of good plant growth and no limitation in root access to the fertilizer. Soybeans may benefit from direct fertilization especially when soil tests are low. Therefore, direct soybean fertilization may be particularly important under a sufficiency fertilizer management approach.

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TABLES

Table 3-1 Location description, soil types, and preliminary soil test results.

		Predominant soil		Precipitation					Soil test †			
Location	County	Series §	Subgroup ‡	Average ¶	2009	2010	2011	2012	pH	O.M.	P #	K ††
				- - - - - - - - - - - - - - mm - - - - - - - - - - - -						g kg^{-1}	- - mg kg^{-1} - -	
Manhattan	Riley	Smolan sil	P. Argiustolls	884	923	704	754	484	5.2	24	38	325
Ottawa	Franklin	Wilson sil	O. Haplustalfs	1010	1187	922	734	536	5.8	29	8	153
Scandia	Republic	Crete sil	P. Argiustolls	690	580	620	522	415	6.7	26	8	519

† Mean values collected from each block at the 0- to 15-cm soil sampling depth prior to study beginning (2005).
§ Soil Type: sil, silt loam.
‡ P, Pachic; O, Oxyaquic
¶ Mean rainfall from 30-yr norm from weather station within 20 km of each study location.
# P, Mehlich-3 test.
†† K, Ammonium-acetate.

Table 3-2 Significance of the F values for the effect of treatment within location and within years of corn early growth, corn phosphorus uptake, corn ear leaf phosphorus concentration, corn grain yield, soybean uppermost trifoliate phosphorus concentration, and soybean seed yield.

	Location		
Year	Manhattan	Ottawa	Scandia
	- - - - - - - - - - - - - - - - - -	p > F	- - - - - - - - - - - - - - - - - -
		Corn Early Growth	
2009	- - †	- -	- -
2010	- -	- -	- -
2011	0.009	< 0.001	< 0.001
2012	0.514	0.475	< 0.001
		Corn Early Season Phosphorus Concentration	
2009	- -	< 0.001	< 0.001
2010	< 0.001	- -	- -
2011	0.001	< 0.001	< 0.001
2012	0.027	< 0.001	< 0.001
		Corn Early Season Phosphorus Uptake	
2009	- -	- -	- -
2010	- -	- -	- -
2011	0.001	< 0.001	< 0.001
2012	0.459	0.2649	< 0.001
		Corn Ear Leaf Phosphorus Concentration	
2009	0.023	0.001	0.001
2010	0.071	- -	- -
2011	0.038	< 0.001	< 0.001
2012	- -	< 0.001	< 0.001
		Corn Grain Yield	
2009	0.851	0.003	< 0.001
2010	0.180	0.003	0.011
2011	0.130	0.015	< 0.001
2012	- -	0.697	0.001
		Soybean Uppermost Trifoliate Phosphorus Concentration	
2009	0.357	< 0.001	0.004
2010	0.320	- -	- -
2011	0.903	< 0.001	< 0.001
2012	0.525	0.001	< 0.001
		Soybean Seed Yield	
2009	0.589	< 0.001	< 0.001
2010	0.432	0.009	0.019
2011	0.970	0.248	0.001
2012	0.687	0.004	0.002

† Dashes indicate missing data for a given location year.

Table 3-3 Corn early growth biomass of each treatment at each location by year.

