PROCEEDINGS OF THE NATIONAL SEMINAR ON SULPHUR IN AGRICULTURE

OCTOBER 18 & 19, 1985

TAMIL NADU AGRICULTURAL UNIVERSITY, COIMBATORE

AND

FACT

THE FERTILISERS AND CHEMICALS TRAVANCORE LTD., UDYOGAMANDAL.

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PREFACE

Fertilisers play a key role in increasing food production in our country. Today we are the fourth largest producer and user of this vital input.

With the modernisation of agriculture and the recent shift towards the large scale use of high analysis fertilisers, nutrients other than N,P and K have shot up into prominance. Scientists have pointed out that among these nutrients; Sulphur is the one that warrants immediate attention. Its deficiencies are becoming widespread and crop removals are on the increase. It is estimated that while the present crop removal of Sulphur is around one million tonnes, only 0.35 million is applied to the soil.

Fertilisers and Chemicals Travancore Limited (FACT) has been manufacturing and marketing Sulphur containing fertilisers, namely, Ammonium Phosphate Sulphate (Factamfos 20:20) and Ammonium Sulphate during the last three decades. FACT believes that fertiliser education and rural development are its responsibilites and it has been undertaking a series of activities to promote the use of fertilisers in the South. FACT has sponsored many research programmes on Sulphur in the Southern Agricultural Universities and Research Stations.

I am happy that we have organised a "National Seminar on Sulphur" in collaboration with Tamil Nadu Agricultural University at its Coimbatore campus. Scientists from all over the country have attended this Symposium and presented valuable scientific papers.

I hope that the enclosed proceedings of the above Seminar will be of immense use for the researchers, administrators, extension workers and the fertiliser industry.

N.B.CHANDRAN
CHAIRMAN AND MANAGING DIRECTOR
Fertilizers and Chemicals Travancore Ltd.
Udyogamandal, Kerala

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CONTENTS

ABSTRACTS

PRESIDENTIAL ADDRESS

NUTRIENT SULPHUR

Dr.V. RAJAGOPALAN

Vice-Chancellor, Tamil Nadu Agricultural University,

India achieved a production level of 154 mt. . of food grain during the last year and among the major contributing factors to this spectacular achievement could be the use of chemical fertilizers in a big way. From a meagre quantity 0·05 mt. . of NPK used in 1953-54, the use of fertilizer NPK has increased to a spectacular quantity of nearly eight mt. during 1983-84. To achieve a production of nearly 230 mt. in 2000 AD, it is estimated that nearly 15 mt. of NPK may be necessary. A perusal of some of these vital statistics would go to indicate that much emphasis has been on the "Fertilizer trio" NPK only. Though, it is to be admitted that these "Fertilizer trio, NPK" played the major role and will continue to play in the years to come in increasing the agricultural production, it has to be realised, atleast now, that there are other plant nutrients which may be constraint in agricultural production. Now sulphur seems to have become a real constraint in crop production.

The importance of sulphur for plant growth has been recognised for long and its deficiency in soils and consequent losses in productivity have been reported recently, not until the last one or two decades. The importance of sulphur is equal to that of nitrogen in terms of protein synthesis and in terms of crop uptake it exceeds that of even phosphorus. Inspite of these significant factors, the role played by the sulphur especially under tropical agriculture has not been fully realised during the past, mainly because of the fact that

Presidential Address delivered by Dr. V. Rajagopalan, Vice-Chancellor at the National Seminar on Sulphur in Agriculture at Tamil Nadu Agricultural University, Coimbatore on October 18, 1985.

sulphur deficiency was not a serious problem then. When the crop yields were low and extensive agriculture was practiced the sulphur added through rain, irrigation water, manures and sulphur containing fertilizers were found to be responsible for low demand resulting in no deficiency.

However, during the recent 10 or 15 years, reports started coming in indicating widespread sulphur deficiency, both inherent and induced, which limited crop growth and yield. Since sulphur is also related to the protein synthesis, deficiencies found to cause poor quality crop products (Sulphur is recognised as a "Quality nutrient"). Due to intensification of agriculture, use of improved high-yielding crop varieties and increased use of sulphur-free high analysis fertilizers, there has been a steady decline in the sulphur status in the cultivable soils leading to deficiencies. These interrelated agricultural production technologies have aggrevated the problem and now the stage has come that sulphur deficiency is a constraint to agricultural production and increased agricultural production could be possible only by a rationalised use of sulphur fertilizers.

Under this background it is necessary that steps are taken to identify the situation specific problems in relation to sulphur nutrition, different sulphur sources are properly evaluated and attempts are made to transfer the economically efficient fertilizer use technology in relation NPK and S. The following areas need consideration in the present context.

— Evaluation of sulphur supplying power of the soils and delineation of sulphur deficiencies in the soils under different agro-climatic and ecological situations. Appropriate soil and plant analysis techniques should form the basis for effective evaluation of soil sulphur status. Data have to be generated to identify properly both the inherent and induced sulphur deficiencies.

— Conduct of detailed experiments to evaluate the responses when sulphur responsive crops are grown in sulphur deficient soils and while studying the responses to added sulphur, concurrent assessment should be made with reference to the interactions of sulphur with N, P, K, Zn and Ca.

— Long term monitoring may be necessary so that the continued withholding of sulphur or application of S in the intensive cropping system can be evaluated. Suitable bench mark studies representing the various soil-crop eco-system may be necessary.

— As irrigation waters appear to be good source of sulphur for crops, a proper assessment may be necessary under different situations.

— It is known that some good quantities of sulphur is brought down from the atmosphere through rain, dust and industrial gaseous products. A proper monitoring of this may be necessary.

— Strategies may have to be evolved to use local resources like pyrite, gypsum etc., as we do not have sulphur deposits in the country and it has to be imported at a high cost. While doing so, a detailed and proper appraisal of each source may be necessary before the materials are recommended for use.

— Techniques may have to be evolved for preparing sulphur enriched nitrogenous and phosphatic fertilizers.

— Integrated nutrient management and techniques for increased fertilizer use efficiency in relation to sulphur may be important.

— Use of nutrient sulphur in terms of improving the quality of crop products may be given priority besides any possible yield increase.

Key Note Address

SULPHUR IN INDIAN AGRICULTURE

Dr. M. VELAYUDHAM,
Assistant Director General (Soils), ICAR, New Delhi.

In the last three decades, India's achievement in Agricultural sector is spectacular having attained an annual food production of nearly 156 million tonnes, which has created a situation of food security. So also, the statistics on fertilizer consumption during 1975-76 to 1984-85 reveal that there is a steady increase of nearly 0·6 million tonnes of plant nutrients annually, which is almost three times of the increase recorded in the previous years. During the 7th plan period, it is expected to produce 180 million tonnes of food grain by 1989-90 with the consumption of about 12 million tonnes of fertilizer nutrients.

Further, India's foodgrain requirement would be about 230 million tonnes by 2000 AD to feed its population of almost a thousand million. To meet the projected target of food grain production, fertilizer requirement for 2000 AD has been projected by the National Commission on Agriculture to be 14 million tonnes of nutrient. Further, the production of targeted food grains could be possible only through balanced use of plant nutrients coupled with appropriate management techniques.

At this stage the scientists and the farmers are fully aware of the significance of balanced fertilization through organic and inorganic fertilizers in the food production. However, the balanced fertilization has been apparently restricted with the use of the major nutrients like N, P and K and to some extent the micronutrients such as Zn and Fe. The significance of the so called secondary nutrients in general, particularly sulphur, in the plant nutrition may also be known but this element has been neglected hitherto because of its incidental addition through inorganic fertilizers, recycling of farm wastes in crop production, use of sulphur containing fuels in the industries, addition through rain and irrigation water etc.

As fertilizer use has progressed, we have seen a marked shift towards the production and usage of sulphur free materials, more so, in the intensively cultivated areas. Current estimates are that the annual crop uptakes of S in India is in the neighbourhood of one million tonnes whereas, additions through fertilizers, are around 0·34 million tonnes only. This gap is projected to widen and unless it is bridged, S deficiencies could develop into a serious constraint and even reduce the efficiency of other fertilizer nutrients in the crop production.

The significance of sulphur in the plant nutrition has not been fully recognised till now and only in recent years, sulphur was included in the fertilizer recommendations. In India research on sulphur in a systematic way has been taken up only during the past 10 or 15 years. Widespread deficiencies of sulphur were reported from the groundnut growing soils of Punjab and the tea growing areas of Himachal Pradesh. A number of alluvial, red and laterite soils were considred to be deficient in sulphur. Significant sulphur responses have been reported for more than 30 crops. In the field studies, it has been recorded that each unit of sulphur added to S deficient soils increased the yield of wheat by 12 units, of mustard by 9, of groundnut by 7 and of tubers by 14 units.

Sulphur as an essential nutrient, resembles nitrogen in its role and function in plant production, is comparable to phosphorus in respect of overall crop needs and could be equated with potassium in terms per unit cost. It is essential for the proper functioning of some protolytic enzymes, formation of glucosides in crops like onion and garlic and production of ferrodoxin being the electron acceptor in the photosynthetic process of crop plants besides a role in the biological nitrogen fixation by microbes.

In addition to the above metabolic functions, it is considered as quality element. It highly influences the quality of sugarcane, oilseed and pulses. In tea, the deficiency of sulphur causes "Yellow of Tea" which afects the market values of the exported tea. Apart from increasing the crude protein content of fodders, sulphur plays an important part in determining the optimum N : S ratio. For normal protein production, alfalfa required one unit of sulphur for every10-12 units of nitrogen. Application of sulphur reduced the HCN concentration in cassava.

The gap between crop removals and additions of sulphur through various sources is likely to increase with increasing levels of agricultural production. If 50% of sulphur taken up by crops is to be replaced, it would require the application of 2 million tonnes S at 25% efficiency and 1.7 million tonnes S if the efficiency is taken as 33%. The 0.4 million tonnes of S delivered through fertilizer can be valued at Rs. 1750/t of S. If the prevailing fertilizer prices are compensated for the S at Rs. 1.75 /Kg S, then the per unit cost of N, P and K in S containing fertilizers comes down.

Considering the quantum of available information on S in relation to that on the other elements of importance to Indian Agriculture, an overall stepping up of sulphur research and its coordination seems necessary. Only through research, we can find the overall magnitude of sulphur deficiency, its practical implications and the alleviation of this constraint through suitable technologies. First of all, its need, presence and utility has to be recognised.

Sulphur should not be treated as an extra as this attitude adds to its neglect in fertilizer planning. It should be assigned a value and put to work as a yield-raising input. Fertilizer recommendations should include the application of S wherever conclusive research evidence is available. Data on the sulphur content of fertilizer, deficient areas, response yardsticks etc. should find a regular place in fertilizer and agricultural statistics.

At the present situation, scientists are more concerned due to the depletion of soil sulphur, with continued use of sulphur free high analysis fertilizers, cultivation of high yielding varieties of crops and with little or no cycling of farm wastes. Thus the situation forced us to take up the research projects on sulphur in Agriculture without waiting for the deficiency to occur and to take up this work which probably may be too late to correct the melady. Considering the importance of sulphur in crop production, it has also been decided to take up research projects on sulphur in the ICAR Coordinated project on "Micronutrients" operating at different centres of this country.

In terms of future stagery it has to be fully recognised that S is a neglected plant nutrient and its deficiency reduces the crop yields and affects the quality of the crops. The growing demand for gypsum and other S containing substances in some states of India is partly due to the increasing S deficiency for growing crops in the region. The gap between S supply and crop removal is increasing under the changing pattern of agricultural production and thus 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 croping systems.

Monitoring sulphur addition to the ecosystems from the atmosphere through rain, dust and gaseous deposits at a few selected sites, representative of the major agricultural areas is necessary. Also assessment of SO_4 content in 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 in great detail.

There are clear indications that the intensive cropping combined with the use of high yielding cultivars and heavy application of S free fertilizer are depleting the S supplying reserves of the soil ecosystem and thus limiting the fuel potential of new cropping technologies. In India the amount of S taken up by field crops during 1980 was estimated to be 784,000 tonnes whereas the addition through fertilizers was only 2,50000 tones. 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 this country the sources of S are gypsum, pyrites and other S containing by-products 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, soil scientists, agronomists and economists have to face in order todertermine whether to modify fertilizer contents in order to incorporate S from these sources, or to consider the selection of compound fertilizers and mixtures for different situations. Ammonium sulphate, potassium sulphate and single super phosphate, 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 have to be considerd.

Identifying local sources of sulphate-S, characterising their chemical attributes, determining their supply status and developing a strategy for their use as economic sources of S containing fertilizers is necessary.

I should appreciate the Tamil Nadu Agricultural University and M/s Fertilizers And Chemicals Travancore Limited (FACT) for having organised a National Seminar recognising the importance of sulphur in agriculture at this juncture. I could see from the printed abstract circulated this day that the subject had been well covered with all aspects of sulphur in agriculture. I am sure that this seminar represented by several distinguished scientists from all parts of this country will create an exchange of information and experiences which will definitely bring a new dimension for future research programme on this line and useful conclusions which can directly be passed on to the farming community to adopt it in the crop production.

I am happy to participate and present this key note address this day as one of the alumni of this institution and as a soil scientist. I wish your stay in this campus be pleasant and the deliberations fruitful.

SULPHUR IN INDIAN AGRICULTURE - AN OVERVIEW

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ABSTRACT

Sulphur may have been classified as a secondary plant nutrient, but today, it is of primary practical importance to Indian agiculture. Sulphur deficiency, in India, is reported to occur across diverse soil-crop environments. Perhaps 15-20% of the crop land, scattered in 90 districts may be affected by varying degrees of S-deficiency but no precise estimates of the problem are available. Crop responses and economic advantages from S application are quite attractive, in many cases on par with those resulting from N, P and K applications. Mean responses to S application in the field are (kg yield/kg S) 12-22 for cereals, 6-10 for grain legumes, 4-16 for oilseeds, 70-78 for tubers and 45-78 for forages. Each unit of S applied on S-deficient soils can augment the supply of edible oils by 3.0-3.5 tonnes.

Intensive cropping systems may remove upto 70 kg S/ha/year from the soil. Annual S removal by crops in India is estimated at 0.9-1.0 million tonnes while addition through fertilizers is around 0.35 million tonnes. Thus, it is reasonable to conclude that Indian soils are being depleted of S. This must be checked to ensure optimum responses to other nutrients and investments at the farm Level. By all accounts, S research needs to be intensified and co-ordinated. Delineation of S-deficient areas and derivation of optimum application rates are two priority sectors. Where proven date exist, these should be included in the recommendations for the use of extension advisory services. The agro-economic value of S in fertilizers should receive recognition and fertilizer containing sulphur should preferentially be directed at areas which are also deficient in S in addition to the other primary nutrients concerned.

Agriculture in India has made noteworthy progress since its modernisation began in the early 1950s. During the 1951—1984 period, India's foodgrain production increased by 150%, from 60 to 151 million tonnes per annum. One of the most important factors responsible for such an achievement has been the use of chemical fertilizers. From 60,000 tonnes of nutrients in 1951, India today is the fourth largest user of fertilizers, consuming 8.4 million tonnes of N + P_2O_5 + K_2O during 1984-85. That is a 140-fold increase. About 35-40% of the current food-grain output can be attributed to fertilizers, a figure which is estimated to reach 50-55% by the turn of this century (Randhawa and Tandon, 1982).

The five nutrients of widespread practical importance for Indian farmers are N, P, K, S and Zn. Cases of S-deficiency and crop responses to its application are increasingly being reported (Dev and Kumar, 1982; FAI (NRC), 1984; and Kanwar and Mudahar, 1983). However, the inclusion of S in balanced fertilization programmes has not taken place yet. The absence of consolidated and critically-examined information about this nutrient may be partly responsible for this neglect. For a country which is making large-scale investments and efforts in agricultural development, it is essential to ensure that no limiting factor develops into a constraint which may limit crop yields and in the process reduce the optimum utilization of NPK as well as all other inputs in which the farmers have invested. This overview is based on a more comprehensive analysis of sulphur research and agricultural production in India (Tandon, 1984a).

CAUSES OF SULPHUR DEFICIENCY

Systematic research on S in India began about 25 years ago. Widespread deficiency of S was reported from soils under tea and groundnut in the northern States. Based on soil analyses, a number of alluvial, red and laterite soils were found to be low in available S. Since then, S-deficiency has been reported from several parts of India and in many cases this has been corroborated by yield responses to S application. The major causes of S-deficiency in India are:

- Accelerated removal of S by increasing levels of agricultural production 2.5-3.0 times in 25-30 years).

- Relatively higher net depletion of S per unit crop produced due to removal of straw etc., along with the grain in traditional farming large-scale shifts towards S-free materials in the fertilizer distribution pattern over the years (N : S ratio 1.4 in 1963, 5.5 in 1973 and 11.9 in 1983).

- Particularly stronger shifts towards the use of S-free materials in States having light-textured, intensively cropped soils which produce above average yields (N : S of 11.9 for all India, 25.8 for the Punjab State as an example.)

- Widening gap between the additions and removals of S in agriculture.

- About 40 million hectares under crops which have a high requirement of S per unit grain yield (grain legumes, oilseeds).

- Probability of leaching losses of S from soils in high rainfall area and from light-textured soils under flood irrigation.

There is however, no quantitative account of the S going into or going out of the 143 million hectares cropped each year which takes into account all the components of S addition and removal. A rather preliminary balance sheet of S in Indian agriculture has been attempted (Tandon, 1984a) but obviously a greater deal more needs to be done in this area.

SULPHUR IN SOILS

Total S content of surface soils of India can vary from 19 ppm to 3836 ppm S. Several fold variations are possible within a geographic zone. It can range from 85 to 3836 ppm within a State, from 213 to 582 ppm within a district and from 551 to 2206 ppm within the same catena. Heavy-textured soils generally have more S than medium or light-textured soils. In Bihar and the erstwhile Punjab (which included acidic hilly areas now in Himachal Pradesh) higher S contents were reported from acid soils as compared to alkaline soils but reverse was the case when soils from different parts of the Maharashtra State were studied.

Information on different forms of S in Indian soils has been summarised by Dev and Kumar (1982) and by Kanwar and Randhawa (1974). Organic S, like organic N can contribute to available S for crop use through mineralization. Pathways of the transformation of N and S are similar in many ways. Organic S is generally 8-10% of the organic N. Main components of the S-cycle are presented in Figure 1.

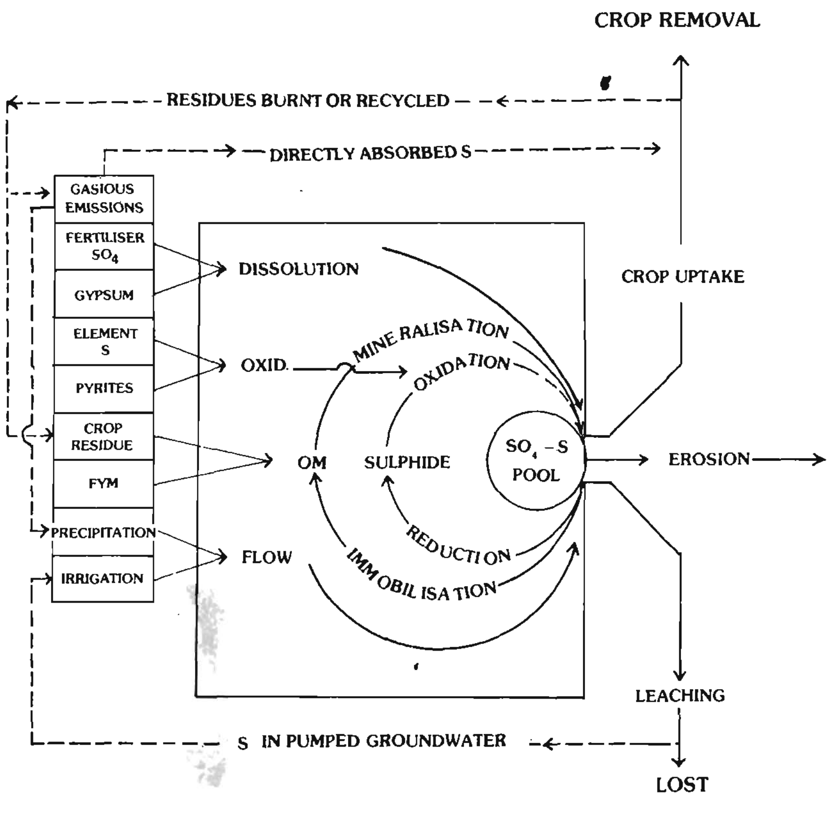
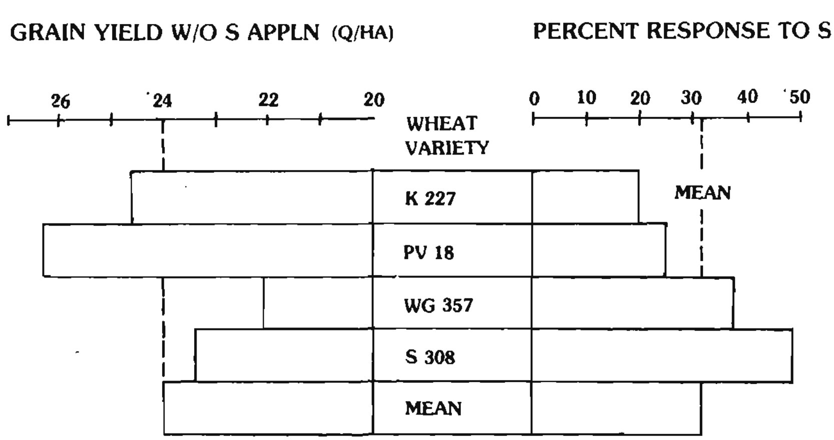


Fig 1. Dynamics of sulphur in the agricultural soils of India

The pool of available S and the fractions which contribute to it are a fair indication of the S-supplying capacity of a soil but a pool-proof description of available soil S is not always possible. This pool has an important bearing on the amounts of S a soil can furnish for the crop's nutrition. The water-soluble sulphate-S in Indian soils is within 10% of the total S, but can vary widely. Almost all the known extractants and techniques have been employed to estimate available S in soils (Dev and Kumar, 1982). Since the 1960s, 10 ppm available S continues to be the most frequently mentioned figure below which a soil is pronounced as deficient in S. In reality, the so called critical limits depend very much on the soil properties, the extraction method used and the crop. These can range from 8 ppm to 30 ppm available S. Available data on differential response of genotypes to S show that even the crop variety used may be an important variable in the calculation and interpretation of such limits (Aulakh et al., 1977). This is illustrated in Figure 2. The author is of the opinion that a condition describing the probability of response should be attached to such critical limits.

Fig. 2



Research in India is more heavily in favour of soil analysis than in favour of integrated soil-plant diagnostic approach for describing the sulphur status of soils and plants.

AREAS OF SULPHUR DEFICIENCY

Consolidation of available information shows that S deficiencies in Indian soils are more extensive and variable than generally thought to be. Although the coarse-textured, low organic matter-containing soils of the plains are more vulnerable (Pasricha et al., 1975), the occurrence of S deficiencies extends well beyond such areas. Some of the areas reported to have a S-deficiency problem are: the Indo-Gangetic alluvial and black soils in U.P., Gujarat, Madhya Pradesh; certain black soils in Maharashtra, tea-growing soils of Himachal Pradesh ; red and laterite soils in Karnataka, Kerala and West Bengal and the mixed red-yellow soil of Uttar Pradesh. Within a State, the probable area deficient in S can vary from negligible in some districts to 40% of the crop land in other districts as in the case of Punjab (Takkar, 1984). Within a district the deficiency of S may be encountered in some soil series but not in others as in the case of Coimbatore district. In cultivated soils, the S status is strongly influenced by a number of other factors such as the cropping pattern, cropping intensity, yield levels, rates and types of fertilizers used, crop residue recycling and factors such as the sulphur status of irrigation waters, proximity to industrial activity etc. Data are available to show that soils initially well-supplied with S can become deficient within a few years of intensive agriculture without a S input (Das and Datta, 1975 and Subba Rao and Ghosh, 1981).

Soils in 90 out of 400 districts may have some degree of a S-deficiency problem. Figure 3 shows the geographic distribution of these districts. This is a very preliminary, tentative S-deficiency map of India. As pointed out earlier it does not mean that all fields in these districts are S-deficient. Nor does it mean that the soils in remaining districts are uniformly well-supplied with S. The fact is that for most districts, information on their S status is not available. One must point out the exclusion of Bihar from the map. Research reports indicate that Bihar soils may be deficient in S but because the

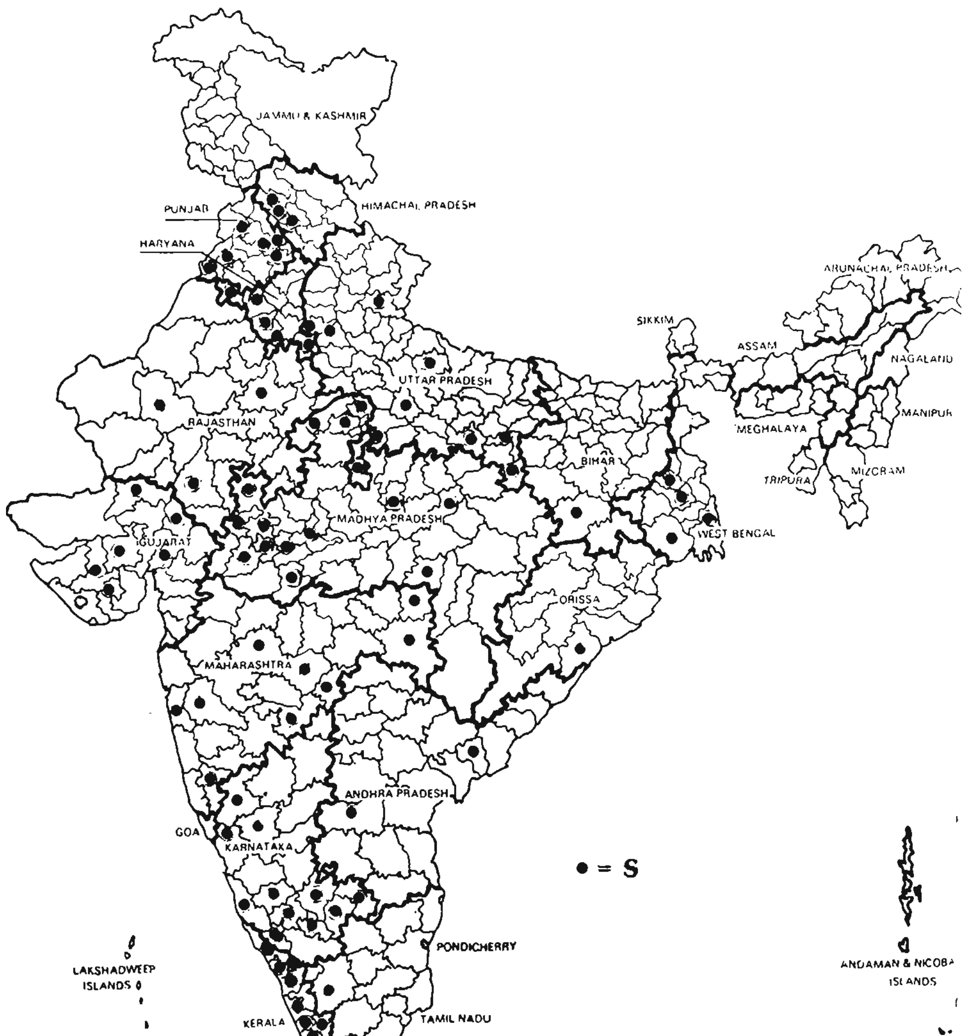


Fig 3. A preliminary map showing areas deficient in sulphur The dotted districts contain probable areas of S-deficiency/S-responsiveness in India (Details in Tandon 1984a)

geographic location of the soils analysed was not stated precisely, the research findings could not be used for mapping. The delineation of S-deficient areas is essential because such an exercise can form the basis for systematic efforts towards S application and correcting its deficiency.

The map in Figure 3 is based on available results (published and unpublished, provided by the research workers) of soil analyses, crop responses and nutrient surveys of standing crops. Sulphur deficiency and yield responses to its application have been reported both from irrigated and rainfed farming systems (Aulakh et al., 1977; Cheema and Arora, 1984; and Das and Datta, 1973 for irrigated and Ankineedu et al., 1983; Singh, 1983; and Rao and Das, 1983 for rainfed).

The heavy-textured calcareous soils in the State of Rajasthan present a different dimension of the role of S in increasing crop yields. Substantial increases in the yields of a number of crops have been reported by the application of elemental sulphur in these soils. Prevention of iron chlorosis is one of the key advantages attributed to S (Jain et al., 1984; and Singh, 1971)

Perhaps 15-20 percent of the cultivated area in India may have some degree of a S deficiency problem. This amounts to 22-29 million ha of the net sown area. Of course, large parts of the country have yet to be surveyed systematically - that is in co-ordination with soil survey and cropping pattern data. This is all the more necessary, particularly in areas where fertilizer application has reached moderate levels, particularly through S-free materials because even without the appearance of visible deficiency symptoms, a S-deficiency can cause 10-34% decrease in the yields.

YIELD RESPONSES TO SULPHUR APPLICATION

Yield responses of 30 crops to sulphur application have been studied in India. These include cereals, millets, legumes, tubers, crucifers, forages, fibres, vegetables etc. Information on some important crops such as grain sorghum which occupies 16 million ha is, however, scanty (Tandon and Kanwar, 1984). Nearly two-thirds of the crop experiments on S have been carried out under field conditions and one-third under greenhouse environments. Priority to crops providing foodgrains and edible oils is evident (Table 1).

Table 1.
Crop-wise pattern of sulphur research in India

Crop	Number of studies		
	Field	Greenhouse	Total
Cereals	11	6	17
Grain legumes *	9	2	11
TOTAL FOOD GRAINS	20	8	28
Groundnut	10	5	15
Mustards	13	5	18
Other Oilseeds	10	7	17
TOTAL OILSEEDS	33	17	50
Fodders	2	5	7
Other crops	12	3	15
ALL CROPS	67	33	100

* Pulses (Tandon, 1984 a)

A summary of yield responses to S application is provided in Table 2. It is based on experimental results obtained from replicated field experiments, except in the case of soybeans. A majority of these responses have been recorded on soils which were low in plant available S, that is less than 10 ppm available S, and in the presence of optimum levels of the other nutrients, mainly, N, P and K.

