CORN AND SOYBEAN RESPONSE TO PHOSPHORUS PLACEMENT UNDER MINIMUM TILLAGE SYSTEMS

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Abstract

Producers often question the need for better fertilizer placement methods in reduced tillage systems. The objective of this study was to evaluate the effects of different placements and rates of phosphorus (P) fertilizer for corn (*Zea mays*) and soybean (*Glycine max*). The study was conducted at 3 locations from 2005 to 2012 (8 years). This paper presents results from one irrigated location. Tillage system was strip till before planting corn; and soybean was planted without previous tillage. Fertilizer placements included: starter, broadcast, deep band, and various combinations. Total fertilizer rates included: 0, 22, 45, and 90 kg P_2O_5 ha^{-1} applied before corn except for two treatments with 45 kg P_2O_5 ha^{-1} applied before soybean. The experimental design was randomized complete block with four replications. Corn ear leaf tissue samples were collected at the VT-R1 growth stage and soybean uppermost fully developed trifoliate were collected at the R3 growth stage. Both were analyzed for P concentration. Corn grain yield and soybean seed yield were evaluated at the end of the growing season. Results showed significant differences ear leaf P concentration, soybean trifoliate P concentration, as well as corn and soybean grain P that were affected by application rate. Corn and soybean yield was significantly increased with high rate P applications in broadcast only and starter plus broadcast. The application of additional fertilizer to soybeans (following the corn with starter plus deep band) was shown to significantly increase soybean trifoliate P concentrations at R3 and yield. However, the additional 45 kg P_2O_5 ha^{-1} had no residual effect on corn yield.

Introduction

With the adoption of reduced tillage practices, P stratification is often a concern as potential issue for plant P availability and therefore, crop yields. In reduced tillage systems, P stratification can occur due to surface applications of fertilizer (Morrison and Chichester, 1994; Mullen and Howard, 1992) without incorporation into the soil (Robbins and Voss, 1991; Karlen et al., 1991) and decomposition of crop residue (Karlen et al., 1991). Strip-tillage has been adopted as reduced tillage option for corn production. Strip-tillage comprises no tillage with conventional tillage in that residue is incorporated in a narrow band and soil is loosened for planting, providing a good alternative for residue management. The addition of fertilizer in a deep band in a combination with strip-till allow for concentrated nutrients directly below the seed. In systems with no tillage, deep band fertilizer has shown to increase soybean yield when compared to broadcast (Bordoli and Mallarino (2000).

In previous studies, starter fertilizer (5cm to the side and 5cm below the seed) has shown the most consistent crop response in reduced tillage systems with low soil test P (STP) (Randall and Hoeft, 1998). Furthermore, Bordoli and Mallarino (1998) showed that placement of fertilizer was not as relevant as STP levels. Broadcasting P fertilizer has shown to increase crop response in soils with low STP (Bordoli and Mallarino, 1991). In Kansas, Schwab et al. (2006) showed that P uptake and grain increased with the application of fertilizer below the soil surface. Regardless of application method, adequate moisture content of soil is essential for P uptake through diffusion (Hira and Singh, 1977).

There are many studies suggesting that STP show greater effect on plant response compared to placement. Placement may become more important as reduced tillage systems are adopted and increases in stratification occur over time, therefore the evaluation of these practices over time in long term studies is necessary. 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) with reduced tillage system.

Materials and methods

The Scandia site is located on the North Central Agronomy Experiment Field and was established in spring of 2005. The soil is classified as a Crete silt loam (fine, smectitic, mesic Pachic Argiustolls). This location had a history of low STP and no-till production practices for more than 5 years before starting this study, and stratification was expected to previously exist. Supplemental irrigation was applied to a corn-soybean rotation. In Kansas, soybeans may not receive fertilizer application as farmers expect residual P from fertilizer applications before corn. Two additional treatments were added before soybean to evaluate soybean response to P fertilizer in addition to residual P. Treatments are described in Table 1.

