EVALUATION OF PHOSPHORUS AND POTASSIUM FERTILITY FOR STRIP-TILLAGE AND NO-TILLAGE CORN-SOYBEAN CROPPING SYSTEMS

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INTRODUCTION

Row-crop agriculture in the Mississippi River Watershed is under intense pressure to reduce nitrogen (N) and phosphorus (P) loads that can eventually exacerbate the hypoxia zone in the Gulf of Mexico. To reduce nutrient and sediments losses, more precise application and placement of nutrients, (especially N and P) along with less tillage, are being proposed. No-till has been a difficult challenge for corn (*Zea mays* L.) growers in Illinois because of early spring wet and cool soil conditions that delay planting and/or seedling development. In addition, the lack of incorporation of surface-applied P and K in no-till systems creates stratification of these nutrients with higher concentrations in the surface compared to the subsurface. Nutrient stratification under no-till can cause runoff to have higher P concentrations, which could create a greater concern for surface water quality. In recent years, strip-till, which is another conservation tillage method, has emerged as an alternative. Strip-tillage is done in the fall by disturbing the soil 7-8 inches deep and creating a residue-free band 4-6 inches wide and 1-2 inches high. The cultivated strip provides the benefits of conventional tillage by creating a good seedbed zone with warmer and dryer soil conditions in early spring; while the undisturbed soil between strips provides the benefits of soil and water conservation of no-till systems (Morrison, 2002). Better seedbed conditions with strip-till have improved crop growth and yield (Morrison, 2002; Randall and Vetsch, 2008; Farmaha et al., 2011). Additionally, in strip-till soil P levels in the soil surface could be effectively reduced as P and K fertilizers are placed deep in the soil during the tillage operation (Farmaha et al., 2011).

The introduction of government programs to encourage soil and water conservation along with the potential to lower costs of operation and all the potential benefits just described is helping strip-till gain popularity in Illinois (Frazee, 2006). One of the most commonly perceived challenges by farmers in relation to adoption of conservation tillage systems is fertilizer management. Traditionally, surface broadcasted P and K fertilizers were incorporated through tillage, resulting in an even distribution of these nutrients in the plow-layer. Conservation tillage systems are characterized by minimal soil disturbance. Limited mobility of surface broadcast P and K fertilizers in combination with reduced mixing of the soil often creates strong vertical stratification with highest P and K concentrations in the surface 2 inches of the soil (Buah et al., 2000; Crozier et al., 1999; Hargrove, 1985; Holanda et al., 1998; Howard et al., 1999). As band applications of P and K are becoming more common, not only vertical stratification, but also a horizontal pattern of high and low fertility across the field is being observed in fields. This is because crops use only a portion of the applied P and K in a band and the residual fertilizer creates a zone of concentrated nutrients that persist for a long time (Miner and Kamprath, 1971).

This horizontal pattern of high and low fertility across the field is most likely to occur in controlled-traffic and strip-till systems where RTK satellite navigation technology makes it possible to plant and band fertilizers always in the same location.

Application of P and K represents a large investment for Illinois farmers, and improving management practices that optimize returns on fertilizer investment is at the forefront of a farmer's agenda. Optimization of P and K fertilizer use can be accomplished by correctly predicting availability of these nutrients for the crop to be grown through soil testing. The vertical stratification and horizontal patterns described for these nutrients present a challenge to accurately predict, through soil sampling and testing, the P and K status of the soil and the need for additional fertilization. Current soil sampling guidelines were developed for fields receiving intensive tillage that evenly incorporated fertilizers throughout the plow-layer. Using these standard soil sampling guidelines might not provide accurate information to aid P and K management under conservation tillage systems with fertilizer band applications. In fact, many Illinois producers that for several years have been doing P and K banding in their conservation tillage fields are facing the challenge of not knowing what the real P and K status of their fields are. Currently in Illinois, as well as in the Midwest, we do not have adequate guidelines on how to collect soil samples from these fields. The few studies that have focused on the interaction of fertilizer placement and strip-till have done so for starter fertilizers (Bermudez and Mallarino, 2004; Vetsch and Randall, 2002). There are no studies that have attempted to determine the impact of subsurface fertilizer band application on soil surface P levels and the potential benefit to lower environmental impact. Finally, the need to determine an appropriate soil sampling scheme for conservation tillage systems has been recognized, but there is still only limited information available, especially in relation to strip-till (Bermudez and Mallarino, 2007; Mallarino, 1996; Mallarino and Borges, 2006; Tyler and Howard, 1991). In a report from the North-Central Region 13 (NCR-13) committee, the topic of soil sampling fields under conservation tillage systems was addressed, but the final conclusion of the report was that there is no universal agreement on the best way to collect soil samples from such fields (Rehm, et al., 2002).

