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RESPONSE OF RICE TO APPLIED SULPHUR

By

SHERINE GEORGE

THESIS

Submitted in partial fulfilment of the
requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture
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Department of Agronomy
COLLEGE OF HORTICULTURE
Vellanikkara - Trichur
Kerala
1989

DECLARATION

I hereby declare that this thesis entitled "Response of Rice to Applied Sulphur" is a bonafide research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or similar title of any other University or Society.

Vellanikkara,
- -1989.

SHERINE GEORGE

CERTIFICATE

Certified that this thesis entitled "Response of Rice to Applied Sulphur" is a record of research work done independently by Miss. SHERINE GEORGE, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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We, the undersigned, members of the Advisory Committee of Miss.SHERINE GEORGE, a candidate for the degree of Master of Science in Agriculture with major in Agronomy, agree that the thesis entitled "Response of Rice to Applied Sulphur" may be submitted by Miss.SHERINE GEORGE, in partial fulfilment of the requirement for the degree.

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SHERINE GEORGE

To my parents

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Introduction

INTRODUCTION

The importance of sulphur for plant growth has been recognised since long, but its deficiency in soils and consequent losses in productivity have been reported only recently (Aiyar, 1945). Sulphur deficiency was not at all a problem during the past when extensive agriculture was practised. The incidental additions of sulphur through inorganic fertilizers, recycling of sulphur through farm wastes and contributions through rain and/or irrigation water were enough to meet the demand of the crops. The introduction of fertilizer responsive high yielding crop varieties, however, increased the demand for soil nutrients other than nitrogen, phosphorus and potassium. Sulphur is one such nutrient, the importance of which has been overlooked both by researchers and farmers as well.

The inadvertent additions of sulphur to soil are decreasing day by day because of the increasing trends in the use of high analysis sulphur-free straight fertilizers. There is every likelihood that this trend may continue in future also because of the economy involved in the handling of the high analysis fertilizers. The crops thus have to depend increasingly upon soil reserves and atmospheric accretions to meet its sulphur requirement. Response to the application of sulphur in different crops have been reported from many parts of India (Shinde *et al*., 1981; Kamat *et al*., 1981; Gupta and Singh, 1983; Arora *et al*., 1983). Acharya (1973) observed crop response to applied sulphur in different soils from Orissa and Maharashtra which showed a sulphur A-value as high as 79 to 128 ppm. Tandon (1984) identified eleven districts of Kerala including Trichur as sulphur deficient areas, where application of sulphur may increase crop yields.

In Kerala rice is the most important food crop occupying an area of 6.63 lakh hectares (FIB, 1988). Though crop response to the application of sulphur in rice has been reported from many other states of India there is no information available on this aspect for Kerala soils. The experiments reported here in were conducted to evaluate the yield response and quality improvement of rice to graded levels of sulphur applied through different fertilizer sources, the effect of sulphur in enhancing nitrogen and phosphorus utilisation, to study the relative uptake of native and applied sulphur and the uptake and the distribution of ^{35}S applied through labelled ammonium sulphate.

Review of Literature

2. REVIEW OF LITERATURE

The essentiality and physiological role of sulphur in plant nutrition have been well documented. Sulphur resembles nitrogen in its function in plants and is comparable to phosphorus in respect of the overall crop needs.

Responses to sulphur application in pulses and oilseed crops are well established (Aulakh *et al.*, 1977 and Singh and Sahu, 1986). The sulphur requirement of cereals was not studied as much because cereals have comparatively low sulphur requirement and these crops often receive sulphur through the traditional fertilizers used as sources of N, P and K. The available literature on sulphur removal by cereals, sulphur status of cereal growing soils, responses of cereals to sulphur application in terms of yield and quality are briefly reviewed in this chapter. The relevant literature available on the relative efficiency of various sulphur containing fertilizers and time and method of application are also reviewed.

2.1. Sulphur Removal by Cereals

The removal of sulphur by cereal crops and their sulphur needs depend mainly on the crop, it's yield level, the site and season characteristics (Dev and Sharma, 1988). The average sulphur removal for producing 1 t of wheat and rice was reported to be 3-4 kg and that for producing 1 t of sorghum and millets to be 5-8 kg (Kanwar and Mudahar, 1983). Das and Datta (1973) and Shaktawat and Singh (1977) reported that a wheat crop producing about 4 t grain per hectare removed 12 kg sulphur. Arora et al. (1983) and Cheema and Arora (1984) found that a sulphur deficient crop receiving a delayed application of sulphur also removed 12 kg sulphur but produced only a grain yield of 2 t ha^{-1}. The studies conducted by Jain et al. (1984) in fine-textured calcareous soils indicated that paddy crop producing 5.14 t ha^{-1} removed 15.7 kg sulphur.

The magnitude of sulphur removal under different cropping systems depends on whether the cropping system is cereal-based or legume-based. Mehta and Raman (1972); Subba Rao and Ghosh (1981) and Nad and Goswami (1984) reported that an intensive cereal-dominant cropping system involving 3-4 crops such as wheat - cowpea - millet removed 30 kg S ha^{-1} $year^{-1}$. Nambiar and Ghosh (1984) found that a soybean - wheat - maize cropping system removed about 49 kg S ha^{-1} $year^{-1}$.

According to Bhat and Ranganathan (1981) the application rates of sulphur to soils where individual crops or different cropping systems were raised should be 2.5 times higher than the removal figures. Higher application rate was suggested to account for the losses of applied sulphur through leaching, adsorption/fixation, volatalisation, immobilization and sulphur use efficiency in different agro-ecosystems (Dev and Sharma, 1988).

It can be inferred from these reports that crop removal of sulphur in intensive cropping systems varies from 30 to 72 kg S ha^{-1} $year^{-1}$. Under comparable conditions a cereal dominated crop sequence may remove 2 kg sulphur per tonne of dry matter production whereas an oil seed-legume system may remove 4-5 kg sulphur per tonne of dry matter production. The type of crop and the yield level are the major determinants of sulphur removal from soil.

2.2. Sulphur Status of Cereal Growing Soils

Total sulphur content of the soils of India varied from 19 ppm to 3836 ppm (Tandon, 1984) and from 213 to 582 ppm within a district (Tiwari et al., 1984). But the total sulphur present in soils is of little value in describing the pool of available sulphur on which crop production is based. Critical limits of available sulphur depend very much on soil properties, extraction method and the crop (Sinha and Ghildyal, 1971; Saggar and Dev, 1974; Tiwari et al., 1983a and Jain et al., 1984). Based on a study with 24 alluvial soils from Kanpur district of Uttar Pradesh, Tiwari et al. (1983b) opined that 11 ppm sulphur by the ammonium acetate - acetic acid method was the critical limit for economic response of rice to sulphur. Tiwari and Dev (1987) reported that available sulphur content in the cultivated soils of India varied widely. Tandon (1984) found that 10 ppm available sulphur was the most frequently used level below which a soil was pronounced deficient.

Based on the sulphur status in different provinces of the country with respect to different forms of sulphur, Kanwar and Mudahar (1983) reported that sulphur deficiency was widespread in Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, Rajasthan, Bihar, West Bengal and many areas of southern India. They also reported that the deficiency was widespread in alluvial (Entisols and Inceptisols), coastal alluvial soils, laterites (Oxisols), red (Alfizols) and black soil (Vertisols) and soils having low organic matter content. Mukopadhyay and Mukopadhyay (1980) and Dev and Sharma (1988) opined that sulphur deficiency was prevalent in coarse textured soils occuring in high rainfall areas which were intensively cultivated and were under multiple cropping. Dev and Sharma (1988) also reported that 15-20 per cent of cropped land in India had some degree of sulphur deficiency problem and both irrigated and rainfed areas came under this category.

2.3. Effect of Sulphur on Crop Yield

a. Rice

Linear response in grain yield to sulphur application was reported by many workers (Das and Datta, 1973; Barthakur and Holder, 1976; Ghosh, 1980; Lathiff and Amarasiri, 1982; Solosamosir and Blair, 1983; Ramanathan and Saravanan, 1985; Cerff et al., 1985; Valera and Haq, 1986; Portch and Islam, 1986; Malavolta et al., 1987; Russel and Chapman, 1988 and Tassic and Delima, 1988). Das and Datta (1973) reported that in an alluvial soil containing 10 ppm available sulphur, application of 30 kg S ha^{-1} increased rice yield by 6.7 q. Sachdev et al. (1982) found that in a sandy loam soil application of sulphur at the rate of 40 kg ha^{-1} increased the dry matter yield of paddy by 81 per cent. Alam et al. (1985) observed increase in grain yield with graded levels of sulphur ranging from 0 to 15 kg ha^{-1} in an alluvial soil containing 11 ppm available sulphur.

