Wheat and Double-crop Soybean Yield Response to Phosphorus and Potassium Fertilization

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soft red winter wheat (*Triticum aestivum* L.) is grown in rotation with soybean [*Glycine max* (L.) Merr.] and grain crops in Arkansas. Farmers often examine crop and production input prices when deciding whether to grow wheat and follow with double-crop or full-season soybeans. The most recent statistics including double-crop soybean production show 610,000 to 750,000 acres were harvested in 2007 and 2008, respectively, with average yields of 33 to 34 bu/acre (USDA-NASS, 2008). Double-crop soybeans once accounted for about 22% of the Arkansas soybean acres and 75% to 87% of the harvested wheat acres.

The influence that wheat production has on the phosphorus (P) and potassium (K) nutritional requirements and yield potential of the following soybean crop are of interest since fertilizer costs and yield potential are important components of crop profitability. Our primary objectives were to determine wheat grain yield response to P and K fertilization rate, evaluate how nutrient uptake and removal of wheat grown for grain influences soybean response to P and K fertilization, evaluate soybean response to fall and spring fertilizer application, and compare soil-test P and K values from samples collected at three different times.

PROCEDURES

In fall 2011, trials were established at the Lon Mann Cotton Research Station (LMCRS) on a Convent silt loam and the Pine Tree Research Station (PTRS) on a Calloway silt loam both following soybean. Each site had two adjacent plot areas designated for the P or K trial. Each experiment contained three factors including fertilizer rate (0, 50, 100, and 150 lb K_2O/acre or 0, 40, 80, and 120 lb P_2O_5/acre), P and K application time (fall, before planting wheat; or spring, after wheat harvest) and wheat management (cover crop or grain). Wheat that was grown as a cover crop received no N fertilizer and was killed with glyphosate, applied with a rolling applicator, at Feekes stage 7.0 on 19 March 2012. Each trial contained 16 treatments arranged as a randomized complete block (RCB) design with a 4 (rate) by 2 (time) by 2 (wheat) factorial arrangement in each of five blocks.

Two composite soil samples (0- to 4-in. depth) were taken in each block from the plots designated to receive no fertilizer with different wheat management practices (cover crop or wheat for grain) to determine mean soil chemical properties. Soil samples were collected from these plots in the fall within one week of the wheat planting date, late February, and late May, following wheat harvest. For the May sampling, composite samples were also collected from two additional plots in each block which included plots that received 80 lb P_2O_5 or 100 lb K_2O/acre from each of the wheat management treatments. Soil was oven-dried at 130 °F, crushed, and passed through a 2-mm sieve for measurement of Mehlich-3 extractable nutrients, organic matter by weight loss on ignition, and soil water pH. Mean values of selected soil chemical properties are listed in Table 1.

AgriPro Coker 9553 wheat was drill-seeded (100 to 120 lb seed/acre) into conventionally tilled beds spaced 38 in. apart on 21 October at the LMCRS. Armor Ricochet wheat was drill-seeded (100 to 120 lb seed/acre) into a conventionally tilled seed bed on 25 October at the PTRS. Individual plots were 20 ft long and 13 ft wide at the PTRS and 22 ft long by 12.7 ft wide at LMCRS with 7.5- and 7.0-in. wide rows, respectively.

Fertilizer treatments were broadcast by hand to the soil surface of each plot within one week after planting wheat for the fall application and on 22 May at LMCRS and 5 June at the PTRS for the spring application following wheat harvest at each site. Each P rate trial included the rates of 0, 40, 80, and 120 lb P_2O_5/acre applied as triple superphosphate. Potassium fertilizer (100 lb muriate of potash/acre) was broadcast-applied to P trials on the same date as fall and spring treatments were applied to ensure that K was not yield limiting. A total of 140 lb N/acre was applied as urea in two equal splits made on 27 February and 19 March. At maturity, grain yields were measured by harvesting all 16 rows of each plot with a small-plot combine at PTRS and 8 rows at LMCRS. Grain yields were adjusted to a uniform moisture content of 13%.