Since it is relatively simple to combine deep placement of P and K with the strip-till operation, these nutrients are normally applied in the row at 6-8 inches below the soil surface. Deep banding of P and K has been shown to enhance fertilizer use efficiency, nutrient availability, and yield (Hairston et al., 1990; Bordoli and Mallarino, 1998; Ebelhar and Varsa, 2000; Borges and Mallarino, 2000), while others have reported no or small benefit to deep-banding compared with broadcast applications (Hudak et al., 1989; Yin and Vyn, 2002a, 2002b; Borges and Mallarino, 2003; Rehm and Lamb, 2004; Farmaha et al., 2011). Despite the increasingly greater interest and adoption of strip-till systems for corn and soybean [*Glycine max* (L.) Merr.] production in Illinois and the Midwest, relatively little is known about P and K nutrient management for this cropping system. The lack of knowledge on how to collect soil samples in strip-till systems to accurately predict P and K fertilization for corn and soybean, and the need to effectively supply those nutrients in the cropping system to improve the profitability of farming operations and sustainability of the environment, constitutes the basis of this study.

MATERIALS AND METHODS

The study was conducted in commercial fields in a corn-soybean rotation with 30-inch row spacing during 2007 to 2011 at three locations within 1 mile radius of each other near Pesotum, Illinois with Drummer silty clay-loam (fine-silty, mixed, mesic Typic Endoaquoll) and Flanagan silt loam (Fine, smectitic, mesic Aquic Argiudolls) soils. The sites had no prior history of banded fertilizer placement and they had been managed with chisel plow after corn and field cultivation after soybean in years prior to the study. The top 7 inches of the soil contained 3.0 to 3.5% organic matter, cation exchange capacity of 17 to 30 milliequivalent per 100 grams of soil and pH (1:1 soil/water ratio) of 5.1 to 6.3.

The study was set up as a split-plot arrangement in a randomized complete-block design with two replications. The main (whole) plot included three tillage/fertilizer placement treatments: no-till/broadcast (NTBC); strip-till/broadcast (STBC); and strip-till/deep-band (STDB). The split-plot treatments were blends of diammonium phosphate (18-46-0) and potassium chloride (0-0-60) made to create seven P-K fertilizer treatments with a control receiving no P or K (0-0 or check). The six additional rates were 46, 69, 92, 115, 138, and 161 lb P_2O_5 acre^{-1} and K_2O acre^{-1}. Corrective nitrogen (N) rates were applied to offset the N content of DAP fertilizer.

Strip-till and fertilizer operations were done always in the fall and corn was planted on the location of the strips the following spring. The soybean crop was also planted on the same crop-row position as corn but no tillage operations were performed for soybean. The location of the tillage and the banded fertilizer was maintained constant by using RTK satellite navigation technology (+/- 1-inch accuracy) (Trimble® Field Manager ™Software) with two GPS receivers, one mounted on the tractor and the other mounted on the tillage bar. Strip-till was performed on 30-inch row-spacing using a strip-till toolbar (DMI, Model 4300) consisting of vertical coulters and row cleaners in front of knifes designed for dry fertilizer application and closing disks behind the knives to cover the knife slit with soil and form a residue-free berm. Broadcast applications were done with a drop spreader (10T Series, Gandy, Owatonna, MN). For the STBC treatment, broadcast applications were performed after the strip-till operation. For the STDB treatment, the fertilizer was banded 6 inches below the soil surface during the tillage operation using a Gandy Orbit Air applicator (Model 6212C, Gandy, Owatonna, MN). All corn plots received a total of 180 lb N acre^{-1}.

Measurements

Soil samples for P and K analysis were collected from each plot every fall after crop harvest except in 2009 when soil samples were collected in the spring because wet soil conditions in the fall prevented access to the field before the soils froze. A composite of 12 soil cores (3/4 inch diameter each) was made for each of four positions with respect to the crop-row: in the crop-row (IR), and in between the crop-rows (BR) 7.5-, 15-, and 22.5-inches from the IR. These BR positions will be referred to as BR-7.5, BR-15 and BR-22.5. Each sample was partitioned into 0- to 4-, 4- to 8- and 8- to 12-inch depth increments. The composite 12 soil-core samples were collected three per each of the positions with respect to the crop-row within a 4-row geo-referenced 10 x 10 ft area in the center of each treatment. Soil samples were analyzed for P and K.

We created a soil P and K test weighted average for the top 8-inch depth for each treatment. In order to determine whole-field test levels, the top 8-inch soil P and K test levels were then used to calculate soil test levels for different sampling scenarios created by various ratios of IR to BR cores: 1:3, 1:2, 1:1, 1:0, 0:3. The 1:2 and 1:1 ratios were calculated from the average of all possible combinations of IR and the appropriate number of BR samples drawn from a population of three BR samples. All these calculated test levels were compared to calculated "True" mean soil test levels for each fertilizer rate treatment. The "True" mean soil test level for the top 8 inches of soil was defined as the value obtained when averaging across the test values from one sample collected at IR and three samples collected at BR (1:3 ratio of IR to BR cores) for the NTBC system.

