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Sulfur Response of Maize in Western Nigeria[1]

B. T. Kang and O. A. Osiname[2]

ABSTRACT

Studies of S deficiency, a problem in certain crops in Africa, have yielded inconclusive and incomplete information. There is little information on the S status of soil in the forest-savanna zone.

Field trials were carried out with maize (*Zea mays* L.) at six locations in the forest and savanna zones of western Nigeria. Sulfur was applied at 0, 7.5, 15.0, 30.0, and 60.0 kg S/ha. Significant yield increases were observed with rates of S application from 7.5 to 30 kg S/ha. The response was more distinctly evident in the savanna than in the forest zone. Silking percentage was enhanced and grain quality improved with S application. No significant residual effect of the applied S was observed in the savanna zone, which was probably due to heavy leaching of the applied S. On these soils S response was observed where the amount of extractable S, extracted with either KH_2PO_4, $Ca(H_2PO_4)_2$, or $NH_4C_2H_3O_2$ was below 4 ppm S. There was no response to S when extractable S levels were equal to or greater than 8.5, 10.0, and 12.0 ppm when soils were extracted with $Ca(H_2PO_4)_2$, $NH_4C_2H_3O$, and KH_2PO_4, respectively. The critical S level in the ear leaf was estimated at about 0.14% S. Although there was a strong correlation between % N and % S in the ear leaf, the N:S ratio was not related to critical S levels in plants.

Additional index words: **Extractable soil S, Tissue S content, N:S ratio, *Zea mays* L.**

SULFUR deficiency problems have been observed in various crops in several parts of Africa (Bolle-Jones, 1964). In West Africa, the importance of S was first recognized by Greenwood (1951), who observed increases in groundnut yields in northern Nigeria with addition of gypsum. Stephens (1960) reported on responses of cereals and Braud (1969) on responses of cotton in West Africa.

An examination of the results of several field trials with cotton in West and Central Africa did not enable Braud (1969) to relate the S problem areas either to the ecology or soil type, although the data presented indicated more frequent S problems in the savanna region. Goldsworthy and Heathcote (1963) observed that S deficiency in groundnuts was most frequent on sites which had recently been left fallow. The response of cotton to S, according to Braud (1969), decreased with cropping. Based on observations in the savanna of northern Nigeria, Bromfield (1972) suggested that S responses were most pronounced immediately after clearing the fallow and again after long continued cropping. In between, there is a period of increased S availability due to mineralization of organic S in the soil. Although some of the soils in northern Nigeria accumulate S in the lower horizons, S deficiency is prevalent in shallow-rooting crops like groundnuts (Bromfield, 1972).

There is less information on the S status of soils in the humid forested tropics and in the transition zone between forest and savanna as represented in western Nigeria, than in the savanna zone. The present study was the initial effort to obtain information on the S nutrition of crops along a transect of decreasing rainfall and increasing duration of the dry season. Maize was the indicator crop.

MATERIALS AND METHODS

Experiments were conducted during the main growing season (April to September) of 1971-1973. Field trials were located at Ikenne and Ibadan (Forest zone), and Oyo, Ogbomosho, Ikoyi, and Kishi (Savanna zone). These locations extended from Ikenne, latitude 6° 55′ N, to Kishi, latitude 9° 5′ N, of western Nigeria. The annual rainfall ranges from 1500 mm in Ikenne to about 1200 mm at Kishi. The experimental design was a randomized complete block with four replications. Sulfur at rates of 0, 7.5, 15.0, 30.0, and 60.0 kg S/ha as ammonium sulfate (28% S) was broadcast and thoroughly worked in the soil with a hand hoe before planting. Each experimental plot received a basal dressing of 50 kg N/ha as ammonium chloride and/or ammonium sulfate to conform with the S rates, 66 kg P/ha as concentrated superphosphate ($\leqslant$ 1% S), and 30 kg K/ha as muriate of potash, before planting. Nitrogen as urea (100 kg N/ha) was side-dressed 4 weeks after planting. Maize cultivar 'NS-1' was planted at Ogbomosho and IITA maize cultivar 'TZA' × 'TZB' was planted at the other locations. The plant population was 53,300 plants/ha. At Ogbomosho a second crop of maize was planted on the same plots in the second year to evaluate the residual effects of the applied S. IITA maize cultivar TZA × TZB was used. Nitrogen, P, and K, but not S, were reapplied the second year as in the first year.

