

Effects of sources and rates of sulfur on crops of economic interest -
Cabbage, Citrus, Corn, Cotton, Dry Beans, Rice, Soybeans and Wheat.

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1. Introduction

- 1.1. Final results on several crops, namely, Guinea Grass, Sweet Sorghum, Rapeseed plant, Coffee and Sugar cane have already been published.
- 1.2. Yield data on other crops will be presented hereby.
- 1.3. Complete informations, as several technical bulletins, are to be presented in the near future.

2. Cereals

2.1. Corn

Table 2-1 gives the results of 5 experiments, all of them conducted in the state of São Paulo during 3 to 4 years depending of local. A total of 15 harvests were made.

As shown in table 2-2, each kg of S applied generate from 20 to 31 kg of grain, a result which compares favorably with the ratio of 1 to 6 up to 21 reported by FAO Fertilizer Program for the nutrients $N + P_2O_5 + K_2O$.

On the other hand it should be pointed out that the yields obtained correspond roughly to 2.5 the Brazilian average corn yield.

2.2. Rice

Experiments with rainfed rice (national average yield about 1,000 kg/ha) were carried out in the State of São Paulo (Guariba), Minas Gerais (S. Sebastião do Paraíso) and Goiás (Goiânia). Table 2-3 presents the results thereof.

Table 2-1 Experimental results with corn (1)

Treatment	LOCATION (2)				
	Anhembi	Bebedouro	Botucatū	Jaboticabal	I.Solteir
	————— kg/hectare —————				
Control	5228	6086	5403	4435	4451
Ammonium Sulfate					
20 kg S/ha	6009	6652	5347	4881	4687
40 kg S/ha	6301	6723	5765	4898	4654
K-Mag					
20 kg S/ha	5896	6842	5852	4958	4477
40 kg S/ha	5890	6548	5597	4898	4466
Phospho-gypsum					
20 kg S/ha	6083	6932	5819	5109	4746
40 kg S/ha	5981	6593	5848	4889	4570

(1) Average of 6 replicates

(2) Anhembi - average of 4 harvests
 Bebedouro - average of 4 harvests
 Botucatū - average of 3 harvests
 Jaboticabal - average of 4 harvests
 I. Solteira - average of 3 harvests

Table 2-2 General average, corn experiments, effect of sources at 20 kg S/ha.

Treatment	Yield kg/ha	kg grain / kg S
Control	5120	-
Ammonium Sulfate	5515	20
K-Mag	5605	24
Phosphogypsum	5738	31

The overall response is shown in Table 2-4. Each kg of S applied as fertilizer gave from 6 to 9 kg of paddy. World results obtained in FAO Fertilizer Program indicate a rates of one to 6 up to 12 for each unit of $N + P_2O_5 + K_2O$.

2.3. Wheat

One experiment was carried out in the State of São Paulo during four consecutive years (1984 to 1987). Only results of three years are presented, however, because of crop failure in the year 1985 due to extreme drought (Table 2-5). Average yields notwithstanding were at least 50% higher than Brazilian national averages in the Central Plateau.

As shown in Table 2-6 each kg of S generated 20 kg of grain.

2.4. General

Although detailed statistical analysis has not been made the following conclusions could be drawn:

- (1) yield increases due to S additions are to be expected with the several cereals under similar conditions,
- (2) for the yields level which prevail in the regions 20 kg of S are sufficient to meet the requirements of the different crops.
- (3) usually the three sources provide the same yield increases.

3. Grain legumes

3.1. Beans

The experiment was carried out in Anhembi, SP, during 3 years. In the third year, however, yields were drastically reduced due to infestation of nematodes. For this reason only results corresponding to the first and second years crops were averaged, as shown in Tables 3-1 and 3-2.

Although the 40 kg S/ha rate gave higher yields, only economic analysis would be able to justify this dosage under practical conditions.