Acharya (1973) observed variation in response of crops to levels of sulphur in different soils. He found that sulphur application up to 90 ppm had significantly increased the dry matter yield of paddy in soils belonging to various textural classes, collected from Sambalpur, Cuttack and Nagpur whereas in soils collected from Bhuvaneswar a significant reduction in dry matter yield was noticed due to application of sulphur beyond 60 ppm. Blair *et al*. (1979) reported that sandy clay loam soils collected from three sites in Indonesia responded differently when sulphur was applied at the rate of 40 to 60 kg ha^{-1}. The yield response varied from 47 to 231 per cent. Tiwari *et al*. (1983b) observed that out of 24 alluvial soils differing widely in available sulphur content, collected from Kanpur district of Uttar Pradesh, 12 soils responded to the application of 50 ppm sulphur and a grain yield increase of 30 per cent was obtained. Pillai and Singh (1975) found that application of 500 kg elemental sulphur per hectare to a calcareous clay loam soil increased paddy yield by 21 q. Alam *et al*. (1986) conducted pot experiments to study the effect of low grade pyrites on two calcareous saline sodic soil under rice - wheat rotation and found that application of pyrites increased the yield of rice and wheat. They also observed that beyond a certain level of pyrites application the trend in soil physical improvement and increase in grain yield was reversed in both the soils.

Chandrasekaran (1965) found that in ill drained soils, addition of sulphate fertilizers prevented the injurious effects on rice by the excessive addition of organic manure and restored the rice yields. Altaf *et al*. (1987) reported that application of zinc and sulphur alone or in combination significantly increased the grain yield of rice cv. BR 4 under both moist and submerged conditions. Effect of sulphur on rice yield under flooded conditions was studied by Islam et al. (1987) and it was observed that paddy yield increased by about 8 per cent with 30 kg S ha^{-1} as gypsum.

Ismunadji (1985) studied the performance of rice cv. IR-36 under simulated submerged and field capacity soil moisture conditions with the application of sulphur up to 80 ppm as sodium sulphate. He found that the number of panicles, number of grains per panicle, thousand grain weight and grain yield were higher under submerged conditions than at field capacity. Momuat et al. (1985) observed that the number of panicles, number of ears per panicle and grain and straw yields of rice cv. IR-50 were improved by the application of 100 kg ammonium sulphate per hectare. While studying the efficiency of S-coated urea on rice Sankaran and Balasubramanian (1985) reported that the number of panicles per unit area and grain yield were significantly increased over control. The effect of sulphur to enhance grain and straw yield of rice was also reported by Biddappa and Sarkunan (1980). They observed that the grain and straw yield were maximum at 60 kg S ha^{-1} and decreased thereafter. From a field trial conducted at Ibague using rice cv. CICA-8 Amaya et al. (1984) concluded that the optimum rate of application of sulphur for maximum yield was 57-114 kg ha^{-1} and beyond that level the yield was decreased due to excess sulphur.

However, lack of response of rice to sulphur application is also reported. Field experiments conducted at Agricultural Research Station, Bhavanisagar during kharif and rabi seasons with rice cv. IET 1444 and IR-20 for the first and second seasons respectively by Jayaramamoorthy et al. (1985) revealed that application of sulphur in any form failed to influence the yield parameters significantly and it was concluded that the native sulphur (30 ppm) was found sufficient to satisfy sulphur requirement of rice in that soil.

b. Wheat

Beneficial influence of sulphur in increasing the grain yield of wheat was reported by Das and Datta (1973), Singh et al. (1980), Bandhe and Lande (1980) and Maslova (1987). Joshi and Seth (1975) found that in sulphur deficient soils, 50 kg S ha^{-1} was optimum for wheat in Rajasthan, but at higher doses of P (100 kg P_2O_5 ha^{-1}), 75 kg S ha^{-1} was needed. In a trial conducted by Shaktawat and Singh (1977) in the clay loam soils of Rajasthan sulphur applied at 100 kg ha^{-1} as elemental sulphur resulted in a grain yield increase by 9 per cent. In black soils of Madhya Pradesh application of 50 kg S ha^{-1} as sodium sulphate increased the grain yield by 16 per cent (Shinde et al., 1981). It was also reported that the grain yield of wheat was increased by 10.88 q ha^{-1} with the application of 120 kg S ha^{-1} as pyrites in alluvial soils of Uttar Pradesh containing 8 ppm available sulphur (PPCL, 1983). Arora et al. (1983) observed that when sulphur was applied at the rate of 10 kg ha^{-1} in the alluvial soils of Punjab, grain yield was increased by 6.69 q. Marked difference in the response of different cultivars to the application of sulphur was observed in Punjab (Aulakh et al., 1977). They recorded an yield increase of 480 to 888 kg ha^{-1} by the application of 25 kg sulphur. Marok (1978) reported that in Punjab wheat cv. PV-18 showed a grain yield response of 1606 to 1840 kg ha^{-1} with single superphosphate than with diammonium phosphate, when compared at an equivalent nitrogen and phosphorus basis and the difference was attributed to sulphur added. In a two year study conducted by Mahler and Maples (1986) to determine the effect of sulphur on grain yield of field grown wheat, sulphur treated plots produced up to two times as much grain yield as in the control plot.

There are some experiments reporting the lack of response to sulphur application. Das and Datta (1973) failed to get any significant response to sulphur application in maize - wheat cropping system until the sixth crop. Similarly, Shinde *et al*. (1980) also observed that the grain and straw yields of wheat var. Kalyansona was not significantly influenced by the application of sulphur. Field research was undertaken by Lamond *et al*. (1986), to evaluate the effect of graded levels of sulphur (0, 17 and 34 kg S ha^{-1}) on winter wheat yields and quality. Their results showed inconsistent yield responses to sulphur application, with all significant yield increases occuring only in sandy, low organic matter soils. Lack of response of winter wheat to sulphur application was reported by Reneau *et al*. (1986) also.

c. *Maize*

There are many reports on positive response of maize to sulphur application. There are a few results otherwise also. Das *et al*. (1975) observed that on an alluvial soil with 10 ppm available sulphur, application of 30 kg S ha^{-1} increased maize grain yield by 4.7 q. In a pot culture experiment in a brown loamy sand, application of sulphur upto 20 ppm significantly increased the drymatter yield

(Jaggi *et al.*, 1977 and Dev *et al.*, 1979). Experiments were conducted to assess the effect of sulphur fertilization on maize var. Ganga-101 under irrigated conditions on sandy soils with graded levels ranging from 10 to 45 kg ha^{-1} and it was concluded that response could be expected in terms of grain yield under soil conditions where organic matter and extractable sulphates were low (Singh, 1980).

Field and laboratory studies were conducted by Kline *et al.* (1986) to evaluate the response of irrigated corn to sulphur fertilization on different soil types using graded levels of sulphur in the range of 0 to 100 kg ha^{-1}. It was concluded that corn grain yields were not significantly influenced by sulphur application. Lack of response to sulphur application to maize was also reported by Sims *et al.* (1988).

d. Millets

Studies on the response of millets to the application of sulphur is limited. Bandhe and Lande (1980) reported that in black soils of Maharashtra having 8 ppm available sulphur, 50 kg S ha^{-1} resulted in 3.3 per cent increase in the grain yield of sorghum. Jain (1970) evaluated the response of pearl millet in Rajasthan and found that an application of 7.5 kg S ha^{-1} as ammonium sulphate increased the yield by 15 per cent.

The above review reveals that marked increase in yield can be expected with sulphur application to rice, wheat, maize and millets for depending on the soil characteristics. These responses to sulphur are obtained when all other factors of production including the rates of nitrogen, phosphorus and potassium application are at optimum levels. Variability in responsiveness to sulphur application does exist in different cultivars of the same crop which also needs to be precisely assessed for giving meaningful recommendations.

2.4. Effect of Sulphur on Crop Quality

Sulphur is an important constituent of cysteine, cystine and methionine, three of the eight essential aminoacids and helps in the formation of protein and thereby affecting the quality of the produce. It is also required in the formation of chlorophyl, vitamins, glutathion, co-enzyme A and many other chemical compounds that are involved in N - fixation and photosynthesis.

Das and Datta (1973) studied the effect of sulphur fertilization on protein, nonprotein nitrogen, tryptophan and methionine content of rice and wheat. The results indicated that the application of sulphur increased the protein content of both paddy and wheat grains and the effect was more pronounced when sulphur was applied in combination with higher levels of nitrogen. An increase in sulphur containing aminoacids and the protein content of wheat, maize and rice was observed by Das et al. (1975) consequent to the application of sulphur. Similar results were also reported for pearl millet (Jain, 1981) and sorghum (Singh et al., 1983).

However, Jayaramamoorthy et al. (1985) found that the crude protein content of rice was not affected by application of sulphur in any form. Lack of response was also reported in maize (Quilgley and Jung, 1985) and wheat (Lamond et al., 1986 and Mahler and Maples, 1987).

It can be deduced from the studies reviewed above that the two most frequently observed effects of sulphur on crop quality of cereals are increase in the content of sulphur containing aminoacids and plant proteins.

2.5. Sulphur Status of Cereals and Nutrient Indexing

Sulphur contents of various cereal crops as reported by Mengel and Kirkby (1982) indicated that wheat contained 0.17 per cent sulphur, maize - 0.17 per cent, barley - 0.18 per cent and oats - 0.18 per cent. In wheat at ear emergence stage a concentration of 0.3 to 0.4 per cent sulphur in the top leaves was found to be optimum (Arora et al., 1983). In an attempt in indexing sulphur status of wheat crop in Punjab, a survey conducted by Cheema and Arora (1984) revealed that 89 per cent of plants suffering from sulphur deficiency, were having less than 0.2 per cent sulphur. Reneau et al. (1986) also reported that sulphur concentration of 0.2 per cent in the flag leaf at Feekes growth stage-10 was sufficient for high yields. Mahler and Maples (1986) observed that minimum sulphur concentration in the plant tissue of wheat for maximum yield ranged from 1.3 to 2.73 g S kg^{-1}.

