Maize Grain Yield Response to Sulphur Fertilization in Central America

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Researchers have reported sulphur (S) deficiencies in many of the maize production areas of Central America. Work by Fox and Blair (8) indicated that although S deficiencies occur frequently in the humid tropics, the problem is not as widespread as might be expected. In general, many variable-charge soils in the tropics are capable of absorbing significant amounts of SO_4 when soil pH is low (13). Kamprath *et al.* (10) indicated that the adsorption of SO_4 is dependent upon its concentration and soil pH, since adsorption is limited above pH 6.5. Sulphur deficiencies would be more critical if not for the SO_4 retention by variable-charge soils which can buffer the S supply (8). Weathered or intensely-leached soils in the tropics are those where the potential for S deficiencies are expected to become worse with time.

Because of the geology of the Central American region, volcanic ash has a widespread effect in soils where maize production systems are located. Blair and Lefroy (2) and the International Fertilizer Development Center (9) have shown that S deficiencies can be found in soils derived from volcanic ash due to the presence of allophane which can bind organic forms of S. Blair and Lefroy (2) indicated that weathered tropical soils generally have a higher anion exchange capacity versus temperate soils and a greater capacity to adsorb SO_4. Alternatively, Chao *et al.* (6) conducted studies that suggested that anion exchange was not involved in the retention of SO_4. Further work by Blair (1) noted the tendency for rapid removal of bases from the profile of soils formed in the humid tropics under high moisture percolation. Experiments which Pearson *et al.* (12) conducted showed that 90% of all water soluble bases were leached as SO_4 in acid Latosol and Red-Yellow Podzol profiles. In the maize plant tissue studies, critical S levels have been determined but invariably showed poor correlation with yield (7,11).

Maize production in Central America is unique because over 65% of the area cultivated to this crop is on eroded or eroding hillsides. Each year, 2,000,000 ha are cultivated to maize in Central America with over 65% of the production on predominantly eroded or eroding hill slope soils that have been affected to a greater or lesser degree by volcanic ash. In El Salvador, almost 80% of the maize production takes place on marginal sloping ground. This represents approximately 320,000 ha cultivated to maize on marginal land, about 15% of the total area in the country. The use of minimum or zero tillage is one of various alternatives that can be used as a soil conservation measure. However, this practice on already neutral-to-acid soils can result in increased acidity in the surface soil horizon (4,5). The common annual practice of burning surface residues prior to planting in Central America is a major problem with respect to soil erosion and can volatilize up to 75% of the S present in organic residues (15).

Blair *et al.* (3) indicated that phosphate ions are effective in both displacing previously adsorbed SO_4 and in reducing the capacity of the surface to adsorb SO_4. Furthermore, phosphate replacement of SO_4 on the adsorption sites of soils along with the continued use of non S-containing phosphorus (P) fertilizers may lead to a decline in the S status of some tropical soils (3).

Materials and Methods

Fifty-three fertilizer experiments were established in maize (*Zea mays* L.) production areas within Central America from 1989-91 (Table 1). Each experiment employed a randomized com-

Table 1. Locations where P and S method-source experiments were conducted in Central America, 1989-91.

Country	*1989*	*1990*	*1991*
Panamá	Las Tablas	Las Tablas	Cocobola
	La Honda	La Honda	La Honda
	Parita	Parita	Parita
		Las Comadres	
Costa Rica	Esparza		
Nicaragua		Nindirí	
		Posoltega	
El Salvador	Metalio Guaymango	Metalio Guaymango	Metalio Guaymango
	Sacacoyo	Opico Quezaltepeque	
Honduras	Caguira	Siguatepeque	
	El Tejar		
	Esperanza		
	Ologisí		
Guatemala	La Máquina	Jutiapa	Cuyuta
	Zacapa	La Máquina C-16	San Gerónimo
	Retalhuleu	La Máquina B-6	La Máquina
	Jutiapa PC	San Gerónimo	
	Jutiapa AM	Chimaltenango 1	
	Jutiapa VT	Chimaltenango 2	
	Cuyuta	Zacapa	

