Sulphur and Food Production in the Tropical Countries—Problems, Projections and Policy Implications*

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A fast rate of growth of population, increasing food needs and the widening gap between consumption and production of food in the developing countries, particularly in the tropics and sub-tropics of Asia, Africa and Latin America, call attention to those aspects of crop fertilization that have been neglected or have potential for affecting crop production significantly. Increasing land productivity and expansion of the area under agriculture are two planks of a strategy for increasing the production and fertilizer use is the kingpin of this strategy because of its major contribution to yield.

The importance of NPK in increasing production is well recognized but sulphur, which is ranking third or fourth in the mineral composition of plants and is essential for the synthesis of proteins, vitamins and sulphur-containing essential amino acids, has been ignored. In the tropics, much research has been done on the use of phosphate, which is required in amounts not more than sulphur in most cases, but little is known about the use of sulphur. The reasons for this, specifically in developing tropical countries, are many. But the most important ones are the prevalence of subsistence agriculture, low crop yields and the incidental supply of sulphur through farmyard manure and such conventional fertilizers as ammonium sulphate and single superphosphate, irrigation water and the atmosphere.

However, the situation is changing rapidly because of the intensification of agriculture, based on high crop yields, multiple cropping, use of improved cultivars, and increasing use of high analysis sulphur-free fertilizers, coupled with environmental regulations restricting sulphur emissions—all of which create large gaps between the supply of S to soil and its requirements by crops. Bush fallowing is being replaced by continuous cropping accompanied by the use of lime, phosphates and low-sulphur fertilizers which, under the effect of normal leaching in tropical soils, makes them progressively poorer in available sulphur. Sulphur deficiencies are thus growing and the full potentials of agricultural production in tropical countries are not being realized. The cause is the replacement of fertilizers with high sulphur content by fertilizers with low S content. Evidence for this is given in data on the share of sulphur in nitrogenous and phosphatic fertilizers from 1950 to 1980 in India, as shown in table 1.

Recognizing this growing imbalance of S in fertilizers, and the increasing evidence of S deficiency, particularly in the semi-arid tropics, Kanwar and Mudahar (1983) made a critical review of S problems in tropical countries. Some of the important observations of this study are discussed here.

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*Special lecture delivered at the Golden Jubilee celebration of the Indian Society of Soil Science at New Delhi on 8th December, 1984. This lecture is based on the joint study by Dr. J.S. Kanwar and Dr. Mohinder S. Mudahar at the International Fertilizer Development Center, Muscle Shoals, Post Box 2040, Alabama 35660, USA

J. Indian Soc. Soil Sci. Vol. 32 : 583—94, 1984

Table 1. *Changes in the use of sulphur consumption in fertilizers* (%)

Year	Share of AS+ ASN in total N	Share of SSP in total P_2O_5
1951/52	100	100
1965/66	51	81
1980/81	3	16

Source : Kanwar and Mudahar (1983)

Sulphur in Plant Nutrition

Sulphur in plants is required for the synthesis of three essential S-containing amino acids--cystine, cystein and methionine. It is required for the formation of chlorophyll, vitamins, glucosides, ferrodoxins and certain disulphide linkages, besides activation of proteolytic enzymes and A T P sulphurylase.

It is not in doubt that sulphur is a necessary nutrient for plant growth. But the way in which sulphur performs its valuable functions, and how it interacts in the soil with living matter and with other nutrients, are not well known. Although considerable empirical information is available, more precise information is needed on these interactions. This is particularly important for agricultural administrators in tropical countries, who consider phosphate and lime to be the key factors of sound fertilizer practice but do not see to appreciate their effect in causing greater leaching losses of sulphate ions in tropical soils.

The disproportionately higher use of nitrogen and phosphate in comparison with sulphur, which results in widening ratios of N:S and P:S in fertilizer use is evident from data from India and Brazil (Table 2). This imbalance affects the efficiency of fertilizers, impairs the quality of crop produce, and accelerates the removal of sulphate from the soil.

Sulphur differs from nitrogen in that, unlike nitrogen, its deficiency is first seen in young, rather than old leaves and, under conditions of N deficiency, S deficiency is often masked and becomes indistinguishable from the former.