According to Pillai and Singh (1975) sulphur content of flag leaf of rice was correlated well with grain yield. It was also well documented that the most sulphur deficient rice plants had less than 0.16 per cent sulphur in the leaf blades and shoots at tillering and the attainment of 90 per cent of the yield was associated with sulphur content of 0.17 per cent or more (Tiwari et al., 1983b).

N:S ratio in the plants is also taken as a diagnostic tool to determine the sulphur deficiency/sufficiency levels. In general this ratio varies from 14:1 for cereals to 17:1

for legumes and 15:1 for most other crops. Dev et al. (1979) recorded a constant N:S ratio of 16:1 in maize where as Grains and Phatax (1982) suggested an N:S ratio of 15-16:1 for optimum yield. Tiwari et al. (1983b) reported that in rice at maturity, the critical N:S ratio was 15:1. An experiment conducted by Reneau et al. (1986) in wheat indicated that a N:S ratio of 18:1 in the flag leaf at Feekes growth stage-10 was sufficient for high yields. However, Mahler and Maples (1986) opined that minimum N:S ratio in wheat plant tissues for maximum yield ranged from 9.5 to 19.2.

The optimum sulphur concentration for maximum yield varies with the crop, stage of growth of the crop and the plant part concerned. In general an N:S ratio of 15:1 is considered optimum for most of the crops.

2.6. Sulphur A-values and Relative Efficiency of Native and Applied Sources

Acharya (1973) reported that the average A-value of sulphur for four different soils collected from Sambalpur, Cuttack and Bhubaneswar from Orissa and Nagpur from Maharashtra were found to be 93, 128, 84 and 79 ppm respectively and the optimum limits of sulphur in these soils for maximum yield of paddy was obtained by adding 60 ppm sulphur to the respective A-values. He also found that utilization of native sulphur was increased due to sulphur application upto 30 ppm beyond which more of fertilizer sulphur had been utilized. In a study using labelled gypsum in rice Sachdev et al. (1982) observed that the percentage sulphur derived from the fertilizer in the plant and grain of paddy at maturity was 44.6 and 61.9 respectively.

In wheat, Shinde et al. (1980) reported that A-value of soil sulphur increased by the application of sulphur, but the per cent utilization of applied sulphur decreased significantly when the level was higher than 20 kg S ha^{-1}. He found that the grain yields were related to the utilization of fertilizer sulphur, but not to the A-values of soil and the per cent utilization of fertilizer sulphur was negatively related to the A-values of soil sulphur. Jaggi et al. (1977) studied sulphur uptake and drymatter production in maize at different growth stages as affected by native and applied sulphur. They observed a preferential absorption of soil sulphur at moderate levels of applied sulphur and a reduced absorption of applied sulphur with an increase in the rate of application. It was also reported that the applied sulphur increased the per cent utilization of native sulphur at all growth stages at moderate level of sulphur application.

It is found that A-values of soil sulphur increase with the application of sulphur and the per cent utilization of applied sulphur decreases with an increase in the rate of application. However, the results are inconsistent and needs further confirmation.

2.7. Relative Effectiveness of Various Sources

Pillai and Singh (1975) reported that out of the four sources of soil applied sulphur, elemental sulphur was the best for preventing chlorosis and increasing rice grain yields in calcalcareous soils. Solossmosir and Blair (1983) observed that sulphur uptake in rice was not significantly different between gypsum, elemental sulphur and ammonium sulphate sources confirming the suitability of fine (100 per cent 60 mesh) elemental sulphur as a source for rice, whereas Paulraj et al. (1985) reported that gypsum was an easily available and cheaper source of sulphur than elemental sulphur. Chien et al. (1987) compared the relative agronomic effectiveness (RAE) of powdered elemental sulphur to that of gypsum and found that the RAE value for powdered elemental sulphur was superior to gypsum. However, Chien et al. (1988) reported that elemental sulphur and gypsum incorporated with urea were equally effective in increasing the rice grain yield.

The relative superiority of ammonium sulphate over the other sources like pyrites, gypsum ,elemental sulphur and sulphur coated urea was reported by different workers (Corpuz and Momuat, 1984; Ramanathan and Saravanan, 1985 and Lamond et al., 1986). In a study by Arora et al. (1983) on wheat in Ludhiana district of Punjab, the addition of sulphur through gypsum, pyrite or ammonium sulphate increased the rice yield and the increase varied in the decreasing order of ammonium sulphate, pyrite and gypsum. Alam et al. (1985) studied the efficiency of gypsum, ammonium sulphate, elemental sulphur and sulphur coated urea as source of sulphur to rice and the results proved that ammonium sulphate was superior to other sources.

Tiwari et al. (1984) found that wheat yield increased by 18 and 36 per cent over control by the application of 60 and 120 kg S ha^{-1} respectively applied as pyrite. Alam et al. (1985) reported that yield of rice and wheat increased significantly following application of sulphur through pyrites. However, there was little information regarding the periodicity of application of this material (Dev and Sharma, 1988).

It can be seen from the reports of the above workers that for correcting sulphur deficiencies under normal soil conditions, materials containing sulphate-sulphur are preferable and can be used depending up on their local availability, economics and simultaneous need for the application of other nutrients such as N, P, K and Ca. For calcareous soils elemental sulphur is found to be superior over other materials.

2.8. Time and Method of Application

In general, the application of sulphate containing fertilizers during final land preparation or before seeding was recommended (Dev and Sharma, 1988). But Corpuz and Momuat (1984) opined that in wetland rice soils sulphur containing fertilizers should be broadcast 10 days after transplanting and it should never be applied at planting and incorporated with the mud or deep placed in the mud. Cheema and Arora (1984) found that sulphur deficiency in a 45 day-old wheat crop was corrected at least partially by sulphur application at that stage.

In a trial conducted by Lamond et al. (1986) to study the effect of sulphur fertilization on wheat yield it was found that surface broadcasting and surface banding were equally effective. Chien et al. (1987) reported that in a green house evaluation of elemental sulphur and gypsum for flooded rice, the various sulphur placement methods demonstrated the following order of agronomic effectiveness -

elemental sulphur surface broadcast = incorporation > deep placement. Rice response to gypsum on the other hand, was found to be the same, irrespective of the placement method. Incorporated gypsum and elemental sulphur showed only very poor residual value because a substantial amount of fertilizer was taken up by the first crop (Chien *et al.*, 1988).

The sulphur containing fertilizers are recommended to be surface broadcast at the time of land preparation or at the time of sowing except for elemental sulphur, which should be applied about a month before sowing to allow for oxidation.

The literature reviewed here clearly illustrates that sulphur deficiency is fairly and frequently reported from a wide range of soils in various states of India. No studies have been conducted in Kerala on the response of rice to applied sulphur. Responses to fertilizer sulphur can be expected in acid laterite soils of Kerala.

Materials and Methods

3. MATERIALS AND METHODS

The studies reported herein were designed to obtain information on the response of rice to applied sulphur. The factors under investigation were graded levels and sources of sulphur. The relative contribution of basally applied and top dressed sulphur towards sulphur uptake by the plant, utilization of native and applied sulphur and the distribution pattern of sulphur in the plant were also studied. One field experiment and a pot culture experiment were conducted for this purpose.

3.1. Experiment I: Influence of Levels and Sources of Sulphur on Growth, Yield and Quality of Rice

3.1.1. Site, Climate and Soil

The experiment was conducted at the Agricultural Research Station, Mannuthy under the Kerala Agricultural University. The research station is located at 12° 32' N latitude and 74° E longitude. The experimental field lies at an altitude of 22 m above MSL. This area enjoys a typical humid tropical climate. The weather data for the cropping period is given in Appendix I.

The experimental area is a double-crop wet land and has been under bulk crop of paddy for the previous two seasons.

The experiment was conducted during the virippu season (from June to September) of 1988. The soil of the experimental field was sandy clay loam in texture. The physical and chemical properties of the soil are presented in Table 1.

3.1.2. Variety

Rice variety, Jaya was used for the investigation. Jaya is a high yielding photoinsensitive variety with white long bold grains. It has a duration of 120-125 days.

3.1.3. Fertilizer Materials

Ammonium sulphate (20.5% N, 24% S), ammonium phosphate sulphate (20% N, 20% P_2O_5 and 15% S), elemental sulphur urea (46% N), phosphoric acid (72.4% P_2O_5) and muriate of potash (60% K_2O) were used as the sources of different nutrients in this study.

3.1.4. Treatments

The treatments consisted of combinations of four levels of sulphur, three sources of sulphur and two time of application of ammonium sulphate. These together were considered as four sources of sulphur as given below.

