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Grain Sorghum and Soybean Cropping Sequence Affect Yield and Fertilizer N Requirement

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Abstract
In the eastern Great Plains, grain sorghum [*Sorghum bicolor* (L.) Moench] and soybean [*Glycine max* (L.) Merr.] are commonly grown in rotation, but the effects of cropping sequence on yield and fertilizer N management have not been thoroughly evaluated in this region. A 10-year field study was conducted in southeastern Kansas to evaluate the effects of various grain sorghum and soybean cropping sequences on grain yield of both crops, and to determine the influence of two fertilizer nitrogen rates (75 and 135 lb/acre) on grain yield and N concentration of plant and grain for rotated and non-rotated grain sorghum. Cropping sequences were: (i) 1st, 2nd, 3rd, 4th, and 5th year of each crop after 5 years of the other crop; (ii) an annual rotation of each crop; and (iii) continuous monoculture of each crop. Grain yield of both soybean and grain sorghum were highest for the 1st-year crop after five years of the other crop, averaging 33 and 25% more than yield of the respective monoculture crop. Grain yield of both crops declined with increasing years of consecutive planting. Rotated grain sorghum (1st year and annually) yields were increased only 5% or less with greater than 75 lb of N per acre, whereas non-rotated grain sorghum yields averaged 15% greater when N rate was increased to 135 lb/acre. The addition of higher fertilizer N to non-rotated grain sorghum, however, did not compensate for the rotation effect with soybean. Plant and grain N concentrations also were higher for rotated grain sorghum than for monoculture. The results from this long-term study clearly demonstrate the beneficial effect of crop rotation on soybean and grain sorghum yield and also show that the fertilizer N requirement for grain sorghum is reduced significantly when it is rotated with soybean.

Introduction
Crop rotation is an important management practice that has been used for centuries to increase grain yield. Numerous studies, especially in the northern Corn Belt region of the USA, have shown lower corn (*Zea mays* L.) yield when grown continuously (monoculture) than when rotated with soybean (6,11), but uncovering the reasons for these benefits has proven difficult.

Researchers generally have concluded that the crop rotation effect on grain yield is the result of many interacting factors. Studies have shown that crop rotation affects root growth and distribution (12), water use efficiency (3), plant nutrient concentration (4) and plant development (14). Research conducted in Minnesota showed that the yield response of corn and soybean to rotation was not due to beneficial or negative effects of above-ground residue (5). However, based on results from several long-term crop rotation studies conducted both in Colorado and Minnesota, researchers have suggested that corn may leave a soil environment that improves growth and efficiency of some following crops, although this beneficial interaction appears to be crop-specific (1). The rotation effect also has been shown to be greater in a low-yielding environment than in a normal growing season (16).

Crop rotation also influences fertilizer N management. Fertilizer N rates needed to maximize corn yields have been shown to be lower for corn following soybean than for corn following corn (2,17). A credit of 1 lb of N for every bushel of soybean harvested up to a maximum credit of 40 lb of N per acre is commonly used when making fertilizer N recommendations, although research has shown that this value varies significantly with year and location (2). Some producers are hesitant to reduce N rates because crops could become N-deficient in higher yielding growing season environments. In Kansas, the fertilizer N recommendations for corn or grain sorghum following a non-legume crop are based upon yield goal and soil organic matter (OM) content (%) (9).

It is commonly assumed that the difference in N fertilizer requirement between rotated and non-rotated grain sorghum occurs because soybean biologically fix N and leave some of this N for succeeding crops. However, others have suggested that differences in N fertilizer requirement are better explained by differences in amounts of N immobilized during residue decomposition than by mineralization of biologically fixed N associated with the soybean (7). Thus, some researchers have concluded that the main value of soybean residue appears to be long-term maintenance of soil N to ensure adequate delivery to future crops (13).