Data were analyzed with the MIXED procedure of SAS (SAS Institute, 2009). Year and block and their interactions with treatments were considered random effects. The fixed effects were tillage/fertilizer placement, fertilizer rate, position with respect to the crop-row and soil depth. Observations were treated as independent measurements because there were no significant correlations between the observations. The LS Means for significant fixed effects were further analyzed by obtaining F tests for simple effects by the SLICE option in the PROC MIXED procedure of SAS (SAS Institute, 2009). The SLICE option was also used to analyze the change in soil P and K test levels between the start of the experiment and 2010 at each level of the fixed effects. In this analysis, year was also considered a fixed effect. Finally, the SLICE option was used to compare soil P and K test levels of different sampling scenarios to the "True" mean.

RESULTS AND DISCUSSION

Corn yields were significantly higher with strip-till (STBC and STDB) compared with NTBC (Figure 1). In general, P and K rate increased corn yield relative to the check (Figure 2). The highest yield difference was 13 bushels acre^{-1} with the 69 lb P_2O_5 and K_2O acre^{-1} rate compared with the unfertilized check. There was not a significant interaction between tillage/fertilizer placement and fertilization rate, which indicates the yield response to P and K fertilization rate was similar across tillage/fertilizer placement treatments. This lack of interaction illustrates that there is no benefit, in terms of seed yield, for deep-banding the fertilizer relative to broadcasting it. The lack of interaction also indicates that the yield increase observed for the strip-till treatments over the no-till treatment was the result of a tillage effect. Further analysis showed that corn yields for the unfertilized check was 175 bushels acre^{-1} for the NTBC treatment and significantly lower than 182 bushels acre^{-1} for the STBC and 184 bushels acre^{-1}for the STDB treatment. There were no differences in soybean yield due to tillage/fertilizer placement (Figure 3), though the trend for higher yields with STDB over NTBC was consistent on both years. Similarly, there was no effect of fertilization rate or an interaction with tillage/fertilizer placement for soybean yield (data not shown). It is important to note, however, that soybeans were planted on the old strip-till location, but no tillage operations were done for the soybean crop. So, we were only able to quantify soybean response to the residual effect of strip-tillage and fertilizer applications.

The buildup of P and K in the soil surface of the NTBC system was substantial, even over a short-time period (Figure 4). While these soils already had some vertical nutrient stratification before the study begun, it is possible that some crop nutrient cycling from deeper soil layers to the surface may have contributed to the stratification observed for the unfertilized treatment. Nonetheless, the effect of broadcast applications is evident when contrasting soil test levels of the fertilized treatments to the unfertilized treatment. This vertical stratification with higher concentrations in the soil surface and sharp decline with increasing soil depth can create some problems when trying to correctly determine soil fertility if the sampling depth is not appropriate. Table 1 shows the effect of sampling depth on the test values for the field represented in Figure 4. Illinois P and K fertilizer recommendations were developed based on a 7-inch sample depth. In a nutrient stratified field, collecting deeper samples will bias the results towards lower test values, while collecting shallower samples will bias the results towards higher test values. Based on a buildup and maintenance approach to fertilization, values from a deep sample will result in higher fertilization rates while shallow samples will result in lower fertilization rates. Inaccurate information from deep samples may not result in yield reduction, but can result in over-fertilization or lower return on fertilizer investment, especially in leased farmland. Inaccurate information from shallow samples can result in yield reduction if actual test values are below the critical level needed to maximize yield, but results indicate no need for fertilization or application of a low fertilizer rate. In the example in Table 1, the 7-inch depth sample for the 115 rate shows values, for all practical purposes, at the critical level of 40 lb P $acre^{-1}$ and 300 lb K $acre^{-1}$ needed to maximize yield (Fernández and Hoeft, 2009). Shallow samples would give the false impression that test levels are above the critical level, within the maintenance range of the recommendations (Fernández and Hoeft, 2009).