Surface soil (0 to 15 cm depth) was collected from each plot prior to fertilizer applications. At the Ikoyi and Ogbomosho sites profile samples were collected at harvest time from plots which had received the 0, 30, and 60 kg S treatments. Sulfur in the surface soil samples was extracted using the following extractions: $NH_4C_2H_3O_2$ (Bardsley and Lancaster, 1960), $Ca(H_2PO_4)_2$ (Fox et al., 1964), and KH_2PO_4 (Ensminger, 1954); S in the profile samples was extracted using $NH_4C_2H_3O_2$ (Bardsley and Lancaster, 1960). Sulfate sulfur in the extract was measured using the turbidimetric method (Chesnin and Yien, 1950). The following additional analyses were performed: particle size, by the hydrometer method; pH, using a 1:1 soil-water ratio, soil organic carbon, using the Walkley and Black method; CEC estimated from sum of exchangeable cations including hydrogen and aluminum.

The number of plants/plot which had reached silk stage was taken 60 days after planting. Maize grain yield adjusted to 12% moisture was also determined at harvest.

Nitrogen content in ear leaf samples collected at silking time was determined using a micro-Kjeldahl method. Sulfur content was measured by turbidimetric method after fusion of plant material with sodium carbonate and redissolved in 6 *N* HCl (Sanford and Lancaster, 1962). Part of the plant samples was wet-digested using a mixture of HNO_3-$HClO_4$; P content was measured using a Technicon Auto-analyzer, K and Ca were measured with a flame photometer, while the Mn content was measured using a Perkin Elmer 403 atomic absorption spectrometer.

EXPERIMENTAL RESULTS

Soil Analysis

The physical and chemical properties of the surface soils of the experimental sites are presented in Table 1. Except for the Ikenne site, the surface soils are

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Table 1. Characteristics of surface soil from field trial sites.

Site	Soil series	7th Approx.	Mechanical analysis Sand	Silt	Clay	pH	Organic C	Total N	CEC	Extractable-S KH_2PO_4	$Ca(H_2PO_4)_2$	$NH_4C_2H_3O_2$
			%				%	%	meq/100 g	ppm		
Ikenne	Alagba	Paleustalf	76	1	23	5.9	1.08	0.09	5.46	12.00	8.50	10.00
Ibadan	Apomu	Usthorthent †	86	5	9	6.0	0.80	0.09	4.30	3.00	3.80	3.30
Oyo	Apomu	Ustipsamment †	86	7	7	5.4	0.62	0.05	2.89	2.00	2.50	3.70
Ikoyi	Shante	Ustipsamment	80	11	9	5.6	0.68	0.05	3.87	2.80	2.80	2.90
Ogbomosho	Shante	Ustipsamment	83	10	7	5.8	0.68	0.05	3.87	2.00	2.50	2.20
Kishi	Omo	Paleustalf	68	21	11	6.2	0.90	0.06	6.05	3.50	2.80	3.50

† Proposed subgroup.

sandy and low in clay, organic C, and N. The forest zone soil at Ikenne, which was recently cleared from secondary regrowth, contained much extractable S, while at Ibadan, where the loamy sandy soil was recently cleared of mixed grasses and scattered shrubs, extractable S was low. At the other sites, which were located in the savanna zone and recently cleared from tall grass vegetation, amounts of S extracted by the various extractants were uniformly low.

There was little change with depth in the amount of extractable S in the (no) S plots at Ikoyi and Ogbomosho (Fig. 1). Although addition of S increased extractable S, there was also a considerable leaching of the applied S during the cropping period from the surface horizon to lower depths. From the data on the S distribution in the profile and the estimated S uptake by the crop, about 80% of the applied S could be accounted for at the Ogbomosho site with 60 kg S/ha rate. The rest of the applied S appeared to be leached out to larger depth than 90 cm.

Growth and Yield

With the exception of the Ikenne site, S deficiency symptoms were observed on plots which were not S fertilized. Symptoms were most severe at the Ogbomosho site. Deficient plants were stunted and showed pale bud leaves.

Despite the large differences in the numbers of plants silking 60 days after planting at the various sites (Table 2), addition of S tended to enhance silking on the S deficient sites.

Sulfur application did not affect maize grain yield at the Ikenne site (Table 3). Grain yields were significantly increased at Ibadan, Oyo, Ikoyi, and Kishi by applications of 7.5 kg S/ha. At Ogbomosho, where a more pronounced S deficiency was observed, a significant yield response was observed with 30 kg S/ha rate. Addition of 30 kg S/ha at Ogbomosho increased the yield by almost 100% over the control. Regression analysis of the S rate applied and maize grain yield shows a curvilinear relationship for each of the Ibadan, Ogbomosho, and Ikoyi sites.

