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EFFECTS OF IRRIGATION AND SULPHUR APPLICATION ON SOYBEANS GROWN ON A NORFOLK LOAMY SAND

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ABSTRACT

Plant sulphur deficiencies may develop in the Coastal Plain of Southeastern United States because of the humid climate and low soil sulfate levels. This study was conducted to evaluate the interactive effect of irrigation and sulphur fertilization on dry matter accumulation, yield, and sulphur content of Bragg (Glycine Max (L.) Merr) soybeans grown on a Norfolk loamy sand (Typic Paleudult). Rainfall distribution was sufficient to prevent plant moisture stress until the late flowering stage, but a subsequent drought during the pod fill stage resulted in an 86% yield increase due to irrigation. Dry matter accumulation was also increased by 26% during the seed development stage with irrigation.

Sulphur fertilization had no significant effect on soybean yield or dry matter accumulation. However, sulphur concentration in soybean leaves and stems were significantly higher in the sulphur-amended plots during the vegetative growth stage. Neither irrigation nor applied sulphur affected soybean protein or oil content. Increased yield and biomass production under irrigated conditions significantly reduced soil SO_4-S levels.

INTRODUCTION

Soil and plant sulphur deficiencies are recognized as a widespread problem throughout the world.[5] These deficiencies are intensified by (a) increased use of high analyses fertilizers and S-free pesticides, (b) increased crop production, and (c) reduced industrial SO_2 emissions into the atmosphere. Although an equivalent amount of one million tons per year of sulphur is being applied in the U. S. as fertilizer, the potential plant consumption rate has been calculated to be between 2.5 and 4.0 million tons.[2]

Sulphur deficiencies in the Coastal Plain of the Southeastern U.S. are perpetuated by coarse textured soils and the humid climate. Ensminger[8] reported that the surface horizon of many coarse-textured Alabama soils had negligible sulfate absorption capacity. Low sulfate adsorption coupled with periods of high precipitation in the Coastal Plain results in leaching of sulfate-sulphur from the surface horizon. Three years after the culminated application of 1865 kg/ha of S (over a 17 year period), Ensminger[8] found no acetate extractable sulfate-sulphur at the 0- to 45-cm depth in a Norfolk sandy loam.

Sulfates leached from the surface horizon are often retained by the fine textured subsoil. Alabama soils, which could not retain sulfates in the A-horizon, could absorb from 17 to 261 ppm of this nutrient in the B-horizon[8]. Plants can extract sulfates from the subsoil once roots have extended into this zone; however, many of these soils have physical barriers which limit root penetration[4]. In addition to nutrient deficiencies, plants grown on soils with physical barriers often undergo moisture stress because of the low water-holding capacity of these soils.[12,6] Subsoiling and irrigation can eliminate these physical problems, and these management practices are increasing in the Southeastern United States.[13,7,3] However, irrigation could hasten leaching of sulfates from the surface horizon and increase the possibility of plant sulphur deficiencies early in the growing season.

The objectives of this field study were to assess the effect of irrigation and applied sulphur on yield, biomass, and sulphur accumulation in soybeans grown on a Coastal Plain soil.

MATERIAL AND METHODS

A Norfolk loamy sand (Typic Paleudult) was selected as the site for this experiment because of its coarse texture (1.48 bulk density of Ap horizon), low organic matter content (1.38%), and history of high analyses fertilizer application. Research plots (5.8 m by 13.7 m) were disked and fertilized with 220 kg/ha of 0-14-22 fertilizer. Experimental treatments were arrayed in a completely randomized block design and consisted of: (1) irrigation plus sulphur (W_1S_1); (2) irrigation plus no sulphur (W_1S_o); (3) no irrigation plus sulphur (W_oS_1); and (4) no irrigation plus no sulphur (W_oS_o). Sulphur was applied at the rate of 44.8 kg/ha of S in the form of gypsum to half of the plots. The remaining plots received 45 kg/ha of Ca as calcitic limestone. Irrigation water was applied by Bi-wall trickle irrigation tubing[1] to maintain soil matric potential below -0.25 bar at the 60-cm depth. Tensiometers were placed in the rows at depths of 30, 60, 90, 120, and 150 cm. 'Bragg' soybeans (group VII maturity class) were planted on 12 June 1978.