	Year					
	2011			2012		
Treatment †	Manhattan	Ottawa	Scandia	Manhattan	Ottawa	Scandia §
	- g plant^{-1} - - - - - - - - - - - - - - - - - - -					
0-0-0	2.31 e ‡	2.36 d	3.46 f	2.46	2.95	20.07 f
22-0-0	3.00 bcde	2.85 cd	4.53 ed	3.55	2.90	22.81 def
0-45-0	2.54 de	3.35 bc	4.02 ef	2.04	2.80	21.64 ef
22-22-0	2.96 bcde	2.98 c	5.05 d	3.13	2.82	24.09 cde
0-0-45	3.02 bcde	2.89 cd	5.17 cd	2.36	2.77	22.84 def
22-0-22	3.71 ab	2.85 cd	6.11 abc	3.79	3.11	27.61 ab
0-90-0	2.74 cde	3.36 bc	4.91 ed	2.19	2.68	23.81 ce
22-67-0	3.10 bcd	3.69 ab	4.89 ed	2.94	2.89	21.91 ef
0-0-90	2.92 cde	3.31 bc	6.68 a	3.01	3.07	26.19 abc
22-0-67	3.95 a	3.67 ab	6.20 ab	1.44	2.41	28.46 a
22-22-0	3.40 abc	3.30 bc	5.25 bcd	2.68	2.43	23.95 cde
22-67-0	3.43 abc	4.02 a	6.82 a	2.07	2.66	25.20 bcd
0-45-0 ¶	- -	3.61 ab	- -	- -	2.66	- -

† Denotes kg ha^{-1} of P_2O_5 applied as Starter-Broadcast-Deep Band respectively.
§ Samples were collected later in the season (V9 growth stage).
‡ Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.
¶ This treatment is combined with a tillage operation, only found at Ottawa.

Table 3-4 Corn early season phosphorus concentration of each treatment at each location by year.

Treatment †	Location								
	Manhattan			Ottawa			Scandia		
	2010	2011	2012	2009	2011	2012	2009	2011	2012 §
	- P Concentration g kg^{-1} -								
0-0-0	3.2 f ‡	3.3 d	2.3 c	3.2 g	3.3 g	3.8 h	2.8 e	2.7 f	1.9 e
22-0-0	3.6 cde	3.7 bcd	2.8 bc	4.3 cde	3.9 ef	4.7 defg	2.8 e	3.1 ef	2.3 ed
0-45-0	3.5 def	3.6 cd	2.8 bc	3.5 fg	3.9 ef	4.3 g	3.0 de	3.4 cde	2.3 ed
22-22-0	3.7 bcde	4.1 ab	3.5 ab	4.0 e	4.2 bcd	4.7 cdefg	3.0 de	3.3 de	2.5 cd
0-0-45	3.3 ef	3.8 bcd	3.1 abc	4.1 e	4.0 def	4.6 efg	4.0 b	3.6 abcd	2.7 bcd
22-0-22	3.6 cde	4.0 abc	3.5 ab	4.2 de	4.0 def	5.0 bcde	4.0 b	3.5 bcd	2.3 ed
0-90-0	3.9 ab	3.7 bcd	2.7 bc	3.6 f	3.8 f	4.5 fg	3.2 cd	3.5 bcd	3.1 ab
22-67-0	3.8 abc	4.1 ab	3.4 ab	4.8 b	4.2 bcd	4.8 cdef	3.0 de	3.7 abc	3.1 ab
0-0-90	3.7 abc	4.1 ab	3.5 ab	4.6 bc	4.5 ab	5.2 abc	4.4 a	3.8 ab	3.0 abc
22-0-67	4.2 a	4.3 a	4.0 a	5.4 a	4.6 a	5.5 a	4.1 ab	3.8 ab	3.2 a
22-22-0	3.9 ab	4.2 ab	3.6 ab	4.5 bcd	4.1 cde	5.0 abcd	3.3 c	3.5 bcd	3.0 abc
22-67-0	3.9 ab	4.4 a	4.0 a	4.6 bc	4.4 abc	5.2 abc	2.9 e	3.9 a	3.1 ab
0-45-0 ¶	- -	- -	- -	3.6 f	4.0 def	4.5 fg	- -	- -	- -

† Denotes kg ha^{-1} of P_2O_5 applied as Starter-Broadcast-Deep Band respectively.
§ Samples were collected later in the season (V9 growth stage).
‡ Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.
¶ This treatment is combined with a tillage operation, only found at Ottawa.

Table 3-5 Corn early season phosphorus uptake of each treatment at each location by year.