Maize ears from the no S treatment were smaller, contained fewer grains, and were dull in color as compared with those from the S fertilized plots. At the Ogbomosho site where yellow maize cultivar NS-1 was used, the grain color from the no S treatment was pale yellowish and with S application was yellowish red, indicating an increase in the carotene content of the grain. Fox (1956) also observed an increase in the vitamin A content of alfalfa with S application.

Table 2. Effect of S application on percentage of plants silking 60 days after planting.

S rate	Site: Ibadan	Oyo	Ogbomosho	Ikoyi	Kishi
kg/ha	%				
0	52 a*	26 a	45 a	60 a	74 b
7.5	65 b	40 b	49 ab	67 ab	91 c
15.0	67 b	39 b	59 c	71 ab	70 a
30.0	70 b	39 b	53 abc	72 ab	90 c
60.0	66 b	36 b	58 bc	81 b	82 bc

* Values within columns followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test.

Table 3. Grain yield response of maize to sulfur application.

S rate	Site: Ikenne	Ibadan	Oyo	Ogbomosho	Ikoyi	Kishi
	kg/ha					
0	4,960*	2,320 a	2,380 a	1,782 a	3,260 a	5,944 a
7.5	5,160	2,700 ab	3,000 b	2,364 ab	3,880 b	6,861 b
15.0	5,180	2,840 b	2,740 ab	2,831 b	3,840 b	6,222 ab
30.0	5,320	3,000 b	2,960 b	3,530 bc	4,320 b	6,667 b
60.0	4,840	2,700 ab	3,200 b	3,240 bc	4,060 b	6,833 b

* Values within columns followed by the same letter or no letter are not significantly different at 5% level according to Duncan's multiple range test.

The residual effect of the applied S at Ogbomoshe was investigated Grain yield of second-year maize is shown in Table 4. Although the yield tended to multiply with increasing rate of previously applied S, the yield differences were not statistically significant.

Plant Analysis

Sulfur application significantly increased the S content of the ear leaf at the Ibadan, Oyo, Ogbomosho, and Kishi sites, where there was an S response on the crop (Table 5). At Ikenne, where no S response was observed, S application did not affect the S content in the ear leaf. Despite the increase in the leaf S content with S application in the crop grown in the savanna region (Oyo, Ogbomosho, and Kishi), the leaf S content was lower even with the higher S treatment ($\leqslant$ 0.15% S), compared with those grown in the forest region (Ikenne and Ibadan). The total S content in the ear leaf was also significantly correlated with the relative grain yield of the maize (Fig. 2).

The N content of ear leaf was also increased with increasing rates of S application at the Ibadan, Oyo, Ogbomosho, and Kishi sites (Table 5). The largest increase in the N content in the leaf was obtained at Ogbomosho, the most S deficient site; while at Ikenne (no S response), S fertilization produced no significant effects on the N content. The overall effect was a

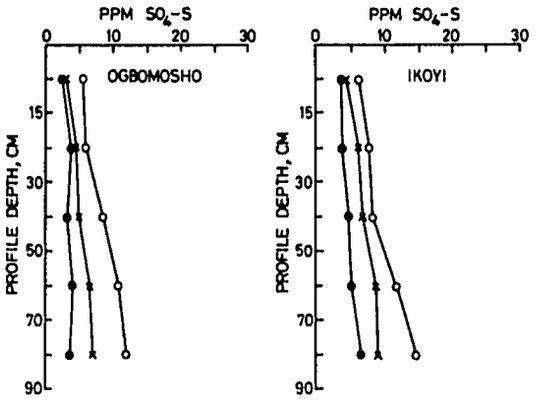

Fig. 1. Distribution of NH_4- acetate extractable S with soil depth, as affected by S application (●——●) 0 kg S/ha; x——x 30 kg S/ha; O——O 60 kg S/ha) at harvest time.