Table 2.
Average yield increases of crops to sulphur application in India

No.	Crop	Studies Averaged	Yield without S addition (q/ha)	Response to S (%) Range	Mean
1.	Wheat	6	26.1	9-186	27
2.	Rice	3	36.0	15-70	36
3.	Maize	1	51.0		10
4.	Pearl millet	1	14.3		15
5.	Chickpea	2	16.2	30-47	38
6.	Lentil	1	15.0		27
7.	Blackgram	1	8.4		23
8.	Kidney bean	1	4.5		51
9.	Groundnut	7	13.7	7-34	15
10.	Mustard	11	10.08	4-127	31
11.	Rai *	3	12.5	9-68	26
12.	Taramira@	1	4.5		88
13.	Sunflower	4	10.7	12-38	27
14.	Soybean+	4	7.3	22-34	27
15.	Potato	3	119	7-38	30
16.	Cassava	1	194		18
17.	Jute	1	19.3		21
18.	Tea	1	31.9		28
19.	Sugarcane	1	731		28
20.	Onion	3	24.8	2-41	19
21.	Sorghum++	1	226		35
22.	Berseem	1	109		49

* - Rai = Indian mustard = *Brassica juncea*
@ - Taramira = Rocket salad = *Eruca sativa*
\+ - Soybean data in terms of dry matter from greenhouse experiments. All other data from field experiments and economic yield.
++ - Sorghum grown for fodder
Experimental details and sources of information in Tandon (1984 a).

Mean yield increases due to S application ranged from 10 to 88% with a majority of cases recording 20-50% yield increase. For those crops where three or more sets of data are available for averaging, the mean yield response to S application was: groundnut 15%, onion 19%, wheat 27%, sunflower 27%, potato 30%, mustard 31% and paddy rice 36%. The mean response ratios in terms of kg extra yield per kg S applied were in the range of 12-22 for cereals, 6-10 for grain legumes, 4-16 for oilseeds, 70-78 for tubers and 45-78 for forages. These responses are based on rates of S application ranging from 25 to 120 kg S/ha but a majority of S applications were between 30 and 60 kg S/ha.

Considering that a response ratio of 9-10 kg grain per kg is commonly taken for agricultural planning in India, the yield responses to S are generally on par with those for N, P and K and in some cases even better depending upon the degree of deficiency and the level of S application. As described later, yield responses to S are also economically attractive.

CROP QUALITY

The crop quality aspect most frequently studied in India is the effect of sulphur on the oil content of oil seeds. Sulphur application can increase oil production by increasing seed yields or oil content in the seeds or by both. The effect of S on the oil content of some oilseeds is shown in Figure 4. Sulphur application resulted in 5-9% more oil in the seeds. With the domestic production of edible oils well below the requirements, S is clearly a key input in augmenting the supplies of oilseeds. Sulphur has also been known to increase the synthesis of amino acids, proteins, chlorophyll, starch etc., in plants. It can improve the quality of sugarcane juice and reduce the HCN concentration in certain crops including forages.

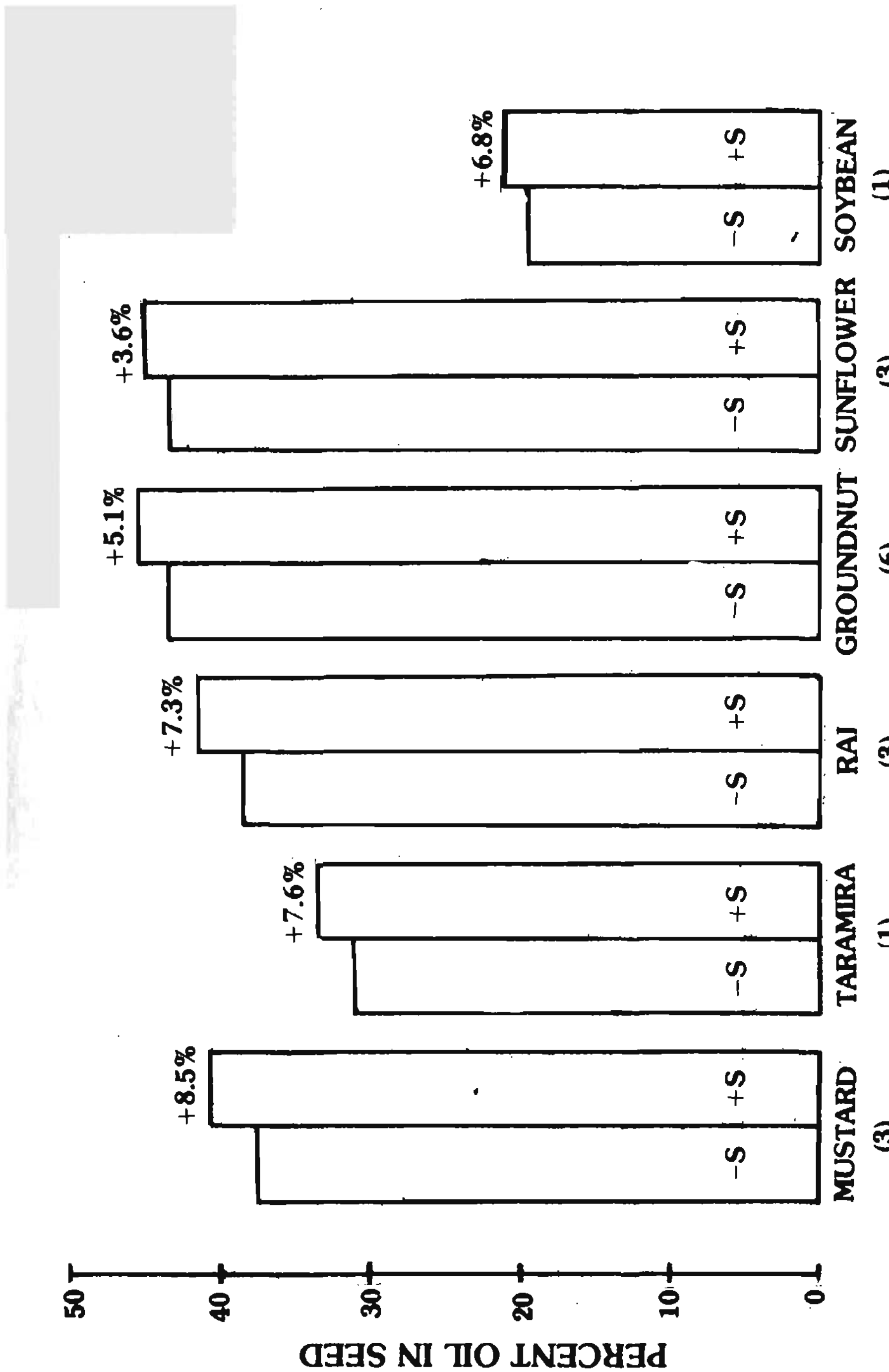


Fig 4 Effect of sulphur application (+S) on the oil content of some important oilseeds in India. Number in ( ) indicate the number of studies averaged

SULPHUR UPTAKE AND REQUIREMENTS

A cereal crop producing 4 t/ha of grain can remove 12-16 kg of S. Intensive cropping sequences can remove 30-72 kg S/ha/year under Indian conditions (Mehta and Raman, 1972; Nad and Goswami, 1984; Subba Rao and Ghosh, 1981). Data on two different cropping systems under comparable soil-climatic conditions show that at similar levels of dry matter production, a crucifer-legume-legume sequence removed 2.5 times more S than a cereal-legume-millet sequence. In a study for S in tropical countries a net requirement of 6 kg S per tonne of grain production has been reported, the requirement being in the order : oilseeds > pulses > cereals > millets (Kanwar and Mudahar, 1983).

In India the current removal of S by agricultural crops may be in the neighbourhood of 0.9-1.0 million tonnes S (Tandon, 1984a), that is about 5.3 kg S/ha of gross cropped area and 6.4 kg/ha of net cropped area. The sulphur input through fertilizers in use is about 0.35 million tonnes S (Tandon, 1984b). The overall S input varies from negligible in many States to an average of 4 kg S/ha in Andhra Pradesh. Some trends in the addition of S and its relationship with fertilizer N are given in Table 3. Unless corrective measures are taken, the gap between the additions and removals of S in Indian agriculture may widen in future with chances of nutritional imbalances and adverse effect on crop yields and quality. As a rule of thumb, crop removals of S are comparable to the removals of P. Sulphur needs of Indian agriculture will depend upon the magnitude of S deficiency in the soils, how much of the S removed should be applied and what is the efficiency of fertilizer S. If 50% of the S removed by crops is to be applied, this would indicate a S requirement of 0.9 million tonnes at 50% efficiency and 1.9 million tonnes S at 25% efficiency, the latter figure being closer to the figures on crop recovery of added S which have been reported in Indian literature (Dev and Kumar, 1982).

Table 3.
Trends in the addition of sulphur through fertilizers and the relation of sulphur with growth in nitrogen use in India

Fertilizer	Percent share of different fertilizers 1962-63	1972-73	1982-83
Ammonium sulphate (24)	76	59	36
Ammonium sulphate nitrate (12)	2	2	0
Single superphosphate (12)	21	30	43
Ammonium phosphate sulphate (15)	1	5	10
Diammonium phosphate (3)	0	4	8
Potassium sulphate (18)	0	neg	1
Zinc sulphate (15)	0	neg	2
Rock phosphate (4)	0	neg	1
Gypsum (13-20) *	?	?	?
Total S (thousand tonnes)	297	316	341
Total N (thousand tonnes)	426	1,742	4,034
N : S consumption ratio	1.4	5.5	11.9

* Quantities of gypsum used as a fertilizer not available,
Source: Tandon (1984 b). Based on data in FAI Fertilizer Statistics.

If the entire quantity of S removed by crops is to be added and the leaching losses have to be compensated for, the S requirement will go up. On the other hand, if the contribution from organic manures, irrigation waters, precipitation etc., is taken into account, the S requirements will again have to be modified. There are major gaps in our present information which make it difficult to make very accurate calculations. In tea, for example, the crop may require 20 kg S/ha but to compensate for leaching losses and other limitations, an annual application of 2-2.5 times the uptake is advocated (Bhat and Ranganathan, 1981).

POTENTIAL GAINS FROM SULPHUR APPLICATION

Assuming that 15-20% of the crop land may be affected by some degree of a S-deficiency problem, an area of 22-29 m. ha is involved. Each 0.1 tonne (100 kg) increase in grain yield due to 'S' application can add 2.2-2.9 million tonnes to grain production levels. Average yield increase of 0.2-0.5 tonnes/ha of grain due to S application in S-deficient areas is realistic. From planning point of view the production yardstick of 10 kg grain/kg nutrient used for NPK can be safely extended to S also.

Further, available data show that each kg of fertilizer S can add 3-3.5 kg to the edible oil production and contribute towards making the country self-sufficient in this commodity of human consumption. Yet there is no value-tag on fertilizer S because the quantities present in fertilizer are either ignored, passed of as "extras" or in some cases even described as impurities. Steps have to be taken to integrate S in agro-economic exercises. To make a beginning and as an illustration, a farmgate price of Rs. 1.75/kg S is taken here. This price is comparable to the price of S in gypsum which is the most common locally-available material.

At Rs. 1.75 kg S, for example, the S being distributed through various fertilizers in India can be valued at Rs. 600 million. The yield responses, when subjected to economic analyses indicate that quite high rates of return are possible from S application. On an average, each Rupee invested in S produced wheat worth Rs. 11, mustard seed worth Rs. 16, groundnut worth Rs. 11, and tubers worth Rs. 17 on sôils deficient in S and requiring its application for realising optimum yields.

It is necessary to include S in fertilizer recommendations where research date show its deficiency and these have been verified by field experiments. In this way, the extension workers will become aware of the importance of S in their areas, there will be a sound basis for advising farmers and finally, the research findings will be put to practical use.

FERTILIZERS CONTAINING SULPHUR

Some S-containing fertilizers of importance to agriculture are listed in Table 4. In India, ammonium sulphate, single superphosphate and ammonium phosphate account for 90 per cent of the S added through fertilizers. There has been a tremendous renewal of interest in the production and use of single superphosphate in recent years in India. This interest is continuing.

Table 4.
Nutrient content of some sulphur-containing materials of relevance to agriculture

Material	Nutrient content in percent			
	S	N	P_2O_5	K_2O
Ammonium sulphate	24	21		
Ammonium sulphate nitrate	15	26		
Ammonium phosphate sulphate	15	20	20	
Single superphosphate	12		16	
Pottassium sulphate	18			50
Sulphate of potash magnesia	16-22			22
Elemental sulphur	85-100			
Gypsum	13-20			
Phosphogypsum	11			
Zinc sulphate	15			
Iron pyrites	22-24			

Agricultural grade gypsum is quite often advocated as a source of S. It is primarily used as an amendment for the reclamation of salt-affected soils. Locally available agricultural grade pyrites are also being promoted as a S-fertilizer. Elemental S is largely imported. It is used as a raw material in fertilizer and other industries and not currently used as a S-fertilizer, Research has shown that it can be gainfully used for the treatment of heavy textured calcareous soils resulting in 7-102% increase in crop yields.

Choice of the most appropriate S-fertilizer to be used will depend on the soil, the crop, the time of application, local availability and cost. As a very general guideline, a sulphur application of 20-50 kg S/ha is indicated for most field crops in S-deficient areas. There is a need to formulate recommendations for S application based on field experiments, response surfaces and input : output price relationships.

AREAS FOR FUTURE RESEARCH ON SULPHUR

Only through research we can find out the overall magnitude of sulphur deficiency, its practical implications and the formulation of programme for its alleviation. As there are a number of gaps in information, the need for intensification of S research cannot be emphasized. Some areas of research are suggested below :

i) Delineation of S-deficient areas on a systematic and phased manner in co-ordination with soil survey data.

ii) In areas suspected to be deficient in S, the survey of selected fields for the S status of standing crops and to use such data for the computation of critical levels.

iii) A re-orientation in the soil analysis-dominated S research towards an integrated soil-plant diagnostic approach in studying the S needs of different farming systems.

iv) Establishing the S requirements of intensive cropping systems and the contribution of S from various sources to the soil.

v) Field verification trials to test the validity of critical limits obtained under greenhouse conditions.

vi) Research into the various factors (soil, crop, genotypes, management) which affect the critical levels of S.

vii) Emphasis on the critical concentrations of S in plant tissues at early enough stage of crop growth to enable corrective action.

viii) Systematic initiation of fertilizer experiments with S on the farmers' fields as has been the practice with NPK and Zn.

ix) Regular monitoring of S brought in by irrigation waters and by precipitation.

x) Initiation of controlled experiments, possibly using radio-active S-labelled irrigation water to estimate the fate of S additions through irrigation and its contribution to crop nutrition.

xi) Research towards the computation of S-balance sheets in well-characterized soil-crop environments, separately for irrigated and rainfed situations.

xii) Inclusion of S experiments in the research programmes of the All India Co-ordinated Agronomic Experiments Project, the All India Co-ordinated Research project for Dryland Agriculture (particularly for oilseeds and pulses) and the Soil Test Crop Response Project.

xiii) Estimation of the difference between S uptake and its removal from the field for sugarcane, plantation crops and the extent of recycling.

xiv) Large - scale testing of the Olsen's sodium bicarbonate method for the estimation of available S, as this method is in wide use for the estimation of available P. If found suitable, this will enable many soil testing laboratories to advise on S with a small amount of additional work.

xv) Initiation of pilot projects to study the efficacy of using elemental S for increasing the productivity of heavy-textured calcareous soils.

xvi) Estimation of optimum rates of S application from medium long-term experiments taking into account any carry over effects and the contribution from non-fertilizer sources.

(xvii) Res. on economics of S-applicn

(xviii) Res. prodn of S-containing NPK fert

xvii) Research on the economics of sulphur application.

xviii) Involvement of soil testing laboratories in surveying the nutrient status of soils and crops in bench mark villages.

xix) Research into the production of S-containing NPK fertilizers.

xx) Creation of a research network or co-ordinated research project for sulphur in soils, plants and fertilizers.

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FUTUROLOGY OF FERTILIZER SULPHUR

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INTRODUCTION

As the modernisation of agriculture progresses, it becomes necessary to monitor whether any new factors of importance have emerged. In dynamic multi-component systems, new factors emerge along the course. Such factors, if taken into account, can increase crop yields. If neglected, the result is a possible production and lower efficiency of all other inputs and investments. One such factor of increasing importance is Sulphur (Tandon, 1984).

During the past few years, sulphur as plant nutrient has been receiving attention worldwide. While reports of S-deficiency and crop responses to S-application are increasing, the contribution from traditional sources of S is on the decline. It is revealing how within a period of 20 years, the incidence of S-deficiency has spread from one to nine countries in Latin America, from 7 to 19 countries in Africa, from 4 to 8 countries in Asia and from 13 to 35 States within the U.S.A. (The Sulphur Institute, 1982).

A critical perusal of the research documents in relation to fertilizer sulphur under Indian situations revealed the following.

(i) Major reasons for the growing incidence of S deficiency are

1. Increased levels of agricultural production leading to proportionate increases in S-uptake and its removal.
2. Depletion of native soil S through heavy crop removals and leacing losses, besides some microbial changes.

3. Major shift towards the increased use of high analysis 'S' free fertilizers.

4. Wide-spread soil erosion leading to loss of the top soil containing organic matter and associated nutrients.

5. Intensification of agriculture based primarily on NPK application as in some States of India.

6. Continued neglect of organic manures and other organic wastes.

7. Cultivation of improved high yielding crop varieties which need more nutrients including sulphur.

(ii) Areas of sulphur deficiency

Although sulphur deficiency is reported to be widespread and found to be a constraint in increased agricultural production systematic delineation of such problem areas is yet to be made precisely. So far, problems relating to S deficiency have been reported from 90 out of 400 districts in India (Table 1).

In Tamil Nadu, S-deficiency is generally suspected in sandy soils. Soil samples from the Vyologam series (lateriate) and Irugur and Thallakanur series (Red sandy) were found to contain less than 10 ppm available S (Manickam, 1983).

Table 1.

Districts where widespread S-deficiency is reported (Source: Fertilizer News, 31: 1986)

States	Districts
Andhra Pradesh	Kurnool, West Godavari
Bihar	Ranchi
Delhi	Delhi

Table 1. (Continued)

Contd...

States	Districts
Gujarat	Amret, Bavaskantha, Junagadh, Kheda, Rajkot, Sabarkantha, Surendranagar
Haryana	Bhiwani, Gurgaon, Hisar, Mohindergarh, Sirsa
Himachal Pradesh	Hamirpur, Kangra, Uma
Karnataka	Bangalore, Belgaum, Chickmagalur, Coorg, Dharwad, Hassan, Kolar, Mandya, North Canara, South Canara,. Tumkur
Kerala	All districts
Maharashtra	Aurangabad, Bhandra, Chandrapur, Kolhapur, Nanded, Osmanabad, Parbhani, Pune, Raigad
Madhya Pradesh	Bolaghat, Bhind, Dewar, Dhar, East Niwar, Gwalior, Indore, Jabalpur, Mandsaur, Morena, Ratlan, Sagar Sehore, Ujjaini
Orissa	Ganjam
Punjab	Faridkot, Ferozepur, Kapurthala, Ludhiana, Paliala, Copar
Rajasthan	Jaipur, Jodhpur, Udaipur
Tamil Nadu	Coimbatore
Uttar Pradesh	Allahabad, Bulandshahr, Farukhbad, Hardoi, Jhansi, Kanpur, Lalitpur, Mirzapur, Nainital, Sitapur, Varanasi
West Bengal	Birbhum, Burdwar, Midnapur, Zu-Parganas

It is abundantly clear that S-deficiency in India is fairly and frequently reported across the Indo-Gangetic alluviums, tea soils of Himachal Pradesh red-yellow soils of Bundalkhand region, red and laterite soils of Karnataka, Kerala, West Bengal and Tamil Nadu, alluvial and black soils of Madhya Pradesh, several black soil areas of Maharashtra and Tamil Nadu, across Gujarat and in the southern part of Rajasthan State.

Perhaps, 15 to 20 percent of cropland (22 to 29 million hectares) in India may have some degree of sulphur deficiency problems. Both irrigated and rainfed areas are found affected. Further, in many intensively cropped areas, S-deficiency may be partly marked by the sulphur brought in by irrigation water.

If one attributes an assumed grain yield loss of 200 kg per hectare, due to S-deficiency, this would be equivalent to a production loss of 4.5 to 5.8 million tonnes grain every year from an area of 22 to 29 million ha (Tandon, 1984).

(iii) Removals of sulphur

Crop removal of sulphur in intensive cropping system varies from 30 to 72 kg S/ha/year. Under comparable conditions, a cereal dominated crop sequence may remove 2 kg S/tonne dry matter production, whereas, an oilseed-legume system may remove 4-5 kg S/tonne dry matter production. The type of crop and the yield level are the major determinants of sulphur removal from soils (Table 2).

Table 2.

Some estimates of crop uptake of N, P, K, and S in relation to yield (Source : Jain et al., 1984)

Crop	Yield (q/ha)	Total uptake by crop (kg/ha)			
		N	P	K	S
paddy	51.4		27.8	179.5	15.7
Blackgram	8.9	70.8	5.6	50.1	5.1
Greengram	8.7	82.0	12.5	90.4	6.5
Sunflower	23.8	114.2	26.4	141.3	16.8
Mustard	26.0	130.9	25.3	133.3	44.9
Alfalfa	919	755	79.4	669	45.9
Sugarcane	876	180	29.5	270	26.4

In a recent study, S uptake by field crops in India was estimated at 784 thousand tonnes in 1980, which was projected to reach 1.33 million tonnes S by the year 2000 (Kanwar and Mudahar, 1983). These workers considered a 6 kg S uptake for each tonne of food grain production, probably including oilseeds in the term food grains. These data indicate the major role of sulphur in increased agricultural production in the years to come.

(iv) Additions of Sulphur

Major sources which provide nutrient sulphur towards crop production in India are the soil sulphur and that added through fertilizers, organic manures, amendments, irrigation water and rainfall.

A number of fertilizers used primarily as sources of N, P and K also carry 12 to 24 per cent S. These fertilizers are estimated to be adding 341 thousand tonnes S based on 1982-83 statistics. A statewise analysis of the S added through fertilizers is given in Table 3. Two States, Andhra Pradesh and Gujarat, accounted for over 100 thousand tonnes or 30 per cent of total S additions.

Organic manures such as FYM, compost etc., may add sulphur at the rate of 1.5 kg S/tonne of material, but estimates of the quantities actually collected and added to soil are lacking and this needs a careful study in terms of sulphur needs for the future.

(v) Balance Sheet of Sulphur

Due to insufficient data about the various routes through which sulphur is added and removed, it is not yet possible to construct a quantitative and accurate balance sheet of S in Indian agriculture.

Table 3.

Sulphur added thiough different fertilizer materials India (Tandon, 1984)

State	S added (1000 tonnes)	Per cent share of fertilizers in S added				
		AS	SSP	DAP	APS	SOP
Andhra Pradesh	61.1	49	30	1	17	3
Assam	1.6	60	39	1	0	0
Bihar	11.9	74	20	6	0	0
Gujarat	42.3	56	36	7	0	0
Haryana	7.6	8	75	17	0	0
Himachal Pradesh	0.5	0	96	4	0	0
Karnataka	24.3	24	29	5	41	1
Kerala	9.8	27	12	0	61	0
Madhya Pradesh	26.7	17	80	3	0	0
Orissa	4.8	70	29	1	0	0
Punjab	20.8	6	73	21	0	0
Tamil Nadu	29.1	30	34	16	20	0
Uttar Pradesh	24.5	29	55	16	0	0
All India	341	36	44	8	10	1

A preliminary balance sheet of S in Indian agriculture has been put forward in Table 4. A balance sheet on net basis is preferred because the gross additions must be adjusted for their use efficiency, here taken as 25 per cent being the upper

Table 4.

A preliminary balance sheet of S in Indian agriculture

Item	Country basis		Hectare basis		Remarks and assumption
	Gross 000' t	Net 000 t'	Gross kg S	Net kg S	
INPUT					
Fertilizers	341	85	2.0	0.5	Actual for 1982-83
Rainfall	444	111	2.5	0.6	3 kg S/ha/year for 148 m. ha.
Irrigation	788	197	4.5	1.1	30 cm water having 5 ppm S applied to 30% crop land
FYM	263	26	1.5	0.2	FYM at 1 t/ha having 1.5 kg S/ton
Recycling	93	9	0.5	0.1	10% of crop uptake
Total Input	1929	428	11.0	2.5	
OUTPUT					
Crop removal	933	840	5.3	4.8	5 kg S/t food grain
Leaching	?	?	?	?	
Erosion	?	?	?	?	
Immobilization	?	?	?	?	
Balance	+996	−412	+5.7	−2.3	

figure reported (Dev and Kumar, 1982). The question marks are intended to focus attention towards the gaps in our information.

The balance sheet indicates a net negative balance of 0.4 million tonnes S or 2.3 kg S/ha on an average. It indicates the depletion of soil sulphur and an increasing incidence of sulphurdeficiencies unless the gap is bridged by augmenting the application of S to the soils.

(vi) Crop responses to sulphur application

Yield responses of over 30 crops to S application have been reported in India. These include cereals, millets, pulses, oilseeds, forages, tubers, and many others. The mean increase in yield due to S application is 27 per cent (Wheat) 38 per cent (Chick pea), 15 per cent (groundnut), 31 per cent (Mustard), 26 per cent (raya), 27 per cent (sunflower), 30 percent (potato), and 19 per cent (onion), all under field conditions.

The Table 5 will provide an idea of the extent and type of information available on the subject. Mention must be made on two aspects.

(i) When S deficiency is corrected, not only the yield but the efficiency of other nutrients also improves. When S application increased wheat yield by 40 per cent, this was accompanied by the increased uptake of N by 58 per cent, P by 41 per cent, K by 27 per cent and of S by 83 per cent.

(ii) Substantial yield increases have been reported by the application of elemental S as a soil treatment in the calcareous, heavy-textured soils of Rajasthan (Jain *et al.* 1984). Prevention of iron chlorosis is one of the major benefits attributed to S in such cases.

Table 5

Yield responses to sulphur application in India

Crop, State, Soil available S (ppm)	S added (source)	Yield and unit	Crop yield		Reference
			Without sulphur	Per cent increase with S	
1. *Rice*					
Delhi alluvial (10)	30 kg/ha (gypsum)	Grain (q/ha)	44.1	15	Das and Datta (1973)
2. Wheat					
Punjab alluvial (7)	18 kg/ha (As)	,,	7.2	186	Arora et al (1983)
3. Maize					
Delhi alluvial (10)	30 kg/ha (gypsum)	,,	51.0	9	Das et al. (1975)
4. Sorghum					
Maharashtra black (8)	56 kg/ha (AS)	Dry matter (gm)	2.1	33	Badhe and Lande (1980)
5. Blackgram					
U. P. alluvial (8))	30 kg/ha (gypsum)	Grain (q/ha)	8.4	23	Lal and Jaiswal (1979)
6. Greengram					
Rajasthan clay loam	*250 kg/ha* (element)	*Grain* (g/plot)	?	95	*Mehta and* Singh (1979)
7. Sugarcane					
Rajasthan clay loam	500 kg/ha (element)	Cane (q/ha)	731	28	Saroha and Singh (1980)
8. Onion					
Tamil Nadu red sandy loam	20 ppm (AS)	Bulbs (gm)	17.5	83	Balasubramanian et al. (1978)

(vii) Effect of sulphur on crop quality

The effects of sulphur on crop quality are:

(i) Increase in the oil content of oilseeds (Fig.I)

(ii) Increase in the content of S containing amino acids and plant proteins (Table 6).

(iii) Reduction of HCN concentration in cassava (Mohankumar *et al.* 1984) and in sorghum forage (Singh et al, , 1983).

(iv) Increase the starch content of potatoes(Ramamurthy and Susheela Devi, 1981) and of cassava tubers (Mohankumar et al. , 1984).

(v) Improvement of sugar content 5-6%, sugar recovery by 5-8% and the purity of cane juice by 0. 8% as compared to the non-S treatment (Saroha and Singh, 1979).

(viii) Sulphur management for high yields

(i) Optimum dose of Sulphur application rates associated with crop responses vary from 10 kg to 100 kg S/ha when S is applied through material other than elemental S.

(ii) Time and method of S application: In general, the application of S containing fertilizers during final land preparation or before seedling is advocated with the exception of elemental S. Chahal and Virmani (1973) obtained highest yield when 75 per cent of the totel dose of S was applied at sowing and 25 per cent at flowering. Some other suggested schedules of S application to groundnut are (i) apply 25 per cent as basal, 25 per cent at flowering and 50 per cent at peg initiation (Dwivedi, 1981) and (ii) band place the S containing fertilizer near the pegging zone at the early flowering stage (Ankineedu et al. , 1983)

(ix) Use of S enriched nitrogen and phosphorus sources:

In a study on lowland rice, Sankaran and Balasubramanian (1985) found that the use of sulphur coated urea per m², higher yield than ureasupergranules and prilled urea. Jayaramamoorthy *et al.*(1985) reported that gypsum coated urea treatment in rice (IR 20) registered the highest grain and straw yield. Kandasamy and Arulmozhiselvam (1985) cbserved increased availability of sulphur, uptake and yield of rice due to the application of gypsum in proportion with added levels of nitrogen as urea.

Table 6.

Effect of S application on the content of protein and S-containing amino acids in greengram(Source: Kamat et al. , 1981)

Applied S (kg/ha)	Protein (%)	Methionine (g/100 g protein)	Cystine (g/100 g protein)
0	24.4	2.42	2.63
10	24.5	2.45	3.25
20	24.8	3.02	4.58
30	26.3	3.13	3.80

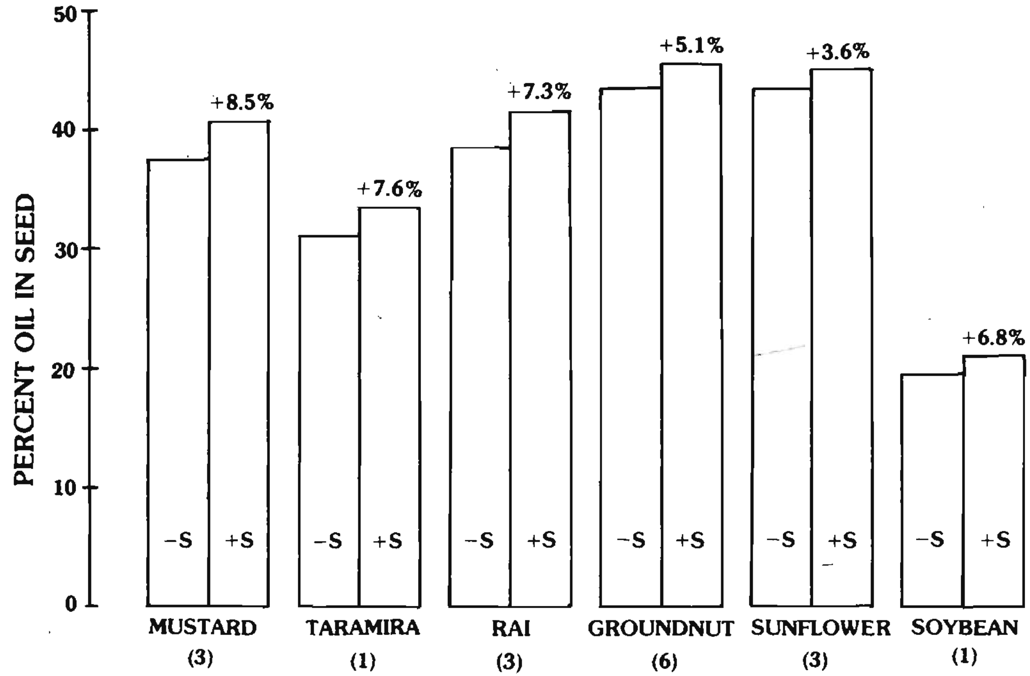

Fig. 1 Effect of 'S' application (+S) on the content of important oilseeds in India. Numbers in ( ) indicate the number of studies averaged (Source: Tandon, 1984)

Future Thrusts

1. Delineation of S-deficient areas on a systematic and phased manner and identifying bench mark areas for future investigations.
2. Establishment of critical limits for different soils supporting major crops and cropping systems.
3. Determination of critical concentration of S in plants at different growth stages which are early enough to take a corrective action,.
4. Field verfication trials to test the critical limits of available S computed under laboratory conditions.
5. Regular monitoring of the sulphur added through irrigation water and rain water.
6. Computation of sulphur balance sheets in well characterised cropping system, both irrigated and rainfed.
7. Estimation of optimum rates of sulphur application based on medium, long term experiments taking into account residual effects and the S input through nonfertilizer sources.