Relatively speaking, accurately determining fertility levels of fields with vertical nutrient stratification is simple if caution is exercised to maintain the correct sampling depth. A much more complicated issue arises when P and K fertilizers are banded, especially in conservation tillage systems or where the fertilizer band is applied in the same location from year to year. Under such systems, in addition to uneven distribution of P and K levels with soil depth, alternating horizontal patterns of high and low fertility develops across the field and makes it difficult to determine whole-field fertility by traditional sampling strategies. This is true even if the location of the fertilizer band is known. Figure 5 for P, and Figure 6 for K, show the change in soil test levels that occurred between 2007 and 2010 for different soil depths and sampling positions with respect to the planting-row for the different tillage/fertilizer placement systems and selected fertilizer rates. When no P or K were applied, both P and K soil test levels decline on the surface layer across all sampling positions and for all tillage/fertilizer placement treatments (Figures 5 and 6). With the maintenance application rate, soil P levels remained unchanged for the broadcast treatments (NTBC and STBC), but there was a substantial increase at the location of the sub-surface band for STDB (Figure 5). Outside of the fertilizer band, soil P levels for STDB decreased similarly to the unfertilized treatment. This would indicate that nutrient uptake occurs to a greater extent on the soil surface regardless of where nutrients are placed. For K, the maintenance application rate showed similar results to the unfertilized treatment, except for STDB where soil K levels increased in response to the fertilizer band (Figure 6). When fertilizer rates were increased above a maintenance application, the P level at the soil surface increased for the broadcast treatments and changes in test levels for STDB were similar as with the maintenance rate (Figure 5). We also observed some downward movement of P below the application band. For K, the high fertilizer rate resulted in no change in soil K levels away from the planting-row and increased K levels at the 0 to 4 inch depth at the planting-row for the broadcast treatments (Figure 6). The STDB treatment showed similar results as those observed for the maintenance rate, and as with the highest P rate, some downward movement of fertilizer below the application band. The increase in soil K levels at the planting-row for the broadcast treatments with the highest K fertilizer rate (and similar trends with the maintenance rate) are most likely the result of K leaching out of standing crops between the time of physiological maturity and harvest. This occurs for K and not P because K is easily leachable from plant materials as this nutrient remains as K^+ ion in the plant, whereas P becomes part of organic compounds that need to be decomposed before P can be released back to the soil.

We determined that since soil test levels for NTBC were uniform across the field (Figures 5 and 6), combining all sampling positions with respect to the planting-row in this system would provide a “True” value of soil fertility. This “True” value could then be compared against various ratios of samples taken in the planting-row (IR) to between the planting-rows (BR) for the STBC and STDB systems (Table 2). Soil sampling the STBC field was in essence the same as sampling the NTBC field and made little difference where samples were taken with respect to the planting-row. The only time fertility levels were different than the “True” value was when samples were collected only from the IR position. As we showed in Figure 6, this is likely because K accumulated in that location as K leaches out of standing crops. For STDB, the best sampling strategy was to take 2 or 3 cores outside the fertilizer band for each core collected from the fertilizer band. Also, a sampling ratio as low as 1:1 IR:BR was adequate if small P and K fertilization rates were used. This would indicate no need to be concerned about how to collect a soil sample when a starter fertilizer is used. A 1:1 or 1:0 IR:BR ratio would produce biased results towards higher test values than the “True” value, whereas avoiding the fertilizer band altogether and sampling only outside the area of the fertilizer band would bias the results towards lower values than the “True” value. Similarly, a shallow sample that “misses” the fertilizer band would produce similar results. The “True” test levels for the 92 lb acre^{-1} P-K fertilizer rate were unexpectedly low for NTBC. We do not have an explanation for these results. Thus, some of the differences or lack of differences observed in Table 2 for this fertilizer rate are likely an artifact of these lower-than-expected “True” test values, and should be interpreted with caution. While our experiment was designed to determine how to soil sample when the location of the fertilizer band is known, it is likely that a similar approach, in which samples are collected perpendicular to the direction of the planting-row at a uniform space increments to represent the soil between two crop-rows should be an adequate approach.

SUMMARY

Strip-till provided yield benefits for corn compared with no-till. However, for the strip-till treatments there were no benefits related to fertilizer placement method. No treatment effects were observed for soybean, though soybeans only received the residual effects of treatments as treatments were always applied to the corn crop. Deep banding increased test levels in the subsurface and reduced soil surface concentrations as there was not a direct application of fertilizer on the soil surface and the crop mined nutrients out of that layer. This study showed that sampling location is an important consideration when the band of fertilizer and the planting row are maintained at the same location across years. Deep banding the fertilizer resulted in high soil P and K at IR and lower concentrations at BR. Downward movement of P and K below the fertilizer band occurred at the highest fertilizer rate. Actual soil test levels can be underestimated if a shallow sampling “misses” the fertilizer band or the location of the band (for P and K) or the planting-row (for K) is not taken into account during sampling. On the other hand, collecting samples always from the location of the fertilizer band would result in overestimation of soil P and K test levels. This can be a serious mistake when the overestimation leads to yield-limiting conditions. In fields where the fertilizer band and planting row maintained constant, a ratio of 1:3 IR to BR sampling procedure should be adequate to estimate soil fertility across a wide range of P and K fertilizer rates and soil test levels.