Although numerous studies have reported on the effects of various corn and soybean cropping sequences on grain yields, few have evaluated the effects of grain sorghum and soybean cropping sequences on grain yields. In the eastern Great Plains, grain sorghum is often grown in rotation with soybean rather than corn because of greater drought tolerance during the critical reproductive stage of growth. In addition, with the rising cost of fertilizer N, as well as environmental concerns from applying excess fertilizer N, the value of using a legume crop, like soybean, in crop rotations needs to be re-affirmed for the growing conditions in this region. Thus, the objectives of this 10-year study were to: (i) evaluate the effects of various grain sorghum and soybean cropping sequences on grain yield of each crop, and (ii) determine the influence of fertilizer N rate on yield and N concentration of both plant leaf and grain of rotated and non-rotated grain sorghum.

Field Study with Grain Sorghum and Soybean Cropping Sequences

Site information. Field studies were conducted from 1992 through 2001 at the Parsons Unit of the Kansas State University Southeast Agricultural Research Center. The soil was a Parsons silt loam (fine, mixed, active, Thermic, Mollic Albaqualf) consisting of a shallow topsoil (<12 inch) overlaying a thick "clay-pan" subsoil. Initial soil chemical characteristics at the 0- to 6-inch depth included a pH (1:1 soil/water) near 7.0, organic matter (OM) of 2.5%, Bray-1 phosphorus of 30 lb/acre, and exchangeable potassium (1 *M* ammonium acetate extract) of 150 lb/acre. Native grass was grown at the site before study establishment.

Cropping systems. Cropping systems consisted of: (i) 5 years of consecutive grain sorghum, followed by 5 years of soybean, arranged so that during each year of the study there occurred a 1st, 2nd, 3rd, 4th, and 5th year of each crop; (ii) an annual rotation of each crop; and (iii) continuous monoculture of each crop. All phases of each cropping system were present each year, making a total of 14 treatments (Table 1). Treatments (20 ft wide by 40 ft long) were arranged in a randomized complete-block design with three replications. The first five years (1992 through 1996) were considered to be study-establishment years.

Table 1. Grain sorghum (GS) and soybean (SB) cropping sequences for 14 treatments from 1992 through 2001, Parsons, KS.

Trt.	Crop sequence by year									
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	SB	GS	GS	GS	GS	GS	SB	SB	SB	SB
2	SB	SB	GS	GS	GS	GS	GS	SB	SB	SB
3	SB	SB	SB	GS	GS	GS	GS	GS	SB	SB
4	SB	SB	SB	SB	GS	GS	GS	GS	GS	SB
5	SB	SB	SB	SB	SB	GS	GS	GS	GS	GS
6	GS	SB	SB	SB	SB	SB	GS	GS	GS	GS
7	GS	GS	SB	SB	SB	SB	SB	GS	GS	GS
8	GS	GS	GS	SB	SB	SB	SB	SB	GS	GS
9	GS	GS	GS	GS	SB	SB	SB	SB	SB	GS
10	GS	GS	GS	GS	GS	SB	SB	SB	SB	SB
11	SB	SB	SB	SB	SB	SB	SB	SB	SB	SB
12	GS	GS	GS	GS	GS	GS	GS	GS	GS	GS
13	GS	SB	GS	SB	GS	SB	GS	SB	GS	SB
14	SB	GS	SB	GS	SB	GS	SB	GS	SB	GS

The first five years (1992 through 1996) were considered to be study-establishment years.
Treatments 1 through 10 were 5-year cycles of consecutive grain sorghum followed by 5 years of soybean.
Treatments 11 and 12 were continuous grain sorghum or continuous soybean.
Treatments 13 and 14 were annual rotations of grain sorghum and soybean.

Fertilizer rates. In early spring of each year, all soybean and grain sorghum plots received N at 15 lb/acre, P_2O_5 at 60 lb/acre, and K_2O at 60 lb/acre, which was broadcast applied and incorporated with primary tillage (chisel plow). Grain sorghum plots also received additional N as urea, which was broadcast applied and incorporated with a field cultivator before planting. From 1992 through 1995, the N rate applied to grain sorghum before planting was 90 lb/acre. Beginning in 1996, each grain sorghum plot (8 rows wide) was split so that two N rates (60 and 120 lb/acre) could be evaluated as subplots (4 rows wide) for each grain sorghum treatment. Thus, the total fertilizer N (early spring + before planting) applied to grain sorghum subplots was either 75 or 135 lb of N per acre. The 75 lb/acre N rate represented the KSU extension recommendation for grain sorghum following soybean with a yield goal of 120 bu/acre and 2.5% OM (115 lb of N per acre with a soybean N credit of 40 lb/acre), whereas the 135 lb/acre N rate was 20 lb/acre more than the recommended level for non-rotated grain sorghum in order to partially compensate for greater immobilization of fertilizer N in a monoculture system where the quantity of crop residues near the soil surface would likely increase with time. Soybean plots did not receive any additional fertilizer N.