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SULPHUR IN SOUTH INDIAN AGRICULTURE

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ABSTRACT

The adoption of scientific agriculture, along with the use of high analysis fertilizers is causing depletion of sulphur in the soils in South India. Increase in yield and quality of crops due to the application of S-containing fertilizers has been recorded in the trials conducted in the South.

Ammonium phosphate sulphate, an NPS complex fertilizer, is an ideal source of sulphur.

The field trials conducted on paddy, cotton, potatoes, tapioca and other crops with the application of ammonium phosphate sulphate have shown significant improvement in quantity and quality of yield.

The importance of NPK in increasing agricultural production is well recognised. However, sulphur has not been given the due emphasis even though it resembles nitrogen in its role and function, compares phosphorus in overall crop needs and equals potassium in terms of unit cost.

Presently, with the advent of scientific agriculture and introduction of S-free fertilizers, this situation has started changing. It is now established that sulphur deficiency can develop into a serious constraint and even reduce the efficiency of other nutrients in crop production. Current estimates show that while application of one million tonnes of sulphur will be necessary to increase the agricultural production, only 0.34 million tonnes are being applied, thus leaving a wide gap.

A stage has now come to give a preference to fertilization with sulphur containing fertilizers for all the crops, especially for high yielding cultivars and in intensive cropping systems.

The vital role sulphur plays presently in agriculture has given it the due recognition as the 'FOURTH MAJOR PLANT NUTRI -ENT'

CONSUMPTION OF SULPHUR IN SOUTH

South India consumes 25% of the plant nutrients presently available in the country. The quantity of sulphur containing fertilizers like ammonium sulphate, superphosphate, etc. , available in the market is much limited. Present emphasis is on concentrated sulphur free fertilizers like urea, diammonium phosphate and NPK complex fertilizers. This has reduced the quantity of sulphur that is applied to the soil. The situation in the South is evident from the following Tables:

Table 1.

Quantities of N, P and S consumed in South India [1000 tonnes]

Years	N	P	S
1963-64	188.8	62.4	89.2
1973-74	517.3	225.5	98.3
1983-84	1277.1	486.8	130.9

It is clear that while the quantity of N and P applied has increased significantly during the last two decades that of sulphur has remained without much change.

Table 2.
Changes in the use of sulphur consumption in fertilizers

State	Share of AS and ASN in total N			Share of SSP in total P		
	63-64	73-74	83-84	63-64	73-74	83-84
Andhra Pradesh	24.6	11.9	2.8	67.4	16.5	9.3
Karnataka	24.3	7.1	2.9	82.1	21.4	1.0
Tamil Nadu	19.8	7.8	2.3	46.5	13.2	12.5
Kerala	60.7	20.6	8.5	54.3	6.6	5.9

The share of nitrogen from ammonium sulphate and ammonium nitrate, which are the main S-containing fertilizers, compared to the total N consumed has very much decreased during the last two decades. The same trend is seen with regard to the share of P from superphosphate as an important source of S compared to the total P consumed. Thus the share of S-fertilizer in the fertilizer scene in south has considerably reduced during the last twenty years.

The disproportionately higher use of N and P in comparison with sulphur has widened the N-S and P-S ratios as shown below. This imbalance affects the efficiency of fertilizers, impairs the quality of the produce besides reducing the quantity of yield. Further, this depletes the sulphur resources in the soil thereby affecting the soil fertility very drastically.

Table 3.
Changes in estimated N : S and P_2O_5 : S ratios

State	N : S Ratio			P_2O_5 : S ratio		
	63-64	73-74	83-84	63-64	73-74	83-84
Andhra Pradesh	1.8	5.4	7.3	0.7	2.6	3.9
Karnataka	2.2	5.2	8.3	0.7	2.4	3.7
Tamil Nadu	3.1	6.3	11.3	0.7	2.2	4.1
Kerala	1.0	2.4	4.3	0.5	1.6	2.1

The widening ratios in N:S and P_2O_5:S can be seen in all the four Southern States of India.

CROP RESPONSES RECORDED IN SOUTH INDIA

Cases of crop response to the application of sulphur is being reported from many parts in the South.

1. Millet and Cow Pea

Application of sulphur containing fertilizers for finger millet and cow pea grown on medium black soil at Coimbatore recorded grain yield increase of 9.1% to 20.0% (Nambiar, 1985).

2. Rice

Application of Factamfos 20-20 to supply 50 kg. sulphur/ha has increased the grain and straw yield of paddy.

Levels of sulphur kg/ha	Sources	Grain yield kg/ha	Straw yield kg/ha
0	Nitrophosphate	2730	2340
50	Factamfos 20-20	3700	2970
	Increase	: 970	630

(Venkata Rao and Rosalind Michael, 1980)

3. Cotton

Application of Factamfos 20-20 as a source of S has increased the yield of cotton and also the net income.

Sulphur Source		Cotton yield kg/ha		Income Rs./ha	
		Suvin	MCU-5	Suvin at Rs./ha	MCU-5 at Rs.6/per kg
No S	17 : 17 : 17	1108	1782	9418	10692
With S	Factamfos 20-20	1374	1883	11679	11298
Increase		266	101	2261	606

(Meenakshisundaram, 1983)

4. Sunflower

The application of S-fertilizers has increased the content of amino acids, cystine and methionine, in sunflower significantly. (Badigar *et al.* 1985).

5. Tomato

Application of S-fertilizers to supply 180 kg/S/ha has increased the quantity as well as quality of tomato.

Level of sulphur kg/ha	Quantity	Quality
	Yield/T/ha	Protein %
0	27.30	1.43
180	35.52	1.75
Increase	8.22	22.3

(Paul Raj *et al.* 1976)

6. Onion

Application of 30 kg S/ha through S-containing fertilizers has increased the quantity and quality of onion.

Soil	Level of sulphur kg/ha	Quantity	Quality	
		Yield kg/ha	S containing amino acid Cystine mg/100 g	Methionine mg/100 g
Red soil	0	1750	15.50	12.25
	30	3250	22.75	20.50
Increase	:	1500	46.8%	67.3%
Black soil	0	2850	12.00	11.62
	30	4500	25.00	31.25
Increase	:	1650	108.3%	168.90%

(Balasubramanian et al., 1978)

7. Potato

Application of **Factamfos** 20-20 to supply 75 kg S/ha has increased the quantity and quality of potato.

Levels of ulphur kg/ha	Source	Quantity		Quality	
		Tuber T/ha	Starch %	Total sugar%	Vitamin C mg/100 g
0	DAP & UREA	6.71	16.3	0.31	9.9
75	**Factamfos 20-20**	9.50	16.8	0.35	13.1
Increase	:	1.79 T	3.0%	12.9%	32.3%

(Ramamurthy and Susheela Devi,1982)

8. TAPIOCA

Research trials have shown that application of Factamfos 20-20 to supply 50 kg S/ha has increased the yield and improved the quality of tapioca.

Levels of sulphur kg/ha	Source	Quantity		Quality		
		Yield T/ha	Starch %	Protein %	Methionine mg/100 g	HCN ug/g
0	17-17-17/ DAP / UREA	19.35	79.4	3.01	0.085	47.2
50	Factamfos 20-20	20.81	84.7	3.08	0.119	44.5

9. TEA

Application of S-containing fertilizers increased the yield of tea by 136 kg/ha, a substantial increase on estate level.

Sulphur	Yield (made tea) kg/ha
Without S	3843
With S	3979

(Subramanya Bhat and Ranganathan, 1980)

It is clear from the above research findings that application of S-containing fertilizers has increased the yield and improved the quality of many crops grown in South India.

IDEAL SOURCE OF SULPHUR

Ammonium phosphate sulphate is the only sulphur containing complex fertilizer presently available in the market. It has as much as 15% sulphur. In the present context, when other S-containing fertilizers like ammonium sulphate and superphosphate are scarce in the market, ammonium phosphate sulphate deserves due recognition.

Besides being an ideal source of sulphur, it carries the following superior qualities:

1. N is completely in ammoniacal form and hence has a higher efficiency.
2. P is entirely in water - soluble form.
3. The N-P chemical combination gives a synergetic effect.– It makes the P mobile in the soil.
4. An ideal source of sulphur - as much as 15% in 1:1 ratio with P.
5. The chemical combination of S with N and P further enhances the efficiency of both the nutrients.
6. Enables split application of K.

   - avoids luxury consumption and wastage of K.
7. Source of most economic P.

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SULPHUR NUTRITION IN MAHARASHTRA AGRICULTURE - A REVIEW

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Sulphur is an essential nutrient and ranks in importance with nitrogen and phosphorus in the formation of plant proteins. Till recently its value as a plant nutrient and fertilizer ingredient has been grossly underestimated. The problem regarding the sulphur status of soils and the degree of its availability and crop responses in different soils has not received much attention in Maharashtra. Very meagre information is available on the sulphur status of soils under varying climatic conditions and different kinds of parent materials such as basalt, granite etc. Thus a short account on the sulphur status of soils, its availability, responses of sulphur to the different crops, and interaction with other elements is reviewed hereunder.

Sulphur status of Maharashtra soils

The content of sulphur in soils of Maharashtra varied widely, either in light textured soils or in those areas which are intensively cultivated and are under multiple cropping. According to a study carried out by Naik and Das (1964) in Maharashtra soils (Table 1) using *Aspergillus niger* method, the laterite, red and alluvial soils are low in available suplhur status, thus containing less than 10 ppm. Black soils and coastal alluvial soils were comparatively richer in sulphur content. Among the black soils, 70 per cent of the samples contained more than 10 ppm whereas all the saline and alkali soils showed extremely high content of sulphur.

Table 1.
Available S content of Maharashtra soils
Naik and Das (1964)

Soil type/ Location	pH range	No. of samples analysed	S (ppm) Minimum	S (ppm) Maximum	Mean	No. of samples containing less than 10 ppm
Laterite	4-6	7	4.225	14.35	8.31	5
Red	5-7	19	2.159	29.00	8.01	15
Black	7-9	24	4.600	160.00	21.42	7
Coastal alluvial	7-8	2	10.700	17.45	14.02	Nil
Saline and alkali	7-10	6	56.500	2000.00	1074.00	

While studying the different forms of sulphur, and their contents in different soil types of Maharashtra State Tanawade *et al.* (1976) reported (Table 2) that the total sulphur varied from 96 ppm (sandy clay) to 513 ppm (clayey) with an average value of 265 ppm. The organic sulphur constituted 55 per cent of the total sulphur. Among the 40 samples analysed, organic sulphur ranged from 55 ppm (sandy clay loam) to 265 ppm. (clayey soils). The level of organic sulphur did not show any direct correlation' with mean annual rainfall. On the basis of relative percentage, water soluble sulphate sulphur fraction constituted about 11.3 per cent and ranged from 6 ppm (laterite soil) to 54 ppm (clayey soil) with an average of 30 ppm. Water insoluble inorganic sulphur fraction constituted about 33 per cent of total sulphur and ranged from 28 ppm (sandy clay loam) to 196 ppm (clayey soils) with an average of 89 ppm. Further, they concluded that clayey soils of Maharashtra State are richer in all fractions of sulphur while those sandy clay loams are least in the average values for each of four fractions. The relative level of each fraction (total sulphur, organic sulphur, water insoluble and soluble sulphur etc) as well as its distribution is linked with nature Parent material and level of organic matter. Soils derived from basalt are richer in all fractions while those derived from granites and gneisses showed the lowest content.

Lande *et al.* (1977) analysed 31 surface samples of Marathwada region of Maharashtra State (Table 2) for different forms of sulphur and reported that total sulphur ranged from 82.4 to 274.7 ppm with an average of 153.6 ppm. The hydrogen peroxide oxidizable organic sulphur ranged from 35.2 to 132.2 ppm with an average of 71.9 ppm. Water insoluble inorganic sulphur varied from 34.8 to 144.6 ppm with an average of 71.0 ppm. water soluble sulphate sulphur ranged from 8.4 to 42.0 ppm with an average of 15.9 ppm. The water soluble sulphur ranged from 5.4 to 21.1 ppm with an average of 10.7 ppm. On the basis of average values of different fractions of sulphur they are of the order of Total S > Organic S > Water insoluble S > Sulphate sulphur > Water soluble sulphur. About 35.4 per cent of soils were moderately deficient (5-10 ppm) which respend to sulphur fertilization while 64.5 per cent soils contained more than 10 ppm sulphur which do not respond to sulphur fertilization.

RELATIONSHIP BETWEEN FORMS OF SULPHUR AND SOIL PROPERTIES

Among the factors which govern the availability of soil sulphur, organic carbon, soil reaction, clay content and per cent lime are important. Lande *et al* (1977) observed a positive correlation between total, organic and water soluble sulphate sulphur and clay, organic carbon and pH of the soils. There was no significant correlation between $CaCO_3$ and total sulphur, organic, water-soluble and sulphate sulphur. Similarly, Patil *et al.* (1981) analysed forty surface soil samples from different localities of Maharashtra State and reported that total, organic, water-soluble, and water insoluble inorganic sulphur showed positive significant correlation with soil pH, free $CaCO_3$ and clay content of soils. However, no significant correlation have been observed with organic carbon and different forms of sulphur.

Table-2.

Sulphur status of Maharashtra soils

Location	Soil Type	Different forms of S (ppm)				Reference
		Total sulphur	Organic sulphur	Water soluble	Water in-soluble	
Zone IB	Non-lateritic	96-287	55-168	10-21	31-103	Patil *et al.* (1981)
Zone IA	Lateritic	219-315	150-242	6-26	59-69	
Zone II	Clay loam	274-315	139-159	23-30	103-142	
Zone III	Clay	274-452	115-224	36-41	101-187	
Zone IV B	Clayey	246-383	115-183	38-54	93-146	
Zone IV A	Clayey	260-515	128-265	41-52	83-196	
Zone V B	Clayey	287-315	115-158	38-58	66-116	
Zone V A	Sandy clayey	164-141	123-128	13-16	28-47	
Zone VI	Sandy clayey	95-191	54-139	6-16	31-41	
Average		269	146	30	89	
Marathwada Region						
	Clayey	157.08	75.26	10.65	71.16	Lande *et al.* (1977)
	Clayey loam	132.78	60.13	9.13	63.51	
	Sandy clay	153.39	67.46	11.97	73.24	

Table-3

Linear corrlation between soil properties and different fractions of sulphur

Fraction of sulphur	Soil properties				Reference
	pH	$CaCO_3$ (%)	Organic Carbon (%)	Clay (%)	
Total sulphur	+0.60**	−0.34	+0.79**	+0.69**	Lande *et al* (1977)
Organic sulphur	+0.63**	−0.27	+0.69	+0.64**	
Sulphate sulphur	−0.57	−0.35	−0.29	+0.33	
Water insoluble inorganic sulphur	+0.66**	−0.35	−0 66**	+0.64**	
Water - soluble S	+0.61**	−0.37	−0.35**	+0.004**	
Total sulphur	+0.49**	+0.63**	−0.03NS	+0.70**	Patil *et al* (1981)
Organic sulphur	+0.20*	+0.29*	−0.01NS	+0.28	
Water - soluple S	+0.78**	+0.80**	−0.43*	+0.77**	
Water insoluble S	+0.64**	+0.69**	−0.27NS	−0.66**	

* - Significant at 1 per cent level
** - Significant at 5 per cent level
NS - Non-significant

CROP RESPONSE TO SULPHUR FERTILIZATION

A majority of the reports on crop responses to applied sulphur are based on field experiments, but some work has also been conducted in pots for individual crops by various workers for direct and residual studies.

Soybean: Increase in grain yield (5.87-9.240/ha) was observed with graded levels of sulphur (0, 50, 100 and 150 kg S/ha) application (Karle and Ghousikar, 1976).

Sunflower: Raut and Ghousikar (1976) reported that sulphur application appeared to be beneficial to raise sunflower yield in calcareous soils of Marathwada. Twenty three per cent increase in sunflower yield was recorded when 200 kg S/ha was applied.

Gram: The effect of sulphur to enhance grain and straw yields of Bengal gram was noted by Kubde (1970). He reported that 50 kg S/ha treatment increased 10-15% grain and 7.63% straw yield over control in gram.

Sorghum and wheat: A significant increase in dry matter of sorghum (CSH-4) and wheat (S-227) receiving different doses of sulphur through different sulphur containing compounds was also observed by Badhe and Lande (1980). While studying the residual effect of sulphur coated urea on jowar, Raut and Ghonsikar (1976) reported that grain yield of wheat (S-308) treated with S-coated urea was significantly increased over control. The residual effect of S coated urea on jowar crop showed better performance to increase grain yield.

Groundnut: Chaugula (1951-52) obtained increased groundnut pod yields by about 20 to 77 per cent by the application of elemental sulphur whereas Pannikar *et al.* (1961) reported that groundnut yield was increased with the application of gypsum. Naphade (1970) reported that pod yield of groundnut was increased with application of sulphur by 20 to 27 per cent.

SOURCES OF SULPHUR AND THEIR EFFICIENCY:

The efficiency of different sources of sulphur was studied by Barhanpure (1976) and he reported that application of S through calcium sulphate, single superphosphate and elemental S to soil was beneficial to increase dry matter and grain yield of groundnut. Highest pod yield was obtained with application of S through superphosphate as compared to calcium sulphate and elemental sulphur. Badhe and Lande (1980) while studying the sulphur supplying capacity different sulphur bearing compounds reported that Ammonium sulphate, potassium sulphate, calcium sulphate and superphosphate contributed towards its availability as compared to that in control. The availability of S, however, was observed to have increased up to 30 days and thereafter there was a decline in availability, at 45 days and later the same appears to have stabilized. Calcium sulphate contributed more to the availability of S, next being ammonium sulphate and the least contribution was from potassium sulphate. Karle *et al.* (1985) reported that increased dry matter, pod and Kernel yield of groundnut fertilized with sulphur levels through elemental S, gypsum and magnesium sulphate. Among the different sources of S, gypsum is beneficial to increase nodulation and yield attributes of groundnut followed by elemental S and $MgSO_4$.

Interaction of sulphur with other nutrients: Phosphorus and S are two important nutrients for better growth yield of oil-seed crops. A relative change in their levels brings about a considerable effect on growth and yield of legumes and oilseeds. Chopde (1964) reported that combined application of S, N and P was effective to increase nodulation, dry matter and pod yield in groundnut. The interaction between P and S was reported to be synergetic in sunflower and groundnut. Application of S in the absence of P decreased the dry matter and pod yield of soybean (Karle and Ghonsikar, 1976) and sunflower (Raut and Ghonsikar, 1976) but when S was applied with P the effect was synergetic. Similar results were reported by Kubde (1976) for Bengalgram. In a pot culture study, good interaction effect of P and S was noticed in groundnut (Karle and Ghonsikar, 1980). They further reported that application of S with P significantly increased more biomass at various growth stages in groundnut than the application of S alone. An additive and synergetic effect of P and S on uptake of K at various stages in groundnut was also appraised. In a field

Table 4.

EFFECT OF SULPHUR FERTILIZATION ON YIELD OF OILSEEDS

Levels of sulphur (kg/ha)	Soybean (Q/ha)	Sunflower (Q/ha)	Groundnut (Q/ha)			
			Pod	Kernels	Shells	Haulm
0 kg/ha	9-30	7-58	15-54	10-63	4-90	29-43
40 kg/ha	11-71	—	17-41	12-11	5-30	34-32
80 kg/ha	12-81	—	19-13	13-73	5-45	37-46
100 kg/ha	9-32	8-51	—	—	—	—
150 kg/ha	12-70	10-76	—	—	—	—
S. E. ±	0-84	0-30	1-36	1-03	0-54	2-59
C. D. at 5%	2-46	0-88	4-00	3-92	1-59	7-59
Reference	Karle & Ghonsikar (1976)	Raut & Ghonsikar (1976)	Karle (1982)			

Table 5.
Effect of different sources of sulphur on groundnut

Sources of sulphur	Nodules/ plant	Haulm (Q/ha)	Pod (Q/ha)	Kernel (Q/ha)	Shelling percent	Protein percent	Oil %	Oil yield (Q/ha)
Elemental S	157.5	29.26	17.21	11.95	68.78	28.04	49.64	5.94
Gypsum	165.6	33.45	18.88	13.21	69.89	28.29	49.90	6.60
$MgSO_4$	150.0	27.10	15.52	10.44	68.28	27.14	48.37	4.64
S. E. +	0.60	0.96	0.12	0.08	0.05	0.04	0.04	0.04
C.D. at 5%	1.80	2.90	0.38	0.26	0.16	0.14	0.14	0.14

trial of interaction effect of P,S and inoculation in summer groundnut, Karle (1982) observed better significant response of groundnut to P x S interaction to increase nodulation, biomass, pod and kernel yield. He further reported that a relative increase in nodules, biomass, pod and kernels due to P x S interaction was higher as compared to P and S application alone. Besides S and P, boron is essential for root development and formation of root nodule in leguminous plant. Boron facilitates the movement of sugars in plant and prevents excessive polymerisation of sugars at the site of sugar synthesis. Boron helps in lignin and protein synthesis and catalysis and metabolism of carbohydrates.

Since both boron and S perform specific physiological function in plant, it could be expected that lack of one of them or both might result in the retardation of metabolic activities in plant. Some studies have been carried out to findout the interaction of S with boron, Mg and Mn in groundnut. Borade and Gund (1982), Patil *et al.* (1981) and Bulbule (1983) found a positive interaction of B and S for increase in nodulation, biomass, pod and kernel yields in groundnut indicating the significance of such interaction in calcareous soils. The interaction between S and Mg was found to be synergetic to enhance the groundnut pod and haulms over check treatment (Vidhata, 1978). Application of S along with B and Mn significantly increased yield of groundnut (Dongale and Zende, 1976).

Uptake of Sulphur and other Nutrients. S is required by plants in about the same quantities of phosphorus. On plants like wheat, corn, beans and potatoes it may be present in amounts equal or less than P, but in plants like lucerne, cabbage and turnips it may be present in amounts larger than P. Grasses and cereals require smaller amounts of S than do legumes and oilseed crops. Leguminous crops respond to most of the S containing fertilizers and oilseed crops, particularly belonging to cruciferae and leguminaseae have a high sulphur requirement. Chopde (1964) reported that application of S increased the S,N,P, and Ca content in groundnut.

Daftardar (1969) studied the effect of soil application of S at 0 to 200 lb/acre on chemical composition of groundnut and found that N and Ca content of haulm showed an increase while P content decreased with increasing doses of S application. The decrease in P content of haulm with increasing dose of S might be due to transfer of assimilated P to the seed and enhanced the mineral matter of seed. Naphade (1970) reported that S fertilization increased the uptake of N, P and S by pods and hay in general. The uptake of N, P and S was further increased by combining its application with P or nitrogen. Barhanpure (1976) and Vidhata (1978) observed increase in concentration and uptake of N, P, S and K with sulphur fertilization to groundnut. Kubde (1976) observed beneficial effect of S on content of N, P, S and Ca by Bengalgram and the interaction of S with P was synergetic to increase the N content in plant and seeds of bengalgram. Badhe and Lande (1980) reported that content of S varied from 0.112 to 0.176 per cent in sorghum and from 0.120 to 0.176 per cent in wheat and found a significant increase in content of both sorghum and wheat receiving S through different S carriers. The uptake of S by sorghum and wheat was higher due to calcium sulphate followed by ammonium sulphate. Karle and Ghonsikar (1980) found synergetic effect of S and K uptake by groundnut. S application alone or in combination with P increased the absorption of K by groundnut. Karle (1982) reported that S fertilization with P and inoculation to summer groundnut increased content and uptake of N, P and S. The magnitude of N, P and S was much higher by S than P application. Bulbule (1983) found increased content and uptake of N, P, S and B by S application to groundnut.

EFFECT OF SULPHUR ON CROP QUALITY: Plants with high protein content are shown to respond markedly to the application of S. Chopde (1964) observed increase in groundnut oil due to S application. Barhanpure (1976) studied the effect of S bearing compounds on groundnut and showed that the quality of groundnut in respect of crude and true protein and oil content was improved as result of S application. The application of calcium sulphate (30 kg S /ha) increased crude and true protein content by 3.19 and 3.11 per cent respectively. Similar observations were recorded by Vidhata (1978). The amount of S containing amino acids (methionine) and total protein content increased on fertilization with S to bengal gram (Kubde, 1976). Sulphur is a constituent of enzyme acetyl CoA with sulphurhydryl group. In fatty acid synthesis acetyl CoA is converted into melonyl CoA. In this conversion an enzyme thiokinase is involved

The activity of thiokinase enzyme depends upon S supply. An increase in oil content of sunflower and soybean due to S supply was reported by Raut and Ghonsikar (1970) and Karle and Ghonsikar (1976), respectively. The protein and oil content of groundnut kernels increased with S application alone in combination with B (Dongale and Zende, 1976 and Patil *et al.*, 1981). S fertilization alone or in conjunction with P significantly increased the 100 kernel weight, protein and oil contents of summer groundnut (Karle, 1982). Bulbule (1983) reported that S treatment increased the protein and oil content of Kharif groundnut. While studying the response of groundnut to S bearing compounds, Karle *et al.* (1985) reported that gypsum, as source of S increased the protein and oil content in groundnut followed by elemental S and magnesium sulphate.

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SULPHUR NUTRITION IN AGRICULTURAL CROPS

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IMPORTANCE OF SULPHUR IN PLANT NUTRITION

Sulphur is one of the nutrient elements required for plant growth. It is required in large quantities and sometimes even higher than phosphorus by crops, like corn and alfalfa. The uptake of sulphur is double that of phosphorus in tobacco. It is not only required in large quantities but also play important roles in plant growth.

Sulphur is essentially needed for the formation of proteins, vitamins and enzymes. Sulphur is a constituent of the amino acids cystine, cysteine and methionine. Biologically active compounds, like vitamins (thiamine, biotine, vitamin B1) lipolic acid, acetyl coenzyme A, ferredoxin and glutathione contain sulphur as an essential part. Sulphur plays an active role in plant metabolism especially in the synthesis of glucosides in oils. It gives the flavour in onion, garlic and cruciferous plants. It plays the role of electron carrier as ferredoxin in photosynthetic process. Sulphur is needed for the conversion of reduced nitrogen into proteins in legume-rhizobium symbiotic nitrogen fixation. Sulphur is involved in the synthesis as well as breakdown of proteins. Sulphur is needed for the dark reaction of photosynthesis and in the carbohydrate metabolism of plants. Sulphur plays a significant role in the cell and tissue developments. It activates proteolytic enzymes and is needed for the formation of chlorophyll sulphur influences the uptake of phosphorus in plants. Sulphur increases the cold and drought resistances in plants due to the presence of disulphide linkages.

NEED FOR SULPHUR FERTILIZATION

Hitherto sulphur was not applied as a fertilizer nutrient element but supplied along with the other major nutrients or applied as complex or as organic manures and thus the sulphur need was taken care of. However, in the recent years more attention was given for use of high analysis essentially sulphur free fertilizers because of economic handling and transportation. The increased content of nitrogen (urea) and phosphorus (concentrated superphosphate) in the high analysis fertilizers is obtained at the expense of sulphur and other elements which are 'bonus constituents of the more traditional fertilizer materials (ammonium sulphate, superphosphate). The use of organic manures is also declining causing low or nil addition of sulphur to the soil.

The ratios of N : S and P_2O_5 : S are widening because of low supply of sulphur to the soil.

Cnanges in N : S and P_2O_5 : S ratios in India

Year	N : S	P_2O_5 : S
1960-61	0.9	0.2
1970-71	3.8	0.9
1980-81	14.1	4.3

This causes low level of sulphur in soil and leads to deficiency symptoms in many crops resulting in reduced yields.

Through the use of adequate NPK fertilizers, use of high yielding crop varieties and adoption of other improved farming practices, crop yields are increasing and consequently higher quantities of nutrients including sulphur are removed from the soil with every harvest. But only major nutrients (N, P and K) are added as straight fertilizers causing depletion of sulphur in the soil.

Sulphur is mainly held in the soil in association with the soil organic matter. Soluble sulphates do not accumulate in soil and are lost by leaching. Highly leached, low organic and sandy soils contain very little sulphur and causes sulphur deficiency to crops grown in these soils.

Quality of crop produce is more affected due to sulphur deficiency than the yield of crops and in severe deficient areas only the yield affected.

In India, crop removal of S are presently estimated at 0.93 million tonnes as compared to 0.34 million tonnes of S added through fertilizers. This gap is likely to increase with increasing levels of agricultural production. If 50% of the S taken up by crops is to be replaced, it would require the application of 1.9 million tonnes of S at 25% efficiency.

Sulphur deficiency symptoms

Plants suffering from severe sulphur deficiency show very characteristic symptoms. In most cases, sulphur deficiency symptoms are confused or mistaken for nitrogen deficiency symptoms. Some common characteristic deficiency symptoms are, plants are small and spindle shaped with short slender stalks, growth rate is retarded and maturity is often delayed; young leaves are light green to yellowish in colour with even lighter coloured veins; on legumes nodulation is frequently reduced; fruits often do not fully mature and are light green in colour and spotting of leaves may also occur.

Alfalfa : Tillering is reduced, the leaflets are more erect, the new growth remains pale yellow-green and there is reddening of the stems.

Soybeans : Sulphur deficiency causes the pale yellow green colour of the new leaves to persist and gradually the whole plant turns yellow. The leaves become smaller and the internodes are shortened.

Tobacco : The new leaves are pale yellow green and at latter stages it extends to the whole plant. The leaves become smaller and the internodes are shortened.

Maize : Interveinal yellowing. followed by reddening of the stem and leaves are observed. Older leaves remain green.

Cotton : Sulphur deficient cotton shows the typical symptoms of yellowing of the new leaves and reddening of the petioles.

Tomato : In the initial stage stem, veins, petioles and petiolules turn purple and leaves turn yellow. Then the leaflets of older leaves show necrosis at tips and margins and small purple spots appear between the veins. Young leaves are stiff and curve downward. Eventually large irregular necrotic spots appear on these leaves.