Treatment †	Year					
	2011			2012		
	Manhattan	Ottawa	Scandia	Manhattan	Ottawa	Scandia §
	- mg plant^{-1} - - - - - - - - - - - - - - - - - - -					
0-0-0	7.7 f ‡	7.7 g	9.5 g	8.1	11.2	38.9 f
22-0-0	11.2 cdef	11.1 f	14.0 ef	13.2	13.6	52.9 def
0-45-0	9.0 ef	12.9 cdef	13.7 f	7.3	12.1	51.3 ef
22-22-0	12.3 bcde	12.6 def	16.7 def	12.7	13.2	61.1 cde
0-0-45	11.4 bcde	11.8 ef	18.8 cd	8.8	12.6	62.3 bcde
22-0-22	14.9 ab	11.5 f	21.5 bc	15.3	15.8	63.8 bcde
0-90-0	10.2 def	12.6 def	17.1 def	8.3	12.0	73.4 bc
22-67-0	12.7 bcd	15.4 abc	17.7 cde	12.0	13.9	67.2 bcd
0-0-90	12.0 bcde	14.9 bcd	25.4 ab	12.5	15.7	76.7 ab
22-0-67	16.9 a	16.6 ab	23.8 ab	6.2	13.1	91.0 a
22-22-0	14.3 abc	13.7 cdef	18.6 cd	11.4	12.3	70.7 bc
22-67-0	14.8 ab	17.7 a	26.6 a	9.1	13.8	75.0 bc
0-45-0 ¶	- -	14.4 bcde	- -	- -	12.1	- -

† Denotes kg ha^{-1} of P_2O_5 applied as Starter-Broadcast-Deep Band respectively.
§ Samples were collected later in the season (V9 growth stage).
‡ Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.
¶ This treatment is combined with a tillage operation, only found at Ottawa.

Table 3-6 Corn ear leaf tissue phosphorus concentration and soybean uppermost fully open trifoliate phosphorus concentration of each treatment at Manhattan by year.

Treatment †		Corn Years §			Soybean Years			
Corn application	Soybean application	2009	2010	2011	2009	2010	2011	2012
		- - - - - - - - - - - - - - - P Concentration g kg^{-1} - - - - - - - - - - - - - -						
0-0-0	0-0-0	2.6 d ‡	2.5	2.0 c	3.8	3.6	3.1	2.5
22-0-0	0-0-0	2.7 cd	2.6	2.4 ab	4.2	4.0	3.1	2.5
0-45-0	0-0-0	2.7 cd	2.6	2.3 ab	4.3	4.0	3.2	2.5
22-22-0	0-0-0	2.7 cd	2.6	2.5 ab	4.6	4.0	3.1	2.5
0-0-45	0-0-0	3.0 abc	2.4	2.2 bc	4.2	3.7	3.2	2.6
22-0-22	0-0-0	2.9 abc	2.3	2.5 ab	4.4	3.8	3.2	2.5
0-90-0	0-0-0	2.9 abc	2.8	2.2 abc	4.2	3.9	3.1	2.5
22-67-0	0-0-0	2.8 bcd	2.6	2.4 ab	4.5	4.1	3.2	2.8
0-0-90	0-0-0	2.8 bcd	2.6	2.6 a	4.1	3.9	3.1	2.5
22-0-67	0-0-0	3.1 ab	2.6	2.4 ab	4.1	4.0	3.2	2.7
22-22-0	0-45-0	3.3 a	2.7	2.2 bc	4.4	4.0	3.2	2.7
22-67-0	0-45-0	3.0 abc	2.5	2.5 ab	4.3	4.0	3.3	2.8

† Denotes kg ha^{-1} of P_2O_5 applied as Starter-Broadcast-Deep Band respectively.
§ The corn crop at Manhattan didn't produce ears making this measurement unobtainable in 2012.
‡ Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.

Table 3-7 Corn ear leaf tissue phosphorus concentration and soybean uppermost fully open trifoliate phosphorus concentration of each treatment at Ottawa by year.