Soil-test data were subjected to two analysis of variance (ANOVA) procedures. First, data collected at three different times from plots receiving no fertilizer and subjected to different wheat stand management practices (cover or grain) were analyzed as a RCB with a split-plot structure where sample time was the subplot. The objective of this analysis was to determine how wheat management influenced soil-test parameters across time. The second ANOVA was to evaluate how wheat management and nutrient rate influenced soil-test parameters from samples collected in May 2012.

Wheat yield data was analyzed as a RCB design of four nutrient rates with each trial having five blocks. Wheat growing in plots that were to receive P or K fertilizer after wheat harvest were considered as extra observations (n = 20) of 0 lb P_2O_5 or K_2O/acre. Thus, mean yields were based on either five (50, 100, and 150 lb K_2O or 40, 80, or 120 lb P_2O_5/acre) or 25 (0 lb P_2O_5 or K_2O/acre) observations. All ANOVA were performed with the Mixed procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

Soybean was seeded in 15- or 38-in. wide rows on 31 May at LMCRS (Armor 55-R22) and 5 June at the PTRS (Armor 48-R40), respectively, into untilled seedbeds following wheat harvest. At LMCRS, the field was irrigated following wheat harvest to soften the beds and enhance soil conditions for obtaining a uniform stand on top of the beds. At PTRS, the research areas laid fallow waiting for rain to improve seedbed conditions. The post-wheat harvest P and K fertilizer applications were made following wheat harvest and soil sample collection as described previously. Soybean at the PTRS had to be replanted as the rainfall received before planting was not sufficient for uniform emergence. The existing soybean stand was killed and Pioneer 94Y46 soybean was replanted on 26 June. Soybean was irrigated and treated for pests as needed during the season.

Recently matured trifoliate leaf samples were collected (12 to 15/plot) at the R2 stage, dried, ground, digested, and analyzed for nutrient concentrations. Tissue analysis has not yet been completed and will not be summarized in this report. The treatment structure of the soybean trials was a split-split plot where nutrient rate was the whole plot, fertilizer application time was the subplot, and wheat management was the sub-subplot. Soybean receiving no P or K fertilizer (control) was not included in the ANOVA, which was performed by site using the same procedures and interpretation parameters as described for soil and wheat. Single-degree-of-freedom contrasts were used to compare the yield of soybean receiving no fertilizer against yields produced by the two highest fertilizer rates to assess whether P or K fertilization had any overall benefit to yield ($P < 0.10$).

P Source Trial

One additional wheat experiment was established on a Calloway silt loam following soybean at the PTRS to examine wheat yield response to different P fertilizer sources. A composite soil sample was collected from the 0- to 4-in. depth from each replicate within one week of planting (Table 1). Ricochet wheat was drilled seeded on 2 November and managed (in regard to K and N fertilizer) as described for the PTRS wheat double-crop soybean trial.

The fertilizer treatments consisted of four P fertilizer sources including monoammonium phosphate (MAP, 11-52-0), MicroEssentials (MESZ, 12-40-0-10S-1Zn), triple superphosphate (TSP, 0-46-0), and preplant N with each P source applied at rates of 35, 70, and 105 lb P_2O_5/acre. The preplant N treatment was three rates of ammonium sulfate applied at N rates that equaled the amount of N applied as each rate of MAP. Each block also contained three no P and N controls. All P fertilizers were applied to the soil surface on 2 December following wheat emergence. Harvest and ANOVA were performed as described previously.

RESULTS AND DISCUSSION

Site Descriptions

The soil-test P level associated with the average Mehlich-3 extractable P at each site was classified as 'Low' (16 to 25 ppm) at the PTRS-P and 'Medium' (26 to 35 ppm) at LMCRS-P (Table 1). Based on the University of Arkansas Cooperative Extension Service fertilizer guidelines for winter wheat, 60 and 50 lb P_2O_5/acre would have been recommended for the Low and Medium soil-test P levels with little or no yield increase expected at LMCRS-P. Soil-test P in the wheat P source trial was interpreted as Low.

For the K trials, both sites had 'Medium' (91 to 130 ppm K) soil-test K levels and 60 lb K_2O/acre would have been recommended for wheat. A limited amount of previous research has shown little or no yield increase from K fertilization of wheat grown on soils having Medium K availability, but soybean grown following wheat is usually responsive to K fertilization.