Table 1. Physical and chemical nature of soil in the experimental field

Particulars	Value	Method employed
A. Mechanical composition		
Coarse sand (%)	27.2	Robinson's international Pipette method (Piper, 1942)
Fine sand (%)	23.8	
Silt (%)	22.6	
Clay (%)	26.4	
Bulk density	1.52	Core Sampler method (Piper, 1942)
B. Chemical composition		
Organic Carbon (%)	0.661	Walkley and Black method (Soil Survey Staff, 1967)
Total N (%)	0.138	Semi micro-kjeldahl method (Soil Survey Staff, 1967)
Available P (kg ha^{-1})	32.06	Bray I extractant, molybdophosphoric acid method (Jackson, 1958)
Available K (kg ha^{-1})	172.08	Neutral normal ammonium acetate extractant flame photometry (Jackson, 1958)
Available S (ppm)	40	Morgan's sodium acetate-acetic acid extractant, followed by turbidimetric method of determination (Jackson, 1958)
pH	5.84	1:2.5 Soil-water suspension, using a pH meter

(a) Levels of sulphur

S_0 - 0 kg S ha^{-1}

S_1 - 20 kg S ha^{-1}

S_2 - 40 kg S ha^{-1}

S_3 - 60 kg S ha^{-1}

(b) Sources of sulphur

1. Ammonium sulphate - basal dressing
2. Ammonium sulphate - top dressing at panicle initiation
3. Ammonium phosphate sulphate
4. Elemental sulphur

Ammonium phosphate sulphate and elemental sulphur are not usually recommended for top dressing. Hence top dressings with these fertilizers were not included as treatments. There were 13 treatments as detailed below.

Treatment	Notation
1. Sulphur at 20 kg ha^{-1} as ammonium sulphate, basal dressing	S_1 AS
2. Sulphur at 40 kg ha^{-1} as ammonium sulphate, basal dressing	S_2 AS
3. Sulphur at 60 kg ha^{-1} as ammonium sulphate, basal dressing	S_3 AS
4. Sulphur at 20 kg ha^{-1} as ammonium sulphate, top dressing	S_1 AS(T)
5. Sulphur at 40 kg ha^{-1} as ammonium sulphate, top dressing	S_2 AS(T)

6. Sulphur at 60 kg ha^{-1} as ammonium sulphate, top dressing — S_3 AS(T)

7. Sulphur at 20 kg ha^{-1} as ammonium phosphate sulphate, basal dressing — S_1 APS

8. Sulphur at 40 kg ha^{-1} as ammonium phosphate sulphate, basal dressing — S_2 APS

9. Sulphur at 60 kg ha^{-1} as ammonium phosphate sulphate, basal dressing — S_3 APS

10. Sulphur at 20 kg ha^{-1} as elemental sulphur, basal dressing — S_1 ES

11. Sulphur at 40 kg ha^{-1} as elemental sulphur, basal dressing — S_2 ES

12. Sulphur at 60 kg ha^{-1} as elemental sulphur, — S_3 ES

13. Sulphur at 0 kg ha^{-1} (Control) — S_0

3.1.5. Design and Layout

The experiment was laid out as randomized block design and was replicated three times. The layout plan is given in Fig. 1.

3.1.6. Spacing and Plot Size

a. Spacing : 20 x 15 cm

b. Plot size

Gross : 4.6 x 4.5 m

Net : 3.8 x 3.6 m

c. Border rows : Two rows of plants were left as border rows all around each plot. One additional row was

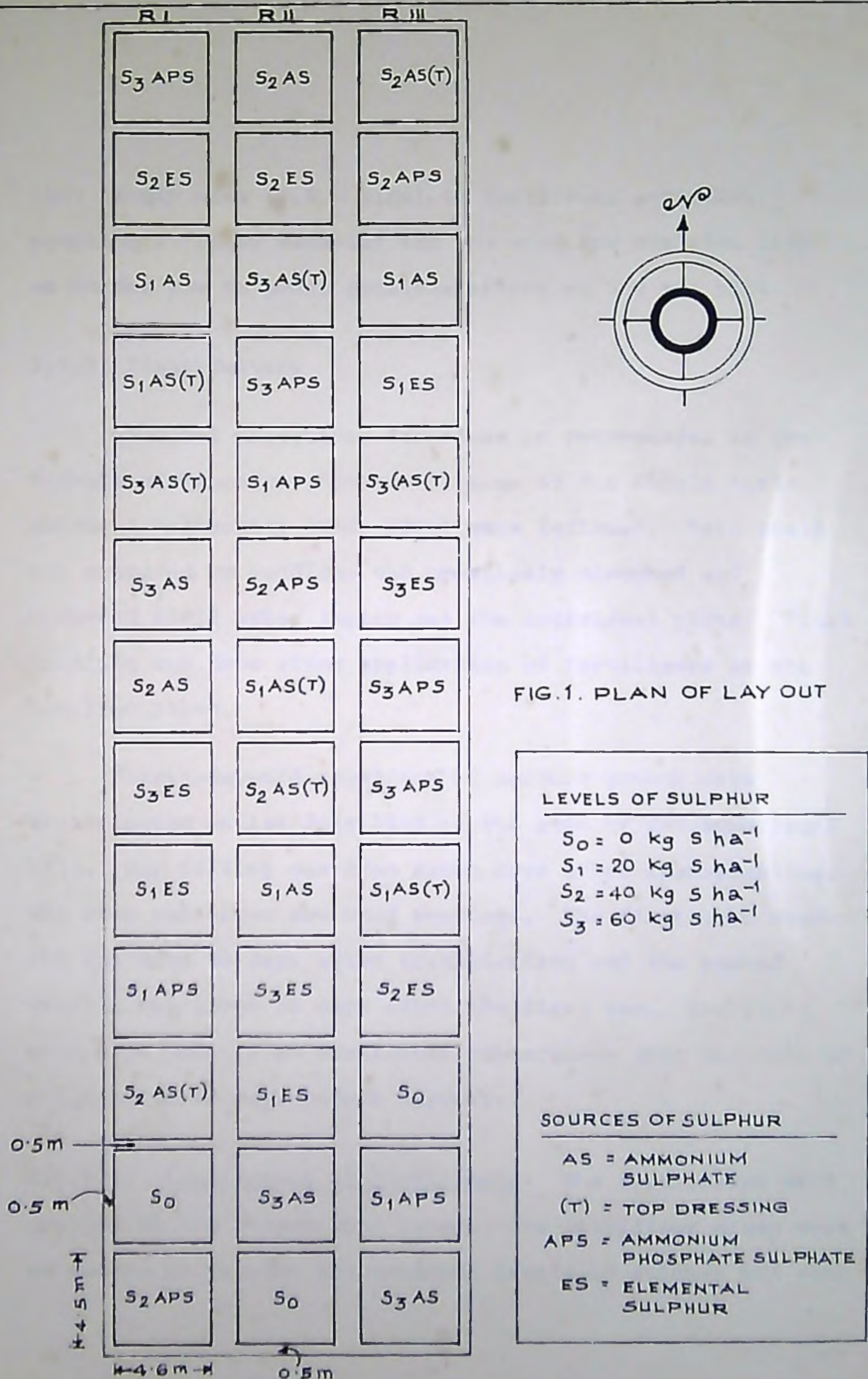


FIG.1. PLAN OF LAY OUT

left length wise (4.6 m side) to facilitate periodical sampling of plant material and the next row was also left as border row to avoid possible effect on the net plot.

3.1.7. Field Culture

Cultural operations for rice, as recommended in the Package of Practices-Recommendations of the Kerala Agricultural University (KAU, 1986) were followed. Main field was prepared by puddling the previously ploughed and harrowed field after laying out the individual plots. Final puddling was done after application of fertilizers to the levelled plots.

Thirty-day-old seedlings of uniform growth were transplanted on 1st July 1988 at the rate of 2-3 seedlings/hill. Gap filling was done seven days after transplanting. The crop was given two hand weedings. The first hand weeding was done 30 days after transplanting and the second weeding was given 30 days after the first one. The plots were kept under 5 cm continuous submergence from the date of planting to 10 days before harvest.

3.1.7.1. <u>Application of fertilizers</u>: The fertilisers were applied at the recommended rates. The fertiliser doses were so chosen as to give the required levels of sulphur but same quantity of N, P and K. Urea and ortho phosphoric acid were the sulphur free sources of N and P used in control plots and to supplement N and P.

The whole of the phosphatic fertilizer, viz. phosphoric acid was diluted and was applied uniformly on the surface. The full dose of sulphur as well as half the doses of nitrogen and potassium depending on the treatment requirements were broadcast uniformly on the soil surface. Final puddling and levelling were done after this. Top dressing of ammonium sulphate as a sulphur source and the second dose of N and K were given at panicle initiation stage.

3.1.7.2. Plant Protection: Ekalux 0.05 per cent and Chlorpyrphos 0.05 per cent were sprayed to control leaf rollers. Malathion 0.1 per cent was sprayed at flowering to control rice bugs.

3.1.7.3. Harvesting: Harvesting was done when more than 80 per cent of grains of the panicle had matured (96 days after planting). Border plants were harvested and removed first. The net plots were then harvested and threshed.