The experimental design was a randomized complete block design with four replications. Starter fertilizer was applied 5cm to the side and 5cm below the seed for corn. Deep band treatments were applied with the strip till operation approximately 15cm deep before planting corn using ammonium polyphosphate (10-34-0). All other plots were strip-tilled to prevent tillage effects, even if P fertilizer was not applied. The strip till operation was only before corn; and soybean was planted without previous tillage. Broadcast application was applied on the soil surface prior to planting using triple superphosphate (0-46-0). Nitrogen (N) was applied as a deep band application with urea ammonium nitrate (UAN; 28-0-0) to balance N in all treatments, therefore preventing a N effect from the 10-34-0 fertilizer.

Initial soil samples were collected in 2005 by collecting one composite sample (by depth) (Table 2). Soil water pH was determined on 1:1 (soil:water). Phosphorus and potassium were determined by Mehlich-3 extraction (Frank et al, 1988). Organic matter was determined by Walkley-Black (Combs and Nathan, 1998). Plant tissue samples were collected during specific growth stages for corn and soybean, corn and soybean grain from 2011 and 2012 has not been analyzed. Fifteen corn ear leaf tissue samples were collected at silking (VT-R1) and analyzed for P concentration. Thirty soybean trifoliate tissue (uppermost fully developed without the petiole), were also collected at the R3 growth stage (Pedersen, 2009). Plants were dried in a forced air oven at 60 degree Celsius for a minimum of 4 days. After drying, plants were ground with a Wiley Mill grinder to pass a 2mm screen and digested using a sulfuric acid and hydrogen peroxide digest (Thomas et al., 1967). Phosphorus concentration was then determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES).

The center 152cm width of each plot was machine harvested. Grain weight was recorded at the end of the growing season and adjusted for 155 and 130 g kg^{-1} moisture for corn and soybean respectively. Grain was ground to pass a 2 mm screen and digested following Thomas et al. (1967) and analyzed for P concentration by ICP-AES.

Data was analyzed by year, and across years using year as a random variable for analysis. Corn and soybean parameters were analyzed using *proc Glimmix* SAS 9.1 (SAS, 2010) to determine if there was a significant (*P=0.05*) response to P treatments. Treatment effects on least square means of corn and soybean yields and grain P concentration, and corn ear leaf, and soybean trifoliate P concentration were separated using Tukey HSD at a significant level of *P=0.05*.

Summary

The study location (Scandia) can be considered high yielding and categorized as "very low" on STP concentrations in the top 7.6 cm soil (Table 2) (Liekam et al., 2003). Initial STP also showed preexisting stratification as P concentrations decreased at 7.6-15 cm depth. Over the 8 year of the study, the effect of P fertilizer rates and placement became more significant (Table 3). One possibility for this crop response could be the reduction in STP as fertilizer applications were generally less than crop removal in most years.

Corn and soybean tissue P concentrations were shown to be effected more by application rates as opposed to fertilizer placement. Corn ear leaf and soybean trifoliate had significantly greater P concentrations in the high rate starter plus broadcast and broadcast only (Table 4 and 5). As in tissue concentration, corn and soybean grain P concentration was affected more by application rate. The effect of fertilizer placement within an application rate was not statistically significant (Table 6 and 7). The low rate with starter plus deep band was not significantly different than any of the high rate treatments in corn and soybean for grain P concentrations (Table 6 and 7).

In the low rate, the application of P fertilizer as starter was shown to increase corn yields when compared to broadcast (Table 8). In the high rates, corn yields were significantly greater in starter plus broadcast when compared to the high rate deep banded only. Soybean yield was more responsive to the treatments with high application rates over the 8 year study (Table 9). This suggests that low application rates may be below corn P removal rates and soybean would require additional P fertilization. Soybean yield increased significantly with fertilizer application via starter plus broadcast when compared to starter with deep band. There was no effect when compared to treatments without the starter band. The application of fertilizer as starter with both broadcast and deep band showed no significant effect on soybean yield. Over 8 years, corn and soybean yield in response to rate and treatment became more significant which could be attributed to the decrease in STP as crop removal exceeds application rates.