Soil Responses to Fertilization Time, Rate, or Wheat Management

Soil-test P and K values of soil receiving no P or K fertilizer changed among sample times (*P*-value < 0.05), averaged across wheat management systems at both sites (Table 2). However, there was no difference in soil-test P between wheat management systems (*P*-value ranged from 0.3827 to 0.9651). The soil sample time by wheat management interaction was significant only for K at the LMCRS (Table 2). In general, soil samples collected in October 2011 and March 2012 had similar soil-test P that was greater than samples collected in May 2012 following wheat harvest, regardless of wheat management. At the PTRS, soil-test K declined with each sample time. At the LMCRS, soil-test K varied among sample times and wheat management systems with the general trend to decline as sample time was delayed. At the LMCRS, soil-test K values were comparable between wheat management systems except following wheat harvest when soil-test K was lowest in soil where wheat was harvested for grain.

Soil-test P and K values from samples collected following wheat harvest were always affected by the fall-applied P and K fertilizer rate ($P < 0.05$), but the wheat management by fertilizer rate interaction was significant only for soil-test K at the LMCRS (Table 3). The interaction showed that soil-test K was lower in soil where wheat was harvested for grain and that fall-applied K fertilizer increased soil-test K with the magnitude of the differences changing between K rates. In all other cases, soil-test P or K, changed in response to fertilization, but not wheat management. Although not statistically significant, soil-test K at the PTRS showed a similar trend as the LMCRS. The results suggest that the Mehlich-3 soil-test method is sensitive enough to detect labile soil nutrients that are removed via winter wheat uptake and a portion of the nutrients added in fertilizer, but soil-test values may fluctuate by 4 or 5 ppm for P and 15 to 50 ppm for K compared with samples collected in the fall.

Wheat Yield Response to Fertilization

Wheat grain yields were not significantly affected by P or K fertilization in these trials (Table 4). This is not overly surprising for K since soil-test K was classified as 'Medium' at each site (Table 1). The most up-to-date correlation between relative wheat grain yield and soil-test P suggests that the critical soil test is 35 ppm P and soil-test values of 18 and 28 ppm would produce relative yields of 87% and 92% (± 3.5% standard error) of maximum (maximum = 95%), respectively. Thus, the expected yield increase from P fertilization was expected to be less than 10%. Prior research has shown that wheat following soybean is less responsive to P than when wheat follows rice or another grain crop that may produce large amounts of residue that might immobilize soil P.

Wheat Yield Response to P Source and Rate

Wheat yield was not affected by P_2O_5 rate (P = 0.1959) or the source by rate interaction (P = 0.7974), but the main effect of P source was significant (P = 0.0535, not shown). Wheat receiving no P or N in the fall produced the lowest yield (94 bu/acre, LSD0.10 = 5 bu/acre) and was not different from the yields of TSP (96 bu/acre) and MAP (99 bu/acre). Wheat fertilized with MESZ (104 bu/acre) and preplant N (102 bu/acre) produced the greatest yields suggesting that the extra N added had a greater effect on yield than P. The P rate yield means support this conclusion since yields tended to increase as P rate, and hence N rate, increased.

Soybean Yield Response to Fertilization

The yield of double-crop soybeans at the LMCRS was significantly affected by significant 2-way interactions involving K fertilization time × rate and fertilization time × wheat management (Table 5). In general, soybean yields were numerically lowest when no K was applied and numerically greatest when 100 or 150 lb K_2O/acre was applied. The wheat management × fertilizer application time interaction showed that soybean following wheat grown as a cover crop tended to produce greater numerical yields than soybean following wheat grown for grain. The only significant difference among soybean yields in this interaction was that K fertilizer applied in the fall to grow wheat as a cover crop produced a greater soybean yield than the other three treatment combinations. Overall, application of 50 to 150 lb K_2O/acre resulted in a 4 bu/acre soybean yield increase at the LMCRS-K site.