3.1.8. Observations

3.1.8.1. Growth characters

a. Plant height: Ten hills were selected randomly for periodical growth observations in each plot. Height was recorded from the base of the plant to the tip of the top most leaf at active tillering and panicle initiation stages. At flowering and harvest stages the height from the base to the tip of the tallest panicle was taken and the mean height worked out.

b. Number of tillers: The total number of tillers were counted from the above 10 hills at active tillering, panicle initiation, flowering and harvest stages and the average is expressed as number of tillers per hill.

c. Leaf area index (LAI): Leaf area index was calculated by adopting the method suggested by Gomes (1972) at active tillering, panicle initiation, flowering and harvest.

d. Dry matter production: The dry weight of grain and straw were added together to get the total dry matter production at harvest.

3.1.8.2. Yield characters

a. Productive tillers: The number of productive tillers were counted from ten hills and their average expressed as number of productive tillers per hill.

b. Panicle length: One panicle from each hill was clipped off randomly. The length in centimetres from the neck to the tip of each panicle was measured and mean length was worked out.

c. Number of grains per panicle: The total number of spikelets of the above ten panicles were counted and the average calculated.

d. Percentage of ripened grains per panicle: Well developed and ripened grains of the above ten panicles were counted and the percentage worked out.

e. Thousand grain weight: One thousand grains were counted from the cleaned produce from each plot and the weight recorded in grammes.

f. Grain yield: The grain yield from each plot was dried, cleaned, winnowed and weighed, and expressed in kg ha^{-1}. The weight was adjusted to 14 per cent moisture.

g. Straw yield: The straw from each plot was dried under sun. The weight was recorded and expressed in kg ha^{-1}.

h. Grain-straw ratio: The ten randomly selected hills were cut from the base, dried in an oven, weighed and threshed. Weight of the straw was estimated after deducting grain weight from the total dry matter. From the dry weight values of grain and straw, the ratio was then worked out.

i. Harvest index: Harvest index was worked out by dividing the economic yield (grain yield ha^{-1}) by biological yield (dry weight of grain and straw at harvest).

3.1.9. Chemical Analysis

3.1.9.1. Plant nutrients: The plant samples collected were dried in a hot air-oven at 75°C, powdered in a Wiley mill and analysed for N, P, K and S content. The following methods were used for analyses.

Nitrogen	:	H_2SO_4 - H_2O_2 digestion followed by the estimation of N colorimetrically using Nessler's reagent (Wolf, 1982).
Phosphorus	:	Diacid digestion (2:1 HNO_3:$HClO_3$) followed by determination of P using by vanado molybdo phosphoric yellow colour method, using a spectrophotometer (Spectronic 20) (Jackson, 1958).
Potassium	:	Diacid digestion followed by estimation of K in the digest using flame photometer (Jackson, 1958).
Sulphur	:	Diacid digestion followed by estimation of S turbidimetrically (Hart, 1961).

The plant analyses were carried out on samples drawn at 30, 45 and 60 days after transplanting and at harvest. At harvest stage the analysis of the crop was done seperately for grain and straw.

3.1.9.2. Protein content of grain: The protein content of the grain was computed by multiplying the nitrogen content of the grain by a factor 6.25 (Simpson *et al*., 1965).

3.1.10. Computation of Nutrient Uptake

Sulphur content of plant samples at active tillering, panicle initiation and flowering were multiplied with dry matter yield and uptake of this nutrient at these stages was computed. The N, P, K and S contents of grain and straw were multiplied with their respective yields and the values thus obtained were added together to get the total uptake.

3.2. Experiment II: Absorption and Distribution of ^{35}S from Ammonium Sulphate in Rice

A pot culture experiment was conducted with rice to study the utilization of applied sulphur by rice, it's pattern of distribution in the plant and availability of native sulphur. Ammonium sulphate labelled with ^{35}S was used as the source of sulphur in this experiment and it was conducted in the green house at the Radiotracer Laboratory of the Kerala Agricultural University, Vellanikkara, Trichur.

3.2.1. Collection and Preparation of Soil Samples for Pot Culture

Soil collected from the rice fields where the field experiment was carried out was used for pot culture. The physico-chemical characteristics of the soil are given in Table 1. Surface soil from 0-20 cm representing the plough layer was collected. The soil was air-dried, gently crushed with wooden mallet and sieved through 2 mm sieve. The sieved soil was used in the pot culture experiment.

The pot culture experiment was conducted during the same season as that of the field trial ie. during the kharif (June-October) of 1988. The experiment was laid out in completely randomised design with four replications. Rice variety Jaya was used as the test crop in this experiment also.

3.2.2. Treatments

Treatments comprised combinations of three levels of sulphur and three methods of application as detailed below.

<u>Levels of sulphur</u>

S_{20} - 20 kg S ha^{-1}

S_{40} - 40 kg S ha^{-1}

S_{60} - 60 kg S ha^{-1}

Method of application

1. Full basal (labelled)
2. ½ basal (labelled) + ½ top dressing (unlabelled)
3. ½ basal (unlabelled) + ½ top dressing (labelled)

An alternate labelling technique was followed in the split application. In the first case, half the total amount of sulphur was applied as basal through ^{35}S labelled ammonium sulphate and the remaining quantity was top dressed through unlabelled ammonium sulphate. In the second case, basal dressing was done with unlabelled ammonium sulphate and top dressing was done with labelled ammonium sulphate. Thus there were altogether 9 treatments as given below.

Treatment	Notation
1. Sulphur at 20 kg ha^{-1} as labelled ammonium sulphate, basal dressing	S_{20} FBL
2. Sulphur at 40 kg ha^{-1} as labelled ammonium sulphate, basal dressing	S_{40} FBL
3. Sulphur at 60 kg ha^{-1} as labelled ammonium sulphate, basal dressing	S_{60} FBL
4. Sulphur at 20 kg ha^{-1} in two equal splits one half as basal application of labelled ammonium sulphate and the other half top dressing of unlabelled ammonium sulphate	S_{20} HBL + HTUL
5. Sulphur at 40 kg ha^{-1} in two equal splits one half as basal application of labelled ammonium sulphate and the other half top dressing of unlabelled ammonium sulphate	S_{40} HBL + HTUL

6. Sulphur at 60 kg ha^{-1} in two equal splits one half as basal application of labelled ammonium sulphate and the other half top dressing of unlabelled ammonium sulphate — S_{60} HBL + HTUL

7. Sulphur at 20 kg ha^{-1} in two equal splits one half as basal application of unlabelled ammonium sulphate and the other half top dressing of labelled ammonium sulphate — S_{20} HBUL + HTL

8. Sulphur at 40 kg ha^{-1} in two equal splits one half as basal application of unlabelled ammonium sulphate and the other half top dressing of labelled ammonium sulphate — S_{40} HBUL + HTL

9. Sulphur at 60 kg ha^{-1} in two equal splits one half as basal application of unlabelled ammonium sulphate and the other half top dressing of labelled ammonium sulphate — S_{60} HBUL + HTL

3.2.3. Preparation of ^{35}S Labelled Ammonium Sulphate Solution and Pot Culture

Twenty grammes of labelled ammonium sulphate ($(NH_4)_2{}^{35}SO_4$) obtained from the Bhabha Atomic Research Centre, Trombay with a specific activity of 0.25 m Ci/g S were diluted to 896 ml to give 22.32 mg ammonium sulphate per ml. Five, 10 and 15 ml of the solution were thus equivalent to S_{20} FBL, S_{40} FBL and S_{60} FBL respectively. One half of these volumes namely 2.5, 5 and 7.5 ml were equivalent to S_{20} HBL + HTUL/S_{20} HBUL + HTL, S_{40} HBL + HTUL/S_{40} HBUL + HTL, S_{60} HBL + HTUL/S_{60} HBUL + HTL respectively.

Unlabelled ammonium sulphate solution was prepared as follows: Two grammes of ammonium sulphate (Analar grade) were dissolved in 179.2 ml distilled water to give 11.16 mg ammonium sulphate per ml. Five, 10 and 15 ml of this solution respectively were equivalent to S_{20} HBL + HTUL/S_{20} HBUL + HTL, S_{40} HBL + HTUL/S_{40} HBUL + HTL, S_{60} HBL + HTUL/S_{60} HBUL + HTL respectively.

Plastic buckets of five litre capacity were cleaned well. Each bucket was filled with 3 kg air-dried and sieved soil. Labelled ammonium sulphate was applied as per the treatment and was mixed with the top 5 cm layer of the soil. Nitrogen, P and K were applied at the rates of 90-45-45 kg N, P_2O_5 and K_2O respectively in accordance with the Package of Practices - Recommendations (KAU, 1986). Phosphoric acid (72.4% P_2O_5) and potassium chloride (62.76% K_2O) were used as the sources for phosphorus and potassium respectively. Nitrogen level was maintained constant by adding equivalent amount of urea on nitrogen basis over and above the contribution from $(NH_4)_2SO_4$ according to the treatment. Twenty five-day-old seedlings were transplanted at the rate of 3 seedlings per bucket. The buckets were serially numbered and arranged randomly. The soil in the buckets was flooded to give about 5 cm standing water. This level was maintained throughout the experimental period. The crop was harvested at full maturity (128 days) on 20th October 1988.

The harvested plant material from each bucket was separately oven dried at 75°C for dry matter determination. The plant material was chopped into small pieces for ^{35}S assay as well as for total sulphur determination.