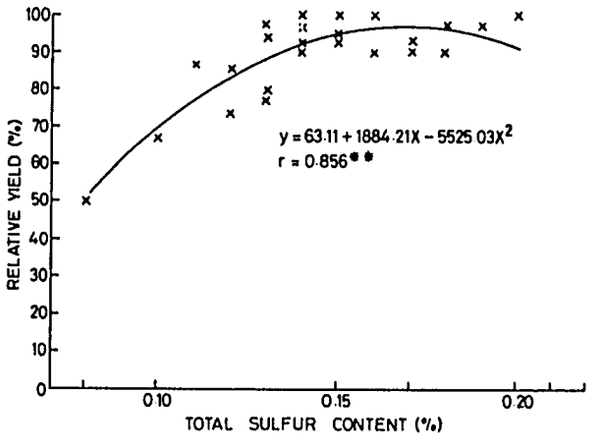

Fig. 2. Relationship between relative maize grain yield and total S content in maize ear leaf.

high correlation between N and S contents in the ear leaf (Fig. 3).

The N:S ratio of the ear leaf varied with location and S treatment (Table 6). Plants from the forest region tended to have lower N:S ratios than those from the savanna zones even when the maize in the savanna was fertilized. No specific reasons can be given for these differences. The N:S ratio decreased with increasing addition of S.

At the Ogbomosho site where the cultivar NS-1 was used, sulfur application increased the Ca and Mn contents of the ear leaf. Because no such relation was observed at the other sites, the increase in Ca and Mn contents might be specific to the cultivar NS-1 or might be due to location effect.

S application did not affect leaf P and K content at any location.

DISCUSSION

The experimental results indicated a significant response to S on the maize at all the experimental sites in the savanna region, while in the forest zone a response to S was observed only at the Ibadan site where the soil has a loamy-sandy texture (Table 3). This observation is also supported by the authors' unpublished greenhouse data, which indicated higher

Table 4. Effect of residual S on grain yield of maize at Ogbomosho.

S rate, kg/ha	0	7.5	15.0	30.0	60.0
Grain yield, kg/ha	2,750	2,900	3,375	3,375	3,360

Table 5. Effect of S treatment on average nutrient content in ear leaves of maize.

Site	S rate	N	P	K	S	Ca	Mn
	kg/ha	%					ppm
Ikenne	0	2.28*	0.40	1.22	0.17	0.46	98
	7.5	2.20	0.42	1.26	0.19	0.51	103
	15.0	2.24	0.43	1.30	0.18	0.45	109
	30.0	2.18	0.39	1.22	0.17	0.48	100
	60.0	2.21	0.39	1.30	0.17	0.46	87
Ibadan	0	1.87 a	0.41	1.83	0.13 a	0.31	98
	7.5	2.29 c	0.41	1.94	0.17 bc	0.31	103
	15.0	2.05 b	0.38	1.78	0.15 b	0.35	114
	30.0	2.25 c	0.41	1.91	0.20 d	0.32	92
	60.0	2.37 c	0.40	1.74	0.18 c	0.35	119
Oyo	0	2.00 a	0.36	2.20	0.12 a	0.25	54
	7.5	2.02 ab	0.35	2.14	0.13 ab	0.27	60
	15.0	2.25 bc	0.34	2.04	0.12 ab	0.27	65
	30.0	2.19 abc	0.32	2.10	0.15 b	0.26	54
	60.0	2.29 c	0.34	2.21	0.14 b	0.28	55
Ogbomosho	0	1.78 a	0.21	1.41	0.08 a	0.39 a	51 a
	7.5	1.85 a	0.19	1.41	0.10 b	0.43 ab	62 ab
	15.0	2.20 c	0.21	1.53	0.13 c	0.49 ab	67 ab
	30.0	2.05 b	0.21	1.48	0.14 cd	0.54 b	69 ab
	60.0	2.12 bc	0.18	1.44	0.14 d	0.52 b	80 b
Kishi	0	2.12 a	0.32	2.00	0.12 a	0.53	59
	7.5	2.18 ab	0.30	1.85	0.13 a	0.53	73
	15.0	2.16 ab	0.30	1.89	0.14 b	0.49	66
	30.0	2.22 ab	0.30	1.93	0.14 ab	0.52	68
	60.0	2.34 b	0.29	2.08	0.15 b	0.47	73

* Values within columns followed by the same letter or no letter are not significantly different at 5% level according to Duncan's multiple range test.

Table 6. Effect of S treatment on N/S ratio in ear leaves of maize.

	Site				
S rate	Ikenne	Ibadan	Oyo	Ogbomosho	Kishi
kg/ha					
0	13.4	14.3	17.4	21.4	18.5
7.5	11.7	13.8	15.6	18.0	16.8
15.0	12.5	13.7	18.7	16.5	15.3
30.0	13.2	11.3	15.1	15.2	15.8
60.0	13.2	13.3	16.0	15.2	15.6

incidence of S deficiency in soils collected from the savanna region of Western State of Nigeria. Several factors may contribute to the higher incidence of S deficiency in the savanna soils:

1) the existing traditional method of annually burning the vegetation which leads to losses of S to the air;
2) the sandy texture of most of the soils, which promotes leaching losses;
3) low recycling of the S with the natural grass vegetation;
4) little use of fertilizers.