Table 2. *Changes in estimated N : S and P_2O_5 : S ratios in total fertilizer consumption in India and Brazil over time*

Year	N : S ratios		P_2O_5 : S ratios	
	India	Brazil	India	Brazil
1960/61	0.9	0.9	0.2	1.1
1970/71	3.8	1.1	0.9	1.5
1980/81	14.1	1.8	4.3	4.1

Source : Kanwar and Mudahar (1983)

Sulphur in Food Production and Human Nutrition

A survey of available evidence indicates that sulphur deficiency in the soil adversely affects not only crop yields but also the nutritional quality of the crop. The data, although scanty, cannot be overlooked because of the serious nutritional consequences of sulphur deficiency.

Sulphur deficiencies cause a reduction in the amount of S-containing essential amino acids in groundnuts, pulses, and cereals that are potentially disastrous for cereal consuming countries. The shortage of food, particularly of oilseeds and pulses, the widening protein gap, and an increasing S deficiency are contributing causes of malnutrition and hunger in developing countries of the tropics.

Zake (1972) found that S fertilization increased the methionine content of finger millet to such an extent that the daily S amino acid requirement of an adult was reduced from 1325 to 725 mg/day.

In India, Das *et al.* (1975) observed that sulphur application showed a favourable effect on the content of essential amino acids and S-containing amino acids in the grains of maize, wheat, and rice, thus improving grain quality of these three important cereals (Table 3). Singh *et al.* (1970) observed the beneficial effect of fertilization with S on protein and oil content of groundnut and mustard (Table 4). Dube and Misra (1970) reported the beneficial effect of S applied through fertilizers on peas, chickpea, blackgram, and groundnut (Table 5). In East Java, Indonesia, where the rice crop suffered from S deficiency, the addition of ammonium sulphate was found to be superior to urea in increasing the yield as well as the methionine and protein contents of the grain (Ismunadji & Zulkarnaini 1978; Blair & Till 1981).

Table 3. *Effect of sulphur fertilization on protein : total essential amino acids of cereals in India*

Crop and fertilizer level	Total essential amino acids (mg/100 g flour)	Protein (%)
Maize		
N160 S0	4,357	10.50
N160 S30	4,596	11.00
Wheat		
N160 S0	6,406	17.27
N160 S30	6,672	18.64
Rice		
N160 S0	3,643	8.15
N160 S30	4,412	11.31

Source : Das *et al.* (1975)

Table 4. *Effect of 44 kg S/ha on oil, protein and methionine content in groundnut and mustard*

Crop	Oil increase over the control (%)	Protein increase over the control (%)	Methionine increase over the control (%)
Groundnut	6.2	8.4	21.07
Groundnut	4.0	4.5	22.80
Mustard	3.0	4.2	8.50

Source : Singh *et al.* (1970)

Table 5. *Effect of sulphur application on protein in pulses*

Crop	Protein (%)	
	+ S	−S
Peas (*P. sativum*)	20.0	16.0
Chickpea (*C. arietinum*)	17.0	10.5
Blackgram (*Phaseolus mungo*)	19.0	13.8
Groundnut (*Arachis hypogaea*)	21.0	15.0

Source : Dube and Misra (1970)

There is much evidence that sulphur fertilization improves the quality of pasture legumes and grasses in all tropical countries and, thus, directly affects animal health. The magnitude of the effect of sulphur deficiency on the quality of food for both human beings and animals in the tropical countries cannot be quantified accurately because of inadequate research data. The general decline in the percentage share of the total S uptake required for the production of pulses, oilseeds, and groundnuts in India and Nigeria during 1960,1980, and estimates for 2000 AD (Kanwar & Mudahar 1983) indicates the potential impact of sulphur deficiency on the nutrition of the people who depend on these foods as sources of sulphur-containing amino acids (Table 6). The phenomenal rise in the production and export of soybean from Brazil overstrains the sulphur reserves of the soil and creates a greater need for their replenishment.