Treatment †		Corn Years §			Soybean Years §		
Corn application	Soybean application	2009	2011	2012	2009	2011	2012
		- - - - - - - - - - - - - - P Concentration g kg^{-1} - - - - - - - - - - - - - -					
0-0-0	0-0-0	2.3 c ‡	2.0 h	2.3 h	3.2 e	2.8 e	3.0 e
22-0-0	0-0-0	2.6 bc	2.5 fg	2.8 fg	3.4 de	3.0 bcd	3.6 bc
0-45-0	0-0-0	2.5 bc	2.4 g	2.7 g	3.6 cd	2.9 de	3.1 ed
22-22-0	0-0-0	2.7 b	2.8 de	3.0 def	4.1 ab	3.0 bcd	3.5 c
0-0-45	0-0-0	2.6 bc	2.6 efg	3.2 cd	3.7 cd	3.0 bcd	3.5 bc
22-0-22	0-0-0	2.7 b	2.9 cde	2.9 efg	3.8 bc	3.1 abc	3.5 c
0-90-0	0-0-0	2.6 bc	2.7 def	2.7 g	3.8 bc	3.0 cd	3.4 dc
22-67-0	0-0-0	2.6 bc	3.0 bcd	3.1 cde	4.2 a	3.2 ab	3.6 bc
0-0-90	0-0-0	3.2 a	3.1 bc	3.8 a	3.8 bc	3.4 a	3.7 abc
22-0-67	0-0-0	3.3 a	3.3 ab	3.6 ab	3.5 cde	3.3 a	3.9 ab
22-22-0	0-45-0	2.8 b	3.0 bcd	3.4 bc	4.1 ab	3.2 ab	3.7 abc
22-67-0	0-45-0	2.6 bc	3.4 a	3.3 bc	4.3 a	3.4 a	4.0 a
0-45-0 ¶	0-0-0	2.6 bc	2.7 def	2.8 fg	3.4 de	3.1 bcd	3.6 bc

† Denotes kg ha^{-1} of P_2O_5 applied as Starter-Broadcast-Deep Band respectively.
§ The 2010 tissue data needed here is not available.
‡ Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.
¶ This treatment is combined with a tillage operation, only found at Ottawa.

Table 3-8 Corn ear leaf tissue phosphorus concentration and soybean uppermost fully open trifoliate phosphorus concentration of each treatment at Scandia by year.

Treatment †		Corn Years §			Soybean Years §		
Corn application	Soybean application	2009	2011	2012	2009	2011	2012
		- - - - - - - - - - - - - - P Concentration g kg^{-1} - - - - - - - - - - - - - -					
0-0-0	0-0-0	2.1 e ‡	2.7 e	1.9 d	3.0 d	2.6 f	2.8 g
22-0-0	0-0-0	2.5 bcd	2.3 d	2.0 cd	3.6 abc	2.7 ef	3.0 fg
0-45-0	0-0-0	2.2 de	2.5 cd	2.2 bc	3.5 bcd	3.0 cd	3.1 defg
22-22-0	0-0-0	2.3 cde	2.6 bcd	2.2 bc	3.6 abc	2.8 def	3.4 bcde
0-0-45	0-0-0	2.3 cde	2.5 cd	2.0 cd	3.8 ab	3.1 cd	3.1 efg
22-0-22	0-0-0	2.5 bcd	2.5 cd	2.0 cd	3.7 ab	2.9 de	3.3 cdef
0-90-0	0-0-0	2.4 bcd	2.7 abc	2.4 a	4.0 a	3.5 a	3.5 abc
22-67-0	0-0-0	2.7 ab	2.8 ab	2.3 ab	3.7 ab	3.4 ab	3.6 ab
0-0-90	0-0-0	2.3 cde	2.5 cd	2.1 cd	3.2 cd	2.9 de	3.3 bcdef
22-0-67	0-0-0	2.6 bc	2.4 cd	2.2 bc	3.5 bcd	3.0 cd	3.4 bcde
22-22-0	0-45-0	2.9 a	2.9 a	2.3 ab	3.9 ab	3.2 bc	3.8 a
22-67-0	0-45-0	2.4 bcd	2.6 bcd	2.5 a	3.9 ab	3.5 a	3.5 abc

† Denotes kg ha^{-1} of P_2O_5 applied as Starter-Broadcast-Deep Band respectively.
§ The 2010 tissue data needed here is not available.
‡ Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.