plete block design with three replications. These experiments were designed to evaluate monocropped maize grain yield response to additions of S as hydrated gypsum (18.6%S) at varying P fertilizer rates: 0, 13, 26, and 39 kg ha^{-1} as triple superphosphate. In each experiment, other treatments were also included to evaluate response to applied P, legume intercropping, and other soil management variables. However, only those comparisons that related to S response for monocropped maize are included in this report. Yield response to S fertilization was determined as the yield differential between means (treatment combination receiving S minus the same treatment combination not receiving S) for each experiment. Regional S response was evaluated by plotting the yield differential due to S against the average yields for all treatments at each site (environmental mean). Environmental means were determined by averaging the yields of all plots (30-48 plots per experiment) from a given experiment. Nitrogen (N) as urea (46%N) was applied at a rate of 100 kg N ha^{-1} in all experiments. Maize germplasm used for each experiment was the best available genotype for the environment in each country (hybrids or open pollinated varieties). The plot size was 4 to 6 rows (0.7-1.2 m row spacing), 5 m in length which resulted in a net harvested plot area for yield of 10 to 20 m^2 at all locations. Because of the altered row width, plant populations ranged from 45,000 to 65,000 plants ha^{-1}. Weeds were controlled with pre-emergence herbicides and manual weeding at each location.

Ears were hand harvested from the center 2 to 4 rows. The number of ears, plant population, plant height, lodging, and grain moisture data were obtained in each plot. Additional information for each site included slope, rainfall, and elevation. A standard analysis of variance with non-orthogonal single degree of freedom contrasts was used to evaluate treatments. An analysis over locations was also performed.

Results and Discussion

Maize grain yields were significantly greater when N and S were both applied as compared to N applications alone. The average yields were 0.36 $\pm$ 0.12 Mg ha^{-1} for the 1990 trials and 0.23 $\pm$ 0.12 Mg ha^{-1} for the 1991 trials (Figure 1). When N, P, and S were applied as compared with N and P, maize grain yield response to applied S was less than that noted in the absence of P. The average overall combinations receiving P in Figure 2 were 0.08 Mg ha^{-1}. A positive response to applied S when no P fertilizer was applied was found at 70% of the locations whereas only 60% were found to be positive when both P and S were applied. However, a lower magnitude in response was noted for the latter. Work by Raun and Barreto (14) from

Figure 1. Relationship of the environmental mean versus maize grain yield response to applied S (treatment receiving N and S minus treatment receiving only N), 1990 and 1991 regional trials, Central America.

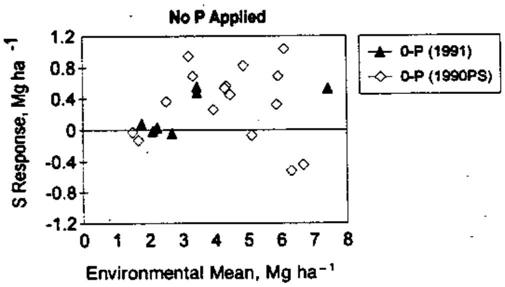
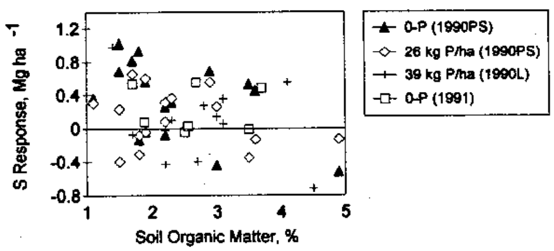


Figure 3. Soil organic matter, % versus maize grain yield response to applied S (combination treatments receiving N, S, and/or P minus the same treatment receiving only N and/or P), 1989, 1990, and 1991 regional trials, Central America.



maize experiments on volcanic ash-derived soils reported the presence of a PxS interaction when both nutrients were applied together in a band. This work suggested that when N-P-S fertilizers are combined together, P was mostly precipitated in the metastable forms of dicalcium phosphate dihydrate and dicalcium phosphate. Consequently, the amount of P fixed as iron and aluminum hydroxides or complexed with amorphous allophane was reduced. In addition, Raun and Barreto (14) indicated that SO_4 blocking of adsorption sites could have increased P availability by reducing the amount of P fixed by the soil. However, when N was applied in a band separate from that of P and S, yields were reduced significantly, suggesting that the method of placement affected the response to applications of P and S.

Grain yield as related to applied S was not a function of the environmental mean whether or not P was applied (Figures 1 and 2). Given the number of trials included in this work, this could suggest that increased rates above 20 kg S ha^{-1} are not necessary even if removal is expected to be higher when the environmental means are greater than 5 Mg ha^{-1}. This could further indicate that even when positive response applied to S was found, increased rates where environmental means were higher would not lead to increased yields since some other climatic or soil factor had become limiting.