Table 2-3 Experimental results with rice (1)

Treatment	LOCATION (2)			AVERAGE
	Guariba	Goiânia	S. Sebastião do Paraíso	
	kg/hectare			
Control	2748	1377	2048	
Ammonium Sulfate				
20 kg S/ha	3137	1519	2028	
40 kg S/ha	3096	1568	1969	
K-Mag				
20 kg S/ha	3076	1537	1885	
40 kg S/ha	3135	1546	2092	
Phospho-gypsum				
20 kg S/ha	2976	1607	2124	
40 kg S/ha	3103	1639	2262	

(1) Average of 6 replicates

(2) Average of 3 harvests for each

Table 2-4 General average, rice experiments, effects of sources at 20 kg S/ha.

Treatment	Yield kg/ha	kg grain / kg S
Control	2057	-
Ammonium Sulfate	2228	9
K-Mag	2166	6
Phosphogypsum	2235	9

Table 2-5 Effect of sources and rates of sulfur on yield of wheat

Treatment	1984	Year		Average	△
		1986	1987		
kg/ha					
Control	1716	1289	1757	1587	-
Ammonium Sulfate					
20 kg S/ha	2121	1577	2271	1990	203
40 kg S/ha	2158	1622	2342	2041	454
K-Mag					
20 kg S/ha	2076	1644	2231	1984	
40 kg S/ha	1994	1511	2285	1930	
Phosphogypsum					
20 kg S/ha	2248	1378	2369	1998	
40 kg S/ha	2292	1417	2241	1983	

Table 2-6 General response of wheat at 20 kg S/ha on grain yield.

Treatment	Yield kg/ha	kg grain / kg S
Control	1587	-
Ammonium Sulfate	1990	20
K-Mag	1984	20
Phosphogypsum	1998	20

Table 3-1 Response of beans to sources and rates of sulfur (1)

Treatment (2)	kg of beans / hectare	
Control	1533	Δ —
Ammonium Sulfate		
20 kg S/ha	1655	122
40 kg S/ha	1793	260
K-Mag		
20 kg S/ha	1580	
40 kg S/ha	1687	
Phosphogypsum		
20 kg S/ha	1669	
40 kg S/ha	1757	

(1) Average of 2 harvests

(2) Average of 6 replicates

Table 3-2 Conversion ratio of S to beans at 20 kg/ha level.

Source	kg of beans / kg of S
Ammonium Sulfate	6
K-Mag	2
Phosphogypsum	7

3.2. Soybeans

Two sets of experiments were conducted.

3.2.1. Sulfur effect

Three experiments were carried out; one in the State of São Paulo (Botucatú), one in Minas Gerais (Conceição das Alagoas) and a third one in the State of Paraná (Bandeirantes).

A summary of the results is given in Table 3-3.

Under the cerrado conditions of Conceição das Alagoas the lower rate of S application gave increases in yield of nearly half a ton.

3.2.2. Nitrogen and sulfur effects

This set of 2 experiments was designed to check the possibility of the N contained in Ammonium Sulfate decreasing yield by inhibition of symbiotic N₂ fixation by root nodules. The S effect in the other hand should also be evaluated as in all previous cases.

Table 3-4 presents the results of the experiments conducted in the states of Minas Gerais (Frutal) and São Paulo (Ilha Solteira). A summary is given in Table 3-5. The following points are observed:

- (1) S has increased soybean production to the extent of 300 kg/ha in Frutal and in Ilha Solteira.
- (2) N application was beneficial in Frutal, having no effect in Ilha Solteira.

3.3. General

The chief results obtained with grain legumes can be summarized as follows:

- (1) in all experiments a S effect was observed.
- (2) S applications at the rate of 20 kg/ha are to be used.
- (3) as a rule all sources were equivalent in their effect on yields.

Table 3-3 Effects of sources and rates of sulfur on soybeans (1)

Treatment	LOCATION (2)		
	Botucatū	C. Alagoas	Bandeirantes
		kg/ha	
Control	1595	2262	2807
Ammonium Sulfate			
20 kg S/ha	1712	2711	2922
40 kg S/ha	1662	2728	2999
K-Mag			
20 kg S/ha	1708	2658	2983
40 kg S/ha	1665	2788	2968
Phosphogypsum			
20 kg S/ha	1627	2632	2926
40 kg S/ha	1683	2727	2929

(1) Average of 6 replicates

- (2) Botucatū - Average of 4 harvests
 C. Alagoas - Average of 4 harvests
 Bandeirantes - Average of 2 harvests

Table 3-4 Overall effect of S at 20 kg S/ha on soybean yields.