The following quantities were computed from total sulphur and ^{35}S activity determinations.

a) Specific activity among plant parts:

The plant parts (leaf, culm, inflorescence stalk and grain) were separated, dried and the dry weight recorded. The total radioactivity and total sulphur were found out separately for each plant part. Specific activity was then worked out in cpm/μg of S for each part.

b) Per cent S derived from fertilizer in plants receiving single application of S (% $Sdff_{FBL}$)

$$= \frac{\text{Specific activity of the plant material (cpm/mg S)}}{\text{Specific activity of the fertilizer (cpm/mg S)}} \times 100$$

c) Per cent S derived from the fertilizer in plants receiving S in two split doses (% $Sdff_{SD}$)

$$= \frac{\text{Specific activity of the plant material (HBL+HTUL)}}{\text{Specific activity of the fertilizer}} \times 100 +$$

$$\frac{\text{Specific activity of the plant material (HBUL+HTL)}}{\text{Specific activity of the fertilizer}} \times 100$$

This equation may be reduced to

$$= \frac{\text{Specific activity of the plant material (HBL+HTUL)} + \text{Specific activity of the plant material (HBUL+HTL)}}{\text{Specific activity of the fertilizer}} \times 100$$

d) Per cent S derived from soil for plants receiving single application of sulphur ($\% \ Sdfs_{FBL}$) = $100 - \% \ Sdff_{FBL}$

e) Per cent S derived from soil. For plants receiving two split doses ($\% \ Sdfs_{SD}$) = $100 - \% \ Sdff_{SD}$

f) A - value (ppm) for single application

$$= \frac{\% \ Sdfs_{FBL}}{\% \ Sdff_{FBL}} \times \mu g \ S \text{ applied/g soil}$$

g) A - value (ppm) for split application

$$= \frac{\% \ Sdfs_{SD}}{\% \ Sdff_{SD}} \times \mu g \ S \text{ applied/g soil}$$

h) Quantity of fertilizer (mg) taken up from the fertilizer by plants receiving single application (FS_{FBL})

$$= \frac{\text{Total cpm in the plant (FBL)}}{\text{Specific activity of the fertilizer}} \text{ or}$$

$$\frac{\% \ Sdff_{FBL} \times \text{total S uptake (FBL)}}{100}$$

i) Quantity of sulphur (mg) taken up from the fertilizer by plants receiving two split doses (FS_{SD})

$$= \frac{\text{Total cpm in the plant (SD)}}{\text{Specific activity of the fertilizer}} \quad \text{or}$$

$$\frac{\%\ Sdff_{SD} \times \text{Total S-uptake (SD)}}{100}$$

j) Per cent utilisation of applied sulphur by plants receiving single application ($\%\ UF_{FBL}$)

$$= \frac{FS_{FBL} \text{ per pot in mg}}{\text{mg S applied per pot}} \times 100$$

k) Per cent utilisation of applied sulphur by plants receiving two split doses ($\%\ UF_{SD}$)

$$= \frac{FS_{SD} \text{ per pot in mg}}{\text{mg S applied per pot}} \times 100$$

3.2.4. Autoradiography

The uptake and distribution of ^{35}S was studied by autoradiography. Two actively growing tillers (117 day-old) one with panicle and the other without panicle were harvested at just above flood water level from a bucket where sulphur was applied basally at the rate of 60 kg ha^{-1} as labelled ammonium sulphate. The specimens were pressed using a herbarium press and dried at 70°C in an oven for 30 min. The specimens were then kept in contact with X-ray film in the dark. After an exposure period of two weeks, the X-ray films were developed using Agil X-ray developer and Agil X-ray fixer and positive prints were taken. After autoradiography all the parts were removed from the plant and the ^{35}S content in each of the plant part was determined.

3.2.5. Chemical Analysis

Total sulphur in the plant samples was estimated in the diacid digest turbidimetrically as already given in Section 3.1.9.1. The sulphur uptake by leaf, culm, inflorescence stalk and grain were estimated separately and added to get the total uptake.

3.2.6. Radioassay of plant samples

One millilitre of the diacid digest of radioactive samples was transferred into scintillation counting vial, containing 15 ml liquid scintillator and the radioactivity was determined in a microcomputer-controlled liquid scintillation system (Rackbeta of Pharmacia (LKB)). The count rates were corrected for background and decay prior to their use in calculations. Since quenching levels in all the digests were more or less constant, quench correction was not carried out.

Composition of liquid scintillator per litre

Naphthalene	- 60 g
PPO	- 4 g
POPOP	- 0.2 g
Methanol	- 100 ml
Ethylene glycol	- 20 ml

These were taken in a 1000 ml volumetric flask and after dissolving in 400 ml dioxane, the volume was made up with dioxane.

3.2.7. Statistical Analysis

The data were statistically analysed selecting appropriate techniques (Panse and Sukhatme, 1978).

Results

Table 2. Effect of levels of sulphur and its sources on plant height at 30 DAP (cm)

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	66	64	62	64
AS (T)	-	64	64	62	63
APS	-	63	64	63	63
ES	-	65	63	63	64
Mean	65	65	64	63	

SEm$\pm$ 0.9

CD (0.05) Levels - 1 Source - NS Levels x source - NS

Table 3. Effect of levels of sulphur and its sources on plant height at 45 DAP (cm)

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	76	74	72	74
AS (T)	-	74	74	72	73
APS	-	71	75	74	73
ES	-	75	73	74	74
Mean	75	74	74	73	

SEm$\pm$ 1

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

Table 4. Effect of levels of sulphur and its sources on plant height at 60 DAP (cm)

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	95	93	91	93
AS (T)	-	95	95	95	95
APS	-	92	94	93	93
ES	-	92	94	93	93
Mean	93	93	94	93	

SEm± 2

CD (0.05) Levels - NS Source - NS levels x source - NS

Table 5. Effect of levels of sulphur and its sources on plant height at harvest (cm)

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	101	100	99	100
AS (T)	-	101	103	102	102
APS	-	99	100	99	100
ES	-	101	98	99	99
Mean	100	100	100	100	

SEm± 2

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

Table 6. Effect of levels of sulphur and its sources on number of tillers per m^2 at 30 DAP

Sources of sulphur	Levels of sulphur ($kg\ ha^{-1}$)				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	320	307	329	319
AS (T)	-	292	299	310	300
APS	-	291	337	311	313
ES	-	308	319	301	309
Mean	317	303	315	313	

SEm$\pm$ 16

CD (0.05) Levels - NS Sources - NS Levels x source - NS

Table 7. Effect of levels of sulphur and its sources on number of tillers per m^2 at 45 DAP

Sources of sulphur	Levels of sulphur ($kg\ ha^{-1}$)				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	346	306	338	330
AS (T)	-	322	339	310	324
APS	-	318	341	327	329
ES	-	317	330	312	320
Mean	328	326	329	322	

SEm$\pm$ 16

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

Table 8. Effect of levels of sulphur and its sources on number of tillers per m^2 at 60 DAP

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	352	322	347	340
AS (T)	-	364	341	326	344
APS	-	344	376	346	355
ES	-	327	350	359	345
Mean	361	347	348	344	

SEm± 19

CD (0.05) Levels - NS Source - NS Levels x source - NS

Table 9. Effect of levels of sulphur and its sources on number of tiller per m^2 at harvest

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	303	305	300	303
AS (T)	-	287	281	333	300
APS	-	297	318	304	306
ES	-	299	291	309	300
Mean	324	296	298	312	

SEm± 18

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

number of tillers (Tables 6-9). Control vs rest comparison was also not significant at any of the growth stages.

4.1.1.3. Leaf area index (LAI)

The main effect of sulphur, sources of sulphur and their interactions failed to exert any significant influence on LAI of the plant at 30 DAP (Table 10). But control vs rest comparison was significant and all the treatments except the treatments where ammonium sulphate was top dressed and elemental sulphur at 40 and 60 kg levels were significantly superior over the control. Elemental sulphur at 20 kg ha^{-1} recorded the maximum leaf area index.

At 45 DAP the main effect of sulphur was not significant (Table 11). The effect of sources was significant. Ammonium sulphate basal dressing resulted in significantly higher leaf area index as compared to ammonium sulphate top dressing and elemental sulphur. Ammonium phosphate sulphate, though showed a higher value than elemental sulphur it was on par with ammonium sulphate. Elemental sulphur recorded the lowest leaf area index. The interaction effects were not significant. But control vs rest was significant. Ammonium sulphate basal dressings at all levels and top dressing at 60 kg S ha^{-1} ammonium

Table 10. Effect of levels of sulphur and its sources on leaf area index (LAI) at 30 DAP

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	5.5	5.6	5.6	5.6
AS (T)	-	4.7	5.0	5.0	4.9
APS	-	5.2	6.0	5.3	5.5
ES	-	6.2	4.6	5.0	5.3
Mean	3.9	5.4	5.3	5.3	

SEm$\pm$ 0.4

CD (.05) Levels - NS Source - NS Levels x source - 1.3

Table 11. Effect of levels of sulphur and its sources on leaf area index (LAI) at 45 DAP

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	6.8	7.1	6.9	6.9
AS (T)	-	5.9	5.7	6.6	6.0
APS	-	5.6	7.1	6.2	6.4
ES	-	6.0	5.1	5.7	5.6
Mean	5.0	6.2	6.3	6.3	

SEm$\pm$ 0.4

CD (.05) Levels - NS Source - 0.6 Levels x source - 1.1

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

phosphate sulphate at 40 and 60 kg S ha^{-1} and elemental sulphur at 20 kg ha^{-1} were significantly superior over the control. The maximum leaf area index was registered by ammonium phosphate sulphate at a sulphur level of 40 kg ha^{-1}.