Only wheat management had a significant influence on soybean yield at the PTRS (Table 6). In both trials soybean yields were greater, albeit by 2 bu/acre, when soybean followed wheat grown as a cover crop. Single-degree-of-freedom contrasts showed that K fertilization (yield average of 100 and 150 lb K_2O/acre) increased the yield of soybean receiving no K fertilizer by an average of 3 bu/acre.

In both P trials, only wheat management significantly affected the yield of the double-crop soybean (Table 6). Soybean yields, averaged across P rates and application times, were greatest following wheat grown as a cover crop and lowest following wheat harvested for grain. This was the opposite of what was found at both sites in the first year of research. The lack of soybean yield response to P fertilization is not surprising since our previous research has shown limited yield benefits from P fertilizer. The correlation relationship suggests that the critical soil-test P is 20 ppm (not shown). Phosphorus fertilization rate, averaged across application times and wheat management systems, had no significant effect on soybean yield.

PRACTICAL APPLICATIONS

Wheat and double-crop soybean yields were not affected by P fertilization in these trials. Wheat yields were also unaffected by K fertilization. Soybean yields were increased significantly or numerically depending on the site-year only by K fertilization. The results indicate that double-crop soybean yield is not greatly affected by fertilizer application time, but can be influenced by land management (winter fallow/cover crop or wheat for grain). Soil-test P and K values changed from the fall to early summer in response to soil sample time (temporal variation), wheat management, and/or fertilization rate. The significant temporal changes in soil-test values make development of accurate fertilizer recommendations more challenging. The temporal changes tend to be more dramatic for K than for P.

Wheat management system has consistently influenced soybean yields for the two years that we have conducted this trial. Each year the system that has produced the greatest yield has been different and may reflect differences in annual weather and field conditions. That said, the soybean yield difference has been relatively small each year. The main purpose of the trial was to characterize whether growing and harvesting wheat for grain production (compared to as a cover crop) influenced how much P or K fertilizer is needed. Our results suggest that double-crop and full-season (planted at same time) soybean seldom respond to P fertilization. The wheat-soybean production system has not changed how soybean yields respond to K fertilizer suggesting that K fertilizer rates for full-season soybean should also be optimal for double-crop soybean.

LITERATURE CITED

(USDA-NASS) United States Department of Agriculture, National Agricultural Statistics Service. 2008. Arkansas Crop Statistics - County estimates by year (On-line). Available at http://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/County_Estimates/index.asp. Washington, DC.

Table 1. Selected soil chemical property means (*n* = 10) from soil samples collected in October 2011 in P and K fertilization trials with winter wheat and double-cropped soybean conducted at the Lon Mann Cotton Research Station (LMCRS) and the Pine Tree Research Station (PTRS) during the 2011-2012 growing season.

		Soil	Mehlich-3 extractable soil nutrients									
Site	SOM	pH	P†	K†	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
	(%)		(ppm)									
LMCRS-P*	1.78	5.8	28	121	750	132	12	9	168	155	1.1	1.9
PTRS-P	2.36	7.3	18	111	1431	236	19	45	168	382	1.1	1.4
PTRS-PS	3.15	7.6	22	93	1832	276	12	22	350	532	2.2	1.7
LMCRS-K	1.65	5.7	28	114	814	156	12	10	158	138	1.2	1.4
PTRS-K	2.46	7.5	15	118	1498	251	20	43	154	433	1.1	1.3

* P = phosphorus; K = potassium; and PS = phosphorus source.

† Standard deviation of soil-test P in P trials was 4.2 ppm for LMCRS-P, 2.5 ppm for PTRS-P, and 1.0 ppm for PTRS-PS and soil-test K in K trials was 7.5 ppm for LMCRS-K and 21 ppm for PTRS-K.

Table 2. Soil-test P and K means (for soil receiving no fertilizer) as affected by soil sample time, wheat management, or their interaction at the Pine Tree Experiment Station (PTRS) and Lon Mann Cotton Research Station (LMCRS) during 2011-2012. Soil-test P data is from the P trials and soil-test K data is from the K trials.

