Evaluation of the Residual Benefits of Boron Fertilization on Soybean and Rice

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Boron deficiency of soybean [*Glycine max* (Merr.) L.] has become a common problem in northeast Arkansas. Research has demonstrated that 0.25 to 1.0 lb B/acre can significantly increase soybean seed yields on alkaline silt loam soils. In contrast, rice (*Oryza sativa* L.) grown in northeast Arkansas has not shown consistent positive or negative yield responses to direct applications of B fertilizer. Some growers have questioned whether B toxicity, especially of rice, could become a problem after years of B fertilization to the soils that are now considered B-deficient for soybean production. Because the soybean-rice rotation is common only in the mid-South rice-producing region of the USA, previous research has not addressed whether a single application of B fertilizer provides residual benefits or increases the risk of B toxicity in subsequent crops such as rice. The objectives of this study were to evaluate i) the immediate and residual influence of a single B application on soybean tissue-B concentration and yield; ii) how B rate applied the previous year influences rice growth, tissue-B concentration, and yield; and iii) the influence of B rate on Mehlich-3-extractable B in the surface and subsoil during a two or three-year period.

PROCEDURES

Experiments were established on a Dewitt silt loam at the Rice Research Extension Center (RREC) near Stuttgart, Ark., and on a Calhoun silt loam at the Pine Tree Branch Station (PTBS) near Colt, Ark., in 2002. Boron deficiency of soybean had not been documented at either site. Research sites were flagged and six B rates (0, 1, 2, 4, 6, and 8 lb B/acre) were randomly assigned to each plot (13-ft wide by 20-ft long). At each site, plot boundaries were maintained from 2002 through 2004. In 2002 (May), a composite soil sample (0- to 6-inch depth) was taken from each plot to determine the initial soil chemical and physical properties. Soil samples were also collected to a depth of 24 inches and divided into 6-inch depth increments to evaluate subsoil chemical properties from each plot designated as an unfertilized control. Composite soil samples were also collected from each plot in 2003 (0- to 6-inch depth samples collected in April) and 2004 (0- to 4-inch depth samples collected in March). Subsoil samples were also taken a second time in 2003 (April) from plots that received 0, 2, 4, and 6 lb B/acre as described previously. Each year, soil was dried in a forced-draft oven at 55°C, crushed, and stored in the sample boxes until processing. Soil-water pH, and Mehlich-3-extractable (1:10 extraction ratio) nutrients, including B, were determined on each sample. Mean values of selected soil chemical properties are listed for each site, year, and depth in Table 1.

Boron fertilizer (0, 1, 2, 4, 6, and 8 lb/acre) was applied to the tilled soil surface in May 2002 as a dry granular fertilizer (Granubor, 15% B) at the RREC and sprayed as a solution (Solubor, 17.5% B) at the PTBS. No additional B was applied to these plots for the duration of the study. Triple superphosphate (100 lb/acre) and muriate of potash (150 lb/acre) fertilizers were broadcast to each site each year. Nitrogen fertilizer (120 lb N/acre as urea) was applied preflood to rice grown at each site in 2003. The RREC site received about 3 tons $CaCO_3$ lime/acre in early March 2002 to increase surface soil pH.

In 2002, soybean ('Caviness' *cv.*) was drill-seeded (15-inch row spacing) on 30 May for the PTBS and 22 May for the RREC. Soybean was managed according to University of Arkansas Cooperative Extension Service recommendations for stand establishment, fertilization, management of pests, and irrigation. Soybean were flood-irrigated with well water at the PTBS and reservoir water at the RREC as needed throughout the growing season. Twenty recently matured trifoliate soybean leaves were sampled at the R2 growth stage, dried to constant weight at 60°C, ground to pass through a 1-mm sieve, and digested for elemental analysis. Soybean yield was determined by harvesting a 5-ft wide section from the middle of each plot and adjusted to 13% moisture for statistical analysis.

In 2003, 'Wells' rice was drill seeded (100 lb seed/acre) in mid-to-late April at the PTBS and RREC. Soil was tilled before seeding at the RREC, but was planted no-till into the previous year's soybean stubble at the PTBS. Rice was managed according to University of Arkansas Cooperative Extension Service recommendations for stand establishment, N fertilization, management of pests, and irrigation. Whole-plant samples were collected at the panicle-differentiation stage by removing all aboveground plant tissues from a 3-ft long section from the first interior row of rice. Twenty flag leaves (removed from leaf sheath at the collar) were collected at the late-boot to early heading stage. All tissue samples were processed as described previously for soybean. Rice yield was determined at maturity by harvesting the middle 4 or 5 rows from the middle of each plot. Grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

In 2004, 'Armor 53K3' soybean were drill-seeded on 11 May at the PTBS and 16 June at the RREC. Soil was tilled before seeding at the RREC, but was planted no-till into the previous year's rice stubble at the PTBS. Twenty recently matured trifoliate leaves were collected from each plot at the V6 and R2 growth stages at each site and processed as described previously. Grain yield was determined as described previously.