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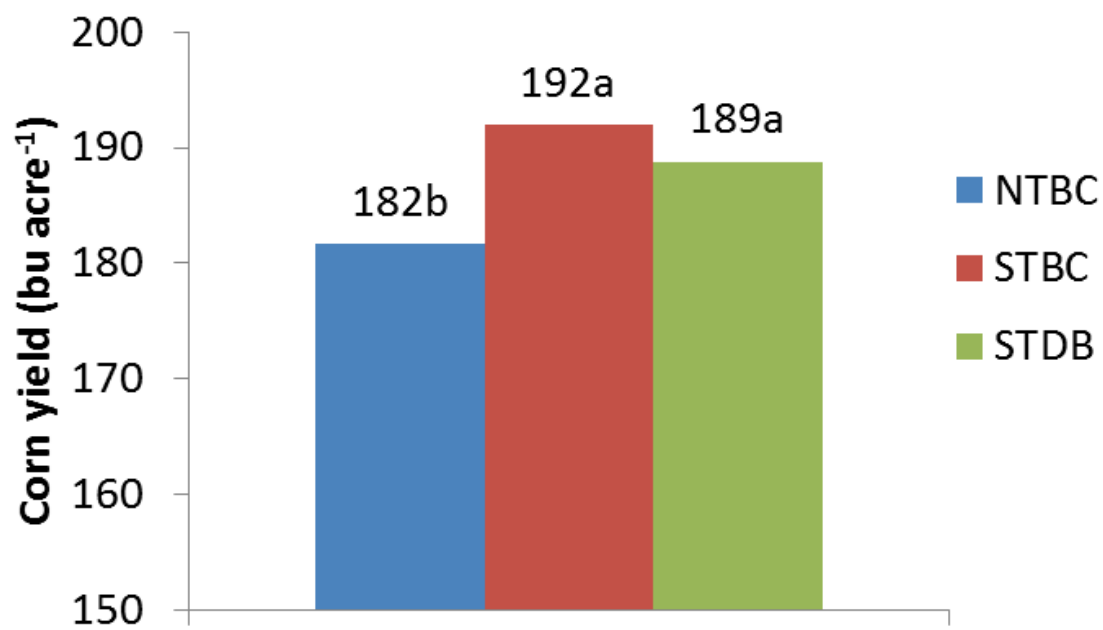

Figure 1. Two-year (2008, 2010) mean corn seed yield as affected by tillage/fertilizer placement treatment [no-till/broadcast (NTBC), strip-till/broadcast (STBC), and strip-till/deep-band (STDB) tillage/fertilizer]. Values followed by same letter are not significantly different (*P*>0.1).

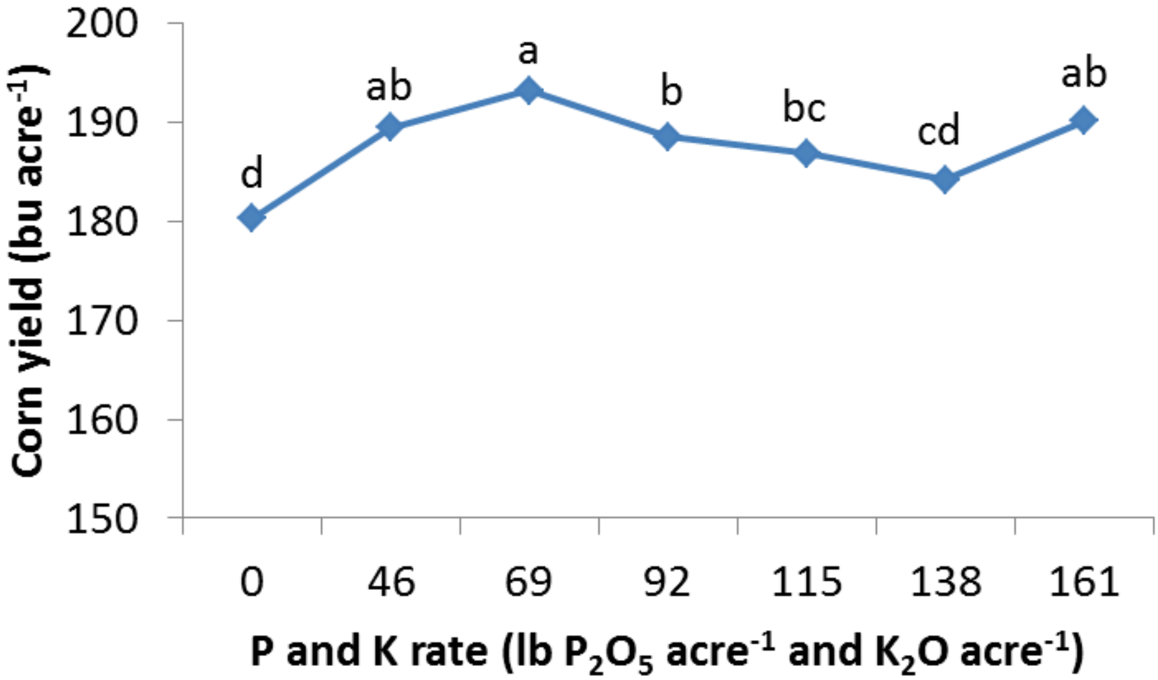

Figure 2. Two-year (2008, 2010) mean corn seed yield as affected by fertilization rate. Same letters indicate no significant difference (P>0.1).