Three soil samples per plot were taken from the A_p, A_2, and B horizon on 26 July 1978. Soil pH and exchangeable cation and phosphorous concentrations were measured according to standard Georgia soil testing procedures.[11] The results of these analyses are summarized in Table 1. Additional soil samples were taken on 2 July 1979 at 30 cm intervals to a depth of 90 cm. Sulfate-sulphur was measured on all samples according to the Wisconsin soil testing procedure.[14]

Soybeans plants (from 30 cm of row) were sampled 45, 72, 92, and 114 days after planting and fractionated by anatomical parts (i.e. leaves, stems, petioles, and pods). Days 45, 72, 92, and 114 coincided with the growth stages V_n, R_3, R_5, and R_6, respectively. The samples were washed, dried at 70°C, weighed for biomass, and ground by a Wiley Mill to pass a 20 mesh screen. Plant samples were analyzed for total S with a LECO Sulfur Determinator using 0.35 g of plant material, 0.7 g of vanadium pentoxide accelerator, 1.5 g of Lenocel (combustion accelerator), and 1 vanadium pentoxide van-o-disc.

Total Kjeldahl nitrogen was determined by digesting 0.25 g of plant tissue with 7 ml of acid (97 g H_2SeO_3 + 4.04 L of H_2SO_4) and 3 ml of 30% H_2O_2 at 400°C for one hour. The digest was diluted to 75 ml and analyzed on a Technicon AutoAnalyzer II.

Experimental data evaluation consisting of analysis of variance and least significant difference at P (.05) were compiled by standard statistical procedures.

TABLE 1

Characteristics of a Norfolk Loamy Sand

Horizon	Depth (cm)	pH	Ca	Mg	K	P
			ppm			
A_p	0-23	6.5	1120	197	219	181
A_2	23-36	6.2	520	175	116	93
B	36-43	5.1	900	202	328	2

RESULTS AND DISCUSSION

Plant Analysis

Rainfall distribution totaling 27.5 cm was adequate during the soybean vegetative stage to maintain the soil matric potential below -0.25 bar. Since irrigation was not required until after flowering, soil moisture status was not an operative variable during the first two sampling dates. A seasonal drought began 60 days after planting, and only 6.4 cm of precipitation fell over the next 40-day period. Irrigation totaling 20.5 cm was required during this period to maintain desired soil matric potentials. On days 92 and 114, the 800 mb isodepth in the nonirrigated plots was at the 60- and 120-cm depth, respectively. The beginning of the drought coincided with pod development, and plants in the nonirrigated plots were stressed during this period.

Sulphur deficiencies, which generally occur early in the growing season, were not apparent in this study. Due to adequate soil moisture conditions, soybean roots probably penetrated the subsoil early in the season and began utilizing subsoil sulphur. Sulphur concentration of soybean leaves (Table 2) were within the average range (0.22 - 0.28%) cited by Small and Ohlrogge.[15]

Although soil sulfate levels in the unamended plots were sufficient to prevent nutrient deficiencies, the concentration of plant sulphur was lower in these plots than in the sulphur-amended plots (Table 2). During the vegetative stage (Day 45), sulphur fertilization significantly increased the concentration of this nutrient by 12 and 15% in the leaves and stems, respectively. Additionally, sulphur fertilization increased the concentration of this nutrient in the petioles by 7% (not statistically significant). Sulphur levels in the leaves remained highest in the amended plots during flowering, but there was a decline in the sulphur concentration of the stems and petioles. This decline may be attributed to a delay in nutrient accumulation as compared to dry matter accumulation. Henderson and Kamprath[9] reported similar trends for nitrogen and

TABLE 2

Sulphur Concentration in Soybean Leaves, Stems, Petioles, and Pods as Affected by Irrigation and Sulphur Application.

Days After Planting	Sulphur Conc. (%)				LSD
	W_oS_o	W_oS_1	W_1S_o	W_1S_1	.05
	Leaves				
45	.229	.262	.233	.259	.02
72	.254	.279	.258	.274	.03
92	.272	.261	.273	.267	.02
114	.231	.258	.250	.249	.02
	Stems				
45	.221	.255	.219	.251	.03
72	.200	.219	.193	.218	.03
92	.177	.241	.240	.237	.05
114	.147	.186	.210	.202	.04
	Petioles				
45	.158	.166	.161	.176	.03
72	.146	.146	.142	.152	.02
92	.132	.153	.170	.153	.03
114	.116	.145	.143	.139	.03
	Pods				
92	.171	.181	.200	.177	.02
114	.225	.225	.225	.232	.02

phosphorus. Maximum accumulation of sulphur in leaves occurred by Day 72 in the amended plots, whereas it was delayed until later in the unamended plots.