Each experiment was a randomized complete block design with six replications. Analysis of variance procedures were conducted with the PROC GLM procedure in SAS (SAS Institute, Inc., Cary, N.C.). Locations were analyzed separately. Mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS

Soil Analysis

Surface soil samples collected from each plot in 2002 contained similar concentrations of Mehlich-3-extractable B indicating that each test site was relatively uniform with regard to soil-test B. In 2003, one year after B was applied, B-application rate significantly affected Mehlich-3-extractable B in the surface soil samples at each site (Table 2). For each site, Mehlich-3-extractable B increased linearly as B-application rate increased. Linear regression for both sites indicated that Mehlich-3-extractable B increased by about 0.10 mg B/kg/1 lb elemental B ($r^2 = 0.4730$) applied the previous year (2002). Mehlich-3-extractable B in the 6- to 12-inch soil depth was also affected by B application rate (only four rates evaluated) at the PTBS. Compared with the unfertilized control (0.22 mg B/kg), Mehlich-3 B in the 6- to 12-inch depth was significantly increased only by application of 6 lb B/acre (0.31 mg B/kg). At the RREC, subsoil-B concentrations were not affected by B application rate and averaged 0.16 mg B/kg.

By 2004, two years after B was applied, B-rate significantly affected Mehlich-3-extractable B only at the PTBS (Table 2). Mehlich-3-extractable B increased by about 0.05 mg B/kg soil/1 lb B ($r^2 = 0.6203$) two years after B application suggesting that Mehlich-3-extractable B decreases as time after application increases. The lack of significant differences among B rates at the RREC in 2003 and 2004 were at least partially due to the large coefficient of variation values (Table 2), which may been caused by i) application of granular B rather than a B solution and/or ii) movement of B and soil within and among plots from tillage. At the RREC, B was applied as a granular fertilizer, rather than a solution, due to windy conditions at the time of application.

Soybean and Rice Response to B Fertilization

Soybean seed yields in 2002 and 2004 and rice grain yields in 2003 were not influenced by B-application rate (Table 3). Soybean trifoliate leaf-B concentrations at the R2 growth stage were significantly affected by B-application rate at both sites in 2002 (Table 4). In general, trifoliate leaf-B concentration increased as B application rate increased. Soybean B concentrations exceeded 60 mg B/kg, the proposed toxic concentration, when 1 lb B/acre was applied at the PTBS and when 4 lb B/acre was applied at the RREC. Although significant yield decreases from B fertilization were not measured, soybean yields at both sites tended to decline numerically when >4 lb B/acre was applied (Table 3).

Boron concentrations of rice flag leaves in 2003 significantly increased as B-application rate increased at both sites (Table 4). Whole-plant rice B concentrations at panicle differentiation showed similar results as flag leaves (data not shown). In 2004, mature trifoliate soybean leaves collected at the V6 stage at both sites were also significantly increased by B-application rate, two years after B fertilizer was applied (Table 4). At the PTBS, trifoliate leaf-B concentrations were also affected by B rate at the R2 stage. The B concentration of the untreated control at the R2 stage was similar to that at the V6 stage, but B concentrations were numerically greater for B rates > 0 lb B/acre between samples times. Rice (2003) and soybean (2004) tissue-B concentration data suggest that a single application of B increases B uptake by future crops. The residual effect of B fertilization increases as B-application rate increases and lasts for at least two years. Compared with the unfertilized control, application of 1 lb B/acre, the maximal rate recommended for soybean, significantly increased soybean trifoliate leaf-B concentration in 2004 only at the PTBS. Tissue analysis for the R2 samples collected at the RREC are not yet complete.

PRACTICAL APPLICATIONS

Increasing the B-fertilizer rate applied in 2002 significantly increased Mehlich-3-extractable B in the 0- to 4- or 6-inch soil depths at both locations in 2003 and only at the PTBS in 2004, but generally had little influence on subsoil-B concentrations. Application of high B rates (>1 lb B/acre) in 2002 had no residual, negative influence on rice (2003) or soybean (2004) growth and yield. Application of recommended rates of B to soybean once every two years in a rice-soybean rotation may slightly increase soil-test B and provide sufficient residual B for future crops so that B fertilization frequency or rate of application may be reduced or possibly omitted after several years of application. Recommended rates of B would likely have to be applied for many years before sufficient soil-B accumulated to cause B toxicity in flood-irrigated rice and/or irrigated-soybean grown on alkaline soils in northeast Arkansas. Additional research is needed to interpret Mehlich-3-extractable B and determine how long a single application of B influences subsequent crop B nutrition.

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Table 1. Selected soil chemical property means for two experiments initiated at the Pine Tree Branch Station (PTBS) and Rice Research Extension Center (RREC) in 2002.