Treatment	Yield kg/ha	kg beans / kg S
Control	2221	-
Ammonium Sulfate	2448	11
K-Mag	2449	11
Phosphogypsum	2395	9

Table 3-4 Response of soybeans to Nitrogen and to Sulfur (1)

Treatment	LOCATION (2)	
	Frutal	Ilha Solteira
<u>Control A</u>		
0 kg N/ha		
0 kg S/ha	1788	2549
<u>K-Mag</u>		
0 kg N/ha		
20 kg S/ha	2029	2537
40 kg S/ha	2058	2815
<u>Phosphogypsum</u>		
0 kg N/ha		
20 kg S/ha	2138	2641
40 kg S/ha	2109	2613
<u>Control B</u>		
35 kg N/ha		
0 kg S/ha	2022	2559
<u>Ammonium Sulfate</u>		
35 kg N/ha		
20 kg S/ha	2110 (322)	2463
40 kg S/ha	2114 (326)	2616 - 67
<u>K-Mag</u>		
35 kg N/ha		
20 kg S/ha	2155	2561
40 kg S/ha	2094	2643
<u>Phosphogypsum</u>		
35 kg N/ha		
20 kg S/ha	2133	2616
40 kg S/ha	2135	2769

(1) Average of 6 replicates

(2) Frutal - Average of 3 harvests

I. Solteira - Average of 2 harvests

Table 3-5 Comparison of S effect, at 20 kg level of supply, in the presence and absence of Nitrogen on soybean.

Treatment	kg/ha	kg grain/ kg S	kg grain/ kg S (ave)
No N, no S	2168	-	
K-Mag	2283	6	
Phosphogypsum	2389	11	8
N, no S	2290	-	
Ammonium Sulfate	2286	6	
K-Mag	2358	10	
Phosphogypsum	2374	10	8

Table 3-6 Response of cabbage to S application at Botucatu, SP.

Treatment	kg/ha	Δ	kg cabbage/ kg S
Control	4759	-	-
Ammonium Sulfate			
30 kg S/ha	4943	184	6
60 kg S/ha	5012	253	-
90 kg S/ha	5180	421	-
K-Mag			
30 kg S/ha	4773		0,5
60 kg S/ha	4992		-
90 kg S/ha	5034		-
Phosphogypsum			
30 kg S/ha	5786		34
60 kg S/ha	5187		-
90 kg S/ha	4849		-

4. Cabbage

As shown in Table 4-1 a response to S was obtained. The element should be recommended at the lower rate, that is, 30 kg per hectare.

5. Cotton

Four experiments were carried out in the State of São Paulo. The results (Tables 5-1 and 5-2) show the following points of interest:

- (1) striking increases in productivity of seed cotton were obtained.
- (2) an intermediate rate (30 kg S/ha) could be recommended in the general practice under similar conditions.

6. Citrus

The results obtained in the experiment carried out in Araraquara, SP, on orange trees beginning to bear, are shown in Table 6-1. Here again:

- (1) a good response to S was observed.
- (2) an intermediate rate (45 kg S/ha) could be recommended for citrus under similar conditions.

7. Summary

- 7.1. This report deals with the results of 21 field experiments (882 experimental plots) and 54 harvests of temporary (corn, rice, wheat, beans, soybeans, cabbage, cotton) and perinnial crops (citrus) conducted in 4 states of Brazil during one to five years.
- 7.2. The total cost of these trials should amount to about US\$ 216,000.00, not considering the salary of the scientific personnel involved.
- 7.3. A general overview of the results is presented in Table 7-1.