During pod and seed development (Day 92) under irrigated conditions, sulphur levels in all plant parts were numerically lower in the amended plots than in the unamended plots. However, under nonirrigated conditions, sulphur levels in stems, petioles, and pods were lower in the unamended plots. Generally, these trends continued as the seeds matured (Day 114). There was a substantial decrease in sulphur levels of all vegetative plant parts during seed development. Reduced sulphur levels in vegetative portions of plants indicates the translocation of protein synthesizing elements to seeds. Similar trends have been reported for nitrogen and phosphorus.[9]

Applied sulphur had no significant effect on dry matter accumulation during the vegetative and flowering stages (Table 3). However, during pod and seed development, sulphur application increased dry matter in the nonirrigated and irrigated plots by 25% and 20%, respectively. This increase was due to higher trifoliate and pod production. Vegetative matter accumulation, other than pods, had decreased in all treatments except W_oS_o as the seed matured. Decreased accumulation of vegetative matter, other than pods, was a result of leaf drop; but no estimates of this were made. There was no difference in total dry matter accumulation on Day 114 between sulphur treatments under nonirrigated conditions. However, amended plots had higher pod weights and their leaf weights had decreased by 45%, whereas leaf weight remained unchanged in the unamended plots. Dry matter accumulation under irrigated conditions was 16% higher in the amended plots than in the unamended plots on Day 114.

Although applied sulphur slightly increased the concentration of this nutrient in leaves, stems, and petioles, it had no effect on total uptake during the vegetative and flowering stages (Table 4). Total S uptake was 20% higher in the amended plots than in the unamended plots under irrigated and nonirrigated conditions as the seed matured. Higher sulphur uptake in the irrigated, sulphur-

TABLE 3

Dry Matter Accumulation as Affected by Irrigation and Sulphur Application

Days After Planting	Dry Matter (g)				
	W_oS_o	W_oS_1	W_1S_o	W_1S_1	LSD .05
45	5.5	5.7	6.0	5.3	2.28
72	16.4	18.0	23.2	20.9	9.94
92	18.6	23.2	27.6	33.0	9.90
114	30.4	31.7	36.3	42.2	15.75

TABLE 4

Calculated Sulphur Uptake by Soybean Tops as Affected by Irrigation and Sulphur Application

Days After Planting	Sulphur Uptake (kg/ha)				
	W_oS_o	W_oS_1	W_1S_o	W_1S_1	LSD .05
45	3.35	3.72	3.52	3.49	1.35
72	9.36	10.60	12.90	12.10	5.40
92	9.58	13.43	16.68	18.67	5.37
114	14.25	17.15	21.01	25.23	8.32

amended plots (W_1S_1) was a function of higher dry matter accumulation, whereas higher uptake in the nonirrigated, sulphur-amended plots (W_oS_1) was a function of higher sulphur concentrations in the vegetative portion of the plant.

Sulphur fertilization had no effect on plant nitrogen concentration during the growing season, although higher plant sulphur concentrations resulting from fertilization reduced the N:S ratio in the leaves and stems slightly during the vegetative stage (Table 5). There was no effect on petiole N:S ratios at this stage. During the reproductive stage, nitrogen uptake and accumulation exceeded that of sulphur, resulting in wider N:S ratios as compared with the vegetative stage.