Cucumber : Growth is restricted. Leaves remain small, particularly younger ones and they bend downwards and are pale green to yellow. In contrast to N deficiency, yellowing is least pronounced in older leaves. Margins of younger leaves are serrate in shape.

Lettuce : The whole plant turns yellow. The heart of the plant turns greenish yellow and the growth is restricted; Leaves become less crinkled, thicker and stiffer than normal.

Palms : In some leaves the chlorosis develops uniformly whilst in others it takes the form of pale green or white interveinal streaking. As the deficiency becomes more severe, small orange or brown necrotic spots appear on the older leaves, which eventually develop a terminal necrosis.

Sugarcane : Leads to the yellowing of leaves and finally chlorosis will develop. Stunted growth is seen and sucrose content of cane is reduced.

Wheat : Leads to stunted growth and dry matter production is reduced. Biomass production is limited resulting in formation of patches in the field. The width of the leaf is reduced and leaves show pale yellow colour. The older leaves start withering prematurely. Panicle length is reduced.

Sorghum : Yellowing in the leaves appear first followed by bleaching and even whitish leaves may appear. White streaks appear in the leaves.

Groundnut : Plants are small with young leaves light green to yellowish colour.

Potato : Sulphur deficient potato leaves turn light green to yellowish colour. Spotting of leaves may also occur.

Coffee : Young leaves are affected first. They turn light green to yellow colour. Often interveinal chlorosis occurs exposing the veins only with green colour.

Rice : Yellowing is observed in leaves. Plants are small with short slender stalks resulting reduced height. Number of panicles is reduced and yield is affected.

Tea : Yellowing in the leaves called as 'tea yellows'.

Turnips : A marked redness develops in lower leaves. It starts in the leaf veins and gradually spreads to the interveinal tissue.

Sources of sulphur .

Atmospheric sulphur : Most fuels contain some sulphur. Coal and certain fuel oils have high sulphur content. When these fuels are burn sulphur dioxide is released into the atmosphere and may be deposited in the soil by rainfall or absorbed directly by soils and plants. Sulphur dioxide being heavier than air settles out of the atmosphere over relatively short distances from the centre of the industrial belt. The addition through this source therefore varies considerably and on an average it may be about 5 kg S/ha per year.

Irrigation water : Dissolved sulphates are present in varying amounts in irrigation waters in different areas. It may range from 0 ppm in certain areas to 500 ppm in other areas. The river waters contain the lowest amount of sulphur near their sources and increases as the flow is supplemented by drainage water from cultivated and fertilized areas. Well waters vary in their S content depending upon the source of rocks through which they pass.

Animal manure : Animal manure contains varying amounts of sulphur compounds along with other plant nutrients. When it is returned to the soil, the sulphur and other plant nutrients contained in it are available for crop use. However, this source is inadequate to meet the entire crop requirement of high yielding varieties and intensive agriculture. This may range from 0-2 kg S/ha.

Crop residues : When the crop residues are added back to the soil, the removed sulphur and other nutrients to a certain extent are returned back to the soil. However, in practice most of the crop residues are not added back but utilized in some other ways. This source may account for 0-2 kg S/ha.

Sulphur containing pesticides : Insecticides, fungicides and herbicides which contain sulphur when applied to the soil and crop adds a certain amount of sulphur to the soil. The residues of these pesticides go to the soil and supplies the sulphur nutrient along with other nutrients. This source may be limited and is not a main source.

Soil sulphur : Most of the sulphur present in the soil is in organic form. Soluble sulphates seldom accumulate in soils because they are lost by leaching. However, in arid regions soluble sulphate salts accumulate as gypsum and in such conditions sulphur deficiency may not occur. Highly leached, low organic and sandy soils contain very little sulphur. In regions of high rainfall, sulphur accumulates in the sub-soil where sulphate is adsorbed by iron and aluminium oxides. The breakdown of organic matter and subsequent release of sulphur, is in many cases not sufficiently rapid to meet the increased plant demands under highly intensified agriculture. Organic sulphur content ranges from 10 to 2600 ppm Water-soluble sulphur varies from 1 to 25 ppm.

Fertilizer sulphur : Fertilizer sources of sulphur contribute to a great extent the need of the crops. There are different sources of sulphur containing fertilizers. Many sulphur containing fertilizers are available for use. Some contain large quantities of sulphur and the use of such materials will improve the soil fertility with respect to sulphur.

Sulphur content of fertilizers

Name of Fertilizer	Sulphur content (%)
Ammonium sulphate	23.7
Ammonium phosphate	4.5
Ammonium phosphate sulphate	15.4
Ammonium polysulphide	45.0
Ammonium nitrate sulphate	5.4
Ammonium sulphate nitrate	15.1
Basic slag	3.4
Copper sulphate	12.8
Elemental sulphur	85.0
Ferrous sulphate	18.8
Gypsum	23.5
Iron pyrites	23.0
Magnesium sulphate	12.4
Manganese sulphate	16.0
Potassium magnesium sulphate	22.4
Potassium sulphate	17.8
Superphosphate	12.4
Urea sulphur	10.0
Zinc sulphate	17.8

Sulphur in fertilizers is present either as readily soluble sulphate form or in forms which must undergo change in soil before it can be used by plants.

Choice of the most appropriate sulphur containing fertilizer to be used will depend on the soil, the crop, the time of application, local availability and costs.

CROP RESPONSES

Responses to application of sulphur are reported for many crops. In rice, sulphur in the form of gypsum at 1/2 tonne gypsum/ha along with required N recorded the highest grain yield. Sulphur coated urea gave significantly higher tillering and rice grain yield compared to ordinary urea at equal dose of N.

Amino acids, viz., cystine and methionine contents were found increased in onion due to increased levels of S application as ammonium sulphate and calcium sulphate. Sulphur application increases the pulses yield also. Soybean and cowpea yields were increased with N,P, K and S compared to N, P and K only. Oil seed crops were found to respond to S application by way of higher seed and oil yield. Groundnut yield increased by 50 % due to application of gypsum. The baking quality of wheat is directly related to the level of S in the grain The yield and quality of tea, tobacco, cotton, tapioca and coffee are also influenced by sulphur.

The quantity of sulphur to be applied depends upon the type of soil and nature of crops to be raised. Correct approach is to analyse the soil for S status and apply as per recommendation according to S status of soil. In the absence of soil test data, as a general practice, S can be applied at one-fifth the rate of N fertilization for all crops except legumes where the S dose has to be equal or more than that of N application.

LONG TERM EFFECT OF INTENSIVE CROPPING AND FERTILIZER USE ON SULPHUR AVAILABILITY TO RICE IN AN INCEPTISOL

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ABSTRACT

In a long term fertilizer experiment (rice-rice sequence), changes brought about in the available sulphur status of the soil due to continuous use of NPK fertilizers were studied. Available sulphur status decreased from 20 to 9.5 ppm when S-free NPK fertilizers were used for 13 years whereas it increased to 30.8 and 39.5 ppm respectively when NPK fertilizers, containing 45 and 67.5 kg sulphur were applied per hectare per season. With application of S-free NPK fertilizers, there was 21% decrease in grain yield in 1984-85 Kharif but no decline in yield was noticed in the summer crop because around 10 kg S/ha was added through irrigation water. Response studies over the period 1971-72 to 1984-85 showed positive response to sulphur in in Kharif in most of the years and its magnitude increased with progress of cropping cycles. This preliminary study indicated that an application of 44 kg S/ha/cropping cycle would be necessary to maintain the sulphur status of the inceptisol.

Sulphur deficiency in rice and response to fertilizer sulphur have been reported recently (Blair et al., 1979b and Ghosh, 1980). But there is very little research done on the sulphur fertilizer need of rice under intensive cropping system and the effect of continuous use of S-free fertilizers. The present study was undertaken to evaluate the long-term effects of NPK fertilizers on the available sulphur status of a sandy soil and the response to fertilizer sulphur in rice-rice cropping system.

Materials and Methods

The long-term fertilizer experiment has been laid out since 1972 on a medium land situated on a rolling topography inside the Central Research Station of O. U. A. T., Bhubaneswar.

The soil is sandy in the surface 0-20 cm grading to clay loam and clayey in the lower horizons, moderately acidic (pH 5.6), low in organic matter ((0.27% OC) , high in Olsen's p (31 kg/ha) and very low in respect of NH_4OAC-extractable-K (25 kg/ha). The soil contained 20 ppm $CaCl_2$ extractable-S. The soil has been classified as Aeric haplaquept.

The field remains ill drained during most part of the rainy season because of the closeness of the water-table and the rice crop is affected with iron toxicitv in scattered patches. Initially the experiment was laid out with 9 treatments and 3 replications in randomised complete block design and two more treatments were added subsequently in the year 1973-74. Details of the treatments are reported in Table 1.

The field is irrigated from a nearby lake. Occasionally sewage water is used for irrigation towards the last part of summer season in case the tank gets dry.

During 1984-85 cropping cycle, Kharif and summer rice crops were grown taking rice cultivars paratap and OR-26-2014-4 respectively. Standard cultural practices were adopted.

During Kharif the crop was raised mostly as a rainfed crop and only two irrigations amounting to about 10 cm water were given towards the end of the season. Sulphur content of the water ranged from 0.50 to 0.52 ppm. During summer season about 60 cm water was used from tank and 15 cm from sewage for irrigating the crop. Sulphur content of tank water ranged from 0.92 to 1.5 ppm and that of sewage water from 1.5 to 1.75 ppm on different dates of irrigation.

Rice plant samples were collected from individual subplots at panicle initiation stage in both the seasons and oven dry (70° C) plant materials were analysed for their sulphur content. For this 1 gm ground plant samples was taken in 100 ml erlenemayer flask with seed solution of K_2SO_4 containing 1 mg S and was digested in HNO_3 $HC1O_4$ (Blancher *et al* 1965) The digestate was made to 50 cc and S in 2.5 ml of extract was estimated by modified turbidometric method of Massoumi and Cornfield (1963) described by Hoeft *et al* (1973). Surface

Table 1.

Details of treatments of the long-term fertilizer experiment (Bhubaneswar)

Tr. No.	Treatment	$N-P_2O_5-K_2O$ Kg/ha/crop as fertilizer	Sources of NPK	$SO_4^{=}$ - S applied to each crop kg/ka
1.	50% NPK	50—30—30	CAN/Urea. SSP, MOP	22.5
2.	100% NPK (Weedicide)	100—60—60	-do-	45.0
3.	100% NPK	150—90—90	-do-	67.5
4.	100% NPK	100—60—60	-do-	45.0
5.	100% NPK + $ZnSO_4$ at 25 kg/ha	100—60—60	-do-	47.8
6.	100% NP	100—60—0	CAN/UREA. SSP	45.0
7.	100% N	100—0—0	CAN/Urea	—
8.	100% NPK — F.Y.M. 10 t/ha/year	100—60—60	CAN/Urea, SSP, MOP	45.0
9.	100% NPK (-S)	100—60—60	Urea, UAP, MOP	—
10.	Soil test based NPK dose*	Variable	CAN/Urea, SSP, MOP	Variable
11.	Control	0—0—0		—

* 100% NK up to Kharif 1981-82 and converted to soil test based fertilizer schedule since 1981-82 summer season.

Abbreviations - CAN - Calcium Ammonium Nitrate, SSP - Single superphosphate. MOP - Muriate of potash, UAP - Urea Ammonium Phosphate soil samples from individual treatment subplots were collected following the harvest of the rice crops. Available S in air dry samples was extracted using two extractants viz., 0 15% $CaCl_2$ (William and Stecinbergs, 1959) and NaH_2PO_4 solution (500 ppm P) in acetic acid medium (Cooper, 1968). Sulphur in suitable aliquot of both the extracts was estimated by modified turbidiometric method referred above. Sulphur content of the irrigation water sample collected on different dates was also determined turbidiometrically.

At harvest, grain and straw yields were recorded and the data were subjected to statistical analysis to evaluate the crop response. Crop response to S over the period 1971-72 to 1984-85 were also evaluated making use of the yield data recorded in the annual reports of the research project.

RESULTS AND DISCUSSION

Effect on available sulphur status of soil

Both $CaCl_2$ and $Na_2H_2PO_4$ solutions extracted almost comparable amounts of sulphur from the respective treatments. Probably there was negligible amounts of adsorbed SO_4 to be extracted by the phosphate extractant. Continuous use of phosphate fertilizer has resulted residual P accumulation in the soil (Anon, 1984). Adsorption of residual P, might have led to SO_4 desorption (Bromfield, 1972). Therefore, the estimation mostly included SO_4 S and the amounts extracted by 0.15% $CaCl_2$ from various treatments have been recorded in Table 2.

Available S estimated *after* the *harvest* of *Kharif* rice was found to be lowest (9.5 ppm) in the treatment which received S-free NPK fertilizer (Tr 9) On the other hand, the treatment which received 67.5 kg S/ha every season through SSP (Tr.3) contained highest amount of 39.5 ppm available sulphur followed by 35.8 ppm in the treatment which received 45 kg S/ha/season through SSP besides about 22 kg S/ha through FYM (Tr. 8). Regular application of S-free fertilizer for 13 years has resulted in around 50% reduction in the available S status of the soil whereas application of sulphur containing NPK fertilizer at 100 and 150% level has raised the status by 50 and

Table 2.

Effect of treatments on available S status of soil, S content in rice plants and grain yield of rice in 1984-85 cropping cycle

Tr. No.	Treatment	Available S (ppm)		S content in plant (%)		Grain yield (q/ha)	
		Kharif	Summer	Kharif	Summer	Kharif	Summer
1.	50% NPK	16.8	11.1	0.11	0.14	25.53	32.53
2.	100% NPK (Weedicide)	29.3	14.0	0.12	0.18	30.33	34.74
3.	150% NPK	39.5	25.7	0.14	0.18	33.00	38.63
4.	100% NPK	30.8	16.2	0.13	0.15	32.00	37.67
5.	100% NPK + $ZnSO_4$	26.7	20.2	0.12	0.15	28 00	38.68
6.	100% NP	30.0	18.0	0.13	0.16	22.83	30.65
7.	100% N	14.5	5.9	0.11	0.12	20.00	28.91
8.	100% NPK + F.Y.M.	35.8	22.5	0.12	0.15	37.00	46.37
9.	100% NPK (-S)	9.5	5.2	0.10	0.11	25.17	36.53
10.	Soil test based	20.7	13.0	0.12	0.14	35.17	46.07
11.	Control	12.7	5.9	0.10	0.10	18.17	18.37
	S. E. (m)	1.7	2.7	0.007	0.013	1.50	1.81
	C. D. (5%)	5.1	8.1	0.02	0.04	4.43	5.34
Initial Status as on 1971-72		20. 1					

100% respectively as compared to the *initial* status in 1972. Results suggest that a portion of the $CaSO_4 \times H_2O$ applied regularly through SSP has accumulated in the soil inspite of the probability of heavy leaching loss. The relationship between the change in $CaCl_2$ extractable S status and the rate of S applied through NPK fertilizer predicts that an application of 44 Kg S/ha cropping cycle would be necessary to prevent soil depletion under the situation.

Amounts of available S estimated after the harvest of umme rice from various treatments were somewhat lower as compared to the amounts extracted after harvest of Kharif rice. The soil samples in summer season were collected the next day following heavy summer shower. Displacement of SO_4 S from the surface to lower horizons cannot be over-ruled under such situation. However, the results show a similar sequence in available S status in the various treatments as it was observed after Kharif season.

Effect on S-content of rice plant

Sulphur content of the rice plants at panicle initiation stage in various treatments have been recorded in Table 2. Rice plants in the treatment which received S-free NPK fertilizer (Tr.9) contained 0.10 and 0.11% S respectively in Kharif and summer seasons. Compared to this, the plants in the treatment receiving sulphur containing fertilizer (Tr 4) contained 0.13 and 0.15% S. The relationship between the available S status of soil and S content in rice plants in various treatments was found to be highly significant for both the seasons ($Y = 0.901 + 0.00114x$ $r = 0.896^{**}$ for Kharif and $Y = 0.101 + 0.003x$ $r = 0.806^{**}$ for summer season). Variations in available S status of soil could account for 81 % of the variations in S content of rice plants in Kharif season but only 65% in summer season. This shows that the plants depended more on soil available S in Kharif than in summer season. Probably the 75 cms of irrigation water which contained around 10 kg S/ha supplemented a major portion of the sulphur requirement of the crop in the summer season. In the Kharif season the crop received only two irrigations amounting to 10 cms of water.

This would have hardly supplied 0.5 kg S/ha. Yoshida and Choudhury (1972) have observed that irrigation water with 2.7 ppm S would meet the requirement of the rice crop assuming 50% S recovery. This was further evidenced by the fact that rice plants in respective treatments contained invariably higher percentage of S in summer season than in Kharif season. The other reason which may be assigned for the relatively low S contents in the plants in Kharif season is the relative low availability of S under ill-drained intensive reduced condi-tion which existed in Kharif as compared to the alternate flooded and drained conditions maintained during summer season.

Response to sulphur applied through SSP

Grain yields obtained from various treatments in Kharif and summer season have been reported in Table 2. Upon comparing the mean yields of Tr. 9 which received S-free NPK fertilizer, with those of Tr.4 which received sulphur containing NPK, it is seen that there was a significant response of 6.83 q/ha in Kharif but there was hardly any response in summer season.

According to Yoshida and Choudhury (1979) the critical S content of rice straw decreased from 0.16% at tillering to 0.07% at flowering for maximum yield. Based on this decreasing trend, the critical S content at panicle initiation may be taken as 0.11% Rice plants in Tr. 9 were supposed to be deficient in sulphur in kharif season as they contained 0.10 % S. The deficiency resulted in 21% reduction in yield. On the contrary the rice plants in the said treatment in summer seaon may be considered to be marginally adequate as they contained 0.11% S for which there was no yield reduction. This differential response may be explained on the basis of the difference in S-input applied through irrigation water as has been discussed in the previous section.

Response to S over the period 1971-72 to 1984-85 have been presented in Fig. 2. It was observed that in most of the years there was positive response to S in Kharif season and the probability of significant response has increased with progress of crop year. Significant response of 5.0 to 9.34 q/ha have been obtained in four out of six Kharif seasons since 1979-80. The pooled average response over 13 Kharif seasons works out to be 4.7 q/ha which is 15% of the pooled average yield obtained in the treatment that received S containing NPK fertilizer. This shows that inadequate S availability resulting from intensive cropping with regular application of S-free fertilizer, is limiting the crop yield in Kharif seasons. On the contrary neligible or negative responses were obtained in most of the summer seasons. Although the available S status of the soil has reached the limiting status of less than 10 ppm due to regular application of S-free fertilizer, crop yields were not affected because of the S input through irrigation water and more favourable conditions of sulphur availability in the summer seasons.

It may be concluded that continuous use of S-free fertilizer in rice-rice cropping system will lead to sulphur depletion of light textured soil and bring significant reduction in rice yields. It is recommended to apply 44 kg S/ha/cropping cycle through fertilizers to prevent soil depletion.

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CONTINUOUS USE OF SULPHUR FREE AND SULPHUR CONTAINING FERTILIZERS

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Importance of sulphur in increasing the productivity of crops has been felt only in the recent past, especially after the introduction of high yielding crop varieties, intensive farming practices and use of high analysis fertilizers free from sulphur. Naik and Das (1964) indicated that in India, substantial areas of laterites, red and alluvial soils have found to be deficient in available sulphur. Light textured soils are observed to be more liable to sulphur deficiency due to low organic matter content and lesser ability to protect the sulphate from leaching. Therefore as to evaluate the sulphur status of soil in a cropping system an attempt has been made in the present investigation to study the distribution of different forms of sulphur in the soil after a period of five years due to the application of sulphur rich fertilizers as well as sulphur free fertilizers in the continuous cropping system.

MATERIALS AND METHODS

The Soil of the experimental plot (Long-term fertilizer experimental started in the year 1972) belonging to the Peelamedu series is a typical shallow black soil, clay loam texture with PH of 8.2 and available sulphur 36 ppm ($CaCl_2$ 0.15% extract).

The crop rotation consisted of ragi, cowpea and maize under irrigated condition. The treatments consisted of graded doses of the optimum NPK fertilizers based on soil test values (as ammonium sulphate, superphosphat, muriate of potash and sulphur free fertilizers as urea, diammonium phosphate and muriate of potash). The details are as follows:

T .. 50 per cent NPK plus weedicides

T .. 100 per cent NPK plus weedicides

T_3 .. 150 per cent NPK plus weedicides

T_4 .. 100 per cent NPK plus hand weeding

T_5 .. 100 per cent NPK plus weedicides plus micro-nutrient

T_6 .. 100 per cent NP plus weedicides

T_7 .. 100 per cent N plus weedicides

T_8 .. 100 per cent NPK plus weedicides plus FYM at 10 tons/hectare

T_9 .. 100 per cent NPK (sulphur fee) plus weedicides

T_{10} .. Unmanured control

The surface soil of the year 1972 and surface (0-9") and sub-soil (9" to 18") of the year 1976, which had been collected and stored were used to compare the sulphur status of the soil. Total sulphur present on the soil was determined by method suggested by Choudry and Cornfield (1966). Organic sulphur was estimated by the method suggested by Evans and Roast (1945) and available sulphur was determined by the method of Chesnin and Yien (1951) by using the following extractions by using Morgan's reagent, neutral normal ammonium acetate and normal hydrochloric acid. Inorganic sulphur was obtained by substracting organic sulphur from the total sulphur and organic carbon was estimated by Walkley and Black's method (1934).

RESULTS AND DISCUSSION

The data on different fractions of sulphur status of the soil in the beginning of the experiment (1972) are furnished in Table 1 and Table 2 and organic matter content in Table 3.

a) Total sulphur

i) Treatment : The data showed that the treatment T_7 (N alone recorded maximum content of total sulphur (479. 2 ppm) in soil and it was on par with T_{10} (control) and T_9 (sulphur free) contained a total sulphur of 382.0 ppm The crop yield was poor in T_7 and T_{10} treatments compared to other treatments and this

Table 1

Sulphur Status of the soil

Sl. No.	Treatments	Total sulphur (ppm)		Organic sulphur (ppm)		Inorganic sulphur (ppm)	
		1972	1976	1972	1976	1972	1976
1.	T_1	359.50	426.00	131.75	153.25	222.75	233.75
2.	T_2	255.50	364.20	132.50	209.75	123.00	154.25
3.	T_3	275.75	363.00	135.50	209.00	140.25	120.00
4.	T_4	347.75	368.00	134.75	209.75	213.00	160.50
5.	T_5	275.75	452.50	134.00	148.75	141.50	228.25
6.	T_6	275.75	346.25	132.75	189.50	143.00	204.25
7.	T_7	403.50	479.20	133.50	197.25	270.00	216.25
8.	T_8	403.50	405.20	133.25	253.75	268.00	151.50
9.	T_9	439.50	382.00	136.50	128.50	303.00	225.50
10.	T_{10}	393.50	477.00	132.75	189.25	260.75	391.50

Table 2.
Soil available Sulphur (ppm)

Sl. No.	Treatments	Morgan's extractable sulphur		Neutral N NH OAC extractable sulphur		Normal HC1 extractable sulphur	
		1972	1976	1972	1976	1972	1976
1.	T_1	24.75	24.50	59,75	66.05	92.75	105.3
2.	T_2	23.75	25.50	54.25	69.00	93.25	107.3
3.	T_3	23.75	13.50	45.75	50.07	75.00	111.2
4.	T_4	27.75	14.25	54.50	67.02	64.25	118.0
5.	T_5	24.25	22.75	56.75	70.45	99.00	106.3
6.	T_6	25.75	25.75	45.00	59.15	88.00	118.0
7.	T_7	25.00	22.75	65.75	77.95	69.50	91.6
8.	T_8	23.00	28.25	44.75	77.95	81.00	100 8
9	T_9	23.75	26,50	58.25	54.05	80.00	62 5
10.	T_{10}	24.75	28.00	56.75	51.37	80.75	73 5

Table-3.

Organic matter content of the soil (per cent)

S. No.	Treatment	1972	1976
1.	T_1	0 407	0.705
2.	T_2	0.433	0 772
3.	T_3	0.433	0.664
4.	T_4	0.433	0.718
5.	T_5	0.461	0.705
6.	T_6	0.461	0.745
7.	T_7	0.433	0.691
8.	T_8	0.461	1.057
9.	T_9	0.561	0.732
10,	T_{10}	0.433	0,677

suggested that the uptake and utilization of sulphur by the plants was comparatively low, resulting in greater retention and accumulation of sulphur in the soil.

ii) Year comparison : In general the total sulphur content of the soil was significantly increased from 342.9 ppm to 439.5 ppm after the period of five years (1972 to 1976). This could be attributed to the continuous application of sulphur rich fertilizers viz., ammonium sulphate and superphosphate during the period of five years The results of the present study are in conformity with the observations of Grant and Shakon (1970).

iii) Treatment and year comparison: Except in T_9 the total sulphur content of the year 1976 was higher in all other treatments than that of the year 1972. The total sulphur status of the soil was significantly reduced in T_9 treatment (439 50 ppm to 382 ppm). This might be due to the use of sulphur free fertilizers like urea and diammonium phosphate during the period.

b) Organic sulphur

i) Treatment: The data revealed that among the treatmens T_8 (100% NPK + FYM) recorded maximum value (253.8 ppm) than other treatments. This might de due to application of farm yard manure continuously in T_8 plot.

ii) Year comparison : The trend of the results showed that the organic sulphur content of the soil increased significantly from 133.9 to 189.5 ppm. As the organic matter content had increased after period of five years, the organic sulphur content of the soil has, also increased (Kanwar and Takker, 1964 and Leela, 1967).

iii) Treatment and year comparison : The analytical data showed that in treatment T_9 the organic sulphur reduced after a period of five years (136.50 ppm to 128.50 ppm). Continuous addition of sulphur free fertilizers like urea and diammonium phosphate could cause the reduction of organic sulphur content of the soil and also high yield of grain and straw might have removed greater amount of sulphur from the surface soil.

c) Available sulphur

i) Treatment : The Morgan's extractable sulphur content of the soil was maximum in T_8 (28.25 ppm) and minimum in T_3 (13 50) and in T_9 it was 26.50 ppm.

ii) Year comparison : The data showed that the Morgan's reagent extractable sulphur generally increased from 24.65 to 31.70 ppm because of the addition of sulphur containing fertilizers in the plots.

iii) Treatment and year comprison : The perusal of the data indicated that in T_8, the available sulphur content of the soil was siguificantly more in 1976 than 1972 and in other treatments the variation was not significant.

Neutral normal ammonium acetate extractable sulphur

i) Treatment : Among the treatments, the available sulphur extracted by neutral normal ammonium acetate was maximum in T_7 (77.95 ppm) and minimum in T_3 (50.08 ppm) and in T_9 the content was 51.38 ppm.

ii) Year comparison : The results revealed that the available sulphur extracted by Neutral normal ammonium acetate was generally increased from 54.15 ppm to 61.72 ppm (1972 to 1976)

iii) Treatments and year comparison : It was observed that the available sulphur extracted by neutral normal ammonium acetate extractable sulphur was more in all the treatments (except T_9 and T_{10}) in 1976 than in 1972.

e) Normal hydrochloric acid extractable sulphur

i) Treatment : Among the treatments T_4 and T_6 (118.00 ppm) recorded higher values than other treatments and the treatment T_9 recorded low value (62.5 ppm).

ii) Year comparison : It was observed that the available sulphur extracted by normal hydrochloric acid was generally increased from 82.35 ppm to 99.50 (1972 to 1976).

iii) Treatments and year comparison : The data showed that treatments the normal extractable sulphur was more in all the treatments (except T_9 and T_{10}) of the year 1976 than in the year 1972.

Among the three extractants used viz., normal hydrochloric acid, neutral normal ammonium acetate and Morgan's reagent, it was observed that normal hydrochloric acid extracted higher proportion of sulphur. Similar findings have been reported by Ayyathurai (1969). This might be due to the ability of the reagent to extract more of organic fraction of sulphur.

The three extractants viz., neutral normal ammonium acetate, normal hydrochloric acid and Morgan's reagent extracted the highest amount of available sulphur in T_7, T_4 and T_8 respectively. There was no consistent pattern with regard to available sulphur extracted by the three different extractants.

In general the available sulphur was more in the samples drawn in the year 1976 than those of 1972. The same trend was observed with all the three different extractant. This might be due to the continuous application of sulphur rich fertilizers. But in T_9, the decreasing trend was observed and this may be due to the continuous addition of sulphur free fertilizers like urea and diammonium phosphate.

f) Inorganic sulphur

i) Treatment : It was observed that inorganic sulphur content of the soil was maximum in T_{10} (391.50 ppm) and minimum in T_3 (120.00 ppm)

ii) Year comparison : The data indicated that the inorganic sulphur content of the soil was slightly decreased from 208.6 ppm to 193.20 ppm but it was not statistically significant.

iii) Treatment and year comparison: It was observed that except in T_1, T_2 T_5 and T_6 the inorganic sulphur content of the soil is in all other treatments was more in the year 1972 than in 1976.

At the end of the fifth year it was observed that the inorganic sulphur content of the soil was slightly reduced. The possible reason for this might be leaching effect of irrigation water, rain water and crop removal of inorganic sulphur from the soil. Some quantity might have been converted to organic pool.

g) Organic Matter

i) Treatments: The antytical data showed that the Organic - matter content of the soil was more in T_8 (1.06 percent) in which farm yard manure was applied. Teru Kubota.

(1971) also reported similar findings. The minimum value was noted at T_3 (0.66 per cent).

ii) Year comparison : It was observed that in general the organic matter content of the soil was slightly more in the year 1976 (0.75 per cent than the year 1972 (0.45 per cent).

iii) Treatment and year comparison : The results indicated that in all the treatments the organic matter content of the soil was more in the year 1976 than in the year 1977. The increasing trend of organic matter content in the soil in a crop rotation was also observed by Singh and Khatri (1972).

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DIFFERENT FORMS OF SULPHUR IN MAJOR SOIL SERIES OF COIMBATORE DISTRICT

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ABSTRACT

Different forms of Sulphur Viz., water soluble sulphur, Morgan's reagent extractable sulphur, Neutral N ammonium acetate extractable sulphur, N HCl extractable sulphur, organic sulphur and total sulphur were estimated in fifteen major soil series of Coimbatore District. Water soluble sulphur varied from 2 to 23 ppm with an average of 18 ppm. Available sulphur extracted by Morgan's reagent, neutral N ammonium acetate and N HCl ranged from 100 to 460 ppm, 54 to 130 ppm and 23 to 110 ppm respectively. Morgan's reagent extractable sulphur significantly correlated with total sulphur (r-0.854).

Organic sulphur content of the soils ranged from 10 to 2630 ppm and the highest organic sulphur was recorded in Dasarapatti soil series (black calcareous-gypsiferrous). Organic sulphur was found to be significantly correlated with organic carbon. Total sulphur content of the soils ranged from 190 to 5700 ppm, the highest being in Dasarapatti soil series. Close relationship was observed between total sulphur and organic carbon content.