Cultural practices. Crops were planted with conventional tillage methods (disk, chisel, disk, and field cultivate) in 30-inch rows at a seeding rate of 60,000 and 120,000 seeds per acre for grain sorghum and soybean, respectively. The grain sorghum hybrid was mid-maturity for the growing region, and the soybean cultivar was maturity group (MG) V. Planting and harvest dates varied according to seasonal conditions. Grain sorghum typically was planted in early May and harvested in mid-September, and soybean was usually planted in early June and harvested in mid-October. Weeds were effectively controlled with preemerege herbicides applied at recommended rates.

Grain harvest. Grain yields of both crops were determined by machine-harvesting the two center rows of each four-row N subplot after end-trimming to 35 ft long. Soybean grain yield did not differ between the grain sorghum subplot N treatments; therefore yields were averaged across the previous years N treatments. Plot grain weights were adjusted to a constant moisture of 12.5% for grain sorghum and 13% for soybean. Soybean seed weights were determined from two random 100-seed samples and adjusted to the same moisture content as grain yields.

Plant, grain, and soil analysis. At grain sorghum heading, plant leaf samples (second leaf from top of plant) were randomly collected from the two center rows of N subplots for each grain sorghum plot. Grain samples also were collected from N subplots of individual grain sorghum plots at harvest. Plant leaf and grain samples were oven-dried, ground (1-mm sieve), and analyzed for N concentration by the KSU Soil and Plant Testing Lab, using recommended procedures for N analysis.

At the conclusion of the study in the fall of 2001, three soil cores (1-inch diameter) at the 0- to 6-inch depth were collected from each of the two N subplots of individual cropping sequence plots and then pooled into one sample. Soil was air-dried before grinding and was analyzed for pH, available P, and exchangeable K by the KSU Soil Testing Lab.

Data analysis. Data were analyzed by year and across years with the MIXED procedure (10) of SAS (SAS Institute Inc., Cary, NC) to evaluate treatment effects. Treatment factors were considered fixed, while REP and YR were treated as random effects. Treatment means were compared by using Fisher's protected LSD (0.05).

Soybean Results

Climatic conditions. Rainfall and average maximum air temperature during the growing season differed yearly over the 5-year period (Table 2), which influenced grain yield responses (Table 3). In 1997, timely rainfall distribution and below-normal air temperatures were favorable for higher-than-normal soybean yields, whereas in 2000 the absence of rainfall in August and above-normal air temperature during the reproductive stage of development resulted in poor yields. In 1998, 1999, and 2001, soybean yields were near average for this growing region of Kansas (38 °N latitude).

Table 2. Monthly rainfall and average monthly maximum air temperature during growing season, Parsons, KS, 1997 through 2001, including 30-year mean.

	1997	1998	1999	2000	2001	30-year
Month	**Rainfall** (inches)					
May	5.30	1.96	6.61	7.26	4.07	5.39
June	7.32	5.41	8.96	9.78	7.13	4.82
July	5.31	5.09	1.02	3.52	1.33	3.83
August	4.39	3.42	0.45	0.00	2.57	3.42
September	5.49	9.02	4.26	2.87	4.08	4.93
October	3.17	7.92	0.88	5.21	4.21	4.04
	Average max. air temperature (°F)					
May	75	81	75	78	79	76
June	83	87	81	82	84	85
July	89	90	92	90	93	91
August	86	89	94	98	94	90
September	81	87	79	88	81	81
October	69	70	72	73	71	71

Table3. Effect of cropping sequence on soybean grain yield, 1997 through 2001, Parsons, KS.