The influence of main effect of sulphur was not significant at 60 DAP also (Table 12). But the sources of sulphur had significant influence on leaf area index. Ammonium sulphate basal dressing recorded significantly higher leaf area index followed by ammonium phosphate sulphate which was on par with elemental sulphur and ammonium sulphate top dressing. The interactions were not significant. Control vs rest comparison was significant. Ammonium sulphate basal dressings at all levels and ammonium phosphate sulphate at 40 kg S ha^{-1} were significantly superior to control and the maximum value was recorded by ammonium sulphate, basal dressing at 60 kg S level.

When the plants were in the harvest stage, the main effect of sulphur, its sources, interaction effects and control vs rest were not significant (Table 13).

In general ammonium sulphate basal application resulted in a higher leaf area index for a longer period. The minimum leaf area index at all the stages was due to elemental sulphur application.

Table 12. Effect of levels of sulphur and its sources on leaf area index (LAI) at 60 DAP

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	6.2	6.3	6.7	6.4
AS (T)	-	5.5	5.6	5.3	5.5
APS	-	5.4	6.2	5.8	5.8
ES	-	5.5	5.5	5.6	5.5
Mean	5.0	5.6	5.9	5.9	

SEm± 0.3

CD (0.05) Levels - NS Source - 0.6 Levels x source - 1.0

Table 13. Effect of levels of sulphur and its sources on leaf area index (LAI) at harvest

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	4.5	3.4	3.6	3.8
AS (T)	-	3.5	3.9	3.8	3.7
APS	-	3.8	3.7	3.8	3.8
ES	-	3.6	3.1	4.0	3.6
Mean	3.7	3.9	3.5	3.8	

SEm± 0.4

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

4.1.1.4. Dry matter production

The dry matter production recorded at harvest showed that the main effect of sulphur, sources of sulphur their interactions and control vs rest comparisons were significant (Table 14).

Among the sulphur levels 20 kg ha^{-1} was significantly superior to 40 kg ha^{-1}, but was on par with 60 kg ha^{-1}. Among the sources elemental sulphur recorded significantly higher values over ammonium sulphate basal dressing, but was on par with ammonium phosphate sulphate and ammonium sulphate top dressing. The interactions were significant. Elemental sulphur at 60 kg S ha^{-1} registered the maximum dry matter production but was on par with the 20 kg level. Elemental sulphur and ammonium sulphate basal dressing at a sulphur level of 40 kg ha^{-1} registered the minimum value for dry matter production. Control vs rest comparison was also significant. All the treatments except sulphur at 40 kg ha^{-1} as elemental sulphur, or ammonium phosphate sulphate or ammonium sulphate basal dressing and sulphur at 60 kg ha^{-1} as ammonium sulphate registered significantly higher dry matter production over control.

Table 14. Effect of levels of sulphur and its sources on dry matter production at harvest (g m^{-2})

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0	S_1	S_2	S_3	
	0	20	40	60	
AS	-	998	763	843	868
AS (T)	-	957	965	903	942
APS	-	985	944	985	971
ES	-	1057	794	1194	1015
Mean	813	999	866	981	

SEm± 48

CD (0.05) Levels - 71 Source - 82 Levels x source - 141

Table 15. Effect of levels of sulphur and its sources on number of productive tillers per hill

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0	S_1	S_2	S_3	
	0	20	40	60	
AS	-	7.5	7.1	7.6	7.4
AS (T)	-	7.6	7.2	7.4	7.4
APS	-	7.9	8.2	7.4	7.8
ES	-	8.3	7.7	7.6	7.8
Mean	7.8	7.8	7.5	7.5	

SEm± 0.4

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

4.1.1.5. Productive tillers

The main effect of sulphur, sources of sulphur and their interactions failed to exert any significant influence on the number of productive tillers (Table 15). Control vs rest comparison was also not significant.

4.1.1.6. Panicle length

The panicle length was not influenced by the main effect of sulphur, its sources or interactions. Control vs rest also was not significant (Table 16).

4.1.1.7. Number of grains per panicle

The main effect of sulphur, sources of sulphur and their interactions failed to produce any significant effect on the number of grains per panicle (Table 17). Control vs rest comparison was also not significant.

4.1.1.8. Percentage of ripened grains per panicle

The main effect of sulphur, sources of sulphur and their interactions failed to exert any significant influence on the percentage of ripened grains per panicle (Table 18). Control vs rest comparison was also not significant.

Table 16. Effect of levels of sulphur and its sources on panicle length (cm)

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	21.8	23.3	22.1	22.4
AS (T)	-	22.6	22.9	23.6	23.0
APS	-	23.0	23.9	22.3	23.0
ES	-	22.5	22.3	22.5	22.4
Mean	22.1	22.5	23.1	22.6	

SEm$\pm$ 0.7

CD (0.05) Levels - NS Source - NS Levels x source - NS

Table 17. Effect of levels of sulphur and its sources on number of grains per panicle

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	117	119	105	113
AS (T)	-	113	129	118	120
APS	-	117	122	126	122
ES	-	114	126	125	122
Mean	111	115	124	119	

SEm$\pm$ 5.0

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

Table 18. Effect of levels of sulphur and its sources on percentage of ripened grains per panicle

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	71	68	70	69
AS (T)	-	72	77	70	73
APS	-	74	72	72	73
ES	-	75	67	71	71
Mean	68	73	71	71	

SEm± 3.0

CD (0.05) Levels - NS Source - NS Levels x source - NS

Table 19. Effect of levels of sulphur and its sources on thousand grain weight (g)

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	30.6	31.1	31.0	30.9
AS (T)	-	31.7	31.3	30.7	31.2
APS	-	31.0	30.9	29.5	30.5
ES	-	31.5	31.0	31.1	31.2
Mean	31.8	31.2	31.1	30.6	

SEm± 0.5

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

4.1.1.9. <u>Thousand grain weight</u>

The main effect of sulphur, sources of sulphur, their interactions and control <u>vs</u> rest were not significant (Table 19).

4.1.1.10. <u>Grain yield</u>

As evident from Table 20 the grain yield was not significantly influenced by the main effect of sulphur or sources of sulphur, but their interactions were significant. Ammonium sulphate at 20 kg S ha^{-1} as basal dressing or ammonium phosphate sulphate and ammonium sulphate top dressing at levels 40 and 60 kg or elemental sulphur at 40 kg S ha^{-1} recorded significantly higher grain yields as compared to the other treatments. Control <u>vs</u> rest comparison was not significant.

4.1.1.11. <u>Straw yield</u>

It was seen that the main effect of sulphur, its sources and their interactions had no significant influence on straw yield (Table 21). Control <u>vs</u> rest was also not significant.

4.1.1.12. <u>Grain-straw ratio</u>

The grain-straw ratio was not significantly influenced by the main effect of sulphur, sources of sulphur and their

Table 20. Effect of levels of sulphur and its sources on grain yield (kg ha^{-1})

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	2276	1940	2217	2144
AS (T)	-	2152	2539	2327	2339
APS	-	2203	2283	2546	2344
ES	-	2144	2373	2191	2236
Mean	2161	2194	2284	2320	

SEm± 112

CD (0.05) Levels - NS Source - NS Levels x source - 328

Table 21. Effect of levels of sulphur and its sources on straw yield (kg ha^{-1})

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	4588	4055	4717	4453
AS (T)	-	3755	4474	4269	4166
APS	-	4471	4223	4359	4351
ES	-	4632	4208	4535	4458
Mean	3826	4362	4240	4470	

SEm± 344

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

interactions (Table 22). Control vs rest comparison was also not significant.

4.1.1.13. Harvest index

Harvest indices were not significantly influenced by either the main effect or sources of sulphur (Table 23). The interaction effects or control vs rest comparison were also not significant.

4.1.2. Quality Aspects

4.1.2.1. Protein content of the grain

The main effect of sulphur on the protein content of the grain was not significant (Table 24). The effect of sources was significant. Elemental sulphur application resulted in significantly higher protein content over ammonium phosphate sulphate and ammonium sulphate application.