Data on the S distribution in the savanna soil profiles (Fig. 1) did not show any S accumulation in the subsoil. These results differ from the results reported by Bromfield (1972) for the soils derived from losses in the northern Guinea Savanna zone of Nigeria. There was considerable downward movement of the applied S from the surface soil during the cropping

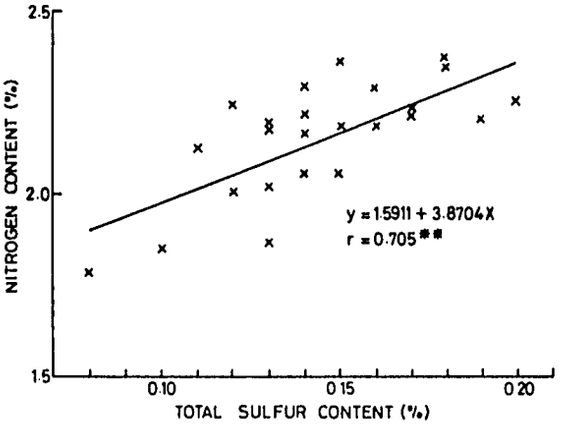

Fig. 3. Relationship between total N and total S contents in maize ear leaf.

period at the Ikoyi and Ogbomosho sites, indicating low sorption of the applied S. This explains in part the small residual effect of the applied S on the second-year crop of maize at Ogbomosho (Table 4) because the crop could probably utilize only part of the subsoil S. The absence of a significant S residual effect might also be due to increased S mineralization of the soil organic matter in the second year of cropping as postulated by Braud (1969) and Bromfield (1972). This is in keeping with the significant yield improvement of the no S treatment during the second year (Table 4). Further research needs to be carried out to verify this possibility.

Considering the consistent response to S application and the significant leaching of the applied S in the savanna region, the logical management practice would be annual application of small dosages of S for maximum yield of maize.

The soil test values for extractable S (Table 1) combined with the maize yield data (Table 3) indicated that S response can be expected when extractable S is below 4 ppm. While at soil test values of 8.5, 10, and 12 ppm S, extracted respectively with $Ca(H_2PO_4)_2$, $NH_4C_2H_3O_2$, and KH_2PO_4, no response to S application is expected. With alfalfa, Fox et al. (1964) considered 7 ppm S extracted with $Ca(H_2PO_4)_2$ as the critical level for S response, while Seim et al. (1969) observed S response with S soil test levels of 10 ppm S extracted with $Ca(H_2PO_4)_2$ and 7.4 ppm S extracted with $NH_4C_2H_3O_2$.

From the relationship between grain yield and total S content in the ear leaf, the critical S level in the ear leaf is estimated at about 0.14% S. This value is lower than the 0.24% S in sweet corn ear leaf as suggested by Daigger and Fox (1973). Part of this discrepancy in values might also be due to differences in the method of digestion of the plant material (Daigger and Fox used nitric-perchloric acid procedure.) Sansum and Robinson (1974) reported that S recovery depends on the method of digestion of plant material, they demonstrated that dry combustion methods give lower S values.

The N:S ratio in plant material has been used as an index to determine the probability for an S response (Pumphrey and Moore, 1965; Saalbach, 1972). Data presented by Dijkshoorn et al. (1960) for graminae indicated a critical N:S ratio of 13.8. Fox considered N:S ratio of 15 as the most desirable for optimum growth of sugarcane. Although the data on the N:S ratio in the ear leaf samples presented in Table 6 showed a decrease in the N:S ratio with increasing sufficiency of S, there were large differences in the N:S ratio between locations. With an abundant S supply the N:S ratios of leaves from the savanna region ranged from 15 to 16, while those from the forest region ranged from 11 to 13. Apparently the N:S ratios fluctuate considerably in the critical range. This agrees with the observation made by Daigger and Fox (1971) who investigated a borderline S deficiency. They also could not find any usefulness of N:S ratio values in the ear leaf of sweet corn for S status diagnosis. This should not preclude the use of N:S ratios for diagnosing extreme or even moderately severe cases of S deficiency.

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