In this study, broadcasting fertilizer was shown to increase corn and soybean yields in combination with starter and in broadcasting only treatments. Even though broadcasting high rates of P fertilizers may lead to stratification, there is potential for a significant yield increase compared to other placement methods. This suggests small effect of fertilizer P placement on yield response and STP should be considered the main factor to determine potential for response. Furthermore producers have flexibility for fertilizer P placement. Despite the inconsistent response to placement, some placement options can contribute to reduce P loses which provide agronomic and environmental benefits in the long term.

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Table 1. Description of treatments

Treatment	Total Applied	Description
	kg P_2O_5 ha^{-1}	
Control	0	Check plots
ST	22	Starter only
LOW BDCST	45	Broadcast only Low Rate
LOW BDCAST+ST	45	22 kg Broadcast+22 kg Starter Low Rate
LOW BND	45	Deep Band only Low Rate
LOW BND+ST	45	22 kg Deep Band+22 kg Starter Low Rate
HI BDCST	90	Broadcast only High Rate
HI BDCST+ST	90	68 kg Broadcast+22 kg Starter High Rate
HI BND	90	Deep Band only High Rate
HI BND+ST	90	68 kg Deep Band+22 kg Starter
HI BDCST+ST+SOY	135	68 kg Broadcast+22 kg Starter+45 kg Broadcast Soybeans
HI BND+ST+SOY	135	68 kg Deep Band+22 kg Starter+45 kg Broadcast Soybeans

Table 2. Initial soil test data collected in Spring 2005 prior starting the experiment

Depth	pH	Phosphorus	Potassium	Organic Matter
---- cm ----		--------------- mg kg^{-1} --------------		---- % ----
0-7.6	6.8	9.5	585	2.8
7.6-15	6.3	5.7	445	2.3
15-23	---	5.1	---	---
23-31	---	5.4	---	---
31-61	---	4.6	---	---

Table 3. Testing the significance of corn and soybean parameters.

	Year							
Sample	2006	2007	2008	2009	2010	2011	2012	Average
	----------------------------- P < F ------------------------------							
Corn Ear Leaf P (%)	0.360	0.149	0.002	<0.001	0.008	<0.001	<0.001	<0.001
Corn Yield (bu/acre)	0.902	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001
Corn Grain P (%)	0.573	0.339	0.152	<0.001	0.026	---	---	<0.001
Soybean R3 Trifoliate P (%)	0.068	0.103	0.099	0.004	<0.001	<0.001	<0.001	<0.001
Soybean Yield (bu/acre)	0.025	<0.001	0.047	<0.001	0.002	<0.001	<0.001	<0.001
Soybean Grain P (%)	0.169	0.230	0.154	0.404	0.002	---	---	<0.001

Table 4. Corn ear leaf phosphorus concentrations over the 8 year field experiment.

Treatment	Year							Average
	2006	2007	2008	2009	2010	2011	2012	
	% P							
Control	0.20b	0.22b	0.22d	0.21e	0.23e	0.21e	0.19d	0.21f
Starter (ST)	0.22a	0.27a	0.25bc	0.25bcd	0.25de	0.23d	0.20cd	0.24e
LOW BDCST	0.23a	0.28a	0.25bc	0.23de	0.26bcd	0.25cd	0.22bc	0.24de
LOW BDCAST+ST	0.22a	0.27ab	0.26abc	0.23cde	0.25cde	0.25bcd	0.21bc	0.24de
LOW BND	0.22ab	0.26ab	0.27ab	0.23cde	0.26bcd	0.25cd	0.20cd	0.24e
LOW BND+ST	0.22a	0.27a	0.27ab	0.25bcd	0.26bcd	0.25cd	0.20cd	0.25cde
HI BDCST	0.23a	0.27a	0.28a	0.24bcd	0.29a	0.27abc	0.24a	0.26ab
HI BDCST+ST	0.23a	0.30a	0.28a	0.26ab	0.27abcd	0.27ab	0.24ab	0.26a
HI BND	0.23a	0.26ab	0.23cd	0.23cde	0.25cde	0.25cd	0.21cd	0.24e
HI BND+ST	0.22a	0.30a	0.26abc	0.26bc	0.27abcd	0.24cd	0.22bc	0.25bcd
HI BDCST+ST+SOY	0.23a	0.26ab	0.27ab	0.28ab	0.28ab	0.29a	0.23ab	0.26a
HI BND+ST+SOY	0.23a	0.27ab	0.27ab	0.24bcd	0.27abc	0.26bc	0.25a	0.26abc

Table 5. Soybean trifoliate phosphorus concentrations over the 8 year field experiment.