Table 6. *Estimated proportion of sulphur uptake by pulses and oilseeds in India and Nigeria*

Crop	Percentage of estimated total S uptake by 15 crops/crop groups					
	India			Nigeria		
	1960	1980	2000	1960	1980	2000
Pulses	14.58	8.26	4.86	—	—	—
Oilseeds	4.76	4.57	3.11	0.50	1.33	1.36
Groundnut	5.29	4.64	3.40	11.68	5.12	3.45

Source : Kanwar and Mudahar (1983)

Sulphur Effects on Crop Production

Generally the average sulphur removal associated with the production of one tonne of food grain for important crop groups is as follows; wheat and rice : 3-4 **kg**; sorghum and millets : 5-8 kg; pulses and legumes : 8 kg and oilseeds : 12 kg.

The crucifers (cabbage, radish, turnip, rape, mustard), onion, garlic, legumes (soybean, groundnut, alfalfa, beans and other pulses), cotton, sugarcane, tea, coffee, and tobacco remove high amounts of S but cereals are less demanding. Any increased need for S in important crops of the tropics creates a greater demand for fertilizer sulphur. Spencer (1975) from Australian experience, has suggested for different crops the following amounts of S fertilizers for S-deficient areas.

Cotton	10—30 kg/ha
Cereals	5—20 ,,
Groundnut	5—10 ,,
Crucifers/forages	40—80 ,,
Rape and mustard	20—60 ,,
Sugarcane	20—40 ,,

The uptake of S depends not only on the S content of the plant but also on the expected yield and the level of fertilization. Thus intensifying the yield level of crops through higher fertilization with NPK will increase the demand for S through fertilizers and manures. It is observed that the S content of rice may vary from 0.034% under S deficiency to 0.16% under sufficiency and simultaneously grain yields may vary from 0.75 to 8.0 t/ha or more (Blair 1979).

Fertilizer Sulphur Enhance Crop Yields

Data on crop responses to fertilizer sulphur from field experiments are rather limited. Available information is mostly confined to areas where, year after year, deficiencies have been observed or where, under the impact of modern agriculture, the full potential of inputs is not being realized because of induced sulphur deficiency. Cases of S deficiency in Sulawesi in Indonesia and in northeast Thailand, Bangladesh, India (Punjab and Haryana), Zimbabwe, central Kenya, northern Nigeria and the Campo Cerrado soils of Brazil are examples attributable to imbalanced fertilizer use in modern agriculture. However, despite the inadequacy of data, the following seven conclusions emerge from results based on field experiments in a number of tropical countries (Kanwar & Mudahar 1983).

1. The deficiency of sulphur in the tropics is widespread, but is not so readily observable as those of nitrogen and phosphorus. Ten countries in Asia, 22 in Africa and 16 in Latin America are reported to show responses to S application (Kanwar & Mudahar 1983). Significant responses to the 'application of sulphate S are expected. In some cases significant increases in crop yield have been obtained in greenhouse studies, and they could be considered as indicative of crop responses to sulphur and thus call for further field research. The studies also indicate that responses to fertilizers, specifically to nitrogen and phosphorus, will increase if the limiting factor, sulphur, is supplied.

2. In Asia sulphur responses were obtained in the 1970s with medium to high doses of fertilizer N, NP or NPK applied to improved cereal cultivars (rice or wheat). Marked responses to sulphur were observed

in oilseeds (groundnut, soybean, rape and mustard), legume forages such as alfalfa and berseem (*Trifolium alexandrinum*) and potatoes. Relevant work in India has been reviewed by Kanwar and Randhawa (1967) and later by Dev and Kumar (1982). It appears that most of the work was confined to coarse-textured soils and to high-yielding cultivars. Whether the problem is localized or extends to large areas has not been determined; nor has the sulphur application for the crop rotation been studied.

In Africa, most relevant research data concern such commercial crops as cotton, groundnut and tea, and it was done before the introduction of high-yielding cultivars, *i.e.*, before the 1970s. Since the introduction of high-yielding cultivars, or the post-independence period, very little research on sulphur fertilization seems to have been done on any crop and initially none on food crops. In view of the great food deficit in this continent, there is a need for intensive and well-coordinated research to assess the need for sulphur fertilizers for food crops.