Introduction

Sulphur is one of the important seconary nutrients required for the plants. It is present in two major forms, viz., organic and inorganic forms. Only in the recent years the importance of sulphur in soil fertility and crop yieid has been recognised. The organic sulphur has been designated as an indicator of reserve sulphur status of soil. Several soil tests have also been proposed for evaluating the available sulphur status of soils. The present study was undertaken to make a detailed assessment of the sulphur status of the soils of Coimbatore district.

Materials and Methods

Fifteen soil samples (0-22 cm) collected from the major soil series of Coimbatore district were used in this study. Organic carbon was estimated by Walkley and Black's method as described by Piper (1950). Water soluble sulphur was estimated by the method of Freney (1957). Available sulphur was extracted by using the different extractants viz., Morgan's reagent, neutral normal ammonium acetate and N.HCl and the extracted sulphur was determined turbidimetrically (Chesnin and Yien, 1951). Organic sulphur was estimated by the method of Evans and Rost (1945), whereas total sulphur was determined by the method of Chaudhry and Cornfield (1966).

Results and Discussion

The different forms of sulphur and organic carbon are given in Table 1. Water soluble sulphur varied from 2 to 23 ppm with an average of 18 ppm. The percentage of water soluble sulphur to total sulphur ranged from 0·008 to 6·00 per cent with a mean of 2·21 per cent. The proportion of this form of sulphur was high in Noyyal and Suriyanallur soil series (alluvial and colluvial soils respectively), whereas it was low in Dasarapatti series (black calcareous soil). Water soluble sulphur was significantly correlated with total sulphur (r - 0·636*).

Table-1

Different forms of sulphur (ppm)

Soil Series	Water soluble sulphur	Morgan's reagent extractable sulphur	Neutral N. ammonium acetate extractable sulphur	N.HCl extractable sulphur	Organic sulphur	Total sulphur	Organic carbon%
Dasarapatti (black calcareous)	5	440	60	110	2630	5700	0·81
Irugur (red non-calcareous)	2	100	67	34	70	750	0·54
Palladam (red calcareous)	5	160	67	58	20	190	0·84
Peelamedu (black calcareous)	2	500	60	97	120	730	0·63
Noyyal (alluvial non-calcareous)	5	400	54	39	30	780	0·78
Palathurai (red calcareous)	5	150	100	38	100	500	1·66
Pichanur (red non-calcareous)	5	160	67	51	60	200	0·49
Tulukkanur (red calcareous)	5	160	67	56	90	370	1·17
Wannapatti (red non-calcareous)	7	190	85	23	80	500	1·17
Vellalur (red non-calcareous)	5	210	80	46	50	390	1·34
Kallivalasu (alluvial calcareous)	2	320	94	91	130	350	1·89
Suriyanallur (colluvial)	5	230	94	95	150	800	0·46
Ammapettai (black calcareous)	10	560	80	96	380	700	0·38
Kuppandapalayam (brown calcareous)	23	390	110	87	460	1700	0·46
Manupatti (—do—)	7	200	130	59	10	1200	0·22

Available sulphur extracted by Morgan's reagent, neutral normal ammonium acetate and N. HCl ranged from 100 to 460 ppm, 54 to 130 ppm and 23 to 110 ppm respectively. The available sulphur extracted by neutral normal ammonium acetate and N. HCl was low compared to the available sulphur extracted by Morgan's reagent. Morgan's reagent extractable sulphur was high in Ammapettai soil series (black calcareous soils) followed by Peelamedu soil series (black calcareous soils). The percentage of available sulphur extracted by Morgan's reagent to total sulphur was from 14 to 94 with a mean of 46·7 and high proportion was recorded in Kallivalasu soil series (alluvial calcareous soil). Morgan's reagent extractable sulphur significantly correlated with total sulphur (r = 0·854**). The available sulphur extracted by neutral N ammonium ace. tate and N HCL to total sulphur were from 1 to 33 per cent and 1 to 14 per cent respectively. The low proportion of ne utral normal ammonium acetate and acid extractable sulphur was also reported by Leela (1967) and Ayyathurai (1969) in Kerala and Tamil Nadu soils respectively.

Organic sulphur content of the soils varied widely among the soil series and it ranged from 10 to 260 ppm. The highest organic sulphur was recorded in Dasarapatti soil series (black calcareous soils) while it was very low in Manupatti soil series (brown calcareous soils). Organic sulphur percentage to total sulphur was from 10 to 6168 ppm with a mean of 28·4 per cent. In general, the proportion of organic sulphur to total sulphur was low in these soils as reported by Kanwar and Takkar (1964) and Ayyathurai (1969). Under tropical climatic condition the organic matter is oxidised and the organic sulphur might have been converted into inorganic form resulting in low organic sulphur in these soils. Organic sulphur was found to be significantly correlated with organic carbon (r = 0·535*).

Total sulphur content of the soils varied widely among the soil series and it ranged from 190 to 5700 ppm. It was observed that the soils of Dasarapatti series (black calcareous soils) recorded high amount of total sulphur and this might be due to gypsiferrous nature of the soil. Close relationship was observed between total sulphur and organic carbon content (r = 0·588*) and such relationship was also observed by Leela (1967) and Ayyathurai (1969).

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EFFECT OF SULPHUR APPLICATION ON THE YIELD AND QUALITY OF ONION (Allium cepa L.)

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ABSTRACT

An experiment was conducted to study the effect of different sources of sulphur viz., ammonium sulphate and calcium sulphate on the yield and quality of onion bulb in two soils (red and black soils). The levels of sulphur tried were 0, 10, 20 and 30 Kg S/ha. Black soil recorded the highest yield of onion bulb and there was no significant difference in the yield of onion bulb due to the different levels of sulphur eventhough the highest yield was observed at 20 Kg S/ha. The amino acids, viz., cystine and methionine increased with increase in levels of sulphur. Among the sources of sulphur, calcium sulphate was found to be superior. Among the treatments, application of sulphur at 30 Kg / ha either as ammonium sulphate or calcium sulphate was found to increase the pyruvic acid content of the onion bulb. There was no significant difference between the two soils studied on pyruvic acid content.

Introduction

Sulphur is one of the essential plant nutrients which forms a constituent of protein. It is one of the important secondary nutrients required for the plants for the synthesis of aminoacids, cystine and methionine and hence for protein elaboration. Tisdate *et al.* (1950) observed that in alfalfa the percentage of methionine and cystine increased with increase in concentration of sulphur. Schwimnet *et al.* (1962) found that the pyruvic acid formed was one of the measure of pungency of onion and garlic. The present study was undertaken to gain a better understanding of the effect of different sources of sulphur on the quality of onion in the two soils of Coimbatore District.

Materials and Methods

A pot experiment was conducted to study the effect different forms of sulphur on the quality of onion using two representative soils viz. Red (Irugur series) and Black (Dasarpatti series). The soils were ground well to pass through 2 mm sieve and 5 kg of soil was taken in each pot. There were seven levels of sulphur treatments (Table I). All the treatments received recommended doses of N, P, K. The entire quantity of sulphur was applied as basal dose two days prior to sowing. Onion variety culture 1094-63 B of Millet Breeding Station, Tamil Nadu Agricultural University, Coimbatore was used. The crop was harvested affer 75 days and the bulbs under different treatments were analysed for sulphur containing amino acid and pyruvic acid following Block *et al.* (1958) and Hart and Fisher (1971) methods respectively.

Results and Discussion

The results of yield data, amino acid and pyruvic acid content of onion bulb are given in Table No. I. Significant differences between soil types was observed with respect to bulb yield. This might be due to the higher amounts of available nitrogen, phosphorus and sulphur in black soils compared to red soil. There was no significant difference in the yield of onion bulb due to different levels of sulphur eventhough the highest yield was observed at 20 Kg S/ha. There was no significant difference between the two sources of sulphur viz., ammonium sulphate and calcium sulphate. The results agreed with the findings of Peterson *et al.* (1960).

The amino acid content cystine and methione increased with increase in dose of sulphur. This was in accordance with the report of Tisdale *et al.* (1960). Red soil was found to be significantly superior to black soil. Among the treatments also there was significant differences with regard to the content of cystine. Application of sulphur at 30 kg/ha was superior to other treatments in both the soils. Among the sources, calcium sulphate was found to be superior. The increase in concentration of sulphur containing amino acids might be due to the increased uptake of sulphur and protein synthesis.

Table 1

Yield, aminoacid and pyruvic acid content of onion bulb (mean values)

Soil type	Treatments	Yield (g/pot)		Amino acid (g)		Pyruvic acid moln/g
		Straw	Bulb	Cystine	Methionine	
Red	0.0 kg Sulphur(control)	22.5	17.5	15.50	12.25	2.0
do	10.0 kg ammonium sulphate	22.5	17.5	17.25	13.47	2.0
do	20.0 kg do as do	12.5	27.5	20.50	17.75	2.7
do	30.0 kg do as do	20.0	32.5	22.75	20.50	4.0
do	10.0 kg do as calcium sulphate	15.0	20.0	16.75	21.70	1.7
do	20.0 kg do as do	27.5	32.0	22.0	36.37	2.2
do	30.0 kg do as do	15.0	32.5	24.50	38.97	3.5
Black	0.0 kg Sulphur(control)	17.5	28.5	12.00	11.62	2.0
do	10.0 kg do as ammonium sulphate	27.5	32.5	16.00	21.25	2.2
do	20.0 kg do as do	25.0	45.0	17.75	29.12	3.2
do	30.0 kg do as do	17.5	25.0	25.00	31.25	4.0
do	10.0 kg do calcium sulphate	17.5	45.0	17.50	22.75	1.2
do	20.0 kg do as do	22.5	46.0	20.50	34.50	2.2
do	30.0 kg do as do	17.5	32.5	22.25	62.75	2.9

Cystine C.D.(P = 0.05) = 0.563
Methionine C.D.(P = 0.05) = 0.289
Treatment C.D.(P = 0.05) = 0.791
Soil C.D.(P = 0.05) = 1.06
Source C.D.(P = 0 05) = 0.563
Treatment C D (P = 0.05) = 1.05

There was no significant differences between red and black soils with reference to the pyruvic acid content of the bulbs. Among the treatments, application of sulphur at 30 kg/ha was found to be superior but it was on par with 20 kg/ha. There was an increase in pyruvic acio content with increase in sulphur application and this may be due to increased synthesis of volatile sulphur compounds.

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RESPONSE OF BLACKGRAM TO SULPHUR FERTILIZATION ON MAJOR SOILS OF TAMIL NADU

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ABSTRACT

A pot culture study was conducted to find out the response of blackgram (var. Co 3) to the application of sulphur in major soils of Tamil Nadu. Application of 15 ppm sulphur was found to produce significant variation in yield of grain. Among the soils, black soil collected from Aruppukkottai Ramnad District recorded the highest yield. Similar trend was observed for the yield of stover also. Sulphur fertilization was found to improve the quality of grain as well as stover by increasing the contents of nitrogen, phosphorus and sulphur. The study revealed the necessity for the application of sulphur at 15 ppm to blackgram to attain maximum yield as well as better quality of the produce.

Snlphur is one of the essential nutrient elements which is closely associated in plant metabolism, especially in protein synthesis (Aulakh *et al.* 1976) Numerous crop species such as maize, cotton, jute, tea. coffee, oilseeds, pulses, etc., have been found to respond to the application of sulphur (Dev *et al.* 1979; Kumar and Singh, 1977; Mandal *et al.* 1983; Subramanya Bhat and Renganathan, 1980; Badiger *et al.*, 1982 and Aulakh and Passischa, 1977) Beneficial effect of sulphur application on the quality of produce has also been reported (Chopra and Kannan, 1966). In the present investigation an attempt has been made to study the effect of sulphur on yield and composition of blackgram in major soils of Tamil Nadu.

Experimental

A pot culture experiment was carried out with 15 soils representing various available sulphur status (Table 1) using blackgram (var. CO 3) as a test crop. Five kg of soil was added to each of the pot and 5 levels of sulphur (O, 5, 10, 15 and 20 ppm) were imposed as ammonium sulphate, balancing the nitrogen level by urea. A common basal dose of 20 ppm P as $H_3 PO_4$ and 4 ppm K as muriate of potash was applied to all the pots and the treatments were replicated two times. Uniformly 6 seeds were sown and after germination 3 plants were maintained per pot. The irrigation was done with deionized water. After 10 weeks of growth the crop was harvested at maturity and the yields of grain and straw were recorded treatmentwise. The representative plant samples were collected, washed with distilled water, dried in an oven, washed and powdered in willy mill with stainless steel blade. The amount of sulphur was determined turbidimetrically as per the procedure outlined by Chesnin and Yien (1950). The total N, P and K were estimated following Kjeldahl method (Humphry, 1956), Vanadomolybdate phosphoric yellow method and with flame photometer (Jackson, 1967) respectively.

Table 1.

Initial analysis of soil samples

S.No.	Soil	Location	EC	pH	Org. carbon	Av.S (by $CaCl_2$ 0.15%)
S_1	Red soil	Charapuram	0.20	8.4	0.26	8.0
S_2	Black soil	Coimbatore	0.27	8.3	0.41	36.0
S_3	Alluvial soil	Virunchi	0.30	7.0	0.22	5.6
S_4	Red soil	Usilampatty	0.45	7.0	0.34	10.0
S_5	Red soil	Bhavanisagar	0.21	8.0	0.31	29.0
S_6	Red soil	Palani	0.57	6.9	0.21	8.9
S_7	Black soil	Aruppukkottai	0.24	8.3	0.50	40.0
S_8	Red soil	Manaparai	0.28	7.3	0.30	11.3
S_9	Laterite soil	Ooty	0.13	4.6	4.20	34.0
S_{10}	Red soil	Vadavalli	0.30	7.4	0.25	24.0
S_{11}	Red soil	Salem	0.24	7.7	0.35	18.0
S_{12}	Red soil	Periyakulam	0.60	7.6	0.53	10.0
S_{13}	Alluvial soil	Tiruchi	0.38	6.8	0.50	20.0
S_{14}	Alluvial soil	Noyal				
S_{15}	Brown soil	Dharmapuri	0.28	7.3	0.38	14.0

A significant influence for the added sulphur was noticed with reference to grain yield of blackgram. The highest yield was obtained with 15 ppm sulphur and further increase in dose to 20 ppm S failed to bring out significant advantage over 15 ppm sulphur indicating sufficiency of 15 ppm sulphur to blackgram. The yield increase at this level was about 24% over control. Similar increase in yield was recorded by Shinde (1983) in black soils of Madhya Pradesh up to 15 ppm sulphur.

Among the soils, the black soil collected from Aruppukkottai, Ramnad District (S_7) recorded the maximum yield (13.82 g/pot) which was closely followed by Noyal alluvium (S_{14}), Tiruchi Alluvium (S_{13}) and laterite soil (S_9) collected from Ooty. The red soil collected from Vadavalli (S_{10}) registered the lowest yield.

A significant interaction was found to exist between sulphur levels and soils. The data showed that sulphur application had significant and positive response on grain yield in six soils (S_1, S_3, S_4, S_6, S_8 and S_{12}) while in the remaining soils (S_2, S_5, S_7, S_9, S_{10}, S_{11}, S_{13}, S_{14} and S_{15}) the addition of sulphur did not cause marked variation in grain yield. Similar to that of main effect of levels of sulphur high response was observed for 15 ppm S level in all the soils except S_2, S_3, S_{12} and S_{14} soils and both 15 and 20 ppm levels were on par. In all the levels of sulphur, S_7 soil recorded highest grain yield and S_{10} recorded the minimum yield which again followed the trend of the main effect results.

Yield of stover

A similar trend as that of grain yield was noticed with respect of yield of stover also. However, the interaction effect was not brought out with reference to this paramater. The findings of Aulakh and Dev (1977) adds support for the trend of increase in dry matter with applied sulphur observed in the present study.

Results and Discussion

Effect of applied sulphur on grain yield of blackgram

Table 2.

Effect of sulphur on grain and stover yields (Mean of 2 replications)

Soil	Grain Yield (l/Pot) L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}	Stover Yield (l/Pot) L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}
S_1	6.58	7.95	8.73	10.25	9.78	9.80	11.55	14.40	15.70	15.25
S_2	10.15	10.14	10.65	10.65	10.65	15.25	15.25	15.44	15.60	15.55
S_3	5.07	6.60	7.83	9.50	9.50	8.40	10.30	11.66	14.65	14.40
S_4	5.85	6.50	8.25	9.85	9.40	9.00	10.73	13.10	14.93	14.98
S_5	7.93	7.90	8.01	8.26	8.14	10.40	10.45	11.01	12.06	11.50
S_6	6.65	7.60	8.16	9.69	9.54	11.80	13.40	14.90	16.30	15.99
S_7	13.90	13.75	13.90	13.90	13.66	19.15	19.15	19.35	19.30	18.80
S_8	6.00	7.34	8.75	9.70	9.44	9.60	11.60	14.30	15.83	15.50
S_9	10.35	10.40	11.10	11.20	10.95	16.39	17.60	17.90	17.83	17.65
S_{10}	4.63	4.84	4.60	5.25	4.85	7.30	7.81	8.15	8.80	8.56
S_{11}	5.80	5.85	5.82	6.63	5.95	12.35	12.85	13.15	13.70	13.48
S_{12}	5.95	7.53	8.70	10.05	10.30	10.95	13.40	15.35	16.75	16.05
S_{13}	10.96	11.55	11.40	11.71	11.30	16.61	18.18	18.28	18.25	18.70
S_{14}	10.70	11.60	11.65	11.55	11.66	15.23	15.64	16.22	16.15	16.65
S_{15}	6.90	7.45	7.93	7.80	7.90	11.30	11.45	11.30	11.94	11.65

Table 3.

Nitrogen content (percent) (Mean of two replications)

Soil	Black gram grain					Blackgram Stover				
	L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}	L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}
S_1	3.01	3.80	3.79	3.87	3.88	1.54	1.65	1.79	1.80	1.83
S_2	3.27	3.65	3.77	3.81	3.81	1.78	1.78	1.88	1.88	1.91
S_3	3.24	3.69	3.85	3.88	3.99	1.56	1.58	1.60	1.59	1.69
S_4	3.15	3.32	3.65	3.71	3.77	1.60	1.67	1.79	1.82	1.87
S_5	3.20	3.24	3.49	4.07	4.52	1.62	1.69	1.79	1.86	1.86
S_6	3.20	3.24	3.49	4.07	4.52	1.62	1.69	1.79	1.86	1.86
S_7	3.36	3.56	3.66	4.24	4.22	1.83	1.87	1.84	1.87	1.87
S_8	3.10	3.37	3.97	3.76	3.94	1.64	1.89	2.00	2.01	2.01
S_9	3.65	3.80	3.81	3.81	4.01	1.70	1.85	1.94	1.95	1.96
S_{10}	3.36	3.50	3.41	3.43	3.76	1.70	1.78	1.81	1.82	1.83
S_{11}	3.23	3.41	3.65	3.61	3.72	1.60	1.65	1.90	1.91	1.93
S_{12}	2.39	2.56	2.89	3.35	3.32	1.61	1.82	1.84	1.85	1.86
S_{13}	2.89	3.44	3.77	3.75	3.79	1.83	1.90	1.94	1.95	1.95
S_{14}	3.34	3.38	3.46	3.80	3.61	1.67	1.83	1.86	1.88	1.88
S_{15}	2.82	3.31	3.46	3.53	3.09	1.61	1.76	1.77	1.82	1.83

Table 4.

Phosphorus content (percent) (Mean of two replications)

Soil	Blackgram grain					Blackgram Stover				
	L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}	L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}
S_1	0.32	0.35	0.36	0.36	0.38	0.20	0.20	0.20	0.20	0.20
S_2	0.33	0.34	0.35	0.37	0.38	0.21	0.21	0.22	0.22	0.22
S_3	0.32	0.34	0.35	0.37	0.38	0.19	0.19	0.20	0.19	0.20
S_4	0.33	0.33	0.34	0.34	0.35	0.21	0.22	0.2	0.22	0.21
S_5	0.34	0.33	0.34	0.34	0.36	0.21	0.21	0.21	0.22	0.21
S_6	0.29	0.31	0.31	0.36	0.35	0.20	0.20	0.21	0.21	0.20
S_7	0.36	0.36	0.38	0.36	0.34	0.22	0.23	0.23	0.24	0.24
S_8	0.31	0.35	0.35	0.34	0.35	0.20	0.21	0.21	0.21	0.21
S_9	0.39	0.39	0.39	0.39	0.40	0.23	0.23	0.23	0.24	0.24
S_{10}	0.34	0.35	0.35	0.35	0.36	0.19	0.20	0.20	0.20	0.20
S_{11}	0.35	0.36	0.36	0.36	0.37	0.21	0.21	0.21	0.21	0.22
S_{12}	0.31	0.33	0.34	0.33	0.33	0.20	0.21	0.22	0.22	0.21
S_{13}	0.31	0.33	0.34	0.36	0.35	0.22	0.23	0.23	0.23	0.23
S_{14}	0.36	0.38	0.40	0.41	0.39	0.22	0.22	0.22	0.21	0.22
S_{15}	0.30	0.31	0.33	0.34	0.19	0.20	0.20	0.20	0.20	0.20

Table 5.
Potassium content (percent) (Mean of two replications)

Soil	Blackgram grain					Blackgram Stover				
	L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}	L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}
S_1	1.90	2.01	2.05	2.10	2.01	1.50	1.48	1.60	1.55	1.59
S_2	2.00	2.01	2.05	2.30	2.40	1.81	1.83	1.82	1.79	1.79
S_3	1.60	1.72	1.70	1.80	1.80	1.43	1.46	1.42	1.46	1.45
S_4	1.50	1.51	1.60	1.60	1.60	1.51	1.56	1.63	1.65	1.60
S_5	1.90	2.11	2.11	2.10	2.12	1.48	1.48	1.53	1.50	1.60
S_6	1.60	1.81	1.81	1.92	1.91	1.45	1.45	1.50	1.50	1.60
S_7	2.10	2.11	2.12	2.11	2.22	1.78	1.78	1.69	1.75	1.83
S_8	1.30	1.61	1.61	1.81	1.72	1.91	1.86	1.88	1.87	1.79
S_9	2.00	2.11	2.01	2.12	2.13	1.99	2.01	1.96	2.03	2.03
S_{10}	1.30	1.31	1.32	1.41	1.32	1.43	1.53	1.55	1.52	1.47
S_{11}	1.71	1.81	1.82	1.81	1.82	1.65	1.60	1.59	1.62	1.60
S_{12}	1.40	1.62	1.63	1.62	1.62	1.41	1.42	1.49	1.43	1.45
S_{13}	1.31	1.51	1.41	1.41	1.56	2.05	2.10	2.14	2.00	2.68
S_{14}	2.11	2.01	2.12	2.22	2.22	1.83	1.82	1.94	2.15	1.95
S_{15}	1.50	1.41	1.70	1.51	1.31	1.60	1.63	1.60	1.64	1.60

Table 6.

Sul-hur content (percent) (Mean of two replications)

Soil	Blackgram grain					Blackgram Stover				
	L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}	L_0	L_5	L_{10} (Sulphur levels)	L_{15}	L_{20}
S_1	0.11	0.14	0.16	0.19	0.19	0.25	0.34	0.36	0.42	0.42
S_2	0.14	0.15	0.17	0.19	0.21	0.31	0.39	0.43	0.45	0.47
S_3	0.12	0.16	0.17	0.18	0.20	0.21	0.28	0.31	0.34	0.36
S_4	0.13	0.17	0.19	0.20	0.21	0.27	0.35	0.38	0.41	0.42
S_5	0.14	0.15	0.17	0.19	0.19	0.31	0.36	0.42	0.43	0.44
S_6	0.14	0.16	0.17	0.18	0.19	0.21	0.34	0.36	0.39	0.41
S_7	0.18	0.20	0.20	0.22	0.23	0.31	0.36	0.37	0.39	0.41
S_8	0.12	0.14	0.16	0.17	0.21	0.22	0.27	0.32	0.35	0.40
S_9	0.13	0.16	0.19	0.21	0.20	0.30	0.34	0.38	0.38	0.40
S_{10}	0.15	0.18	0.19	0.20	0.20	0.30	0.31	0.35	0.38	0.41
S_{11}	0.14	0.14	0.15	0.17	0.19	0.27	0.28	0.28	0.30	0.32
S_{12}	0.12	0.13	0.14	0.15	0.18	0.27	0.32	0.34	0.36	0.36
S_{13}	0.14	0.17	0.21	0.21	0.22	0.28	0.33	0.37	0.39	0.39
S_{14}	0.15	0.17	0.19	0.22	0.22	0.32	0.37	0.39	0.39	0.40
S_{15}	0.14	0.16	0.18	0.18	0.20	0.21	0.26	0.30	0.36	0.39

Nutrient content

Nitrogen content in grain and stover: the nitrogen content of grain as well as that of stover was found significantly altered by applied sulphur. The highest nitrogen content (3. 88% in grain and, 1. 87% in stover) was recorded at 20 ppm sulphur. However, the level at 15 ppm sulphur was found to remain on par with 20 ppm sulphur. The result was in agreement to the earlier observations of Aulakh (1976). The increase in nitrogen concentration especially in legumes may be due to influence of sulphur on nitrogen fixation by increasing number and size of the nodules as reported by Jordan (1954) besides induced growth leading to increased uptake of nitrogen by the plant.

Phosphorus content: The applied sulphur was found to increase the phosphorus content of grain and stover in a significant measure with a higher magnitude for grain, while the levels at 15 and 20 ppm sulphur were significantly different in case of grain and all the levels of added sulphur remained on par in the case of stover.

Potassium content: The potassium content of grain was found significantly varying due to sulphur fertilization. Even though there was not much variation among the different levels of sulphur tried, a definite increase was associated when compared to the control

Sulphur content: A highly significant influence for the applied sulphur was noticed with reference to content of sulphur in grain and stover. Each increment of sulphur produced a significant increase over the lower level. Since the sulphur is released as ion immediately after application due to highly soluble nature, increased uptake by the plant is quite evident. This trend corroborates with the findings of Kumar *et al.* (1981).

The results indicate the beneficial effects to sulphur fertilization in terms of increased yield and quality of blackgram.

EFFECT OF SULPHUR ON YIELD AND GRAIN QUALITY OF BLACKGRAM AND GREENGRAM

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ABSTRACT

Results of a field experiment conducted to study the effect of sulphur application as gypsum and elemental sulphur showed that the application of elemental sulphur at 55.5 kg/ha significantly increased the protein content of blackgram grain, whereas the application of gypsum at 200 kg/ha significantly increased the protein content of greengram grain. But methionine content, dry matter production and yield remained unaffected by the application of either gypsum or sulphur in both the crops.

Among the grain legumes blackgram and greengram are the two major pulses used next to redgram in Tamil Nadu. The sulphur containing amino acids are the limiting amino acids in pulses. Several workers (Chopra and Kanwar, 1966; Singh et al., 1970; Gupta and Gupta, 1972; Kamat et al., 1981 and Lal and Jaiswal, 1981) have studied the effect of sulphur application on the protein and methionine content, dry matter production and yield on different legumes. The present work was carried out to study the effect of sulphur compounds on the protein and methionine content, dry matter production and yield of blackgram and greengram grains.

EXPERIMENTAL METHODS

A field experiment was laid out in randomised block design with three replications and nine treatments at the Millet Breeding Station of Tamil Nadu Agricultural University, Coimbatore during Rabi and Kharif 84. The red loamy soil (Typic Haplustalf) of the experimental field had available nitrogen of 62.7 kg/ha and pH 7.9. Sulphur was applied in two different forms as gypsum and elemental sulphur at 4 levels in two different stages of plant growth. Gypsum was applied at 100, 200, 300 kg/ha as basal application and 100 kg/ha basal + 100 kg/ha at flowering stage. Elemental sulphur at 18.5, 37.0, 55.5 kg/ha basal application and 18.5 basal + 18.5 kg/ha at flowering stage, were the other treatments along with a control. The trials were conducted in plots of 4×3 m size and all of them received same fertilizer dose and plant protection measures.

Blackgram var. CO 5 was sown during end of November, 1984. The crop was harvested after 75 days from sowing. Greengram var. CO 4 was sown during the middle of July, 1984 and harvested during first week of October 1984. The grain samples were analysed for total nitrogen by microkejdahl method and protein content was calculated by multiplying N content by the factor 6.25. The sulphur containing amino acid methionine was estimated by the colorimetric method (Horn *et al.*, 1946).

RESULTS AND DISCUSSION

The data regarding the average yield, protein content, methionine content and dry matter production of blackgram and greengram show that the application of sulphur compounds in both the forms either gypsum or elemental sulphur had no effect on the grain yield of both the pulses. The results are in accordance with the results of Gupta and Gupta (1972) and Kamat *et al.* (1981) who reported that sulphur, irrespective of its mode of application has not affected the yield of pea and greengram respectively. But the results are in contrast with the findings of Chopta and Kanwar (1966) who reported sulphur application as $CaSO_4$ with NPK resulted in 50 percent increase in the yield of groundnut. Singh et al. (1970) reported that the yield of groundnut increased significantly irrespective of the form of sulphur applied and Lal and Jaiswal (1981) reported that 30 kg sulphur/ha (as gypsum) increased seed yield of urd; further increases in sulphur dose decreased the grain yield. Hence, it is evident that the sulphur application has varied effects on grain yield in different crops and in different soil.

Table.

Effect of sulphur compounds on yield and grain quality of blackgram and greengram

Treatment	Blackgram CO 5				Greengram CO 4			
	Yield of grain g/ plot	Protein (%)	Methio-nine mg/ 100 mg protein	DMP g/ plant	Yield of seeds g/ plot	Protein (%)	Methio-nine mg/ 100 mg protein	DMP g/ plant
Gypsum								
1. 100 kg/ha basal application	234.93	22.38	1.83	3.53	533.3	21.25	1.35	6.0
2. 200 kg/ha basal application	339.77	22.18	1.85	4.18	420.0	24.02	1.26	6.5
3. 300 kg/ha basal application	415.53	22.33	1.82	3.45	540.0	23.40	1.16	6.8
4. 100 kg/ha basal and another 100 kg/ha at flowering	333.70	21.53	1.97	4.57	433.3	23.48	1.28	8.0
Elemental Sulphur								
5. 18.5 kg/ha basal application	300.27	21.53	2.01	3.80	513.3	23.77	1.23	8.0
6. 37.0 ,,	354.80	21.88	1.81	4.58	393.3	23.53	1.21	6.8
7. 55.5 ,,	333.97	23.96	1.75	4.02	493.3	21.81	1.21	7.7
8. 18.5 kg/ha basal and another 18.5 kg/ ha at flowering	406.13	21.55	1.85	4.48	586.7	20.45	1.23	7.3
9. Control	377.90	21.09	1.53	5.22	386.7	22.30	1.24	6.8
S.E.	NS	0.5714	NS	NS	NS	0.674	NS	NS
C.D.	NS	1.21	NS	NS	NS	2.02	NS	NS

The average protein content of the blackgram and greengram grains increased by the application of sulphur compounds. Sulphur applied as elemental sulphur at 55.5 kg/ha significantly increased the protein content of the blackgram grain. Application of gypsum at 200 kg/ha has increased the protein content of the greengram grain significantly. Singh *et al.*. (1970), Gupta and Gupta (1972) and Kamat et al. (1981) have also reported that the sulphur application increased the protein content of groundnut, pea and greengram respectively. But Chopra and Kanwar (1966) reported that application of sulphur alone, decreased the protein content of groundnut, but application of sulphur as $CaSO_4$ in combination with N, NP and NPK increased the total protein content of groundnut.