For the different trials included in this analysis, the magnitude of response to applied S was greater when soil organic matter was less than 2.5% (Figure 3). Soil organic matter levels were generally lower at the sites where slopes were greater. The lower soil organic matter levels are also associated with those sites where maize has been produced continuously and where increased weathering, such as higher rainfall and lower elevation, was expected. Because the majority of the experiments were conducted at sites where organic matter levels were less than 3%, the range restricted rigorous testing of the before mentioned hypotheses. Similarly, the response to applied S was greater when soil magnesium (Mg) and calcium (Ca) were low: <4 and <8.5 cmol kg^{-1} (Figures 4 and 5). The sites where soil organic matter levels were low were also low in soil Mg and Ca.

Figure 2. Relationship of the environmental mean versus maize grain yield response to applied S (treatment receiving N, S, and P minus treatment receiving only N and P), 1990 and 1991 regional trials, Central America.

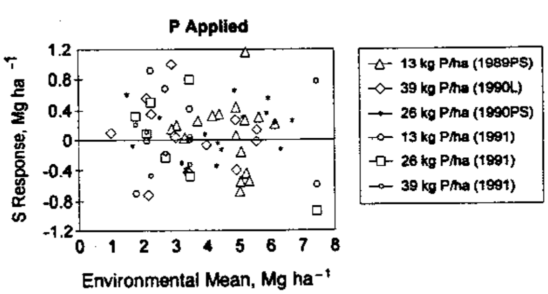


Figure 4. Soil Mg versus maize grain yield response to applied S (combination treatments receiving N S, and/or P minus the same treatment receiving only N and/or P), 1989 and 1990 regional trials, Central America.

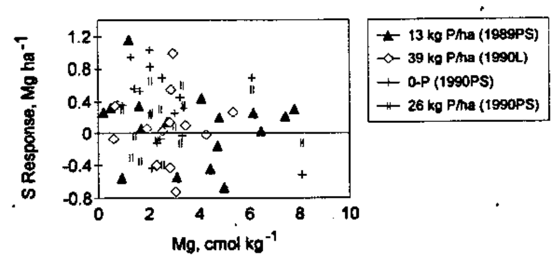


Figure 5. Soil Ca versus maize grain yield response to applied S (combination treatments receiving N, S, and/or P minus the same treatment receiving only N and/or P), 1989 and 1990 regional trials, Central America.

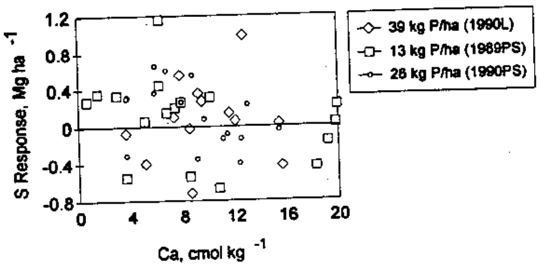
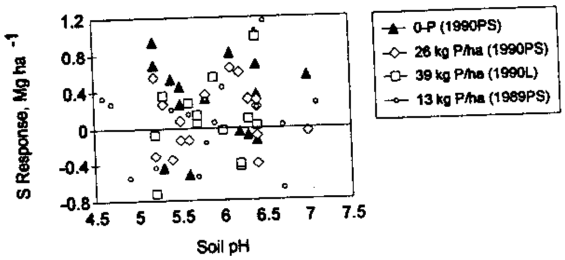


Figure 6. Soil pH versus maize grain yield response to applied S (combination treatments receiving N, S, and/or P minus the same treatment receiving only N and/or P), 1989, 1990, and 1991 regional trials, Central America.



Maize grain yield response to applied S demonstrated no clear relationship with soil pH (Figure 6). Work by Kamprath *et al.* (10) indicated that anion exchange is significant in weathered soils (1:1 clay minerals) and those with pH < 6.5. In addition, Kamprath *et al.* (10) indicated that increasing the phosphate concentration in solution reduced the amount of SO_4 adsorbed by the soil. Only three of the regional trials conducted in 1989, 1990, and 1991 had a soil pH in excess of 6.5—most were below 6.0. Given the weathered tropical soils evaluated in these experiments, it was not surprising to find a significant PxS interaction (grain yield response to applied S in presence and absence of P) noted in Figures 1 and 2.