In Latin America most research data relate to improved cultivars of rice, maize, soybean, cotton, coffee, beans and pasture legumes. Marked responses were obtained in the Campo Cerrado soils of Brazil, the highly weathered soils of the uplands, and the soils of volcanic origin in Colombia, Mexico, and Central America.

3. At present the sulphur deficiency under high-yielding cultivars may appear to be confined to those soils that are inherently poor. As the intensity of cropping and level of fertilization increases, sulphur deficiency may become a serious limiting factor, especially because of the decline in sulphur input from such high-analysis fertilizers as urea, triple superphosphate and potassium chloride that are free from sulphur or have low contents. It is observed that each additional 100 kg N, P_2O_5 and K_2O provided through these fertilizers causes a reduction of 120.0, 66.5 and 35.2 kg S, respectively. The changing shares of S in fertilizers over time in India brings out this issue vividly (Table 1).

There are clear indications that in Asia, particularly in India, Bangladesh and Indonesia, intensive cropping, combined with the use of high-yielding cultivars and heavy applications of sulphur-free fertilizer, are overstraining the sulphur supply reserves of the soil ecosystem and thus limiting the full potential of new cropping technologies. In 1980 the amount of sulphur taken up by field crops in India and Indonesia was estimated to be 784,000 and 130,000 tonnes, respectively whereas the corresponding addition through fertilizers was only 250,000 and 48,000 tonnes. It is a paradox that, while mountains of phosphogypsum, a by-product of the fertilizer industry, are accumulating, the crops are starving due to S deficiency in these countries.

4. A comparison of sulphur supply sources indicates that generally gypsum, or other sulphate sources, have proved to be the most effective additions for most soils and crops. The modifying effects of time and the method and dose of application have also been evident in many studies. Even a less efficient substance could become an effective sulphur sources if the cost : benefit relationship is favourable. However, economic evaluation of sulphur supply sources has generally been ignored.

5. In most tropical countries the sources of sulphur are gypsum, pyrites, or other sulphur-containing byproducts of agriculture and industry. Technology needs to be developed for the use of these substances as economic sources of S for plant nutrition. This is a challenge which the technologists, agronomists and economists have to face in order to determine whether to modify fertilizer contents, in order to incorporate sulphur from these sources, or to consider the selection of compound fertilizers and mixtures for different situations. Ammonium sulphate, potassium sulphate and single superphosphate, the traditional fertilizers, continue to be good sources of S in addition to primary plant nutrients. But, because of their short supply and higher cost, rational use of these for specific crops and soils has to be considered.

6. Long-term studies with tea, coffee and coconut have shown that sulphur-containing fertilizers, if continuously applied, build up reserves of adsorbed sulphate in soils which, in turn, reduce the amount of sulphur to be used annually. The results of two long-term experiments, one at Samaru (northern Nigeria) (Bromfield 1972) and the other at New Delhi (northern India) (Rao & Ghosh 1981), clearly indicate changes in S supply from soil under extensive and intensive cropping systems (Figure 1). Long-term studies and monitoring of changes in the status of nutrients in the soils through long-term experiments elsewhere may be desirable.

7. Finally, research experience in tropical agriculture also shows that both phosphate and lime accelerate losses of sulphate. Ensminger (1954) reported that after 18 years of fertilization with various rates of phosphate and sulphate the extraction of sulphate in the Cecil sandy loam soil (top 15 cm) was lowest with the highest level of phosphate use despite the high amount of sulphate added with it (Table 7). The effect of lime in reducing extractable sulphate from soils is shown in table 8. Thus the acid soils of the tropics, high in exchangeable aluminium are more prone to S deficiency. They require fertilizer management practices, or use of fertilizer products, that can reduce such losses without affecting the usefulness of the lime and phosphate applications.