Year	Site	Soil depth	pH	Mehlich-3-extractable soil nutrients P	K	Ca	Mg	Na	S	Mn	Zn	B
		(in.)		------------------				(mg/kg soil)				------------------
2002	PTBS	0 to 6	7.9	20	96	1629	289	94	20	121	2.0	0.83
2002	PTBS	6 to 12	6.6	7	63	1009	247	115	19	166	0.8	0.12
2002	PTBS	12 to 18	4.9	5	64	497	177	107	27	79	0.8	0.09
2002	PTBS	18 to 24	5.0	6	77	480	220	161	19	82	1.4	0.13
2003	PTBS	0 to 6	7.6	22	102	1973	322	59	11	126	1.5	--[z]
2003	PTBS	6 to 12	4.8	5	53	1125	267	92	16	191	0.7	--
2003	PTBS	12 to 18	4.7	4	52	473	169	101	31	72	0.8	0.18
2003	PTBS	18 to 24	4.7	4	68	423	224	167	22	84	1.4	0.22
2004	PTBS	0 to 4	7.9	23	121	1949	295	43	11	96	2.0	--
2002	RREC	0 to 6	6.3	10	109	938	179	92	21	141	0.7	0.32
2002	RREC	6 to 12	7.6	2	66	1098	216	234	7	139	0.3	0.09
2002	RREC	12 to 18	6.3	2	91	905	215	336	18	27	0.3	0.09
2002	RREC	18 to 24	5.3	2	160	780	193	530	43	28	0.4	0.09
2003	RREC	0 to 6	6.9	14	110	1167	241	82	14	192	5.3	--
2003	RREC	6 to 12	7.0	3	55	1292	234	174	10	190	0.5	0.16
2003	RREC	12 to 18	6.4	3	62	1060	240	247	13	41	0.4	0.07
2003	RREC	18 to 24	5.2	2	110	855	214	424	33	26	0.5	0.05
2004	RREC	0 to 4	6.2	11	135	858	178	49	12	111	4.4	--

[z] '--' indicates that Mehlich-3-extractable B was affected by previous B applications and values are listed in the text or in Table 2.

Table 2. The influence of B-application rate (applied in May 2002) on surface soil Mehlich-3-extractable B concentration in 2003 and 2004 at the Pine Tree Branch Station (PTBS) and Rice Research Extension Center (RREC).

B fertilizer rate	Site-year PTBS-2003	PTBS-2004	RREC-2003	RREC-2004
(lb B/acre)	------------------	(mg Mehlich-3-extractable B/kg soil)		------------------
0	0.48	0.19	0.40	0.10
1	0.58	0.28	0.43	0.09
2	0.75	0.39	0.57	0.11
4	0.95	0.43	0.69	0.14
6	1.01	0.56	0.73	0.14
8	1.28	0.57	1.40	0.26
LSD(0.10)	0.21	0.11	0.46	NS[z]
P-value	<0.0001	<0.0001	0.0184	0.1570
C.V., %	24.7	26.2	53.0	85.6

[z] NS, not significant at the 0.10 level.

Table 3. The influence of B-application rate (applied in May 2002) on soybean yields in 2002 and 2004 and rice yields in 2003 at the Pine Tree Branch Station (PTBS) and Rice Research Extension Center (RREC).

B fertilizer	Soybean 2002		Rice 2003		Soybean 2004	
rate	PTBS	RREC	PTBS	RREC	PTBS	RREC
	(bu/acre)					
0	71	51	156	176	57	50
1	71	52	152	175	52	49
2	69	50	154	180	55	49
4	76	48	152	172	56	47
6	67	44	160	171	59	42
8	66	44	155	173	55	49
LSD(0.10)	6	NS[z]	NS	NS	NS	NS
P-value	0.0892	0.643	0.7382	0.9616	0.7058	0.3293
C.V., %	8.5	18.4	6.5	10.3	13.5	11.5

[z] NS, not significant at the 0.10 level.

Table 4. The influence of B-application rate (applied in May 2002) on mature trifoliate leaf-B concentrations of soybean in 2002 (R2 stage) and 2004 (V6 and R2 stages) and flag leaf-B concentrations of rice at heading in 2003 at the Pine Tree Branch Station (PTBS) and Rice Research Extension Center (RREC).

	Soybean 2002		Rice 2003		Soybean 2004 (stage/site)		
B fertilizer	Trifoliate leaves		Flag leaves		Trifoliate leaves		
rate	R2PTBS	R2RREC	PTBS	RREC	V6PTBS	R2PTBS	V6RREC
(lb B/acre)	[Tissue-B concentration (mg B/kg)]						
0	56.0	39.6	6.1	6.1	29.0	30.7	49.6
1	66.2	45.8	6.0	6.3	32.6	43.9	49.9
2	83.1	51.8	7.3	6.4	36.3	45.7	50.5
4	74.3	61.1	7.5	6.2	37.3	48.9	53.4
6	84.7	61.6	8.8	7.2	36.7	51.5	52.3
8	122.4	72.6	9.3	7.2	39.1	50.8	54.9
LSD (0.10)	23.4	10.3	0.9	0.8	2.5	2.5	2.9
P-value	0.0014	0.0001	<0.0001	0.0132	<0.0001	<0.0001	0.0274
C.V., %	29.2	17.5	9.9	9.7	7.1	5.5	5.8