Treatment	Year							Average
	2006	2007	2008	2009	2010	2011	2012	
	% P							
Control	0.28d	0.24bc	0.31c	0.30d	0.30f	0.26f	0.26f	0.28e
Starter (ST)	0.30bcd	0.25abc	0.32bc	0.36abc	0.35cde	0.27ef	0.30e	0.31d
LOW BDCST	0.32abcd	0.25abc	0.32c	0.35bcd	0.34e	0.30cd	0.32cde	0.31cd
LOW BDCAST+ST	0.34ab	0.26abc	0.34ab	0.35abc	0.37abcd	0.28def	0.34bc	0.33bc
LOW BND	0.30cd	0.24bc	0.33abc	0.38ab	0.35cde	0.31cd	0.31de	0.31cd
LOW BND+ST	0.33abc	0.24bc	0.31c	0.36ab	0.37abc	0.28de	0.33cd	0.32cd
HI BDCST	0.33abc	0.24bc	0.32bc	0.40a	0.34de	0.35a	0.36ab	0.33ab
HI BDCST+ST	0.33abc	0.25bc	0.33abc	0.37ab	0.39a	0.34ab	0.36ab	0.34ab
HI BND	0.31bcd	0.23c	0.32c	0.32cd	0.35bcde	0.29de	0.33cd	0.31d
HI BND+ST	0.31abcd	0.26ab	0.33abc	0.35bcd	0.34cde	0.30cd	0.34bc	0.32cd
HI BDCST+ST+SOY	0.34abc	0.27a	0.35a	0.39ab	0.38ab	0.32bc	0.38a	0.35a
HI BND+ST+SOY	0.36a	0.26abc	0.33abc	0.40ab	0.36bcde	0.35a	0.36ab	0.34a

Table 6. Corn grain phosphorus concentrations following harvest over the 8 year field experiment.

Treatment	Year 2006		2007		2008		2009		2010		Average	
	% P											
Control	0.23	abc	0.26	a	0.24	c	0.18	d	0.22	c	0.23	e
Starter (ST)	0.24	abc	0.26	a	0.26	abc	0.22	bc	0.22	c	0.24	de
LOW BDCST	0.23	abc	0.23	ab	0.26	bc	0.22	c	0.24	abc	0.23	de
LOW BDCAST+ST	0.23	abc	0.25	ab	0.26	bc	0.24	abc	0.23	bc	0.24	bcd
LOW BND	0.22	bc	0.22	b	0.27	abc	0.24	abc	0.24	bc	0.24	de
LOW BND+ST	0.22	c	0.24	ab	0.28	abc	0.25	a	0.25	ab	0.25	abcd
HI BDCST	0.23	abc	0.26	a	0.3	a	0.22	bc	0.27	a	0.25	ab
HI BDCST+ST	0.25	a	0.25	ab	0.27	abc	0.24	abc	0.27	a	0.26	a
HI BND	0.24	abc	0.26	a	0.28	ab	0.22	c	0.24	abc	0.25	abcd
HI BND+ST	0.25	ab	0.23	ab	0.29	ab	0.25	ab	0.26	ab	0.25	ab
HI BDCST+ST+SOY	0.24	abc	0.26	a	0.29	ab	0.26	a	0.26	ab	0.26	a
HI BND+ST+SOY	0.23	abc	0.25	ab	0.29	ab	0.25	ab	0.25	abc	0.25	abc

Table 7. Soybean seed phosphorus concentrations following harvest over the 8 year field experiment.