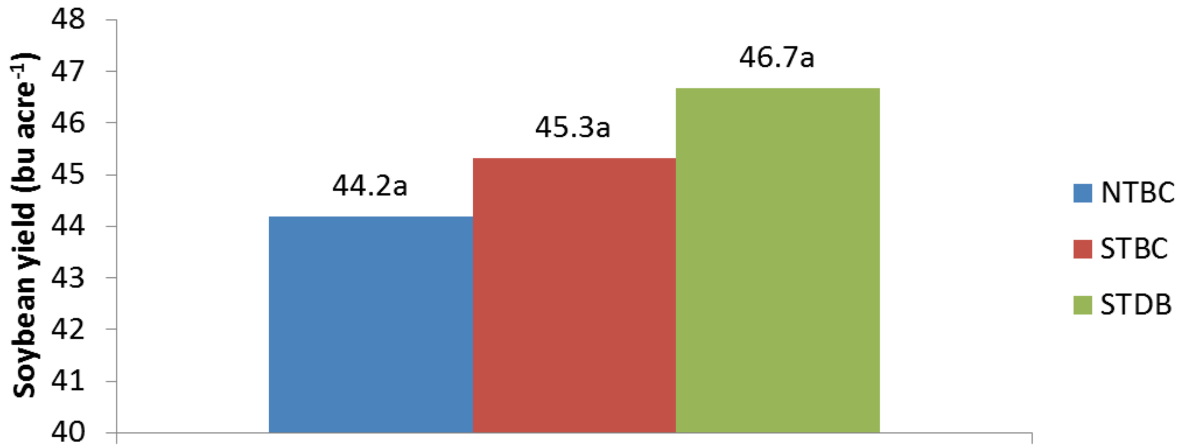

Figure 3. Two-year (2009, 2011) mean soybean seed yield as affected by tillage/fertilizer placement treatment [no-till/broadcast (NTBC), strip-till/broadcast (STBC), and strip-till/deep-band (STDB) tillage/fertilizer]. Values followed by same letter are not significantly different (*P*>0.1).

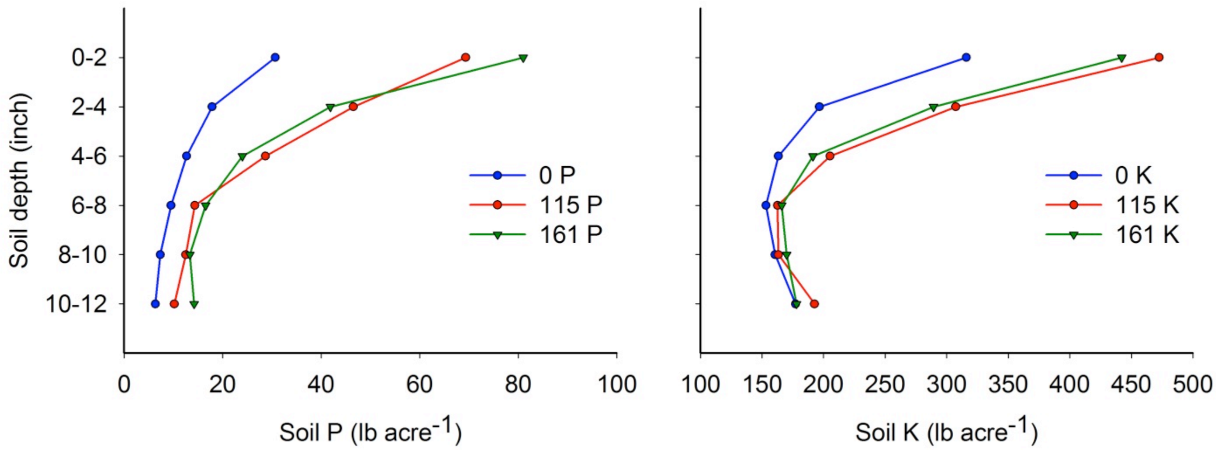

Figure 4. Soil P and K test levels as affected by soil depth for the no-till broadcast (NTBC) system at the end of two crop rotation cycles and two applications of 0, 115, and 161 lb acre^{-1} of P_2O_5 and K_2O.