How convincing is the evidence of a regional response to S fertilization from this sample of 53 maize-growing environments? The magnitude and variability of individual trial responses are important elements. However, low experimental precision for treatment comparisons is a limiting factor in declaring statistical significance for observed S yield responses except in a few localized instances. Using average levels of variability from these trials, one must observe a yield differential of approximately 0.8 tons ha^{-1} between two treatment means with an average of three replications before statistical differences can be declared significant at the 5% confidence level. When analyzed by site, less than 20% of all S comparisons were declared statistically significant at the 5% probability level. Nevertheless, in this sample of preplanned treatment comparisons (S versus No S), consistency of treatment effects across the environments should be considered when deciding on the strength of the evidence for accepting or rejecting the existence of a particular treatment effect. In this case, despite the variability of the results, S fertilization benefits are obvious from these data.

Localized yield responses have been identified in the following areas of Central America: Guatemala (Cuyuta, Chimaltenango), Panama (Azuero), and El Salvador (Opico Quezaltepeque). However, lower variability estimates might be necessary to statistically detect yield responses due to S fertilization throughout the region. Increased yields with S fertilization in the absence of P might suggest either greater soil S availability or enhanced soil P availability (14). The differential response to S fertilization in the presence or absence of P might be important in generating appropriate fertilizer recommendations for maize production systems in soils affected by volcanic ash.

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REFERENCES

1. Blair, G.J. 1988. Chemistry of sulphur and sulphur cycle in the tropics. SI 1/1-10. *In* Sulphur in Indian Agriculture. Proc. TSI-FAI Symposium. The Sulphur Institute, Washington, DC.
2. Blair, G.J., and R.D.B. Lefroy. 1987. Sulphur cycling in tropical soils and the agronomic impact of increasing use of S-free fertilizers, increased crop production and burning of crop residues. *In* Proc. of the Symp. on Fert. Sulphur Requirements and Sources in Developing Countries of Asia and the Pacific. The Sulphur Institute, Washington, DC.
3. Blair, G.J., C.P. Mamaril, P. Umar, A.E.O. Momuat, and C. Momuat. 1979. Sulfur nutrition of rice. I. A survey of soils of South Sulawesi, Indonesia. Agron. J. 71:473-477.

4. Blevins, R.L., L.W. Murdock, and G.W. Thomas. 1978. Effect of lime application of no-tillage and conventionally tilled corn. Agron. J. 70:322-326.

5. Blevins, R.L., G.W. Thomas, and P.L. Cornelius. 1977. Influence of no-tillage and nitrogen fertilization on certain oil properties after 5 years of continuous corn. Agron. J. 69:383-386.

6. Chao, Tsun Tien, M.E. Harward, and S.C. Fang. 1962. Adsorption and desorption phenomena of sulfate ions in soils. Soil Sci. Soc. Am. Proc. 25:234-237.

7. Daigger, L.A., and R.L. Fox. 1971. Nitrogen and sulfur nutrition of sweet corn in relation to fertilization and water composition. Agron. J. 63:729-730.

8. Fox, R.L., and G.J. Blair. 1986. Plant response to sulfur in tropical soils. *In* Tabatabai, M.A. (ed.) Sulfur in Agriculture. Agronomy 27:729-730.

9. International Fertilizer Development Center. 1979. Sulfur in the tropics. Technical bulletin IFDC-T-012. Muscle Shoals, Alabama, U.S.A.

10. Kamprath, E.J., W.L. Nelson, and J.W. Fitts. 1958. The effect of pH, sulfate and phosphate concentrations on the adsorption of sulfate by soils. Soil Sci. Soc. Am. Proc. 20:463-466.

11. Kang, B.T., and O.A. Osiname. 1976. Sulfur response of maize in western Nigeria. Agron. J. 68:333-336.

12. Pearson, R.W., F. Abruna, and J. Vicente-Chandler. 1962. Effect of lime and nitrogen applications on downward movement of calcium and magnesium in two humid tropical soils of Puerto Rico. Soil Sci. 93:77-82.

13. Probert, M.E., and S.S.R. Samosir. 1983. Sulfur in non-flooded tropical soils. p. 15-27. *In* G.J. Blair and A.R. Till (eds.) Sulfur in Southeast Asian and South Pacific Agriculture. Research for Development Seminar, Ciawi, Indonesia. 23-27 May 1983. Univ. New England, Armidale, Australia.

14. Raun, W.R., and H.J. Barreto. 1991. Maize yield response as affected by sulfur, phosphorus and nitrogen as banded applications on a volcanic ash derived tropical soil. Commun. in Soil Sci. and Plant Anal. 22 (15-16) 1661-1676.

15. Sanchez, Pedro A. 1976. Properties and management of soils in the tropics. John Wiley & Sons. New York, NY.