Table 3-9 Average yield of each treatment at Manhattan by year.

Treatment †		Corn Years §			Soybean Years			
Corn application	Soybean application	2009	2010	2011	2009	2010	2011	2012
		- - - - - - - Mg ha^{-1} - - - - - -			- - - - - - - - - - - - kg ha^{-1} - - - - - - - - - - - -			
0-0-0	0-0-0	12.68	8.15	4.43	3568	2228	2492	1721
22-0-0	0-0-0	12.62	8.36	4.60	3447	2194	2440	1683
0-45-0	0-0-0	12.65	7.80	4.48	4109	2174	2339	1701
22-22-0	0-0-0	12.89	8.16	4.35	4027	2371	2278	1757
0-0-45	0-0-0	11.15	6.53	4.48	3828	2118	2461	1755
22-0-22	0-0-0	12.01	6.99	4.16	3518	1982	2406	1915
0-90-0	0-0-0	12.66	8.86	5.49	3965	2236	2371	1706
22-67-0	0-0-0	12.38	7.79	5.14	3897	2367	2491	1911
0-0-90	0-0-0	12.66	7.62	3.92	3726	2166	2391	1810
22-0-67	0-0-0	12.50	7.53	4.81	3506	1885	2368	1858
22-22-0	0-45-0	12.93	7.38	4.98	3678	2181	2362	1866
22-67-0	0-45-0	12.88	6.53	4.85	4050	2311	2515	1901

† Denotes kg ha^{-1} of P_2O_5 applied as Starter-Broadcast-Deep Band respectively.

§ The corn crop at Manhattan produced no measureable yield for the 2012 year.

Table 3-10 Average yield of each treatment at Ottawa by year.

Treatment †		Corn Years				Soybean Years			
Corn application	Soybean application	2009	2010	2011	2012	2009	2010	2011	2012
		- - - - - - - - - - - - Mg ha^{-1} - - - - - - - - - - - -				- - - - - - - - - - - - - - kg ha^{-1} - - - - - - - - - - - - - -			
0-0-0	0-0-0	8.77 ef **§**	5.53 b	2.13 c	0.60	3155 d	2002 d	2178	1747 d
22-0-0	0-0-0	8.80 ef	5.62 b	2.37 bc	0.80	3352 cd	2329 ab	2253	1889 cd
0-45-0	0-0-0	8.95 bcdef	6.25 a	2.40 bc	0.72	3616 ab	2319 abc	2371	1928 cd
22-22-0	0-0-0	8.91 def	6.41 a	2.56 ab	0.87	3642 a	2165 c	2391	1997 abc
0-0-45	0-0-0	9.60 a	6.41 a	2.37 bc	0.85	3688 a	2237 abc	2321	1944 bcd
22-0-22	0-0-0	8.93 cdef	6.69 a	2.52 ab	0.86	3672 a	2221 abc	2544	2141 ab
0-90-0	0-0-0	9.42 abcd	6.28 a	2.61 ab	0.84	3677 a	2190 bc	2428	1979 bc
22-67-0	0-0-0	9.28 abcde	6.34 a	2.79 a	0.84	3742 a	2265 abc	2472	2077 abc
0-0-90	0-0-0	8.90 def	6.39 a	2.57 ab	1.24	3794 a	2264 abc	2537	2199 a
22-0-67	0-0-0	8.71 f	6.25 a	2.61 ab	0.81	3544 abc	2279 abc	2292	2074 abc
22-22-0	0-45-0	9.46 abc	6.42 a	2.57 ab	0.77	3639 ab	2201 abc	2363	1970 bc
22-67-0	0-45-0	8.64 f	6.50 a	2.61 ab	0.75	3733 a	2350 a	2389	2188 a
0-45-0 ‡	0-0-0	9.48 ab	6.50 a	2.46 b	1.01	3384 bcd	2297 abc	2175	1997 abc

† Denotes kg ha^{-1} of P_2O_5 applied as Starter-Broadcast-Deep Band respectively.

§ Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.

‡ This treatment is combined with a tillage operation, only found at Ottawa.