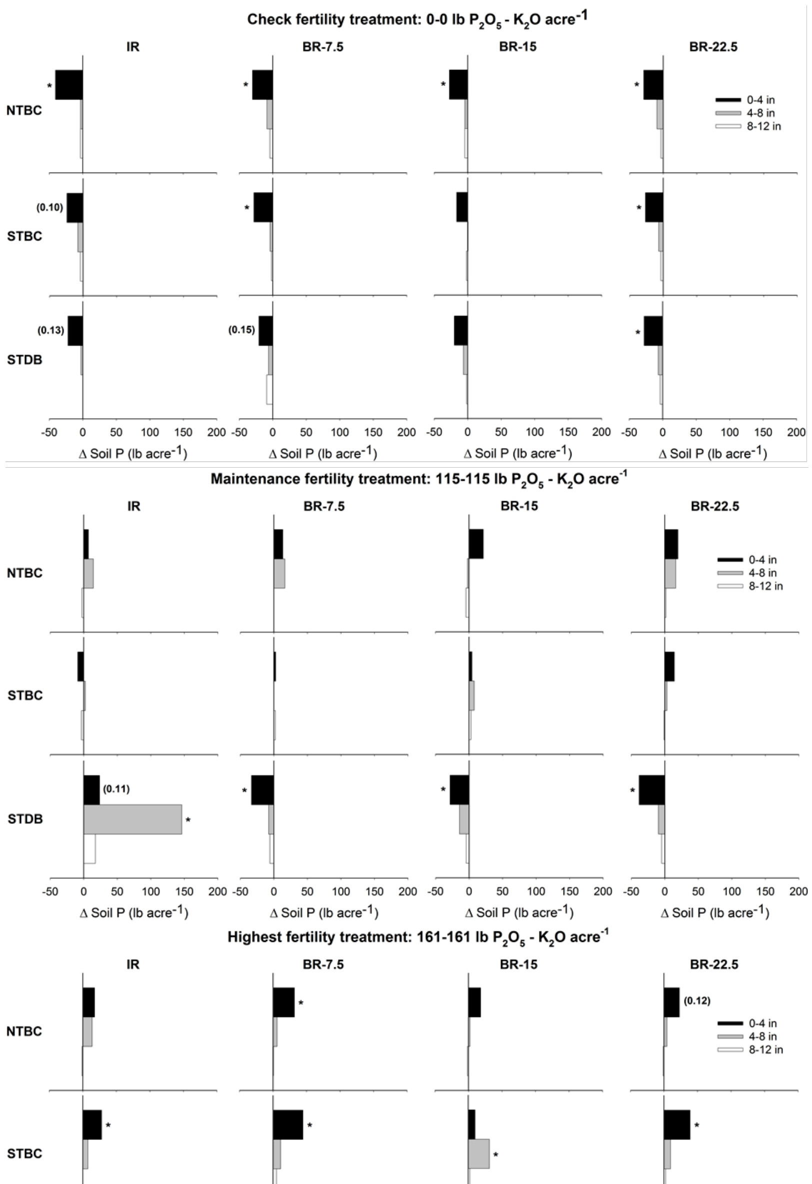

Figure 5. Change in mean soil P test level from pre-treatment levels in 2007 to fall 2010 at various soil depth increments for different positions with respect to the planting-row [in the planting-row (IR) and between the planting-rows (BR) 7.5-, 15-, and 22.5-in from the IR] for no-till/broadcast (NTBC), strip-till/broadcast (STBC), and strip-till/deep-band (STDB) tillage/fertilizer placement treatments and three fertilizer rates. * Indicate significant differences at P <0.1; actual probability indicated between parenthesis for $0.15 \geq P \geq 0.1$.