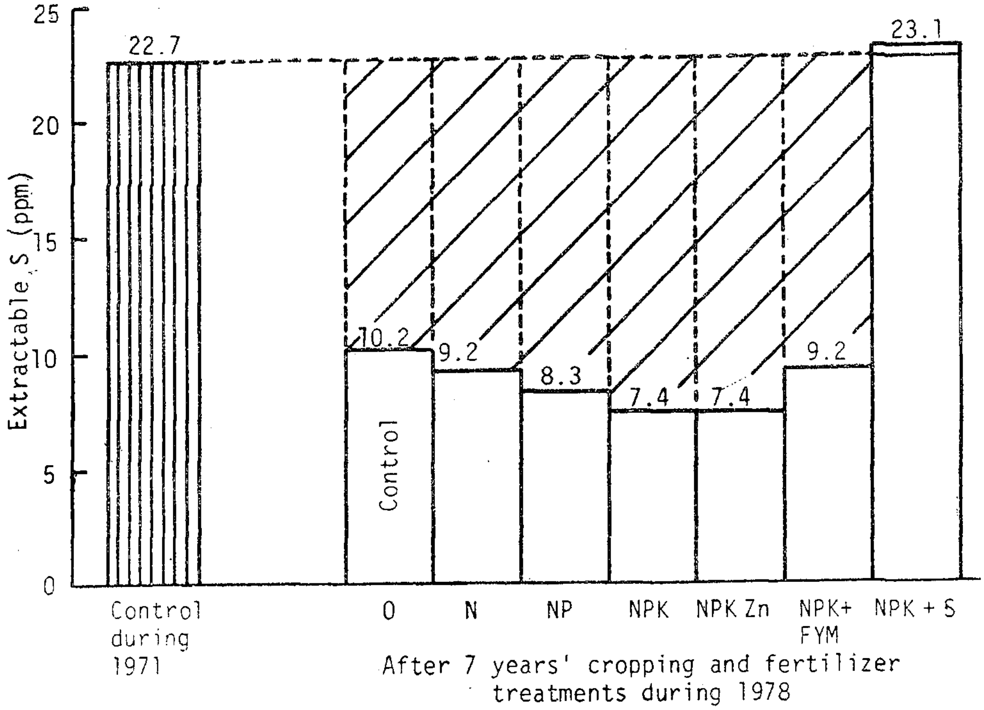

Fig. 1. Changes in S status under intensive cropping and different fertilizer treatments at IARI, New Delhi, India. (Area covered by cross hatching shows the reduction in extractable S)

Source : Rao and Ghosh (1981)

Table 7. *Sulphate* (SO_4) *content of Cecil sandy loam (0-15 cm) after 18 years of fertilization with various rates of P and S*

Amounts applied		Extractable SO_4-S
P	SO_4-S	
—(kg/ha)—		(ppm)
0	450	61
511	1,151	33
1022	1,864	1

Source : Ensminger (1954)

Table 8. *Effect of liming and leaching for 10 days on soil* SO_4 *content of Mount view soils*

Liming rate (t/ha)	pH	Leaching loss of SO_4 (%)
Typic Paleudult, silty loam		
0.0	4.3	15
0.5	4.7	19
1.0	5.0	24
2.0	5.6	34
Typic Paleudult, FSC loam		
0.0	4.5	41
1.0	6.3	64
2.5	7.0	71

Source : Korentajer *et al.* (1983)

Sulphur Status of Tropical Soils

The low amounts of organic carbon and hence, low S reserves in the surface of tropical soils, are increasingly exhausted by continuous cropping, leaching and the lack of replenishment of the nutrients lost. The coarse-textured and highly-weathered soils of the tropics, such as Ultisols, Oxisols and Alfisols besides Incepitsols are either inherently deficient in S or are likely to become more deficient after the clearing and burning of the vegetation and continuous cropping. The changes in S trends in virgin and continuously-cropped lands of Brazil and Nigeria indicate that induced S deficiency will soon become a limiting factor for crop production (McClung *et al.* 1959; Bromfield 1972).

The changing scenario of fertilizer use is accentuating the S deficiency problem. Kanwar and Mudahar (1983) have concluded from published information that the priority areas for research on sulphur-deficient soils and crops are as indicated in table 9.

Sulphur Balance Sheet and Likely Scenarios

The S balance sheet in a soil will depend on the external additions and removals. Figure 2 is a schematic diagram of S supply and removal components.