	Soil	Wheat management*			
Site	sample time	Cover crop	Grain	Cover crop	Grain
		(ppm P)		(ppm K)	
PTRS	October 2010	18	18	116	120
	March 2012	18	18	99	97
	May 2012	15	14	78	73
	P-value	0.1717		0.7703	
LMCRS	October 2011	28	29	111 Aa	116 Aa
	March 2012	27	28	100 Ab	101 Ab
	May 2012	25	26	96 Ab	85 Bc
	P-value	0.9936		0.0119	

* For data with a significant 2-way interaction, the lowercase letters compare any two means and uppercase letters compare means between wheat management systems within each sample time. Only the main effect of soil sample time, averaged across wheat management system, was significant for the PTRS and LMCRS soil-test P and PTRS soil-test K.

Table 3. Soil-test P and K means as affected by fertilizer rate and wheat management for soil samples collected in June 2012 at the Lon Mann Cotton Research Station (LMCRS) and Pine Tree Research Station (PTRS). Soil-test P data is from the P trials and soil-test K data is from the K trials.

		Wheat management			
Site	Nutrient rate*	Cover crop	Grain	Cover crop	Grain
	(lb P_2O_5 or K_2O/acre)	---------------(ppm P)---------------		---------------(ppm K†)-------------	
PTRS	0	15	14	78	73
	80 or 100	20	20	126	118
	P-value	----------------0.3559 ---------------		---------------- 0.7837 --------------	
LMCRS	0	25	26	96 b	85 c
	80 or 100	36	33	125 a	103 b
	P-value	----------------0.3559 ---------------		---------------- 0.0744 --------------	

* Phosphorus applied at 80 lb P_2O_5/acre and potassium applied at 100 lb K_2O/acre.
† For data with a significant 2-way interaction, lowercase letters compare any two means.

Table 4. Wheat grain yield as affected by P or K fertilizer rate at the Lon Mann Cotton Research Station (LMCRS) and the Pine Tree Research Station (PTRS) during the 2011-2012 growing season.

	Phosphorus trials			Potassium trials	
Nutrient rate	LMCRS	PTRS	Nutrient rate	LMCRS	PTRS
(lb P_2O_5/acre)	------------ (bu/acre) ----------		(lb K_2O/acre)	------------ (bu/acre)-----------	
0	56	92	0	56	91
40	57	91	50	57	85
80	55	96	100	55	98
120	56	92	150	54	91
LSD0.10	NS*	NS	LSD0.10	NS	NS
P-value	0.8994	0.5331	*P*-value	0.8055	0.1080
C.V., %	7.8	5.5	C.V., %	8.2	8.4
SDF contrast †	0.9669	0.7391	SDF contrast	0.7050	0.9582

* NS = not significant ($P > 0.10$).
† SDF = single-degree-of-freedom contrast comparing the yield wheat fertilized with P (40, 80, and 120 lb P_2O_5/acre) against wheat receiving no P.

Table 5. Double-crop soybean yield as affected by the two-way interactions between K fertilizer rate and K application time, averaged across wheat management, and wheat management and K fertilizer application time, averaged cross K application rate, at the Lon Mann Cotton Research Station (LMCRS) in 2012.

	K rate (lb K_2O/acre)				Wheat management	
Fertilizer time	0	50	100	150	Cover crop	Grain
	--------------------------------(bu/acre)				--------------------------------	
Fall	60 b*	64 ab	65 ab	67 a	67a	61 b
Spring	61 b	65 ab	65 ab	62 b	64 b	63 b
P-value	------------------ 0.0586 ------------------				------------ 0.0536 ------------	

* Means within a column followed by the same lowercase letter are different at the 0.10 level.

Table 6. Double-crop soybean yield as affected by the main effect of wheat management, averaged across nutrient rates and fertilizer application times, in four nutrient trials conducted at the Lon Mann Cotton Research Station (LMCRS) and Pine Tree Research Station (PTRS) in 2012.

	LMCRS		PTRS	
Wheat management	P trial	K trial	P trial	K trial
	------------------------(bu/acre)		------------------------	
Cover crop	71 a*	66 a	53 a	51 a
Grain	67 b	62 b	51 b	49 b
P-value	0.0103	0.0037	<0.0001	0.0043

* Means within a column followed by the same lowercase letter are different at the 0.10 level.