Cropping sequence*	Soybean grain yield (bu/acre)					
	1997	1998	1999	2000	2001	5-yr avg.
1st yr SB	49.7	32.4	30.5	15.1	35.1	32.6
GS / SB	46.1	30.3	28.1	14.0	32.8	30.3
2nd yr SB	42.8	28.8	27.0	13.2	29.3	28.2
3rd yr SB	39.1	27.1	26.5	12.8	28.0	26.7
4th yr SB	37.9	25.7	25.6	12.7	27.4	25.8
5th yr SB	37.0	25.4	25.0	12.1	26.7	25.2
Continuous SB	36.5	25.1	23.6	11.3	25.8	24.5
LSD (0.05)	2.5	1.3	1.6	0.8	2.0	2.0

* Soybean (SB) grown under monoculture (continuous SB) or with grain sorghum (GS) in the following sequences: GS / SB = alternating 2-yr rotation; 1st yr SB = (GS-GS-GS-GS-GS-SB); 2nd yr SB = (...GS-GS-GS-GS-SB-SB); 3rd yr SB = (...GS-GS-GS-SB-SB-SB); 4th yr SB = (...GS-GS-SB-SB-SB-SB); 5th yr SB = (...GS-SB-SB-SB-SB-SB); continuous SB = (SB-SB-SB-SB-SB-SB..., up to 10th yr).

Grain yields. Soybean yields were significantly affected by cropping sequence during each of the final 5 years of the study (Table 3). The magnitude of yield response to cropping sequence varied with year, but the overall trends were consistent across years. Yields were highest each year for 1st-year soybean after five years of grain sorghum, averaging 33% more than yield of continuous (monoculture) soybean. First-year soybean yields were also 8% greater than those of soybean annually rotated with grain sorghum. Soybean yields continued to decline as the frequency of soybean increased in the cropping sequence, but yield differences were not always statistically significant. In 3 of 5 years, yield of 2nd-year soybean was not significantly different from 3rd-year yield. When averaged across years, there was no significant difference in yield between 4th- and 5th-year and continuous soybean. Soybean yield increases from crop rotation may be partially explained by increased seed weight (*data not shown*). Seed weight averaged 7% greater for 1st-year soybean and annually rotated soybean than continuous soybean, although the reason for this increase is unclear without further yield component evaluations.

Grain Sorghum Results

Grain sorghum yield, as well as leaf and grain N concentration, was significantly affected by cropping sequence, N rate, and the interaction of cropping sequence with N rate (Table 4). Year by treatment interactions also occurred but were primarily influenced by the magnitude of responses; thus grain sorghum results were averaged over the 5 years to show overall trends.

Grain yields. Grain yields were highest for 1st-year sorghum after five years of soybean, but not significantly different from annually rotated sorghum (Table 4). Yields of rotated grain sorghum (1st and annually) were increased only 3 to 5 bu/acre when N rate was increased from 75 to 135 lb/acre. Whereas, yields of 2nd-, 3rd-, 4th-, and 5th-year sorghum, as well as continuous sorghum, were increased from 9 to 15 bu/acre when N rate was increased to 135 lb/acre. Similar to soybean responses, grain sorghum yields continued to decline as the frequency of sorghum increased in the cropping sequence.

Table 4. Effect of cropping sequence and N rate (lb of N per acre) on average grain yield, leaf N, and grain N of grain sorghum from 1997 through 2001, Parsons, KS.

Cropping sequence*	Grain yield (bu/acre)		Leaf N (%)		Grain N (%)	
	75 N	135 N	75 N	135 N	75 N	135 N
1st yr GS	101	104	2.68	2.76	1.62	1.77
SB / GS	97	102	2.63	2.72	1.60	1.73
2nd yr GS	88	97	2.48	2.62	1.53	1.67
3rd yr GS	83	94	2.33	2.56	1.50	1.64
4th yr GS	81	93	2.27	2.51	1.47	1.60
5th yr GS	78	92	2.19	2.48	1.45	1.59
Continuous GS	75	90	2.17	2.47	1.43	1.58
(Avg.)	86	96	2.39	2.59	1.51	1.65
LSD (0.05):						
Same CS, different NR	4		0.10		0.06	
Same NR, different CS	5		0.06		0.06	
Different CS and NR	6		0.10		0.07	

* Grain sorghum (GS) grown under monoculture (continuous GS) or with soybean (SB) in the following sequences: SB / GS = alternating 2-yr rotation; 1st yr GS = (SB-SB-SB-SB-SB-GS); 2nd yr GS = (...SB-SB-SB-SB-GS-GS); 3rd yr GS = (...SB-SB-SB-GS-GS-GS); 4th yr GS = (...SB-SB-GS-GS-GS-GS); 5th yr GS = (...SB-GS-GS-GS-GS-GS); continuous GS = (GS-GS-GS-GS-GS-GS..., up to 10th yr).