Treatment	Year 2006	2007	2008	2009	2010	Average
	% P					
Control	0.48abc	0.48abc	0.42cd	0.41b	0.44c	0.45de
Starter (ST)	0.43c	0.50abc	0.41d	0.43ab	0.44c	0.44e
LOW BDCST	0.48abc	0.48abc	0.44bcd	0.42ab	0.44c	0.45cde
LOW BDCAST+ST	0.49ab	0.47bc	0.45abcd	0.42b	0.51ab	0.47bcd
LOW BND	0.47abc	0.46c	0.44bcd	0.44ab	0.46bc	0.45cde
LOW BND+ST	0.51ab	0.48abc	0.46abcd	0.45ab	0.51ab	0.48ab
HI BDCST	0.47abc	0.51a	0.44abcd	0.46ab	0.49abc	0.47abc
HI BDCST+ST	0.48abc	0.51a	0.46abcd	0.44ab	0.50ab	0.48ab
HI BND	0.46abc	0.50abc	0.46abcd	0.44ab	0.54a	0.48ab
HI BND+ST	0.46bc	0.50ab	0.48abc	0.45ab	0.51ab	0.48ab
HI BDCST+ST+SOY	0.51a	0.49abc	0.48ab	0.45ab	0.54a	0.50a
HI BND+ST+SOY	0.51ab	0.49abc	0.49a	0.48a	0.46bc	0.48ab

Table 8. Corn harvest yields over the 8 year field experiment.

Treatment	Year 2006	2007	2008	2009	2010	2011	2012	Average
	---- bu acre^{-1} ----							
Control	183a	179c	191e	227d	200d	174c	62c	174e
Starter (ST)	188a	220b	229abc	260bc	227bc	207ab	73b	200cd
LOW BDCST	189a	222ab	220cd	258bc	230abc	209ab	73b	200d
LOW BDCAST+ST	191a	229ab	236a	272a	228abc	218ab	74b	207ab
LOW BND	193a	230ab	223bcd	253c	234abc	207ab	76ab	202bcd
LOW BND+ST	188a	226ab	232ab	271a	237abc	211ab	74b	206abcd
HI BDCST	192a	228ab	217d	263abc	234abc	210ab	78ab	203abcd
HI BDCST+ST	190a	230ab	229abc	268ab	243ab	220ab	75ab	208a
HI BND	188a	229ab	228abc	255c	225c	214ab	75b	202bcd
HI BND+ST	190a	228ab	237a	263abc	230abc	214ab	77ab	205abcd
HI BDCST+ST+SOY	175a	228ab	229abc	269ab	244a	221a	72b	206abc
HI BND+ST+SOY	189a	231a	230ab	263abc	237abc	205b	81a	205abcd

Table 9. Soybean harvest yields over the 8 year field experiment.

Treatment	Year 2006	2007	2008	2009	2010	2011	2012	Average
	---- bu acre^{-1} ----							
Control	43d	53e	61bc	59f	53d	59e	28d	51g
Starter (ST)	47bcd	61cd	61bc	60ef	67abc	64de	34bc	56f
LOW BDCST	49abc	62cd	63abc	64cd	64bc	66cd	33c	57ef
LOW BDCAST+ST	51ab	63c	59c	62def	68abc	66cd	35bc	58def
LOW BND	48abc	61cd	64ab	64cde	66bc	68bcd	35bc	58def
LOW BND+ST	49abc	61cd	62bc	67bc	68abc	70abc	35bc	59cde
HI BDCST	47bcd	63cd	63abc	71ab	65bc	73ab	36abc	60bcd
HI BDCST+ST	53a	66b	60c	66cd	72ab	70abcd	37ab	60abc
HI BND	45cd	62cd	64ab	58f	66bc	64cde	36abc	56f
HI BND+ST	48bc	60d	64ab	68bc	62c	68bcd	36abc	58def
HI BDCST+ST+SOY	50ab	65b	63abc	68bc	74a	68abcd	39a	61ab
HI BND+ST+SOY	50ab	70a	66a	73a	66abc	74a	36abc	62a

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