Table 3-11 Average yield of each treatment at Scandia by year.

Treatment †		Corn Years				Soybean Years			
Corn application	Soybean application	2009	2010	2011	2012	2009	2010	2011	2012
		- - - - - - - Mg ha^{-1} - - - - - - -				- - - - - - - kg ha^{-1} - - - - - - -			
0-0-0	0-0-0	14.27 d **§**	9.40 b	10.93 c	3.88 c	3957 f	3789 e	3949 e	1938 d
22-0-0	0-0-0	16.32 bc	14.24 a	12.97 ab	4.56 b	4007 ef	4492 abcd	4293 ed	2268 bc
0-45-0	0-0-0	16.22 bc	14.42 a	13.14 ab	4.59 b	4332 cd	4025 de	4451 cd	2140 cd
22-22-0	0-0-0	17.08 a	14.31 a	13.65 ab	4.62 b	4165 def	4604 abc	4453 cd	2382 abc
0-0-45	0-0-0	15.90 c	14.70 a	12.99 ab	4.75 ab	4295 cde	4412 abcd	4562 bcd	2342 bc
22-0-22	0-0-0	17.02 a	14.90 a	13.23 ab	4.64 b	4503 bc	4554 abcd	4699 abc	2362 abc
0-90-0	0-0-0	16.53 abc	14.65 a	13.15 ab	4.89 ab	4753 ab	4368 bcd	4923 ab	2389 abc
22-67-0	0-0-0	16.82 ab	15.23 a	13.80 ab	4.73 ab	4428 cd	4821 ab	4682 abcd	2496 ab
0-0-90	0-0-0	16.01 c	14.13 a	13.45 ab	4.69 b	3906 f	4438 abcd	4324 cde	2436 ab
22-0-67	0-0-0	16.53 abc	14.43 a	13.40 ab	4.85 ab	4554 bc	4193 cde	4551 bcd	2416 ab
22-22-0	0-45-0	16.87 ab	15.30 a	13.89 a	4.55 b	4583 bc	4972 a	4584 abcd	2624 a
22-67-0	0-45-0	16.51 abc	14.89 a	12.87 b	5.11 a	4933 a	4463 abcd	4971 a	2409 ab

† Denotes kg ha^{-1} of P_2O_5 applied as Starter-Broadcast-Deep Band respectively.

§ Numbers in each row followed by different letters within each effect are statistically significant at the 0.05 probability level.

CHAPTER 4 - CONCLUSION

Hybrid differences can be a significant factor for production management. Throughout the first study we found many differences in hybrid response including: early growth, tissue phosphorus concentrations, as well as grain yield. Other studies have shown similar results when comparing different hybrids. We have also found that with these new advances in hybrid technology for drought tolerance, higher nutrient rates may need to be added if higher yield are consistent to replace the higher removal rates. When estimating the fertilizer amounts needed for these new drought tolerant hybrids, producers will still be able to use the current fertilizer recommendation equations with the adjustment of yield potential. With advances in technology hybrid selection is a big management decision and will continue to require attention for yield optimization including fertilizer management.

Changes in tillage practices may also change some management decisions in crop production. With changes in tillage there may be changes in fertilizer application via different placements. There is some advantages to placement on certain aspects of growth, but when it comes to crop yield it seems that soil test levels and optimum fertilizer rates are the most relevant factors despite of placement methods. There are advantages to early growth or vigor with starter fertilizer application. This could have advantages when uniform stands and fast early growth are critical. These conductions may be especially important in areas prone to high winds or heavy weather during the early growth of the crops.

Another issue we addressed is direct fertilization to soybeans before planting. There could be possible advantages in using this practice as well as we did find higher tissue concentrations in treatments with direct fertilization. There was a tendency to increase seed yield with the direct fertilization applied to the soybean crop, although this was not statistically significant. This practice could be economical if the price of soybeans was favorable or if the price of the fertilizer was low. It is likely that to see a more frequent increase in soybean seed yield with direct fertilization with low soil test or if the previous crop was high yielding, removing high levels of nutrients.