The amount of methionine content of both blackgram and greengram was not affected by the application of sulphur compunds in both the forms. These results are in corraboration with the reports of Gupta and Gupta (1972) who reported that application of sulphur alone has no effect on methionine content of pea, whereas the application of sulphur and molybdenum had significantly increased the methionine content of the grain. Chopra and Kanwar (1966) reported the increased amounts of sulphur containing amino acid of groundnut, when the sulphur was applied as $CaSO_4$ with NPK. Arora and Luthra (1970) and Singh *et al.* (1970) have also reported increased amounts of methionine content in groundnut and Bengalgram respectively by sulphur application.

Dry matter production for both blackgram and greengram was not affected by the application of sulphur compounds in both the forms. This is in agreement with the results of Gupta and Gupta (1972).

The results obtained in the present study indicate that the application of sulphur compunds as gypsum and elemental sulphur had significantly increased the protein content of blackgram and greengram grain, but without affecting the content of sulphur containing amino acid methionine. Further biochemical study at sub-cellular level is required to understand the actual mechanism behind the increased protein content of the grains.

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SULPHUR NUTRITION OF COTTON

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It has been well established that plants need 16 nutrient elements classified as major, secondary and micronutrients. Sulphur has been included as secondary nutrient so far and it is being added to the soil along with other major nutrient to the soil in the form of sulphates. With the use of concentrated and relatively pure forms of high analysis sulphur free fertilizers, the supply of sulphur to crops might become limited. The situation becomes more serious with the cultivation of high yielding varieties. The removal by the crops become more with little or no recycling of wastes. It was therefore planned to study the effect of sulphur application both as sulphur and sulphur containing fertilizers for cotton on yield, quality of seed cotton and oil content.

Since the nutrient sulphur has been applied as supplementary nutrient in the straight fertilizers in the form of sulphate not much work has been done except the fundamental work on the role of the nutrient either in hydroponics or specialised studies to study the symptoms of deficiency. However, with commencement of the use of sulphur free fertilizers studies have been taken up at different centres on different crops.

Venkateswarlu (1971) studied the direct and residual effect of sulphate application in the form of labelled gypsum and has found beneficial effect on direct application to mustard and indirect effect to the following crop of onion.

Blair *et al.* (1979) in their studies on effect of sulphur on rice yield have tried three forms of sulphur viz., gypsum, ammonium sulphate and elemental sulphur and found that yield responses were there, irrespective of the source of sulphur. Number of tillers per hill was reduced from 14.9 to 4.1 in case where no sulphur was applied. Mehta and Singh

(1979) studied the effect of sulphur application on greengram in the form of gypsum, ferrous sulphate and elemental sulphur and found that sulphur had positive role in chlorophyll formation. It increased the uptake of nitrogen, sulphur and potassium and decreased the uptake of iron. Lower yields were associated with higher iron content and vice-versa. Application of sulphur along with NPK and Mg on four different soils viz., sandy chernozum, serozum and brown soil for uptake of nutrients and dry matter production on lucerne increased the dry matter production. Calcium content increased from the initial stages whereas magnesium content increased from second year of harvest. Sulphur content in dry matter was increased in all soils by increase in applied sulphur *(Thomas, 1980)*.

Shanmugham (1984) reviewing the sulphur nutrition of sugarcane has found the usefulness of sulphur containing fertilizer on the quality and setting of jaggery in sugarcane used for the manufacture of jaggery. Tandon (1984) has reviewed work on the role of sulphur in Indian agriculture and has given an exhaustive references on the need of sulphur for crops. He has also suggested if we wait for the deficiency symptoms to appear and then take up research it may become too late. It is therefore, suggested that work on sulphur nutrition and its effect on yield and interaction with other nutrients must be studied in detail.

Therefore an experiment involving the application of sulphur and sulphate forms in fertilizer was taken up at the Central Institute for Cotton Research Regional Station, Coimbatore from 1980 and was completed in 1983. The basis for fixing the sulphur level was taken up on the recommended fertilizer dose as straight fertilizers. In this case, for irrigated cotton a total dose of 80 kg N, 40 Kg of P_2O_5 and 40 kg K_2O ha^1 are recommended. Out of this 40 kg N, P and K are applied at the time of sowing as basal, N in the form of Ammonium sulphate, P in the form of single superphosphate and K in the form of muriate of potash. The balance 40 kg N is applied as top dressing in two split doses at 45 and 60 days after showing.

Therefore, following six treatments were suggested.

1. Control

2. Sulphur alone at 85 kg/ha1

3. Complex fertilizer to supply 40 kg N, P_2O_5 and K_2O/ha1 and urea to supply 40 kg N/ha1

4. Treatment 3 plus sulphur 85 kg/ha1 as basal dressing

5. Ammonium sulphate to supply 40 kg ha1 plus single superphosphate to supply 40 kg P_2O_5 plus muriate of potash to supply 40 kg K_2O/ha1 plus urea to supply 40 kg N/ha1

6. Ammonium phosphate to supply 32 kg N and 40 kg P_2O_5/ha1 plus urea to supply 8 kg N ha1 plus muriate of potash to supply 40 kg K_2O/ha1 plus sulphur at 55 kg/ha 1 as basal dressing plus urea to supply 40 kg N ha1

The experiment was conducted with two varieties viz., Suvin barbadense and MCU 5 VT hirsutum cotton varieties. It was laid out on randomised block design with four replications. The experiment was conducted for three years on the same field and its residual effect was studied for the subsequent year.

The crop was raised during the regular winter season (August-September to February-March). The yield of seed cotton recorded under various treatments are reported in Table 1. For the results of the year 1981-82 the economics of the treatments have been worked out and furnished in Table 2. The oil content of cotton seeds under different treatments during the years have been analysed and furnished in Table 3. The treatmental effect on fibre properties are estimated and furnished in Table 4.

Table 1.
Yield of seed cotton in kg/ha^{-1} over years

Sl. No.	Treatments	Variety	1980-81	1981-82	1982-83	Mean
1.	Control	Suvin	1509	1034	632	1059
2.	Sulphur alone	,,	1357	1103	684	1058
3.	Complex alone	,,	1465	1108	657	1077
4.	Complex + Sulphur	,,	1593	1367	882	1281
5.	Straight fertilizers	,,	1493	1254	777	1175
6.	Ammonium phosphate	,,	1841	1374	789	1335
	Mean		1543	1207	737	1162
7.	Control	MCU 5 VT	1688	1559	1688	1645
8.	Sulphur alone	,,	2037	1612	1557	1735
9.	Complex alone	,,	2357	1783	1763	1967
10.	Complex + Sulphur	,,	1914	1750	2075	1913
11.	Straight fertilizers	,,	1850	1784	1818	1817
12.	Ammonium phosphate	,,	1862	1883	1912	1886
	Mean		1951	1728	1802	1827

	S.E.	C.D. @ 5%		S.E.	C.D. @ 5%
Treatment (T)	44.27	123.90	T × V	62.6	232.8
Variety (V)	22.56	71.56	T × Y	76.7	214.6
Years (Y)	31.30	87.60	V × Y	44.3	123.9
			T × V × Y	108.4	303.6

Mean of treatment over 3 years (1) 1352; (2) 1392; (3) 1522; (4) 1597; (5) 1496; (6) 1610.
Mean of years Y_1 1747; Y_2 1467; Y_3 1269

Table 2.
Economics of the treatment

Treatment	Variety	Yield in kg ha^{-1}	Increase over control	Values of the produce at market rate	Cost of treatment	Net increase or decrease
				Rs.	Rs.	Rs.
1. Control	Suvin	1034	-	-	-	-
2. Sulphur alone	,,	1103	69	587	425	162
3. Complex alone	,,	1108	74	629	854	-225
4. Complex + Sulphur	,,	1367	333	2831	1279	1552
5. Straight fertilizers	,,	1254	220	1870	926	944
6. Ammonium Phosphate	,,	1374	340	2870	1106	1764
7. Control	MCU 5 VT	1559	-	-	-	-
8. Sulphur	,,	1612	53	318	425	-107
9. Complex alone	,,	1782	223	1338	854	484
10. Complex + Sulphur	,,	1750	191	1148	1279	-133
11. Straight fertilizers	,,	1784	225	1350	926	424
12. Ammmonium phosphate	,,	1883	324	1944	1106	838

Table 3.
Percentage of oil

Treatment	Variety	1980-81	1981-82	1982-83	Mean
1. Control	Suvin	24.04	21.86	23.18	23.03
2. Sulphur alone	,,	24.26	23.03	24.84	24.05
3. Complex alone	,,	24.68	20.71	25.40	23.60
4. Complex + Sulphur	,,	23.81	23.20	24.16	23.73
5. Straight fertilizer	,,	24.12	23.34	25.71	24.40
6. Ammonium Phosphate	,,	23.83	22.24	24.59	23.56
7. Control	MCU 5 VT	23.63	20.19	22.60	22.14
8. Sulphur alone	,,	23.42	20.61	22.05	22.05
9. Complex alone	,,	23.43	20.96	23.04	22.15
10. Complex + Sulphur	,,	23.41	19.91	21.27	21.54
11. Straight fertilizer	,,	22.47	21.26	22.92	22.22
12. Ammmonium phosphate	,,	23.16	20.72	23.05	22.31

Table 4.
Fibre properties

Sl. No.	Treatment	Variety	2.5% span mm	in	Fibre fineness micronaire gm/millitex	lb/Sq. in.	Uniformity ratio	Maturity coefficient
1.	Control	Suvin	37.40	1.46	115	2.93	42.00	0.67
2.	Sulphur alone	,,	38.15	1.50	117	3.00	43.25	0.67
3.	Complex alone	,,	37.75	1.49	118	3.01	44.25	0.67
4.	Complex + Sulphur	,,	38.03	1.50	118	2.99	44.00	0.67
5.	Straight fertilizer	,,	37.30	1.47	116	2.94	42.00	0.67
6.	Ammonium Sulphate	,,	38.05	1.50	114	2.89	42.00	0.66
7.	Control	MCU5VT	32.65	1.29	131	3.31	41.25	0.70
8.	Sulphur alone	,,	32.35	1.27	137	3.47	40.75	0.71
9.	Complex alone	,,	32.90	1.30	129	3.28	40.50	0.70
10.	Complex + Sulphur	,,	32.30	1.27	134	3.40	41.00	0.70
11.	Straight fertilizer	,,	32.53	1.28	129	3.28	39.25	0.70
12.	Ammonium phosphate	,,	32.55	1.28	134	3.39	42.00	0.70

Replication, varieties, treatments, years and varieties x years interaction effects showed significant differences. There was decline in yield over years and Suvin recoverded the lowest yield during 1982-83. In general, ammonium phosphate treatment, complex + sulphur treatments have given 19.1 and 18.1 per cent increased yield over control.

In case of Suvin the highest yield has been recorded under ammonium phosphate treatment followed by complex plus sulphur treatment and has given better yield than control and straight fertilizer application treatment.

The variety MCU 5 VT showed a different trend and the treatments complex alone and complex plus sulphur have given better yield than control and straight fertilizer application treatment.

Variety Suvin showed continuous significant response to ammonium phosphate and complex + sulphur application during the three years of treatment whereas in case of variety MCU 5 VT the response has been only from second year onwards. Thus it can be concluded that there is varietal variation in response to sulphur application and in some cases the response may be after one or two applications.

Nutrient uptake: The plant samples collected at the two stages of the crop viz., flowering and maturity stages after recording the dry matter were analysed for nitrogen, phosphorous, potash and sulphur in different plant parts viz., root, stem, leves etc., and the uptake per plant were worked our. There was no difference in the content of nutrient and hence it is to be concluded that nutrient uptake is governed by the dry production which is more for the treatment. In case of sulphur uptake also the same trend has been maintained but in case of MCU 5 VT at the maturity stage there is a greater uptake of sulphur in the sulphur fertilizer applied plots.

Oil content: The seed samples were analysed for oil content and percentage oil was calculated. It can be seen from the data there is not much variation in oil content due to treatments though there is slight variation due to varietis. However, seasonal variation seems to exist. Percentage of oil is low during 1981-82 whereas it has been the same during 1980-81 and 1982-83. Total oil production may be more due to increased yields.

Fibre properties: Lint samples of the different treatments were analysed for fibre properties like length, fibre fineness, uniformity ratio and maturity coefficient. The fibre properties have not been affected due to treatment except that there is a slight increase in micronaire value due to sulphur treatment in case of MCU 5 VT variety.

Residual effect studies

After the third season trial, the residual effect of cumulative application was studied and it was found that there is residual effect and the yield trend followed the same pattern as the treatmental effect.

Yield of seed cotton in kg ha1

Sl. No.	Treatment	Suvin	MCU 5 VT
1.	Control	814	1585
2.	Sulphur alone	889	1843
3.	Complex alone	826	1777
4.	Complex + Sulphur	1065	1906
5.	Straight fertilizer	899	1711
6.	Ammonium phosphate	922	1891
		S.E.	C.D. at 5%
	Treatment	92.2	264.7
	Varieties	53.2	152.8
	Interaction	130.4	374.4

Varieties showed significant difference in yield whereas treatment and interaction were not significant. However, the complex + sulphur treatment has given significicantly more yield than control. Treatment within varieties also showed similar trend. Incase of Suvin, ammonium phosphate and complex + sulphur treatment has given 2.5 per cent and 18.4 per cent increased yield over straight fertilizer treatment. In case of MCU 5 VT the same treatments gave 10.5 per cent and 11.4 per cent higher yields.

Thus the two treatments apart from influencing the main cotton crop, exerts residual effect also to a considerable extent on the subsequent cotton crop.

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SULPHUR FOR TEA

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ABSTRACT

Sulphur requirement of tea in Southern India, based on the available information on the S. deficiencey, the availability and crop removal of S and the response of tea to S or S containing fertilizer is discussed in this paper. Tea plants which produce high quantity of biomass need large amount of S. For producing every 100 kg made tea, the tea plant parts above the pruning cut need 1.01 kg S out of which 0.50 kg S is recycled while 0.51 kg S is removed. An overall analysis shows that the S requirement could best be met by using 20% of annual addition N as ammonium sulphate.

Introduction

Among the mineral nutrients of plants, sulphur (S) is ranking third to sixth in mineral composition depending on plant material production and on crop species. S is essential for formation of the most important S containing amino acids (Cysteine and methionine), synthesis of proteins and vitamins, production of high oil content of oilseeds, formation of flavour imparting compounds mainly in plants of Cruciferae lilliaceae, improving nutritive quality of forages and enhancing the marketing quality of produce of several crops. Protein rich crops and crops with a high production of organic material have a high demand for S. Cruciferous crops (mustard, rape, spinach, cabbage, turnips, mangolds, radish, kale, brassicas) and members of Lilliaceae family (onion, garlic) require considerably more S than most crops (Beaton, 1966). To these crops, appreciably high amount of S is needed for the synthesis of both protein and other constituents such as mercaptans and glucosides. Crops such as sugarcane, maize, Bermuda grass and tobacco which produce high organic matter also have a high demand for S. As tea, produces considerably high quantity of dry matter, it also needs S fairly in large quantities.

Although S deficiency was first noticed in tea more than 50 years ago (Storey & Leach, 1933), it did not influence much in the fertilization policies in many tea growing countries, except in African countries, till recently, probably because the S addition through the incidental supply of conventional fertilizers (ammonium sulphate, superphosphate etc.), the organic recycling and the atmospheric SO_2 could have met the plant demand. However, due to the dramatic increase in tea productivity and the consequent sulphur requirement in southern India, the escalation of cost of S containing N-fertilizers and the availability of cheaper S free high-N fertilizers, much attention is now paid to utilize the available sulphur containing N-fertilizers in the most economic manner to sustain yield trends. From the light of the information available on S deficiency, the results of investigations carried out in southern India on soil availability and crop removal of S, and the response of tea to S containing fertilizers, discussion on the S nutrition of tea and the need for inclusion of S (or S containing fertilizers) in the manuring schedule is made in this paper.

DEFICIENCY AND TOXICITY

S deficiency results in reduction of growth rate of plants and generally the growth of shoots is more affected than that of roots. Since S cannot move against the transpiration stream, the chlorotic symptoms, light green to yellow as the severity advances, occur in the younger and most recently formed leaves. Plants mainly absorb S in the form of sulphate (SO_4 ^{2}). However, evidences show that plants can utilize atmospheric SO_2 as part of their S supply. For more information on the physiology and metabolism of S in plants, reference is made to Mengel and Kirkby (1978) and Thompson (1967).

In 1930 S deficiency was first observed in tea plants in Malawi and the deficiency became known as "tea yellows" (Storey & Leach, 1933). Subsequently, S deficiency and/or response of tea to S containing fertilizers were reported in many tea growing countries. In Malawi, Forbes (1942) reported that any type of organic or inorganic fertilizer containing S in the available form, or in a form which becomes available, could cure "yellows of tea" provided the deficiency has not reached the most advanced stage. Eden (1953) observed from fertilizer experiments in Kenya and Tanzania that the application of ammonium sulphate for 6 years prior to starting of the experiments was sufficient to control " tea yellows" during the two years of experiment. Hesse (1955) observed S deficiency in some tea plantations in Uganda. Ranganathan et al. (1981) described the toxic effects of sulphide sulphur in tea.

SULPHUR CONTENT IN TEA IN RELATION TO OTHER MAJOR NUTRIENTS

Subrahmanya Bhat and Ranganathan (1980) reported S contents of different plant parts of four tea clones. Table 1 gives the S contents of various plant parts in relation to other nutrients. It should be observed that although S content of tea plant is almost in the same order as the P and Mg contents, application of S does not generally play an important role as P fertilization or Mg fertilization (in the form of dolomite) in tea. Generally, crop requirement of S can be assessed in comparison to N and P such N:S and P:S total uptake ratios. A comparative analysis of total uptake ratios of N:S and P:S (Table 2) of tea and other crops show that the relative requirement of S for tea is of the order of cereals. However, in the intensive cultivation system of tea, any disproportionate higher use of N and P in comparison with S results in nutrient imbalance, thus emphasising the need for maintaining a proportionate ratio of N:S in fertilizer schedule.

Table 1.

Sulphur content in different plant parts of tea in relation to other major nutrients

Part	%					
	N	P	K	Ca	Mg	S
Two Leaves and a bud (crop harvested)	4.00	0.50	2.00	0.60	0.30	0.25
Mature foliage	3.28	0.36	0.74	1.25	0.29	0.33
Twigs and foliage	1.42	0.30	0.52	0.62	0.20	0.13
Wood	0.97	0.24	0.20	0.24	0.15	0.13
Whole plant	1.80	0.30	0.43	0.64	0.21	0.20

Table 2.
S removal in relation to removal of N and P of tea compared to some other crops.

Crop	Total uptake ratio	
	N/S	P/S
Tea	9	1.5
Cereals*	6.7–10	1.2–1.5
Legumes*	8.2–10	0.7–1.0
Crucifers*	2.5–5.0	0.4–0.9

*From the graph of Tandon (1984)

RESPONSE OF TEA TO SULPHUR

The importance of sulphur for tea was recognised since early 1940s. In many tea growing countries ammonium sulphate was found to be the west source of N for tea (Table 3) and whose additional response over other N sources was attributed to the response to S.

The results of experiment, "effect of addition of sulphur or gypsum with urea on tea yield" are presented in Table 4. The data clearly show (a) ammonium sulphate is the best source of N and (b) although the difference in crop response among ammonium sulphate, urea + gypsum and urea + sulphur are not statistically significant, there is a definite advantage of adding S in the form ammonium sulphate. Gypsum and flour of sulphur are good sources of S for neutral and alkaline soils. However, only sulphates of strong cations such as NH4+ or K+ are good for acidic soils (Subrahmanya Bhat & Ranganathan, 1980). Accordingly, addition of S in the form of ammonium sulphate especially in the pre-monsoon season serve the dual purpose of serving as an efficient source of N for tea and meeting the sulphur requirement of tea (Venkata Ram, 1980) continuously.

Table 3.

Review of the effect of S or S containing fertilizers on tea in various countries

Country	Response/remarks	Reference
Malawi	Any organic or inorganic fertilizers containing S in available form cure "tea yellows."	Forbes (1942)
India (Assam)	Of the various manures and fertilizers ammonium Sulphate was the most effective for tea	Harler (1950) Gokhale (1956)
India (Himachal Pradesh)	Additional responses of ammonium sulphate and single Superphosphate were attributed to S	Kanwar & Takkar (1966)
India (South)	Ammonium sulphate was the best source of N. 6 to 10% increase in crop observed	Ranganathan & Swaminathan (1968)
Russia	Ammnonium sulphate applied during 6 years sufficient to control "tea yellows" deficiency during next 2 years	Eden (1953)
	Ammonium sulphate was widely used; if other N source was to be used, ammonium sulphate should be at least once in 4 years	Child (1957)
Indonesia	Ammonium sulphate increases tea yields considerably	Pronk (1955)
Sri Lanka	Ammonium sulphate produced higher yields than other N source	Watson & Wettasinghe (1982)
Japan	Ammonium fertilizers resulted in better plant growth and assimilation	Ishigaki (1974)
Iran	Ammonium sulphate produced 15 to 25% higher yields than urea. S. application together with urea reduced the difference	Salardini (1978)

Table 4.
Effect of gypsum or sulphur addition to urea on tea yield

Treatment	S applied kg/ha/2 years	Total yield for 2 years (1978-79) and 1979-80) kg/ha	%
Ammonium sulphate	624	4349	100.0
Calcium ammonium nitrate	-	4232	97.3
Urea	-	4194	96.4
Urea + Gypsum	624	4283	98.5
Urea + Sulphur	624	4264	98.0
C.D. at P = 0.05	-	109	2.5

Source: UPASI Scientific Department Annual Report (1982).

SULPHUR REQUIREMENT OF TEA

From the S content of various plant parts (Table 1) and taking into account the proportionate supporting growth of plant parts, the requirement of S for producing 100 kg of made tea is calculated and presented in Table 5. The data reveal that (a) the plant parts above the pruning cut need 1.01 kg S for supporting 100 kg crop and (b) out of 1.01 kg S assimilated 0.5 kg S is recycled while 0.51 kg S is removed from the field. Therefore for producing a crop of 2000 kg made tea/ha/annum, the net removal is 10.2 kg S.

Table 5.
Sulphur requirement for producing 100 kg made tea.

Part	Proportionate dry weight	S (kg)
1. Flush (crop)	100	0.250
2. Mature foliage	120	0.396
3. Branchlets & twigs	80	0.104
4. Wood	200	0.260
Total assimilated		1.010
Amount recycled * (Parts 2 & 3)		0.500
Amount removed		0.510

Any replenishment of S by way of external addition should also take into account the soil factors associated with sulphate adsorption and leaching in soil, reduction of S to sulphides and possible loss, especially in the acid tea soils, during monsoon periods. Subrahmanya Bhat and Ranganathan (1980) reported that in tea soils of southern India (a) unlike phosphates, sulphates are neither strongly adsorbed in anion exchange sites nor strongly fixed as insoluble salts indicating the possibility of high leaching losses and (b) there is no accumulation of sulphate in soils even after continuous use of ammonium sulphate for several years, thus stressing the need for application of S regularly, and more or less frequent and constant intervals.

Although the actual removal for producing 100 kg of made tea is only 0.51 kg S, the actual application has to be made at 3 to 4 times the actual removal in order to compensate for requirement of plant parts below pruning cut, leaching losses, limitations imposed by transport processes in the soil and possible loss by reduction to sulphides during monsoon periods. This will, therefore, work out to 1.53 to 2.04 kg S for every 100 kg of made tea. Hence, for a crop of 2000 kg made tea/ha/year, the annual requirement would be 30.6 to 40.8 kg S/ha.

Considering the efficiency of ammonium sulphate and soil characteristics, the sulphur need of tea in southern India could best be met by way of applying ammonium sulphate; and accordingly a 20% N usage as ammonium sulphate was recommended for tea annually (Venkata Ram, 1980; Ranganathan and Natesan, 1982). Table 6 shows the S requirement of tea and that added by way of ammonium sulphate at different yield levels as per current recommendation. According to this schedule, a balanced N:S ratio of fertilizer usage for tea in southern India is maintained at 1:0:24.

Table 6.

S requirement and that added by ammonium sulphate at different yield levels

Yield, made tea kg/ha/ annum	Total N recommended for a medium soil kg N/ha/year	S required to be added kg/ ha/annum	S added by ammonium sulphate * kg/ ha/annum
1000	120	15.3-20.4	28.8
2000	200	30.6-40 .8	48.0
3000	250	46.5-61 .2	60.0
4000	350	61.2-81 .6	84.0
5000	450	76.5-102.8	108.0

* at 20% of total N

Sulphur is essential for tea and in southern India addition of sulphur by way of ammonium sulphate is the best way of meeting this nutrient demand. Application of 20% of annual requirement of N as ammonium sulphate is recommended to the tea industry in southern India.

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EFFECT OF NITROGEN SOURCES IN COMBINATION WITH GYPSUM, ZINC SULPHATE AND SULPHUR ON RICE YIELD

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ABSTRACT

To study the effect of combined application of N fertilizers with gypsum, zinc sulphate and elemental s experiments were conducted in a clay loam soil of Cauvery delta for two years during Kuruvai seasons. Among different N sources tried, ammonium sulphate gave marginally higher yields over other sources. Addition of gypsum, $ZnSO_4$ and elemental sulphur had increased the grain yield markedly during 1983 but marginally in 1984 and the yield increase ranged from 8-15% over N fertilizer alone. Combinations of $ZnSO_4$ with ammonium sulphate and S with ammonium chloride and urea were found to be encouraging.

Introduction

The potentiality of new high yielding varieties is not fully expressed due to several environmental constraints. Instead there has been a trend of decline in the rice yield in recent years. Deficiencies of S and Zn mainly seem to have predominant role in causing yield decline in rice in the recent past in considerable areas. These deficiencies are accentuated due to the continuous use of high analysis fertilizers and complete stoppage or inadequate use of organic manures like farm yard manure, compost and green manure etc. Significant responses to S addition have been recorded particularly in Cauvery Thanjavur in recent times. Similarly beneficial effect of Zn was also noticed. Hence this investigation was carried out at Tamill Nadu Rice Research Institute, Aduthurai, to study comprehensively the effect of S sources viz., gypsum, zinc sulphate and elemental sulphur super imposed over the N sources.

Experimental Details

Two field experiments were conducted to study the effect of different sources of N in combination with gypsum, $ZnSO_4$ and sulphur on rice yield in Kuruvai seasons of 1983 and 1984 at Tamil Nadu Rice Research Institute, Aduthurai. Ammonium sulphate, ammonium chloride and urea were the N sources applied at 100 kg N/ha besides they were applied in combination with gypsum, zinc sulphate and elemental sulphur to supply 154 kg S/ha with a common check replicated twice in randomised blocks design. The rice variety ADT 36 was used as the test crop in both the years. Experimental field was a clay loam textured neutral soil having the available N content of 300 kg/ha and available Zn of 5.2. ppm.

Results and discussion

The results on rice grain yield during Kuruvai 1983 indicated that all the fertilizer treatments gave significantly higher grain yields than the control. Among different N sources, ammonium sulphate recroded numerically higer yield than either ammonium chloride or urea. Similar observations were made earlier by Venkataramanan (1981). Application of N fertilizers in combination with gypsum or $ZnSO_4$ or S registered higher grain production than the N fertilizer alone and the percentage increase by the addition of gypsum, $ZnSO_4$ and S were 14.1, 17.32 and 24.8% respectively indicating the response for combined application of N with Zn and S. The beneficial effect of sulphur and Zn was reported by several workers, viz., Verma et al. (1981). Venkataramanan et al., (1981), Nambiyar (1985), Tiwari et al., (1983), Islam et al., (1985) and Tandon, (1985). Combination of S with urea and NH_4C1 was found to be superior than $ZnSO_4$ and gypsum. Ammonium sulphate-zinc sulphate combination seems to have an edge over the rest indicating the beneficial effect of Zn as well.

In Kuruvai, (1984) all the treatments gave significantly higher grain yield than the control. Application of $(NH_4)_2SO_4$ + $ZnSO_4$ recorded numerically higher grain yield than the rest though most of the treatments did not show much variation. This may be due to the complementary effect of Zn and S as reported by Islam et al. (1985). Application of gypsum, $ZnSO_4$

and S along with N did not produce marked variation in rice grain yield as compared to the N application alone during 1984 experiment. However, numerical difference (2 — 3% increase) between the combined application and N alone revealed that for $(NH_4)_2SO_4$ and urea, combined application of $ZnSO_4$ performed better while for NH_4Cl application of S was encouraging.

Overall scrutiny of the two year yield data revealed the beneficial effect of gypsum, $ZnSO_4$ and S over N fertilizer alone and elemental S having an edge over $ZnSO_4$ and gypsum. Gypsum combination was the least effective. Among the sources of N, combinations of $ZnSO_4$ with $(NH_4)_2SO_4$ and S with NH_4Cl and urea were found to be encouraging.

Effect of combined application of N and S on rice grain yield.

Treatments		Grain Yield (kg/ha)		Mean
		1983	1984	
1.	Control	3594	3890	3742
2.	Ammonium sulphate	6633	5638	6136
3.	Ammonium chloride	6528	4895	5712
4.	Urea	6505	5070	5788
	Mean	6555	5201	5870
5.	Ammonium sulphate + Gypsum	7480	5830	6655
6.	Ammonium chloride + Gypsum	7292	4961	6127
7.	Urea + Gypsum	7666	5124	6395
	Mean	7479	5305	6392
8.	Ammonium sulphate + $ZnSO_4$	8558	5839	7199
9.	Ammonium chloride + $ZnSO_4$	7111	4951	6031
10.	Urea + $ZnSO_4$	7402	5293	6348
	Mean	7690	5361	6528
11.	Ammonium sulphate + S	8552	5682	7117
12.	Ammonium chloride + S	8033	5157	6595
13.	Urea + Sulphur	7957	5157	6557
	Mean	8181	5332	6756
C.D.		1185	484	

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STUDIES ON PHOSPHORUS AND SULPHUR NUTRITION IN MUSTARD UNDER RAINFED CONDITIONS

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ABSTRACT

A field experiment was conducted during Rabi seasons of 1980-81 and 81-82 on red sandy loam soils at Indian Grassland and Fooder Research Institute, Jhansi to determine response of mustard cv. Pusa bold to phosphate (0, 20 and 40 kg P2 O5/ha) and sulphur (50 kg sulphur/ha through gypsum soil applied, foliar spray of 0.1% solution of 1N H_2SO_4 and control) nutrition under rainfed conditions. Results revealed that phosphate application significantly enhanced productivity of mustard in both the years, however, the degree of response was not consistent. In 1980-81, significant response was noted up to 40 kg P_2O_5/ha but in 1981-82, it was restricted to only 20 kg P_2O_5/ha. The mean increment in seed yield with 20 kg and 40 kg P_2O_6/ha over control (543 kg/ha) was 48.6% and 62.6%, respectively. As regards sulphur fertilization, both the sources viz., soil applied gypsum and foliar applied sulphuric acid being on par with each other proved highly effective, the mean increase in seed yield over control (609 kg/ha) was to the order of 34.9% and 31.5%, respectively. Further, it was observed that in 1980-81 sulphur fertilization in presense of phosphate (20 kg P_2 O_5/ha) exhibited synergistic effect, pushing up the productivity by 43.4 per cent over no sulphur.