Table 5-1 Response of cotton to sources and rates of sulfur (1)

Treatment	LOCATION (2)			
	Leme	Ituverava	Borborema	Pederneiras (3)
	Δ	Δ	kg/ha	Δ
Control	2461	2342	1627	682
Ammonium Sulfate				
20 kg S/ha	2274	2695 ³⁵³	2104 ⁴⁷⁷	851
40 kg S/ha	2722 ²⁶²	2752 ⁴¹⁰	2041	582
K-Mag				
20 kg S/ha	2246	2503	1911	653
40 kg S/ha	2421	2656	2091	900
Phosphogypsum				
20 kg S/ha	2241	2604	1995	713
40 kg S/ha	2605	2602	2024	892

(1) Average of 6 replicates

(2) Leme and Borborema: average of 3 harvests

Ituverava: average of 2 harvests

Pederneiras: one harvest

(3) Low yields due to water shortage

Table 5-2 Overall effect of sources at the 20 kg rate of application (seed cotton)

Treatment	Yield kg/ha	kg seed cotton/ kg S
Control	1778	-
Ammonium Sulfate	1980	10
K-Mag	1828	2
Phosphogypsum	1888	5

Table 6-1 Response of orange trees to sources and rates of sulfur (1)

Treatment	Yield (2)	
	tons/ha	ca/ha
Control	15	367.64
Ammonium Sulfate		
30 kg S/ha	18 ³	441.17
60 kg S/ha	19 ⁴	
K-Mag		
30 kg S/ha	18	
60 kg S/ha	18	
Phosphogypsum		
30 kg S/ha	19	
60 kg S/ha	21	

(1) Average of 5 replicates

(2) Average of 4 harvests

Table 7-1 A general summary of experimental results.

Crop	Treatment	Yield	
		kg/ha	relative
✶ <u>Corn</u>	Control	5120	100
	Ammonium Sulfate	5515	108
	K-Mag	5605	109
	Phosphogypsum	5738	112
<u>Rice</u>	Control	2057	100
	Ammonium Sulfate	2228	108
	K-Mag	2166	105
	Phosphogypsum	2235	109
<u>Wheat</u>	Control	1587	100
	Ammonium Sulfate	1990	125
	K-Mag	1984	125
	Phosphogypsum	1998	125
<u>Beans</u>	Control	1533	100
	Ammonium Sulfate	1655	108
	K-Mag	1580	103
	Phosphogypsum	1669	109
<u>Soybeans</u>	1. <u>Std. expt.</u>		
	Control	2221	100
	Ammonium Sulfate	2448	110
	K-Mag	2449	110
	Phosphogypsum	2395	108
	2. <u>N & S effect expt.</u>		
	Control (no N no S)	2168	100
	K-Mag	2283	105
	Phosphogypsum	2389	110
	Control (N no S)	2290	106
	Ammonium Sulfate	2286	105
	K-Mag	2358	108
Phosphogypsum	2374	109	
<u>Cabbage</u>	Control	4759	100
	Ammonium Sulfate	4943	104
	K-Mag	4773	100
	Phosphogypsum	5786	121
✶ <u>Cotton</u>	Control	1778	100
	Ammonium Sulfate	1980	111
	K-Mag	1828	103
	Phosphogypsum	1888	106

Table 7-1 A general summary of experimental results (contd).

Crop	Treatment	Yield	
		tons/ha	relative
<u>Orange</u>	Control	15	100
	Ammonium Sulfate	18	120
	K-Mag	18	120
	Phosphogypsum	19	126

7.4. Subject to changes when statistical analysis of data are made, the following general conclusions can be drawn:

7.4.1. Response to S were observed in all experiments particularly in those with more demanding crops established in cerrado soils.

7.4.2. The same effect was usually observed with the three sources.

7.4.3. The best rate of application was either the lower one (20 kg for cereals, cabbage and grain legumes), and an intermediate one for the remaining crops (30 kg S/ha for cotton and 45 for citrus).

8. Recommendations

8.1. The project should be continued.

8.2. Other crops and regions should be covered.

8.3. The interactions between N X S and P X S should be explored.

Piracicaba, December 22, 1989.