Nitrogen-sulphur ratios were slightly lower in the leaves on Days 92 and 114 as compared to Day 72 for all treatments except W_1S_1. These lower values resulted from more translocation of nitrogen than of sulphur from the leaves. Stable N:S ratios in the irrigated, sulphur-amended plots (W_1S_1) were a result of continued accumulation of these nutrients. Under irrigated and nonirrigated conditions, the N:S ratios for stems were slightly lower in the sulphur-amended plots than the unamended plots. No consistent trend could be detected in petiole or pod ratios at

TABLE 5

Ratio of 'Kjeldahl Nitrogen to Total Sulphur' in Soybean Plant Tops as Affected by Irrigation and Sulphur Application

Days After Planting	N:S Ratio			
	W_oS_o	W_oS_1	W_1S_o	W_1S_1
	Leaves			
45	13	12	13	11
72	17	16	16	17
92	15	15	13	17
114	14	12	14	16
	Stems			
45	6	5	6	5
72	8	7	7	7
92	8	6	7	6
114	7	6	5	6
	Petioles			
45	8	7	7	7
72	13	13	13	12
92	13	11	10	12
114	11	9	9	10
	Pods			
92	25	23	22	24
114	19	19	19	19

this stage, although plants from the nonirrigated plots generally had lower nitrogen and sulphur levels than plants from irrigated plots.

Generally, the N:S ratios in the leaves and petioles followed the same trend as the seeds matured. In stems, these ratios remained constant in the sulphur-amended plots, but were lower in the unamended plots. The N:S ratios for pods were similar for all treatments on Day 114, but were lower than during the earlier stage. Although the ratios were similar in all treatments, there was a distinct difference in nitrogen and sulphur accumulation among the treatments. Nitrogen-sulphur accumulation rates decreased in the following order: $W_1S_1 > W_1S_o > W_oS_1 > W_oS_o$.

Neither irrigation nor applied sulphur significantly affected the protein or oil content of soybeans (Table 6). Although mean soybeans yields were 131 and 190 kg/ha higher with sulphur fertilization under nonirrigated and irrigated conditions, respectively, these differences were not statistically significant (Table 6). However, irrigation significantly increased yields by 1396 kg/ha.

Soil Analysis

Sulfate-sulphur levels of the A_p and A_2 horizon ranged from 8- to 12-ppm on 26 July 1978 (Table 7). These values are in agreement with those reported by Jones et al.[10] Although heavy leaching may occur on this soil, sulfate losses are constantly being replenished by sulfate deposition from rainfall and absorption from the air. Jones et al.[10] reported that 19.8 kg/ha of sulphur was added to the soil from air and precipitation in South Carolina in 1977. Sulphur application had no significant effect on soil SO_4-S levels in 1978. Periods of intense rainfall occurred shortly after sulphur had been applied to half the plots. In the 41-day interval between sulphur application and soil sampling, precipitation totaling 24.5 cm was recorded. Consequently, applied sulphur may

TABLE 6

Yield, Protein, and Oil Content of Soybeans as Affected by Irrigation and Sulphur Application

Treatment	Yield (kg/ha)	Protein (%)	Oil (%)
W_oS_o	1548	41.2	20.6
W_oS_1	1679	40.8	20.8
W_1S_o	2914	40.8	20.5
W_1S_1	3104	40.1	20.9
$LSD_{.05}$	349	2.2	1.3

have been diluted beyond detection limits or leached beyond the sampling depth.

Soil SO_4-S levels were significantly lower in the irrigated plots in July 1979 (Table 7). Lower SO_4-S levels in the irrigated plots were observed throughout the 90-cm sampling profile. These lower SO_4-S levels may be attributed to higher plant uptake of this nutrient and increased leaching due to the high conductivity of the moist irrigated soil.

CONCLUSIONS

Sulphur fertilization significantly increased the concentration of this nutrient in the vegetative portion of soybean plants. Although applied sulphur did not affect plant nitrogen concentrations, it influenced total nitrogen uptake and the N:S ratio. Increased yield and biomass production under irrigated conditions and depletion of soil SO_4-S may necessitate supplemental sulphur fertilization in the future. These results are not conclusive, but the data does indicate that further research is needed to evaluate the

TABLE 7

Soil SO_4 Levels after Sulphur Application

Sampling Depth (cm)	W_oS_o	W_oS_1	W_1S_o	W_1S_1	LSD .05
			ppm		
			1978		
0-23 (A_p)	12	9	10	10	4
23-36 (A_2)	10	8	10	9	4
36-43 (B)	65	56	65	64	30
			1979		
0-30	12	12	8	7	3
30-60	48	52	22	20	18
60-90	169	181	144	132	21

response to sulphur fertilization of irrigated soybeans in the Coastal Plain of the southeastern United States.

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