Mustard (Brassica juncea (L) Czern & Coss) is the chief oilseed crop of northern India. Endowed with deep root system and amenable to advanced planting, it is generally grown on residual moisture under rainfed conditions where nutrient stress continues to be one of the formidable barriers for low productivity. Fertilizer use in rainfed mustard which, of course, is seldomy practiced, is restricted only to nitrogenous ones, despite experimental evidences on positive response to applied phosphate (Bhan and Singh, 1974 and Patel et al., 1980). The degree of response to P, however, depends upon soil type, profile moisture, P status of the soil and cropping pattern

Besides N and P, sulphur has been reported to be one of the limiting factors for increasing oilseed production in northern India where the soils are marginal to medium in sulphur content (Kanwar and Randhawa, 1967). This problem is likely to be further aggravated with the recent trend of increased use of high grade fertilizers free from sulphur. High sulphur requirement of mustard owing to its high content of sulphur containing amino acids and essential oils and favourable effect of sulphour fertilization on seed yield and oil content have been reported by Singh and Singh (1978) and Aulakh et al. (1980). Further, the beneficial role of sulphur in mobilising soil phosphorous and its utilization by mustard has been elucidated by Virmani and Gulathi (1977). Such information are, however, quite meagre and are not available for agro-ecological zones of Bundlekhand. In view of the above, the present investigation was undertaken to work out the phosphate and sulphur requrirement of mustard on alfisols of Bundlekhand under rainfed conditions.

Materials and Methods

The experiment was conducted at the Central Research Farm, Indian Grassland and Fodder Research Institute, Jhansi during Rabi seasons of 1980-81 and 1981-82 under rainfed conditions. The soil (0-25 cm) of the experimental block was red sandy loam (Alfisol) with pH 7.5, organic carbon 0.05 per cent, available phosphate 28.6 kg P_2O_5/ha and exchangeable potash 627 kg K_2O/ha. The moisture content of soil at field capacity and wilting point was 14.0% and 5.2%, respectively.

Treatments comprising all combinations of phosphate levels (0, 20 and 40 kg P_2O_5/ha) and sulphur (no sulphur, 50 kg sulphur/ha through gypsum-soil applied and foliar spray of 0.1% 1N H_2SO_4), were evaluated in randomised block design with 3 replications. Mustard variety Pusa bold was sown in rows 45 cm apart using 6 kg seed/ha on 25 October and 15 October during 1980-81 and 1981-82, respectively with a pre-plant irrigation. The phosphate as per treatment was applied through diammonium phosphate at the time of sowing. An uniform basal application of 40 kg N/ha was done by adjusting the amount of nitrogen available from DAP and supplementing the remaining quantity with urea. The gypsum was ground, drilled in seed furrows along with fertilizers and mixed with soils, Spray of 0.1% 1N sulphuric acid was done on crop canopy at 45th day after seeding through foot pump sprayer using 600 litres water/ha.

Results and Discussion

Perusal of data presented in Table 1 revealed that the *seed yield, in general, was higher in 1980-81 than that in* 1981-82, although the winter rains were more in the later year. This was due to the fact that the prolonged (standard weeks 2 to 5) cloudy and humid weather in January in 1982 led to build up of high population of aphids which damaged the crop despite timely control measures.

Table 1.

Number of siliqua and seed yield of mustard as influenced by phosphorus and sulphur application

	No. of siliqa/plant		Seed yield (kg/ha)		Mean
Treatments	1980-81	1981-82	1980-81	1981-82	
Levels of phosphorus ($kg\ P_2O_5/ha$)					
0	104	101	623	463	543
20	126	125	885	729	807
40	131	130	976	791	833
S.Em ±	4.3	7	28	25	-
C.D. 5 %	12.9	21	85	75	-
Sulphur treatments					
No sulphur	102	102	659	560	609
50 kg sulphur/ha through gypsum	129	129	907	738	822
0.1% H_2SO_4 (IN) foliar spray	130	126	918	685	801
S.Em ±	4.3	7	28	25	-
C.D. 5%	12.9	21	85	75	-

Effect of phosphorus

Phosphate application significantly increased number of siliqua/plant as well as seed yield in both the years (Table 1). Although, the number of siliqua increased with increasing levels of phosphate up to 40 kg P_2O_5/ha but the difference between 20 kg and 40 kg P_2O_5/ha. was not significant.

As regards seed yield, significant response up to 40 kg P_2O_5/ha was observed in 1980-81 but in 1981-82, the response was restricted only up to 20 kg P_2O_5/ha. The mean increase in seed yield with 20 kg and 40 kg P_2O_5/ha over control was to the order of 48.6% and 62.6%, respectively. The phosphate efficiency (kg grain per kg P_2O_5 applied) at 20 kg and 40 kg P_2O_5/ha in 1980-81 was 13.1 kg and 8.8 kg, respectively, whereas the corresponding values in 1981-82 were 13.3 kg and 8.2 kg. Since the soil was medium in available phosphorus, higher response to applied phosphate could not be obtained. Bhan and Singh (1974) also reported that in alluvial soils of Agra region which are medium in phosphorus, mustard responded significantly only up to 20 kg P_2O_5/ha. However, Patel et al. (1980) observed significant response up to 50 kg P_2O_5/ha in Saurashtra region.

Effect of sulphur

The number of siliqua/plant as well as the seed yield were significantly influenced with sulphur nutrition in both the years. Soil application of 250 kg gypsum/ha (50 kg sulphur) increased seed yield by 37.6% and 31.6% over control in 1980-81 and 1981-82, respectively. Significant response to sulphur use up to 60-80 kg/ha in mustard has been observed by Joshi et al. (1975) and Pathak and Tripathi (1974) under field conditions. Foliar application of 0.1% sulphuric acid (1N) 45 days after seeding also proved highly effective, recording 39.2% and 22.3% higher yield over control in 1980-81 and 1981-82, respectively. Both the sources of sulphur were found to be equally effective in both years. The number of siliqua/plant exhibited a close positive relationship with seed yield. Singh et. al. (1969) also reported that the number of siliqua had direct effect on seed yield of mustard.

Interaction effect

In 1980–81, sulphur application in presence of phosphate exhibited synergistic effect (Table 2). Foliar spray of 0.1% sulphuric acid (1N) in presene of 20 kg P_2O_5/ha enhanced seed yield by 65% over no phosphate application (632 kg/ha). Further, increase in the level of phosphate could not improve productivity. These results are in conformity of those reported by Virmani and Gulathi (1971) who observed that application of 50 ppm sulphur enhanced uptake and utilization of soil and fertilizer phosphorus and consequently increased mustard yield. Joshi et al. (1973) reported that the best ratio of sulphur to phosphorus for higher productivity of mustard was 0.9 to 1.4. It is thus obvious that balanced fertilization with phosphorous and sulphur is necessary for realising good yields of mustard even under rainfed conditions.

Table 2.

Seed yield (kg/ha) of mustard as influenced by interacton of phosphorus and sulphur

(1980-81)

Sulphur treatments	Levels of phosphorus (kg P_2O_5/ha) 0	20	40
No sulphur	503	693	782
50 kg sulphur/ha through gypsum	735	918	1067
0.1% sulphuric acid (IN) foliar spray	632	1043	1079
S.Em ±	49		
C.D. 5 %	148		

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SALUTARY EFFECT OF SULPHATE FERTILIZER ON RICE IN ILL-DRAINED SOIL

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ABSTRACT

In certain ill-drained rice soils, incorporation of large amount of rice stubbles or excessive addition of organic manures inhibited the rice growth due to injurious effects and reduced the grain yields. Addition of sulphate fertilizers prevented the injurious effects on rice and restored the rice yields. Sulphate was observed to arrest propionate and butyrate formation in soils, thereby thwarting the injurious effects on rice

In ill-drained lowland soils, adverse effect on rice by the organic matter addition has been reported earlier (Desai and Rao, 1957; Lanuza, 1965). Continuous submergence, excessive organic additions and low temperature promote such adverse effect on rice.

Chandrasekaran *et al.* (1972 and 1973) observed the adverse effect of Farm Yard Manure (FYM) on rice in a field experiment and such adverse effect on rice grain yield was partially ramedied by ammonium sulphate but not by urea (vide Table 1). Govindaswamy and Chandrasekaran (1979) showed that because of such adverse effect on rice by straw incorporation, urea addition along with straw could not give as much yield as *urea alone* (vide Table 2).

The author (1970) carried out pot culture experiments in the International Rice Research Institute, Philippines in order to find out the cause of the salutary effect of sulphate on rice under such conditions and the details are furnished.

Table 1.

Grain yield (dry weight in kg / ha)

Sl. No.	Treatments	Mean* value	Significance	Standard error	C. D. P = 0·05	Con- clusion
1.	Control (no manure)	5200·0		362·5	820·0	
2.	Farm yard manure[a] (FYM) at 22 tonnes per hectare	4325·0	Significant		1 4	2 3
3.	FYM at 22 tonnes/ha + Urea to supply 99 kg N/ha[b].	3825·0				
4.	FYM at 22 tonnes / ha plus Ammonium sulphate to supply 99 kg N / ha	5125·0				

* Average of four replications

a - FYM incorporated one week before planting

b - 49·5 kg N / ha applied at base and the remaining half applied after 25 days of planting

Source : S. Chandrasekaran *et al.* (1972 and 1973)

Table 2.
Effect of rice straw incorporation on the yield of rice (g/pot)

Treatment	Grain		Straw	
	Yield	Precentage change over control	Yield	Precentage change over control
Control	13·6	—	13·3	—
Straw incorporation[a]	5·1	-62·5	4·9	-63·2
Urea alone[b]	21·1	55·1	17·9	34·6
Straw incorporation[a] + Urea addition[b]	16·9	24·3	14·0	5·3

a—At 12,350 kg/ha rate /

b—At 123.5 kg N/ha level.

EXPERIMENTAL

POT CULTURE No. 1

Ten kilograms of Maahas soil was taken in a pot and submerged. After 15 days, the following four treatments were given :

1. No green manure (control)
2. Addition of green manure (*Sesbania* sp) matured plants at 2·5% level.
3. Green manure as above plus ammonium sulphate at 200 kg. N/ha
4. Ammonium sulphate (200 kg. N/ha).

Fourteen day old IR 8 seedlings were planted without *leaving any interval after incorporation of green manure.* Fifty grams of wet soil was sampled on 0, 2, 8, 12, 19 and 25 days after planting from the pots separately and analysed for organic acids by gas chromatogram (Laskowski and Broadbent, 1970). Details of soil extraction and instrumentation are furnished

Table 3.

Amount of organic acids in Maahas soils in pot experiment No. 1

Treatments	Organic acids	Days after treatment 0	2	5 (m.mole/100 g soil)[b]	8	12	19	26
Non (control)	Acetic	c	c	0·03	0·03	c	c	0·04
	Propionic							
	Butyric							
	Total	c	c	0·03	0·03	c	c	0·04
Green manure[a]	Acetic	c	0·63	0·78	0·54	0·15	0·26	0·04
	Propionic	0·06	0·06	0·04	0·02	0·01		
		0·09	c	c				
	Total	c	0·78	0·84	0·58	0·17	0·27	
Green manure[a] + Ammonium sulphate[b]	Acetic	c	0·10	0·46	0·18	0·21	0·21	0·04
	Propionic		c	0·03	c	c		
	Butyric		c	c				
	Total	c	0·10	0·49	0·21	0·24	0·21	
Ammonium sulphate[b]	Acetic	c	c	c	c	c	c	c
	Propionic							
	Butyric							
	Total	c	c	c	c	c	c	c

a - Mature green plants of *Sesbania* sp.
b - Dry basis
c - Trace amount (Less than 0.02 m.mole)

a = at 2.5% fresh weight
b = 200 kg N/ha

elsewhere (Chandrasekaran and Yoshida, 1973). The analytical results on organic acids are given in Table 3. After the maturity, the plants were cut, dried and yields of grain and straw were recorded (Table 4).

Table 4.
Rice yields[1] in g per pot[2]

Treatments	Panicle wt.	Straw wt.
No green manure (control)	44·6	34·3
Green manure[a]	28·0	20·9
Green manure[a] + Ammonium sulphate[b]	129·8	76·4
Ammonium sulphate[b]	123·2	75·9

1—Average of three replications
2—Two plants per pot
a = 2.5 % fresh weight
b = At 200 kg N/ha

POT CULTURE No. 2

Another experiment was carried on similar lines with Maahas soil but with different treatments viz.,

1. No green manure (control)
2. Green manure alone (2·5% level)
3. Green manure + Ammonium sulphate (to supply 200 kg N/ha)
4. Green manure + Ammonium chloride (to supply 200 kg N/ha)

After planting IR 8 rice seedings, soil samples from the pots were analysed for organic acids on 0, 5, 14, 17, 19, 22 and 25 days interval Organic acids are furnished(Table 5.)

Table 5.

Amount of organic acids in Maahas soils in pot culture experiment No. 2[a]

Treatments	Organic acids	Days after treatment 0	5	14 (m.mole/100 g soil)[b]	17	19	22	25
None (control)	Acetic	0 02	c	0·02	c	0·20	c	c
	Propionic							
	Butyric							
	Total	0·02	c	0·02	c	0·20	c	
Green nanure[a]	Acetic	0·02	1·51	2·83	1·63	1·60	1·10	0·30
	Propionic		0·15	0·35	0·55	0·40	0·20	0·10
	Butyric							
	Total	0·02	1·66	3·18	2·18	2·00	1·30	0·4 0
Green manure[a] + Ammonium sulphate[b]	Acetic	0·02	1·34	1·88	1·22	1·21	0·30	
	Propionic		0·10	0·26	0·17	0·10		
	Butyric							
	Total	0·02	1·44	2·14	1·39	1·31	0·30	
Green manure[a] + Ammonium sulphate[b]	Acetic	0·02	1·37	1·89	1·54	1·60	1·20	0·60
	Propionic		0·15	0·27	0·44	0·42	0·21	0·10
	Butyric							
	Total	0·02	0·02	2·16	1·98	2·02	0·41	0·60

a – Mature green plants of *Sesbania* sp.
b – Dry basis
c – Trace amount (Less than 0.02 m.mole)

a = at 2.5% fresh weight
b = 200 kg N/ha

RESULTS

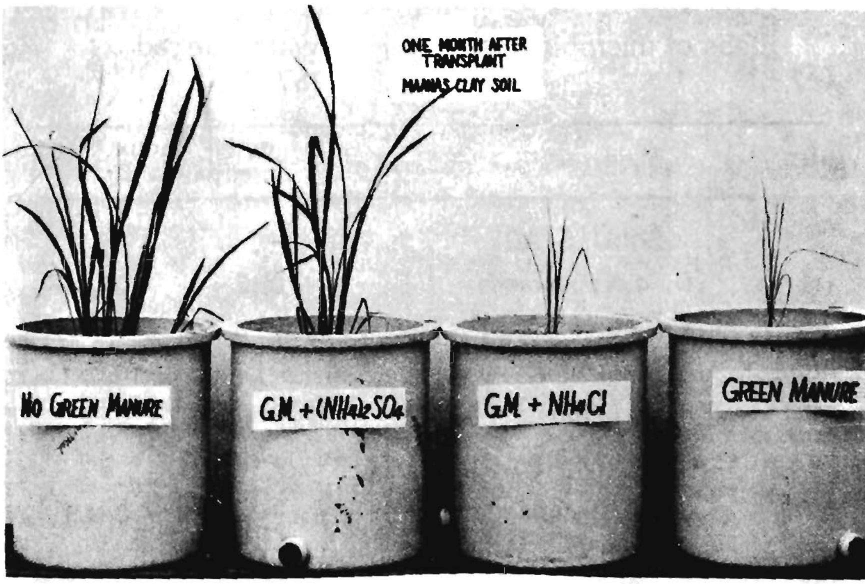
In pot experiment one, as compared to control soils with green manure analysed higher amounts of organic acids amounting to a total of 0·78, 0·08 and 0·58 millimhos per 100 g of dry soil on 2, 5 and 8 days respectively. On 12 and 19 days also, small amounts of acetate and propionate persisted and on 26 days the acid level came down on par with control (Table 3). Ammonium sulphate addition along with green manure retarded especially the propionic and butyric acids. In respect of grain and straw yields, the order among the four treatments was as follows :

Green manure < no green manure < green manure plus ammonium sulphate < ammonium sulphate.

Addition of green manure alone brought down the yield. Such adverse effect was alleviated by addition of ammonium sulphate along with green manure (Table 4).

In pot culture number two, the soil with green manure addition analysed a similar pattern of organic acid production as that with green manure plus ammonium chloride (Table 5). But in the soils with green manure plus ammonium sulphate, propionic acid was suppressed. Rice plant growth was stunted in both green manure as well as in green manure plus ammonium chloride treated pots Rice plant growth though inhibited initially by green manure was improved by ammonium sulphate (Plate I), in their combination.

Plate: 1



DISCUSSION

Pyruvate, a metabolite of organic matter breakdown is the starting substrate which is either degraded into simple components or synthesised into higher acids such as propionate or butyrate depending upon the environment Sulphate when present adequately in anaerobic soils, promotes pyruvate breakdown to form acetyl phosphate at first by a number of *Clostridium* sp. and later accelerates this to acetate plus ATP by *Desulfovibrio desulfuricans*. In this process, sulphate undergoes reduction to sulphide thus preventing any new formation of propinate or butyrate.

Propionic and butyric acids form the substrates for the methane forming bacteria. Conversion of organic acids to methane is associated with a substantial drop in redox potential. Sulphate interception of organic matter breakdown products is in between high and low redox potentials (vide Table 6). Change in fermentation pathway of organic substrate by the sulphate is responsible for thwarting the injurious effects on rice plants (Plate I). Under strictly anaerobic condition, it has been shown earlier, (Chandrasekaran and Yoshida, 1972) propionate and butyrate disintegrate readily by the interception of sulphate resulting in greater amount of acetic acid, an intermediary breakdown product of the former acids.

Table 6.
Steps of microbial metabolism in water-logged soils (Takai *et al.*, 1957)

Step	Main reaction	Initial Redox potential (volts)	
	FIRST STAGE		
1st	O_2 disappearance	+ 0·6	+ 0·5
2nd	Nitrate reduction	+ 0·6	+ 0·5
3rd	Mn^{2+} formation	+ 0·6	+ 0·5
4th	Fe^{2+} formation	+ 0·6	+ 0·5
	SECOND STAGE		
5th	Sulphide formation	0	– 0·19
6th	Sulphide formation H_2 formation	– 0·15	– 0·22
7th	CH_4 formation	– 0·15	– 0·19

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EFFECT OF BORON AND SULPHUR ON YIELD ATTRIBUTES AND QUALITY OF GROUNDNUT

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ABSTRACT

A field trial was conducted on a medium black cotton soil deficient in available boron and sulphur, to study the effect of four levels each of boron (0.5, 10 and 15 kg. borax/ha) and sulphur (0, 40, 80 and 120 kg S/ha) on yield attributes and quality of groundnut. It was observed that both boron and sulphur alone and in combination, significantly increased haulm, pod and kernel yields with their progressive levels of application. The crude protein, true protein and oil content were increased by boron and sulphur fertilization, while oil yield was substantially increased with boron and sulphur applied alone or in combination.

Groudnut, being an oilseed crop and a legume, efforts to increase its yield and quality are constantly being made to further its economic value through fertilization with major nutrients. Sulphur is now recognised to be an important nutrient for oilseeds because it plays a key role in protein and oil synthesis. The importance of sulphur fertilization to the oilseed crops is stressed by Dalal and Kanway (1962) in Punjab State, Naphade (1970), Barhanpue (1976) and Karle (1982) in Maharashtra State. The beneficial effect of boron to enhance nodulation absorption of nutrients, yield attributes and qualitative aspects of groundnut was reported by Rudra Raju and Raju (1978), Patil and Mahala (1978) and Kulkarni (1982). The combined application of boron and sulphur to groundnut was stressed by Dongale and Zende (1976) and Patil *et al* (1981) for better yields. Since boron and sulphur are essential nutrient elements and they perform specific physiological functions in the plant growth, it could be expected that lack of one of them or both might result in retardation in metabolic activity in the plant. Keeping this point in view, the present investigation was undertaken to study the effect of boron and sulphur in yield attributes and qualitative aspects of groundnut.

MATERIAL AND METHODS

A field trial was laid out in a factorial randomisedl block design replicated three times on a medium black soil deficient in available boron (0·38 ppm) and available sulphur (8·7 ppm), at Agricultural College from M. A. U., Parbhani (M. S.) during monsoon season of 1983-84. Four levels of each of boron (0, 5, 10 and 15 kg borax/ha) and sulphur (0, 40, 80 and 120 kg. elemental sulphur/ha) were incorporated. The experimental soil was clayey (49.82 per cent clay) and calcareous (12·23 per cent $CaCO_3$) in nature and was adequately supplied with nitrogen (25 kg. N/ha) and phosphorus (50 kg. P_2O_5/ha).

The seeds of groundnut variety JL-24 were dibbled at spacing of 15 × 45 cm. in plots of 3 × 4·5 metres. The observation on dry pod and haulm weights were recorded at harvest. Oil was extracted from kernel by soxlet extraction method and total nitrogen in kernels was determined by modified Kjeldahl method (Jackson, 1967). Crude protein content was calculated by multiplying nitrogen content by 6·25

RESULTS AND DISCUSSION

Haulm yield: The data on haulm yield presented in Table 1 give an indication for the significant differences resulting from various treatments of boron and sulphur. Boron fertilization at 15 kg. borax/ha (B3) increased haulm yield at pre-flowering significantly over control, however B1 and B2 levels were at par. Boron treatment showed progressive increase in haulm yield at various stages of growth while it was increased up to pegging stage and declined at harvest. Maximum haulm yield (2742·90 kg/ha) was recorded in B3 (15 kg. borax/ha) treatment at pegging stage. The above results clearly depict that boron fertilization had a linear response on groundnut crop for its vigorous growth. The role of boron in increasing haulm yield in groundnut was noted by Patil and Mahale (1978) and Patil *et al.* (1981), while Kulkarni (1982) reported similar linear response of groundnut to boron fertilization.

Table 1.

Effect of boron and sulphur on haulm yield (kg/ha)

Treatments	Stages of growth			
	Pre-flowering	Mid-flowering	Pegging	Harvest
0 kg. Borax/ha (B0)	440·5	1664·8	2417·6	1488·8
5 kg. Borax/ha (B1)	454·4	1698·8	2482·3	1510·9
10 kg. Borax/ha (B2)	469·4	1731·8	2571·2	1553·8
15 kg. Borax/ha (B3)	480·5	1771·3	2742·9	1576·9
S. E. ±	13·59	15·68	47·07	11·60
C. D. at 5%	37·67	43·80	130·47	32·18
0 kg. S/ha (SO)	390·3	1520·2	2092·7	1362·2
40 kg. S/ha (S1)	435·9	1614·5	2319·4	1466·8
80 kg. S/ha (S2)	484·9	1767·2	2653·9	1569·0
120 kg. S/ha (S3)	538·7	1964·6	3147·9	1732·5
S. E. ±	13·59	15·68	47·07	11·60
C. D. at 5%	37·67	43·80	130·47	32·18
S. E. ± (B × S)	27·18	31·37	94·14	28·21
C. D. at 5%	NS	NS	NS	NS

A progressive but significant increase in haulm yield by different levels of sulphur treatments was noticed at all the stages of growth. Pegging stage recorded maximum haulm yield (3147 · 9 kg/ha) due to sulphur treatment at 120 kg. S/ha level (S3). Barhanpure (1976), Patil *et al.* (1981) and Karle (1982) observed increased ,iaulm yields due to sulphur fertilization in groundnut. Greenwood (1951) noted that the favourable effect of superphosphate on groundnut crop was due to gypsum which contained sulphur. The interaction effect of B and S on haulm yield was found to be non-significant

POD AND KERNEL YIELD

It is evident from Tables 2 and 3 that boron application exhibited progressive substantial increase in pod and kernel yield with its levels. Boron at 15 kg/ha (B3) recorded highest pod (1552 · 9 kg/ha) and kernel (1069 · 60 kg/ha) yields. Role of boron in increasing pod yield was also noted by different workers (Muthuswamy and Sundararajan, 1973; Dongale and Zende, 1976; Kulkarni, 1981; and Patil *et al.* 1981). This shows that boron plays a vital role in helping not only checking the excessive growth of crop but also helping the absorbed nutrients to produce more pod yield of groundnut crop. According to Henry *el at.* (1957) peanut without boron had largest amount of hollow-heart defect which was practically eliminated by boron treatment and the percentage of well developed seeds appeared to be relatively low when boron was not applied.

Sulphur applications had also significant role in increasing pod and kernel yields and increased with levels of its application. Application of 120 kg. S/ha (S3) gave highest pod yield (1982 · 50 kg/ha) and kernel yield (1351 · 0 kg/ha). This could be due to better vegetative growth and translocation of sulphur to fruiting zone for the synthesis of protein and oil in kernels. The results are in accordance with the findings of Dalal *et al.* (1963), Chopra and Kanwar (1966) and Nanak Singh *et al.* (1970). Similarly, Naphoda (1970), Barhanpure (1976), Patil *et al.* (1981) and Karle (1982) also reported increased yields due to sulphur fertilization of groundnut crop.

Interaction of boron and sulphur contributed to enhanced pod and kernel yields (Tables 2 and 3). Boron levels substantially increased pod and kernel yields with all the levels of sulphur fertilization. Boron and sulphur interaction at B3 S3 level (15 kg. Borax/ha + 120 kg/ha) recorded highest pod (2184 ·4 kg/ha) and kernel (1513 · 76 kg/ha) yields. Both the nutrients (B and S) contributed much to the seed development and their combined effects resulted in enhancing the kernel yield significantly. Dongale and Zende (1976) and Patil *et al.* (1981) also reported similar trend of B and S interaction in groundnut.

Table 2

Effect of boron and sulphur on pod and kernel yield (kg/ha)

Levels of boron	Pod yield (kg/ha)				Mean
	Levels of sulphur (kg/ha)				
	0 (S0)	40 (S1)	80 (S2)	120 (S3)	
0 kg. Borax/ha (B0)	870·1	1093·2	1393·6	1797·3	1289·1
5 kg. Borax/ha (B1)	929·4	1057·3	1483·5	1904·0	1367·0
10 kg. Borax/ha (B2)	979·3	1225·7	1572·0	2042·4	1554·8
15 kg Borax/ha (B3)	1032·1	1309·4	1685·9	2184·4	1552·9
Mean	951·2	1196·6	1533·6	1982·5	
S. E. ±	Boron	Sulphur	Boron × Sulphur		
	15·20	15·20	40·50		
C. D. at 5%	42·14	42·14	118·50		

Table 3.

Effect of boron and sulphur on kernel yield (kg/ha)

Levels of Boron	Levels of sulphur (kg/ha)				Mean
	0 (S0)	40 (S1)	80 (S2)	120 (S3)	
0 kg. Borax/ha (B0)	584·3	734·6	937·3	1190·0	866·6
5 kg. Borax/ha (B1)	622·2	680·0	1000·7	1287·2	922·9
10 kg. Borax/ha (B2)	663·0	831·0	1068·8	1392·7	988·7
15 kg. Borax/ha (B3)	705·9	893·2	1160·3	1513·7	1069·6
Mean	809·1	922·2	1141·8	1351·0	
	Boron	Sulphur	Boron × Sulphur		
S. E. ±	10·01	10·01	20·02		
C. D. at 5%	27·74	27·74	55·49		

PROTEIN CONTENT

Plants with high protein content are shown to respond markedly to the application of boron and sulphur. A relative change in their levels brings about a considerable effect on quality of oilseed crops. Scrutiny of the data presented in Table 4 indicate that crude and true protein contents of groundnut kernels increased with levels of boron. The crude protein and true protein ranged from 28·67 to 29·25 per cent and 28·97 to 21·49 per cent respectively. The response of 5 kg. borax/ha (B1) and 10 kg. borax/ha (B2) on crude and true protein contents was inconsistent while 15 kg. borax/ha (B3) significantly increased crude and true protein contents over control and 5 kg. borax/ha treatment. This increase in protein content may be due to the presence of boron. Scripture and McHargue (1943) and Wadleigh and Shive (1939) were of the opinion that boron deficiency often results in accumulation of ammoniacal nitrogen, soluble organic N, amino acids and amides in mature parts of plants and shows corresponding decrease in protein content. Thus the observation recorded in respect of boron in enhancing protein content of oilseed crops are in agreement with the findings of Verma *et al.* (1973), Dongale and Zende (1976), Patil *et al.* (1981) and Kulkarni (1982).

Further scrutiny of the data clearly indicate a significant increase in crude and true protein contents of groundnut with graded levels of sulphur application. Application of 120 kg. S/ha (S3) showed maximum crude (30·19 per cent) and true protein (22·42 per cent) contents. Sulphur is a constituent of amino acids like cystine, cysteine and methionine and helps in conversion of these amino acids into protein (Chopra and Kanwar, 1966). Sulphur provides di-sulphide (-S-S-) bonds for cross linkage of two polypeptide chains and thus helps in formation of protein (Allaway and Thompson, 1966). The increased protein content of groundnut as a result of sulphur fertilization was also reported by Nanak Singh *et al.* (1970), Dube and Mishra (1970), Berhanpure (1976) and Karle (1982). The interaction effect of B and S on protein content was non-significant.

OIL CONTENT AND OIL YIELD

A perusal of the data in Tables 4 and 5 revealed that oil content and oil yield from groundnut kernels were significantly increased with progressive levels of boron application. The magnitude of response of boron to increase oil content in groundnut was of the order of 6·9, 4·0 and 1·6 per cent over control by B3, B2 and B1 treatments. Similarly boron fertilization showed significant increase in oil yield with its level. Similar observations are also recorded by Verma *et al.* (1973), Dongale and Zende (1976), Patil *et al.* (1981) and Kulkarni (1982).