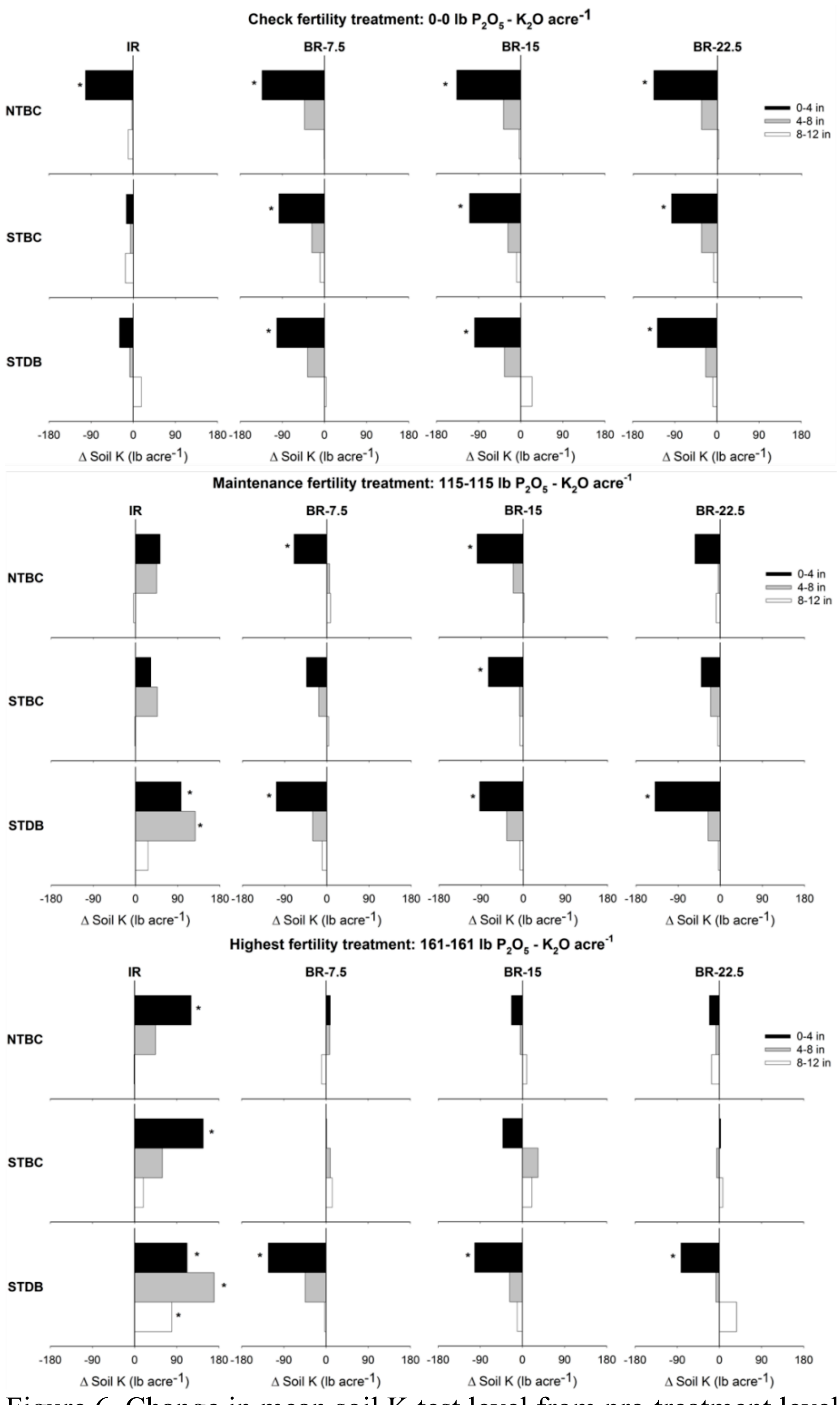

Figure 6. Change in mean soil K test level from pre-treatment levels in 2007 to fall 2010 at various soil depth increments for different positions with respect to the planting-row [in the planting-row (IR) and between the planting-rows (BR) 7.5-, 15-, and 22.5-in from the IR] for no-till/broadcast (NTBC), strip-till/broadcast (STBC), and strip-till/deep-band (STDB) tillage/fertilizer placement treatments and three fertilizer rates. * Indicate significant differences at *P* <0.1.

Table 1. Impact of sampling depth on soil test values (weighted averages) as calculated from data presented in Figure 4, assuming test values were constant for the 2-inch depth increments actually measured.

Sampling depth	Fertilizer rate treatment (lb P_2O_5 acre^{-1}) 0	115	161	Fertilizer rate treatment (lb K_2O acre^{-1}) 0	115	161
inch	—Soil P test level (lb acre^{-1})—			—Soil K test level (lb acre^{-1})—		
2	31	69	81	316	473	442
3	26	62	68	276	418	391
4	24	58	61	256	390	366
5	22	52	54	238	353	331
6	20	48	49	225	328	308
7†	**19**	**43**	**44**	**215**	**305**	**287**
8	18	40	41	207	287	272
9	17	37	38	202	273	261
10	16	34	35	198	262	252
11	15	32	33	196	256	245
12	14	30	32	195	251	239

† Illinois fertilizer recommendations are based on a 7-inch depth sample.

Table 2. Calculated mean soil P and K test level in fall 2010 for the top 8-inches of soil for different P and K fertilizer rates with various ratios of samples collected in the planting-row (IR) to between the planting-rows (BR) for strip-till broadcast (STBC) and strip-till deep-band (STDB) compared to the "True" mean calculated for no-till broadcast (NTBC).

P&K rate	NTBC "True" mean	STBC					STDB				
	1:3	1:3	1:2	1:1	1:0	0:3	1:3	1:2	1:1	1:0	0:3
lb acre^{-1}	lb P acre^{-1}										
0	23	35	34	33	29	37	24	24	23	21	25
46	41	39	38	38	36	39	30	33	38	52	23*
69	39	42	41	39	32	45	39	42	49	70*	28*
92	32	44	43	41	35	46	49*	58*	74*	125*	24
115	51	48	48	46	41	51	50	59	76*	128*	24*
138	47	60	59	56	47	65	51	60	77*	133*	25*
161	52	66	65	64	61	67	45	53	67	111*	23*
	lb K acre^{-1}										
0	256	250	254	262	287	237	239	243	249	269	230*
46	279	264	271	285	327*	243	262	271	288	340*	236*
69	285	295	304	322*	374*	269	276	286	306	366*	246*
92	270	271	276	285	314*	257	297*	309*	335*	411*	259
115	302	293	300	313	353*	273	292	306	335*	422*	249*
138	315	301	309	325	375*	276	323	343*	382*	498*	265*
161	310	322	329	344	385*	298	306	323	357*	460*	254*

* Significant at *P* <0.1.