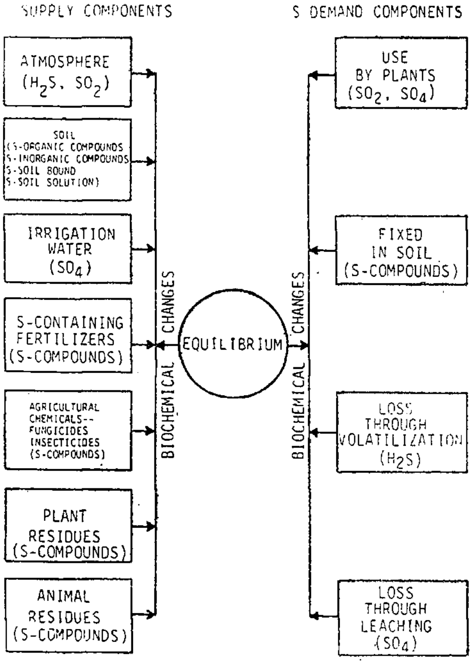

Fig. 2. Components of sulphur supply and demand in the soil-plant-atmosphere system

Table 9. *Priority areas for fertilizer sulphur research and policy*

Country	Areas within the country	Crops
India	Coarse-textured sandy soils of alluvial plains of Punjab, Haryana, Uttar Pradesh, Rajasthan and certain pockets of Gujarat	Groundnut, rape, mustard wheat, maize, chickpeas, soybean, berseem, potatoes
Bangladesh	Lowland rice areas	Rice, wheat, mustard
Thailand	Plateau of northeast Thailand	Rice, soybean, pulses, pasture
Indonesia	Sulawesi, East Java	Rice, pasture
Nigeria	Northern Nigeria	Maize, sorghum, roots, tubers, cowpea, groundnut
Senegal	Central and southern Senegal	Groundnut, cotton, millet, maize
Kenya	(1) Coastal sandy soils (2) Sandy loam soils for Kitale and Songhor regions (3) Volcanic soils near Kilimanjaro (4) Bottom lands of Machakos area	Maize, cotton, pastures
Zimbabwe	Sandy soils	Maize, groundnut, tea
Brazil	Highly-weathered soils of Brazilian Plateau and Campo Cerrado soils of Sao Paulo region	Maize, rice, cotton, pastures soybean, coffee
Colombia	Bogota Highlands Eastern plains (Llanos)	Maize, soybean, beans, pasture, legumes, coffee

Source : Kanwar and Mudahar (1983)

On the basis of estimates for the average S removal and additions, Kanwar and Mudahar (1983) have developed a balance sheet and likely scenarios for subsistence and modern agriculture in the tropics. The balance sheet (Table 10) clearly indicates that serious S problems are emerging in the tropics, particularly under modern intensive agriculture. It indicates the need for S fertilization for replenishing the S deficits. Assuming that S fertilizer efficiency is 28.75 or 57.50%, the fertilizer S required for replenishments can be calculated by multiplying the S deficit by a factor of 3.50 or 1.75, respectively. From the above it may be seen that the S deficit is 0.6, 1.4, 21.1, 50.9 and 38.9 kg/ha, depending upon the level of production, fertilizer use, sulphate content of irrigation water, and subsistence or modern intensive agriculture. The S deficit will rise to 1.6, 2.4, 29.1, 66.9, and 54.9 kg/ha if the applied fertilizers have no S in them. This model can be used for calculating the actual fertilizer S needs for a given ecosystem. Kanwar and Mudahar (1983) have also calculated that fertilizer S required (S deficit × 3.50) will vary from 5.6 to 234.2 kg S/ha under change from subsistence to modern agriculture.