Current interest in using grain of corn and grain sorghum for ethanol production as well as the threat of soybean rust invasion have caused some producers to consider switching from the traditional 2-year rotational system of soybean and either corn or grain sorghum to a monoculture system of corn or grain sorghum. However, in this study, yield of annually rotated grain sorghum at the low N rate was the same as 2nd-yr grain sorghum at the high N rate, averaging 97 bu/acre. Thus, the cost savings in fertilizer N between rotated and non-rotated sorghum, with a yield goal of 100 bu/acre (N at 115 lb/acre) and a 40 lb/acre N credit, would range from $10 to $15/acre, based upon current fertilizer N prices in this region ($0.24 to $0.35/lb of N, for anhydrous ammonia and urea, respectively).

Our results indicated that increased fertilizer N rates alone did not compensate for reduced yields where the frequency of grain sorghum increased in the cropping system. These results are similar to those reported by Gordon and Whitney (8). In contrast Peterson and Varvel (15) reported that yield differences between continuous and soybean rotated with grain sorghum were minimized or removed with increased N applications.

Leaf and grain N. Both leaf and grain N concentrations of grain sorghum were significantly affected by cropping sequence, N rate, and their interaction (Table 4). Leaf N and grain N were significantly greater for 1st-year grain sorghum and sorghum annually rotated with soybean, compared with the other cropping sequences. Nitrogen concentrations in leaf and grain continued to decline with increasing frequency of grain sorghum in the cropping sequence. Leaf and grain N increased with increasing N rate, although the magnitude of response differed with cropping sequence. Results indicated that grain sorghum yield differences between cropping sequences were influenced by the residual N contribution from the previous soybean crop. But other research has shown that part of the N contribution of soybean to 1st-year corn is realized at the expense of subsequent reductions in soil N availability; because soybean budget studies indicate that N removed in grain may substantially exceed biological fixation (17).

Final Soil Test Results

Final soil analyses at the conclusion of the 10-year study showed that soil pH, available P, and exchangeable K were not significantly different among cropping sequence treatments (data not shown). Soil test results suggest that the yearly rates of P and K fertilizer applied were adequate for the grain yields produced. Thus, grain yield differences between cropping sequences were not due to changes in the macro soil nutrients such as P and K or soil pH.

Discussion and Conclusions

Results clearly show that rotating grain sorghum and soybean will result in yield improvements for both crops compared to non-rotated crops. However, in this 10-yr study, the 2-yr rotation of grain sorghum and soybean did not produce maximum soybean yield, indicating that the time period between soybean crops in the cropping sequence may need to be greater than one year for highest yield potential. The optimum rotational scheme likely would include more than two crops in order to distance the time interval between individual crops, but determining rotational crops and sequencing can be a complex process. Thus, the desire to increase diversity and intensity must be balanced with profitability.

In addition, results re-affirm the value of using a legume crop, such as soybean, in the crop rotation to reduce fertilizer N cost. Yield of grain sorghum when rotated with soybean averaged nearly 100 bu/acre, although yield was increased only 5% or less with greater than 75 lb of N per acre. Whereas, non-rotated grain sorghum that received 135 lb of N per acre yielded less than rotated sorghum at the lower N rate. Plant and grain N analyses of grain sorghum indicated that yield differences between cropping sequences were influenced by the residual N contribution from the previous soybean crop. Results from this study show that grain sorghum producers in the eastern Great Plains region can reduce fertilizer N rate by as much as 40 lb of N per acre when sorghum follows soybean and still maintain optimum yield potential, which is an important consideration with the rising cost of fertilizer N.

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