Table 4.
Effect of boron and sulphur on quality of groundnut

Treatments	Crude protein (percent)	True protein (percent)	Oil (percent)	Oil yield (kg/ha)
B0	28·67	20·97	48·15	414·83
B1	28·64	21·15	48·96	452·74
B2	29·03	21·33	50·10	495·07
B3	29·25	21·49	51·50	547·46
S. E. ±	0·13	0·09	11·60	7·14
C. D. at 5%	0·37	0·26	32·18	19·79
S0	27·96	20·23	49.20	317·31
S1	28·47	20·80	49·53	401·90
S2	29·17	20·50	49·85	520·93
S3	30·19	22·42	50·11	677·84
S. E. ±	0·13	0·09	11·60	7·14
C. D. at 5%	0·37	0·26	32·18	19·79
Interaction (B × S)				
S. E. ±	0·27	0·19	23·19	14·28
C. D. at 5%	NS	NS	NS	39·58

Table 5.

Effect of boron and sulphur on oil yield (kg/ha)

Levels of boron	Levels of Sulphur (kg/ha)				Mean
	S0	S1	S2	S3	
B0	279 81	353·40	438·45	486·03	414 43
B1	301·68	381·37	492·29	635 64	452 74
B2	328·11	411·81	537·55	702·85	495·07
B2	359·65	460·72	600·41	786·85	547·46
Mean	317·31	401·90	520·98	677 84	
	Boron	Sulphur	Boron × Sulphur		
S. E. ±	7·14	7·14	14·28		
C. D. at 5%	19·79	19·79	39·58		

Sulphur fertilization also increased the oil content and oil yield with its progressive levels. The response of added sulphur to increase oil content was 1·8 (S3, 1·2 (S2) and 0·6 (S1) per cent over control. In fatty acid synthesis, Acetyl-CoA is converted into malonyl CoA. In this conversion, an enzyme acetic thickness is involved. The activity of this depends upon sulphur supply. Moreover, acetyl CoA itself contains sulphur and sulphur-hydryl group. This may be the reason for increase in oil content of groundnut with sulphur application. The results are in resemblance with the findings of Verma *et al.* (1973), Barhanpure (1976), Patil *et al.* (1981) and Karle (1982) who also reported increased oil content of different oilseed crops due to sulphur application.

Significant and positive effect of boron x sulphur was depicted in the contribution of oil yield. Oil content showed non-significant results with B × S interaction. Interaction effect of B × S in enhancing oil yield was relatively higher than individual application of boron and sulphur. B3 S3 (15 kg. borax + 120 kg. S/ha) interaction recorded highest oil yield (786·85 kg. oil/ha).

In brief, boron and sulphur fertilization is beneficial and effective to increase yield attributes and qualitative aspects of groundnut. Combined application of boron and sulphur to groundnut showed greater kernels, protein and oil yield and is essential to exploit maximum production potentiality of groundnut with good quality seed.

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ABSTRACTS

SULPHUR – THE NEED OF THE HOUR – A REVIEW

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The phenomenal crop yield increases coupled with intensive and multiple cropping systems have resulted in the extensive removal of N, P, K, besides the secondary and trace elements. The changing pattern in fertilizer use with high analysis sulphur-free fertilizers accounts for the occurrence of sulphur deficiency in many areas and in different crop plants. Recent studies indicate the need for the sulphur fertilization considering the vital role played by sulphur in enhancing the yield of the crop and quality of the produce as well. The present paper aims at reviewing the various research for achieving higher agricultural production without sacrificing the quality aspects.

STUDIES OF SULPHUR IN SOILS OF WEST BENGAL

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Analyses of 12 selective soil profiles of five major soil zones of West Bengal showed that except in coastal saline soils, organic sulphur constituted the major fraction of total sulphur. Significant correlations were obtained between organic S and sulphate sulphur, total N and organic C content of the soil.

Considerable variation in C:N, C:S, N:S and C:N:S ratios were observed in soils of different regions. Presence of variable proportion of different components of organic matter in the soil under the influence of different climatic factors was suggested as the reason for variations in S status observed.

Effect of two different moisture sequences with a short period of drying between them and different sulphate levels during incubation revealed considerable immobilisation of sulphate in soils

maintained either at 50% of water-holding capacity or under water-logged condition prior to drying. The extent of immobilisation was found more pronounced when starch or inorganic sulphate sulphur were added. Drying resulted in release of available sulphate sulphur in the soil previously incubated at 50% water-holding capacity and the effect was more conspicuous when starch was added. A short period of drying released sulphate sulphur in available form.

Addition of nitrogenous fertilizer widened the N:S ratio and it resulted in the immobilisation of sulphur in soil.

VERTICAL DISTRIBUTION OF SULPHUR IN SOILS OF HARYANA

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Studies were conducted on eleven soil profiles representing different agro-climatic conditions and cropping pattern in Haryana. Total sulphur varied from 90 to 996 ppm in different soil profiles which generally decreased with increase in depth and was related to electrical conductivity ($r = 0{\cdot}880^{**}$), organic carbon ($r = 0{\cdot}523^{**}$) and silt + clay ($r = 0{\cdot}459^{**}$). Organic sulphur was higher on the surface which decreased with depth in all the profiles. Available sulphur was low in light textured soils and constituted 2·7 to 17.2% of the total sulphur and its content, in general, decreased with depth. Major quantity of the total sulphur was present in inorganic fractions and its distribution followed no definite trend in the profiles.

EFFECT OF SULPHUR-FREE AND SULPHUR CONTAINING FERTILIZERS ON THE YIELD OF CROPS AND AVAILABLE SULPHUR STATUS OF SOIL

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Plants require considerable amount of sulphur for its growth and production and its essentiality as a plant nutrient has been recognised well over years, especially under intensive-cropping and fertilization, aiming at maximum yield. The effect of sulphur added through manures and fertilizers on crop yield and available sulphur status of soil was studied in the long-term fertilizer experiment with a fixed crop sequence of ragi-cowpea-maize (one year rotation). The results of the experiments conducted over a period of 13 years showed that addition of sulphur through sulphur containing fertilizers and manures enhanced the available sulphur status of the soil from 108kg/ha to 134 and 140 kg/ha respectively. Available sulphur status decreased from 108 to 96 kg/ha, when sulphur free NPK fertilizers were used and to 88 kg/ha in the no manure control plot. However, there was no reduction in yield of crops owing to the application of sulphur free fertilizers, as the soil contained sufficient quantity of available sulphur besides being enriched through natural sources viz., irrigation water etc. The maximum yield and available sulphur content were recorded in the farm yard manure treated plots, which might be due to the beneficial effects brought about by the organic matter on the soil environment.

SULPHUR STATUS OF INDIAN SOILS AND ITS ROLE IN AGRICULTURE

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Sulphur, being a major essential nutrient for plants as well as animals, did not draw due attention by the crop scientists till late seventees. Hence, an attempt was made to review the work done on various aspects of sulphur nutrition to agricultural crops in India and abroad. Total S, organic-S, SO_4-S, non SO_4-S and water soluble S were in the range of 240 to 2310, 35 to 937, 3·4 to 81, 60 to 112 and 12 to 1161 ppm respectively. A concentration of 10 ppm available S was considered to be critical for most of the Indian soils. Although a limited extent of sulphur deficiency had been reported, crops such as raya, mustard, groundnut, soybean, rice, barley, maize, etc. responded well to S fertilization. In some cases there was no increase in yield but there was improvement on quality i.e. increase in free-S containing and S—bound amino acids, proteins and vitamins.

DECOMPOSITION OF ORGANIC WASTES AND THEIR EFFECT ON NITROGEN SULPHUR RATIO IN SOIL

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The studies pertain to the effect of four organic wastes (sewage sludge, FYM, paddy husk and brassica pod shell) incorporated into the soil at four levels (0, 15, 30 and 45 t/ha) on the release of nitrogen and sulphur with time and their effect on N-S ratio in soil. The release of available nitrogen and sulphur was governed by their initial carbon content of the organic wastes and

C:N/C:S ratios. The oxidation of paddy husk and brassica pod shell was slow and hence there was immobilization of N with slow release of S. N-S ratio among the different sources was wider in paddy husk and was almost equal in all other sources. N-S ratio was found narrowed with time and reached a constant value of 1·5 to 1·8 in all the sources except paddy husk. Decrease in N-S ratio was sharp in FYM, brassica pod shell and slow in case of sewage sludge.

SULPHUR FERTILIZATION IN RICE

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Field trials were conducted at Agricultural College and Research Institute, Madurai in *kharif* and *rabi* seasons to study the response of indirect sources of sulphur viz, ammonium sulphate and gypsum along with a direct source of elemental sulphur by mixing with urea so as to elicit information on the yield of rice varieties Vaigai and IR 20. The results showed that the application of 100 kg N/ha as urea plus 1/2 t gypsum/ha gave the highest yield. The high cost of sulphur besides its slow availability, restrict the utility when compared to readily available and less costlier gypsum which can accomplish the crop's need.

ROLE OF SULPHUR ON THE UTILIZATION OF NITROGEN IN RICE

S. Jayarammoorthy, T. S. Manickam, C. K. Rajagopal and K. Natarajan

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Field experiments were conducted at Agricultural Research Station, Bhavanisagar during *kharif* and *rabi* of 1981 with rice IET 1444 and IR 20 for the first and second seasons respectively to assess the role of sulphur on the utilization of fertilizer nitrogen by rice. The treatment combinations tried were gypsum coated urea, gypsum-prilled urea mixture, elemental sulphur-prilled urea mixture and NPK alone. The grain and straw yields data of the experiments revealed that the application of sulphur in any form has not influenced the yield parameters since the native sulphur (30 ppm) is found sufficient to satisfy the sulphur requirement of the rice crop. However, gypsum coated urea registered the highest grain and straw yields of rice in both the seasons because of the slow and steady release of nitrogen from gypsum coated urea. The crude protein, apparent nitrogen recovery and nitrogen response ratio recorded under these experiments were again in conformity with the results obtained earlier for grain and straw yields. Besides, the sulphur uptake by the rice and total uptake of sulphur were not significantly influenced by the various sulphur treatments tried.

COMPARATIVE EFFICIENCY OF SULPHUR COATED UREA IN LOWLAND RICE

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Tamil Nadu.

A three year field study was conducted at Tamil Nadu Agrl. University, Aduthurai during *kharif* (June-October) of 1982-83 with the objective of finding out the efficiency of sulphur coated urea in lowland rice. Three urea forms such as sulphur coated urea (SCU), urea supergranules (USG) and prilled urea

(PU) were compared at 0, 58, 87 and 116 kg N/ha. Treatments were replicated four times in a factorial randomised block design. SCU (36% N) was broadcast and incorporated basally. USG (46% N) was applied by hand in the centre of every four hills, 2 days after transplanting. PU was split applied (50% basal, 25% each at active tillering and panicle initiation). A short duration rice variety, ADT 36 (110-115 days) was transplanted at 20 × 10 cm. From the results of the study, it was concluded that SCU promoted the plant height and increased the number of panicles per m^2. Consistently higher grain yields were obtained with SCU followed by USG. During the 3 years of study, SCU gave increased grain yield compared to PU in split doses. Higher N use efficiency was noticed with the application of SCU.

EFFECT OF APPLICATION OF GYPSUM ON AVAILABILITY AND UTILIZATION OF SULPHUR AND NITROGEN IN RICE (cv. IR 50)

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A field experiment was conducted at Agricultural Research Station, Bhavanisagar, to evaluate the effect of different forms of sulphur on the growth, yield, and the uptake of nitrogen and sulphur in rice. Increased application of gypsum in proportion with added levels of nitrogen as urea increased the availability of sulphur, its uptake and yield of rice. Gypsum applied as urea gypsum (gypsum-coated urea) behaved similar to that of gypsum added along with urea as a physical mixture. Both methods of gypsum-urea applications differed significantly from urea alone treatment. The N recovery was higher in gypsum applied treatments indicating positive interaction between N and S uptake.

SULPHUR CONTENT AND UPTAKE IN ONION (CO. 2) AS INFLUENCED BY THE ADDED FYM, MACRO AND MICRONUTRIENTS

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A field experiment was conducted with onion variety CO-2 to study the influence of FYM, macro and micronutrients on the content and uptake of sulphur in a clay textured soil with low available N and P and high available K. The results indicated that application of 50 kg $FeSO_4$ in combination with 25 t/ha of FYM plus 30:30:15 kg/ha of N : P_2O_5 and K_2O respectively significantly increased the sulphur content of onion bulb. However, the uptake was not influenced by these treatments.

EFFECT OF LEVELS OF SULPHUR ON THE YIELD AND COMPOSITION OF SOYBEAN (*Glycin max* (L) Merr.) GREENGRAM (*Vigna radiatus* L.) BLACKGRAM (*Vigna mungo* L.) AND COWPEA (*Vigna sinensis* L.)

K. N. Bansal
J.N. Krishi Vishwa Vidyalaya, Jabalpur.

A field experiment with four types of legumes (soybean, greengram, blackgram and cowpea) and four levels of sulphur viz., 0, 20, 40 and 80 kg S/ha was conducted on alluvial soils at the College of Agriculture, Gwalior. There was significant increase in the yield of legumes, and the magnitude of increase in yield was higher for soybean and cowpea compared to blackgram and greengram. There was also an increase in the concentration and uptake of N, P, K and S in all the legumes under study. A significant negative relationship between N:S ratio and yield suggested that a wider N:S ratio reduced the crop yield drastically.

EFFECT OF SULPHUR FERTILIZATION ON NUTRIENT CONTENT, DRY MATTER PRODUCTION AND YIELD OF PODS IN GROUNDNUT

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Oilseeds Experiment Station (TNAU)
Tindivanam

An experiment was conducted to study the effect of sulphur fertilization on nutrition and yield of groundnut varieties viz., TMV-7 and CO-1 at Oilseeds Experiment Station, Tindivanam, during *Kharif* 1982 and 1983. The results have shown that application of sulphur in the form of sulphur dust (22 kg/ha) increased the total calcium in the stem as against the content in the leaf, in both the varieties. A similar trend was noticed in the total carbohydrate content in the stem. The percentage contribution by leaf, stem and pods to total DMP indicates that sulphur fertilization enhances the efficiency of translocation of assimilates from leaf to pod. This is done by way of higher percentage contribution of weight of pod over and above that of leaf and stem. Significant increases in pod yield were observed in sulphur dust treated plots of TMV-7 and CO-1. However, in TMV-7 both sulphur dust at 22 kg/ha and gypsum at 200 kg/ha remained on par in improving the pod yield. The other yield attributes viz, 100 kernel weight (42.5 g), shelling percentage (76.2%) and oil content (51%) were maximum when treated with sulphur dust. The nutritional status of seed had shown that sulphur dust treatment enhanced the total carbohydrate, protein and oil content in kernels. Basal application of sulphur appeared to be related to higher requirement of sulphur in groundnut.

EFFECT OF SOIL APPLICATION OF SULPHATE ON JAGGERY QUALITY OF SUGARCANE WITH SPECIAL REFERENCE TO UREA vs. AMMONIUM SULPHATE

P. Rakkiyappan, S. Thangavelu and K. C. Rao

Sugarcane Breeding Institute, Coimbatore-641 007.

In a replicated field trial, CO-6806, early maturing and CO-6304, late maturing, varieties were treated with different doses of urea and ammonium sulphate to study the effect of soil added sulphate on jaggery quality on a sandy soil.

Ammonium sulphate treatment had shown higher levels of soil available S and leaf S in all levels of nitrogen dose than urea treatment. Fertilizer x nitrogen dose x variety interaction, was noted in juice and jaggery. Soil available S and leaf S had a positive association but showed no influence on cane and sugar yield. Urea and ammonium sulphate behaved alike in influencing yield of cane and sugar on equal N basis. Net rendement of jaggery associated positively and significantly with sucrose and purity of jaggery.

RESPONSE OF MUSTARD (*Brassica Juncea* L.) TO SULPHUR

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N.D. University of Agriculture and Technology
Kumarganj-Faizabad (U.P.)

A pot culture experiment conducted to study the effect of sulphur on growth, yield and quality of mustard revealed that increase in height and seed yield due to application of sulphur was not significant. However, the oil content in seeds was increased significantly with the increasing levels of sulphur up to 40 ppm.

EFFECT OF APPLIED SULPHUR ON THE YIELD AND UPTAKE IN RAYA (*Brassica juncea*) IN DIFFERENT TEXTURAL GROUPS OF SOILS

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Department of Soil Science Haryana Agricultural University,
Hissar.

A pot culture experiment was conducted with three different textured soils viz., sandy, loam and clay loam. Mustard cultivar *Raya Prakash* was used as a test crop. When only basal nutrients dose except sulphur was applied, dry matter yield was obtained according to the sulphur status (native S) of the soil. Maximum yield and uptake were obtained in case of loamy soil which was high in available sulphur. In sandy soil (S-deficient) plants could not complete their life cycle and died after showing deficiency symptoms. With the application of S, whole plant was found to be green. Dry matter yield increased many folds and sandy soil which was deficient in native-S behaved as good as loamy soil. In fine textured clay loam soil maximum dry matter yield and S uptake were obtained.

UTILIZATION OF SOIL SULPHUR UNDER VARYING SOIL FERTILITY STATUS BY MAJOR OILSEEDS OF MADHYA PRADESH

S. A. Jaipurkar, Girish Puri and S. B. Singha

Department of Soil Science and Agricultural Chemistry,
J.N. Agricultural University, Jabalpur-482 004, (MP)

The relative mean S-concentration (%) in seed and straw were in the order: linseed (0·176) > Niger (0·163) > Safflower (0·134) and linseed (0·143) > Niger (0·137) > Safflower (0·118), respectively. The total S-uptake (kg/ha) was in the order: Safflower (10·32) > Linseed (8·38) > Niger (2·20). The mean S requirement (kg/grain) was 1·21, 0·78 and 0·80 in niger, linseed and safflower respectively. The per cent contribution of available sulphur was in the order: Safflower (1·16) > Linseed (1·10) >

Niger (0·50). Significant influence of soil fertility status on the S-uptake and its requirement was observed. In higher the utilization of soil available sulphur decreased with rise in its S-content ($r = -0{\cdot}6995^{**}$), while its utilization increased with its soil status in the case of safflower and linseed ($r = 0{\cdot}2826^{*}$ and $0{\cdot}4306^{*}$).

STUDY ON AVAILABLE SULPHUR IN SOIL AND ITS UPTAKE BY PEARL MILLETS (BAJRA) AS INFLUENCED BY N AND P APPLICATION

K. S. Gajbhiye

National Bureau of Soil Survey and Land use Planning
Regional Centre, Seminary Hills Nagpur.

An assessment of the available sulphur status was made in a field experiment with N and P fertilization to pearl millet on an alluvial sándy loam. Available sulphur content of soil was declined with N application, while it was increased with P addition. The uptake of sulphur by the crop was found to be enhanced with nitrogen but it remained unaffected with phosphorus application. The combined addition of N and P appeared to be congenial in this respect.

EFFECT OF SULPHUR AND PHOSPHORUS APPLICATION ON THE DRY MATTER YIELD AND NUTRIENT CONTENT OF BLACKGRAM (*Vigna mungo* L.) AT DIFFERENT STAGES OF GROWTH

P. N. Bapat and S. B. Sinha

Department of Soil Science and Agricultural Chemistry,
J.N. Krishi Vishwa Vidyalaya, Jabalpur.

The effect of phosphorus and sulphur application (0, 25, 50 and 75 ppm each) on the growth and composition of phosphorus, total-S and protein-S at different stages of blackgram were examined in a pot experiment. The study revealed an increase in dry matter production, total–S, protein–S and phosphorus content in the blackgram plant up to 50 ppm level, but above this level both P and S had decreased the nutrient content. Both P and S contents decreased due to dilution effect of vegetative growth up to 60 days but increased in the grain at maturity. Sulphur application tended to increase the non-protein S content in the plant at higher dose. The critical values for total-S were 0·235 (20 days) and 0·19 (60 days) and that for S/P ratio was 0·975 at both 40 and 60 days growth.

SEED YIELD AND COMPOSITION OF CORIANDER (*Coriandrum sativum* L.) AS INFLUENCED BY FERTILIZER NITROGEN, PHOSPHORUS AND SULPHUR ON VERTISOLS

Rosalind Michael and M. K. Badiger

Department of Chemistry and Soils, University of Agricultural Sciences, Bangalore–24.

A field experiment was carried out on a vertisol at the University Farm, Siruguppa using coriander as the test crop with treatment combinations of two levels of N i.e, 37·5 and 50 kg/ha, three levels of P_2O_5, i. e, 37·5, 56·25 and 75 kg/ha. and two levels of sulphur 0 and 5 ppm S. Yield and uptake of P and S by coriander seeds were found to be significantly enhanced by application of N, P and S.

SEED YIELD AND IMPROVEMENT IN QUANTITIES OF RADISH (*Raphanus sativus* L.) AS INFLUENCED BY LEVELS OF FERTILIZER POTASSIUM, SULPHUR AND ZINC ON SANDY LOAM SOILS

M. K. Badiger and T. Srinivasa Gowda

Department of Chemistry and Soils, University of Agricultural Sciences, Hebbal, Bangalore - 560 024.

A radish crop was grown on red sandy loam soil with treatment combinations of three levels of potassium viz, 25, 50

and 75 kg. K_2O per ha; three levels of sulphur 0, 5 and 10 ppm and two levels of zinc viz., 0 and 5 ppm for seed production and quality improvements. The study revealed the significant enhancement in the seed yield of radish, owing to the application of K and S. Fractionation of forms of sulphur in seeds indicated marked effect of K and S in the formation of protein-sulphur.

YIELD OF GROUNDNUT AS INFLUENCED BY LEVELS AND SOURCES OF CALCIUM AND SULPHUR ON SANDY LOAM SOILS

B. Shivaraj and M. K. Badiger,
Department of Chemistry and Soils, University of Agricultural Sciences, Bangalore - 560 024

A field study was conducted on red sandy loam soils with groundnut to study the influence of levels and forms of calcium and sulphur on the yield. Treatment combinations included three levels of sulphur, viz., 10, 20 and 30 kg S/ha and calcium 12·5, 25 and 37·5 kg Ca/ha. The forms were gypsum and elemental S as sources of sulphur and calcium oxide for Ca. There were significant improvements in the yield of groundnut kernels, uptake of calcium and sulphur and also in the oil yield. Gypsum or calcium oxide plus elemental sulphur as sources were superior to calcium or sulphur alone.

EFFECT OF SULPHUR AND CALCIUM APPLICATION ON SULPHUR CONTENT OF VARIOUS PLANT PARTS OF POL 2 GROUNDNUT

S. Ramanathan and G. Ramanathan
Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore - 641 003.

A pot experiment conducted in two soils (Tindivanam and Pollachi tracts) to study the effect of application of sulphur and calcium on sulphur content of different plant parts of POL 2 groundnut such as root, shoot, kernel and shell showed significant differences, the treatments with sulphur always recording higher sulphur content than the treatments without sulphur. Higher levels of calcium significantly increased the sulphur content of kernel alone. It had a depressive effect on the sulphur content of shoot

and no effect on content of root and shell. Among the soils tried, Tindivanam soil registered higher sulphur content in root, shoot and kernel.

EFFECT OF SULPHUR APPLICATION ON AVAILABILITY OF NUTRIENTS AT DIFFERENT STAGES OF GROUNDNUT CROP GROWTH IN TWO SOILS

S. Ramanathan and G. Ramanathan
Department of Soil Science and Agricultural Chemistry,
Tamil Nadu Agricultural University, Coimbatore - 641 003.

Significant differences in available S, Ca, Mg, P and K in soils were observed due to differences in stages of groundnut (Var. POL 2) crop growth. Available S, Mg, P and K declined with advancement of crop growth. Available Ca was found to be high in reproductive stage followed by post harvest and vegetative stages. Available S content increased with progressive increase in the levels of added S. S application did not have significant effect on the available Ca, Mg, P and K contents of soils. Aliyarnagar soil had significantly higher available S, P and K than Tindivanam soil, while Tindivanam soil recorded significantly higher available calcium and magnesium than the other soil type.

RESPONSE OF WHEAT CROP IN NEWLY RECLAIMED SALINE-SODIC SOIL INOCULATED WITH SULPHUR AND THIOBACILLI

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Department of Plant Pathology and Agricultural Microbiology,
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India has vast areas of saline-sodic soils which are potentially productive and these soils to a certain extent are reclaimed by the use of soil amendments such as sulphur. The extent of reclamation was usually determined by estimating chemical parameters such as exchangeable sodium percentage, EC, pH etc. However, as the ultimate aim of soil reclamation is to bring the deteriorated soils under cultivation, crop response in these soils can be taken as a practical index of soil reclamation. Therefore, a pot experiment was conducted with a saline sodic soil which was reclaimed by the application of sulphur and inocu-

lation of thiobacilli. Wheat crop was grown in the newly reclaimed soil (unsterilized and sterilized) to find out the extent of reclamation as evidenced by crop response. There was a significant increase in the dry matter production and grain yield of wheat when the soil was treated with sulphur ahd thiobacilli This trend was not observed when the soil was treated either with sulphur alone or with thiobacilli alone and when the soil was sterilized.

RECLAMATION OF ALKALI SOIL USING AN ALKALI TOLERANT SULPHUR OXIDISING BACTERIA

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Department of Agricultural Microbiology
Agricultural College and Research Institute, Madurai.

An alkali tolerant sulphur oxidising bacteria, *Thiobacillus neapolitanus* was isolated from a tank mud soil, at pH 8·5. Acid production by this isolate in growth medium was more with 0·25 per cent sulphur than with 0·1 per cent sulphur. The soil pH of an alkali soil (9·1), when treated with 0·25 per cent sulphur enriched with *T. neapolitanus* was brought down to pH 7·1 after 32 days of incubation.

The physical and chemical properties of the alkali soil (Nargund -pH 9·1), when amended with sulphur (0·25%) pelletted with *T. neapolitanus* were considerably improved, within 30 days. The hydraulic conductivity of the soil was enhanced three fold and flocculation of soil particles was increased by 32 times. About 90 per cent of the added sulphur was oxidised to sulphate, which was reflected in the increased electrical conductivity of the soil. The exchangeable Na^{+} content decreased by 50 per cent with a corresponding increase in the soluble Na^{+} in the unleached alkali soil.

The results indicated the possibility of utilizing *T. neapolitanus* for efficient reclamation of alkali soil.

ROLE OF SULPHUR IN CROP PRODUCTION AND QUALITY IMPROVEMENT OF COMPOST

B. S. Mathur

Department of Soil Science and Agricultural Chemistry, Birsa Agricultural University, Kanke, Ranchi.

In one of the experiments conducted at Agricultural Research Farm, Ranchi (Bihar), application of gypsum increased the yield of soybean and groundnut and the latter responded more to gypsum than the former.

In another experiment, application of sulphur as pyrite along with Mussoorie rock phosphate helped to increase the total P_2O_5 content of the compost. This effect was found to be more pronounced with decreasing levels of S. Application of S to compost charged with high dose of phosphate (8% P_2O_5) had a suppressing effect on the release of P from rock phosphate while it had a favourable effect when charged with low level of phosphate (1% P_2O_5). Sulphur also affected the microbial population probably due to the high acidic medium. Charging the compost with low level of P_2O_5 and S improved the quality of compost.

STUDIES OF OXIDATION OF SULPHUR AND PYRITE IN SOIL

K. K. Kapoor and M. M. Mishra

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The oxidation of sulphur and pyrite was studied in a sandy loam field soil of pH 8·0 Sulphur was oxidized in soil under unsterile conditions only. Pyrite was oxidised in soil both under sterile and unsterile conditions though the oxidation was slow in the absence of microorganisms. *Thiobacilli* were isolated from soil and pyrite by enrichment culture technique. The oxidation of sulphur in soil was enhanced by inoculation of *Thiobacillus*. Pyrite oxidation was also enhanced by inoculation with *T. ferrooxidans* and *T. thiooxidans.*

SULPHUR IN THE CONTROL OF SHEATH ROT OF RICE

S. Natarajan, P. Durairaj, G. Thangamani,
Narayanaswamy, V. Mariappan and R. Jeyarajan.
Tamil Nadu Agricultural University Coimbatore-641 003.

Sheath rot of rice which was considered to be a minor disease is assuming serious proportions and causes yield losses up to 85 per cent. All the cultivated varieties being susceptible to this disease in varying degrees, chemical control forms an important method of checking this disease. Hence three fungicidal trials were conducted during 1979-80, 1980-81 and 1982 *Kharif* seasons with 12 treatments. Carbendazim (0·05 and 0·1%), mancozeb (0·2%) and edifenphos (0·1%) were significantly superior to control in reducing sheath rot incidence and increasing the yield during 1979-80 and 1980-81 while captafol (0·1%) and Panolil (0·1%) were effective during 1980-81. During 1982 *Kharif*, all the fungicides were superior to control in reducing sheath rot incidence, panolil (0·1%) being the most effective followed by mancozeb (0·25%) and captafol (0·125%).

CHEMICAL CONTROL OF REDGRAM STERILITY MOSAIC

K. Sivaprakasam and R. Samiyappan
Department of Plant Pathology
Tamil Nadu Agricultural University, Coimbatore-641 003.

Studies on the efficacy of foliar sprays with wet sulphur 1·5 kg, kelthane 500 ml, rogor 500 ml. and monocrotophos 500 ml. per ha on the incidence of sterility mosaic by the control of mite Vector *Aceria cajani* were made. The results revealed that spray applications with monocrotaphos 500 ml. per ha were highly effective in reducing the incidence of sterility mosaic disease by controlling the vector, followed by rogor 500 ml. kelthane 500 ml. and wet sulphur 1·5 kq. per ha, the mean incidence being 8.26 10·35, 24·87 and 27·17 per cent respecively as against 33·36 per cent in the untreated control.

WETTABLE SULPHUR - A CHEAPER ACARICIDE FOR THE CONTROL OF RED SPIDER MITE *Tetranychus cinnabarinus* (Boisd.) ON BETELVINE (*Piper betle* L.)

M. Sivakumar, R. Rabindran ann T. Marimuthu

All India Co-ordinated Researah Project on Betelvine Diseases, Velur-638 182. (Salem)

Wettable sulphur was found to be the cheapest acaricide n the field experiments conducted with acaricides insecticides iz., monocrotophos (Nuvacron 40 EC) methyl demeton Metasystox 25 EC), wettable sulphur (Sulfex 80 WP), dicofol kelthane 18 EC), ethion (Mit 505 50 EC) and phosalone. Zolone 35 EC) The experiments were laid out in RBD with hree replications. All the chemicals were sprayed at 0·05% oncentration and water spray served as control. The experiment vas repeated for three seasons from April 1984 to July 1985.

Leaf samples were taken at random in each of the reatments on the 3rd and 10th day after each spray and live nites were counted under steroscopic microscope and the per cent nock down of mites was calculated. Leaf yield was assessed in ach of the treatments both by number and weight.

The three-season data show that maximum 'per cent nite kill' was in the beds sprayed with dicofol (mean 50·45) ollowed by ethion, methyl demeton and wet sulphur which gave 43·86, 36·01 and 32·64 per cent kill respectively.

Whileconsidering the cost benefit ratios, application of sulphur was found to be cheaper (1:80 followed by ethion (1:22) and dicofol (1:21). So by using wet sulphur for the control of red spider mite, we can get more return per rupee spent.

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TNAU 18th & 19th OCT.'85
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SEMINAR ON