Table 10. *Sulphur additions, removals, balance and replacement requirements under subsistence and modern agriculture : Likely alternative scenarios*

Sources	Subsistence agriculture		Modern agriculture			Assumptions
	1	2	1	2	3	
1	2	3	4	5	6	7
		........(kg/ha of S)......				
Additions						
1. Atmospheric additions (rain-dust-gaseous)	3.0	3.0	3.0	3.0	3.0	3 kg/ha/annum (means for Nigeria and Kenya are 2.35 and 5.21 kg/ha)
2. Irrigation water						
Rainfed crop	—	—	—	—	—	
Irrigated, 30 cm water	—	2.0	—	—	—	Water* containing 2 ppm SO_4—S
Irrigated, 90 cm water	—	—	6.0	6.0	—	Water containing 2 ppm SO_4—S
Irrigated, 90 cm water	—	—	—	—	30.0	Water containing 10 ppm SO_4—S
3. Fertilizers ($N+P_2O_5+K_2O$)						
15 kg nutrients	1.0	1.0	—	—	—	India's mean in 1970=13.2 kg/ha
120 kg nutrients	—	—	8.0	—	—	Approximately equal to mean of Punjab (India) and 2 times that of Brazil and Indonesia
240 kg nutrients	—	—	—	16.0	16.0	Approximately equal to mean of Ludhiana district in Punjab, India
4. Pesticides and chemicals	—	—	—	—	—	Negligible
5. Farmyard manure (FYM) 1 mt/3 years	0.6	0.6	—	—	—	0.2% S in FYM
2 mt/3 years	—	—	1.2	1.2	1.2	0.2% S in FYM
6. Crop residues	—	—	—	—	—	All removed or burned**
Total Additions	4.6	6.6	18.2	26.2	50.2	

Table 10 (contd)

1	2	3	4	5	6	7
Removals						
1. Crops						
L_{00}	4.6	—	—	—	—	Yield less than 1 mt/ha (mean yield of India 1970)
L_{01},	—	6.9	—	—	—	Irrigated subsistence (yield 50% higher)
L_1, intensive cropping	—	—	36.0			L_1=6 mt/ha food grain/year for 2-3 crops
L_2, intensive cropping	—	—	—	72.0	72.0	L_2=12 mt/ha food grain/year for 2-3 crops
2. Drainage or leaching loss	0.6	0.6	—	—	—	1/2 of estimate of Nigeria and Kenya
	—	—	1.8	3.6	9.6	Higher leaching because of higher SO_4 content and higher irrigation
3. Adsorbed or immobilized S in irrigation water	0.0	0.5	1.5	1.5	7.5	1/4 of S from irrigation water
Total Removals	5.2	8.0	39.3	77.1	89.1	
Balance						
Balance (deficit) I	—0.6	—1.4	—21.1	—50.9	—38.9	Similar share of S in fertilizer as in 1980-81 in India (1/15 of nutrients)
Balance (deficit) II	—1.6	—2.4	—29.1	—66.9	—54.9	Completely S-free fertilizers used
Replacement Requirements						
Fertilizer S required, I	1.1	2.5	36.9	88.1	68.1	S deficit I × 1.75
Fertilizer S required, II	2.8	4.2	50.9	117.1	96.1	S deficit II × 1.75
Fertilizer S required, I	2.2	5.0	73.8	176.2	136.2	S deficit I × 3.50
Fertilizer S required, II	5.6	8.4	101.8	234.2	192.2	S deficit II × 3.50

* Assuming all the SO_4 remains within the root zone, which is not likely

** If burned, some SO_4 may be retained by Ca, K and Mg in ash. However, empirical estimates are not available

Source : Kanwar and Mudahar (1983)

Sulphur Gap Estimates

Kanwar and Mudahar (1983), using data on S uptake by 15 important crop groups (based on actual production data for 1960-80 and the projected production for the year 2000 AD), have calculated the S requirements for 11 tropical countries and the world. The tropical countries are India, Indonesia, Philippines, Kenya, Niger, Nigeria, Sudan, Zimbabwe, Brazil, Colombia and Mexico.

The S gap in India is shown in figure 3. It may be observed that in India there will, with present trends, be a need for 4.665 million tonnes of fertilizer S to replenish the S uptake by the crops by the year 2000 AD.

Strategy to Meet the S Problem

It is recognized that S is a neglected plant nutrient and its deficiency is reducing the yield and quality of groundnut produce and affecting animal nutrition in tropical soils. The growing demand for gypsum and other sulphur-supplying substances in some states of India is partly due to increasing S deficiency for growing crops in the region. The gap between S supply and withdrawal from the soil is increasing under the changing scenario of agricultural production and there is a need for rational fertilizer use policy and an intensification of research on the dynamics of S applied through fertilizers and manures, under different cropping systems.

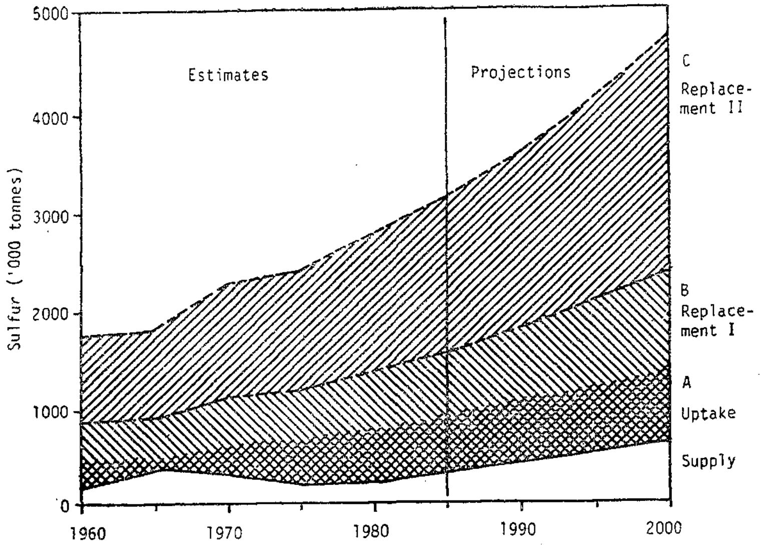

Fig. 3. Estimated sulphur requirements, fertilizer supply and sulphur gaps in India
A=Gap I A+B=Gap II A+B+C=Gap III

Gap I. S uptake—S supplied through fertilizers considering normal traits

Gap II. Replacement—I was calculated by multiplying S uptake by 1.75. Thus area A & B is Gap II

Gap III. Difference between sulphur supply and sulphur replacement requirements with sulphur replacement coefficient of 3.50. Thus area A+B+C is Gap III

Monitoring S accretion to the ecosystem from the atmosphere through rain, dust and gaseous deposition at a few selected sites, representative of the major agricultural areas is necessary. Assessment of sulphate content of irrigation water and its contribution to the S status of soils, crops and nutrient supply, S losses in drainage water and adsorption in the soil need to be studied.

Identifying local sources of sulphate S, characterizing their chemical attributes, determining their supply status and developing a strategy for their use as economic sources of S-containing fertilizers is necessary. For India, it may be desirable to lay greater emphasis on gypsum, pyrites, organic manures and fertilizer mixtures containing sulphur. The fertilizer industry should develop technology for upgrading the sulphate content of triple superphosphate and nitrogenous fertilizers.

Development of a strategy for the use of such byproducts of the fertilizer industry as phosphogypsum, to enrich the nitrogenous, phosphatic and potassic fertilizers with S, should be considered.

Development strategies and economic policies for encouraging the production, pricing, marketing, distribution and use of sulphur-containing fertilizers and soil amendments for improving crop yields and quality are necessary. Preference should be given to fertilization with sulphur-containing fertilizers and in production of pulses, oilseeds, legumes, tea, coffee, tobacco and cereals, especially high-yielding cultivars, and in intensive cropping systems.

To sum up, there is a need to critically examine the fertilizer manufacture, use and research policies in tropical countries and to recognize the importance of S-providing fertilizers for increasing food production and improving its quality. The problem of S deficiency is increasing and present fertilizer manufacture, pricing and distribution policies aggravate it. The widening ratios of N : S and P : S are indicators of the imbalanced use of fertilizers, which affects both the efficiency of fertilizers and the realization of the full potential of improved agricultural technologies. Phosphogypsum, a byproduct of the fertilizer industry, gypsum and other sulphur-containing resources need to be given due consideration in agricultural production.

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