The interaction effects of sources and levels were also significant. The highest protein content was registered by elemental sulphur at 20 kg S ha^{-1} which was significantly superior to all other treatments. Ammonium sulphate top dressing at 40 kg ha^{-1} registered the minimum value,

Table 23. Effect of levels of sulphur and its sources on harvest index

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	0.40	0.36	0.34	0.37
AS (T)	-	0.35	0.41	0.38	0.38
APS	-	0.39	0.38	0.35	0.37
ES	-	0.38	0.43	0.40	0.41
Mean	0.41	0.38	0.40	0.37	

SEm± 0.02

CD (0.05) Levels - NS Source - NS Levels x source - NS

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

Table 22. Effect of levels of sulphur and its sources on grain-straw ratio

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0	S_1	S_2	S_3	
	0	20	40	60	
AS	-	0.66	0.59	0.51	0.59
AS (T)	-	0.55	0.71	0.60	0.62
APS	-	0.62	0.62	0.55	0.60
BS	-	0.63	0.77	0.67	0.69
Mean	0.63	0.61	0.67	0.58	

SEm ± 0.06

CD (0.05) Levels - NS Source - NS Levels x source - NS

Table 24. Effect of levels of sulphur and its sources on protein content of grain (%)

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	12.00	13.0	13.00	12.67
AS (T)	-	12.00	12.0	13.00	12.33
APS	-	12.50	13.0	12.83	12.78
ES	-	14.00	13.0	13.00	13.33
Mean	12.5	12.62	12.75	12.96	

SEm± 0.31

CD (0.05) Levels - NS Source - 0.53 Levels x source - 0.91

Table 25. Effect of levels of sulphur and its sources on nitrogen uptake at harvest (kg ha^{-1})

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	163	124	157	148
AS (T)	-	179	169	160	169
APS	-	158	159	156	158
ES	-	165	133	202	167
Mean	139	166	146	169	

SEm± 8

CD (0.05) Levels - 11 Source - 13 Levels x source - 23

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

which was on par with ammonium sulphate at 20 kg S ha^{-1}. Control *vs* rest comparison was not significant.

4.1.2.2. Uptake of nutrients

The plant uptake of N, P and K recorded at different stages showed that it was significantly different only at harvest stage. Hence data on the uptake of N, P and K during active tillering, panicle initiation and flowering are not presented.

a) Nitrogen uptake

Nitrogen uptake showed significant variation due to the main effect of sulphur, its sources and their interactions (Table 25). Control *vs* rest comparison was also significant. Among the S levels sulphur at 60 kg ha^{-1} and 20 kg ha^{-1} showed significantly higher N uptake values over sulphur at 40 kg ha^{-1}.

When the interactions were considered higher N uptake was recorded for elemental sulphur at 60 kg ha^{-1} and ammonium sulphate top dressing at a sulphur level of 20 kg ha^{-1} which were significantly superior to all other treatments. The minimum value was observed for ammonium sulphate basal dressing at 40 kg sulphur levels which was on par with elemental sulphur at 40 kg S ha^{-1}. Control vs rest comparison was significant. Elemental sulphur at a sulphur level of 20 kg and ammonium sulphate top dressing at a sulphur level of 40 kg were significantly superior to the control.

b) Phosphorus uptake

The main effect of sulphur on phosphorus uptake was significant at harvest (Table 26). Significantly higher values at harvest were recorded when sulphur was applied at the rate of 60 and 20 kg ha^{-1}.

Influence of sources of sulphur on P uptake was significant at harvest. Elemental sulphur recorded the maximum value which was on par with ammonium phosphate sulphate and ammonium sulphate top dressing and ammonium sulphate basal dressing.

Interaction effects were also significant at harvest. Elemental sulphur at 60 kg ha^{-1} was significantly superior to all other treatments. Elemental sulphur at 40 kg ha^{-1} recorded the minimum value. Ammonium sulphate at 20 kg S ha^{-1}, ammonium phosphate sulphate at 40 and 60 kg ha^{-1} and elemental sulphur at 20 and 60 kg ha^{-1} were significantly superior to control.

Table 26. Effect of levels of sulphur and its sources on phosphorus uptake at harvest (kg ha^{-1})

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	21.2	17.2	17.7	18.7
AS (T)	-	20.9	19.4	18.8	19.7
APS	-	19.1	20.0	22.7	20.6
ES	-	21.9	16.0	27.2	21.7
Mean	16.3	20.8	18.3	21.6	

SEm± 1.2

CD (0.05) Levels - 1.8 Source - 2.0 Levels x source - 3.5

Table 27. Effect of levels of sulphur and its sources on potassium uptake at harvest

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	143	115	128	129
AS(T)	-	149	147	131	142
APS	-	140	154	164	153
ES	-	138	112	195	148
Mean	130	142	132	154	

SEm± 7

CD (0.05) Levels - 10 Source - 12 Levels x source - 20

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

c) Potassium uptake

The main effect of sulphur was significant at harvest (Table 27). A significant increase in K uptake was seen with increase in the levels of sulphur.

Influence of sources was also significant at harvest stage. Ammonium phosphate sulphate and elemental sulphur was significantly superior to ammonium sulphate. Elemental sulphur and ammonium sulphate top dressing were on par and were superior to ammonium sulphate basal dressing.

The interactions were significant at harvest. Elemental sulphur application at 60 kg S ha^{-1} recorded the maximum value for potassium uptake which was significantly superior to all other treatments. Elemental sulphur at 40 kg S ha^{-1} recorded the minimum uptake. Control vs rest was not significant.

d) Sulphur uptake

The main effect of sulphur influenced the plant uptake of sulphur significantly at all stages of growth (Tables 28-31). The uptake was significantly increased upto 60 kg S ha^{-1} at 30, 45 and 60 DAP. At harvest sulphur at 60 kg ha^{-1} was significantly superior to sulphur at 40 and 20 kg ha^{-1}, the latter two being on par.

Table 28. Effect of levels of sulphur and its sources on sulphur uptake at 30 DAP (kg ha^{-1})

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	6.1	7.5	9.6	7.7
AS (T)	-	5.4	5.0	5.5	5.3
APS	-	6.5	7.9	8.3	7.6
ES	-	5.9	7.1	8.0	7.0
Mean	4.7	6.0	6.9	7.8	

SEm± 0.5

CD (0.05) Levels - 0.8 Source - 0.9 Levels x source - 1.6

Table 29. Effect of levels of sulphur and its sources on sulphur uptake at 45 DAP (kg ha^{-1})

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	7.9	12.2	13.0	11.0
AS (T)	-	8.3	9.9	12.6	10.3
APS	-	8.4	10.9	13.0	10.7
ES	-	9.7	10.2	12.5	10.8
Mean	8.3	8.6	10.8	12.8	

SEm± 0.7

CD (0.05) Levels - 1.1 Source - NS Levels x source - 2.3

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

Table 30. Effect of levels of sulphur and its sources on sulphur uptake at 60 DAP (kg ha^{-1})

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	13.0	15.2	21.5	16.6
AS (T)	-	13.6	17.0	16.9	15.9
APS	-	11.7	16.2	20.3	16.0
ES	-	13.9	16.3	17.2	15.8
Mean	10.1	13.1	16.2	19.0	

SEm± 1.2

CD (0.05) Levels - 1.8 Source - NS Levels x source - 3.6

Table 31. Effect of levels of sulphur and its sources on sulphur uptake at harvest (kg ha^{-1})

Sources of sulphur	Levels of sulphur (kg ha^{-1})				Mean
	S_0 0	S_1 20	S_2 40	S_3 60	
AS	-	11.8	11.2	14.6	12.5
AS (T)	-	13.4	13.5	13.8	13.6
APS	-	11.9	14.9	16.8	14.5
ES	-	13.7	12.8	21.9	16.1
Mean	8.7	12.7	13.1	16.8	

SEm± 0.8

CD (0.05) Levels - 1.2 Source - 1.4 Levels x source - 2.4

AS = Ammonium sulphate, (T) = Top dressing, APS = Ammonium phosphate sulphate, ES = Elemental sulphur

The effect of sources was significant only at 30 DAP and harvest stages. At 30 DAP ammonium sulphate basal dressing, ammonium phosphate sulphate and elemental sulphur recorded high sulphur uptake values and were superior to ammonium sulphate-top dressing. At harvest, elemental sulphur was found to be superior to all other sources.

Interaction effects of sources and levels were significant only at harvest. Sulphur at 60 kg ha^{-1} as elemental sulphur recorded maximum sulphur uptake at harvest which was significantly superior to all other treatments and ammonium sulphate basal application at 40 kg S ha^{-1} registered the minimum uptake.

Control vs rest was significant at all stages of growth. At 30 DAP all the treatments except ammonium sulphate basal dressing and elemental sulphur at sulphur levels 20 kg, and ammonium sulphate top dressing at all levels were significantly superior over control. At 45 DAP all the treatments except those at 20 kg ha^{-1} and elemental sulphur and ammonium phosphate sulphate at a sulphur level of 40 kg ha^{-1} were superior to control. All the treatments except ammonium sulphate and ammonium phosphate sulphate at 20 kg S ha^{-1} were superior to control at 60 DAP. At harvest stage all the treatments were significantly superior to control.

4.2. Experiment II: Absorption and Distribution of ^{35}S from Ammonium Sulphate in Rice

The effects of graded doses of sulphur supplied as labelled ammonium sulphate and the relative contributions from basal and top dressing were studied in a pot culture.

4.2.1. Specific Activity of ^{35}S in the Plant Parts

Mean specific activities of plant parts namely leaf, culm, inflorescence stalk and grain as well as that of the whole plant are given in the Table 32. Statistical analysis of these data by paired t-test indicated that there were significant differences in specific activities of different plant parts. Generally speaking the specific activity of grain was the highest followed by that of the culm, inflorescence stalk and leaf. This trend was more conspicuous, when the application of the labelled fertilizer was given basally in a single dose. Among these plant parts, only culm and inflorescence stalk had specific activities similar to that obtained for the whole plant as evidenced from the statistical analysis.

4.2.2. Absorption of Soil and Fertilizer Sulphur

The relative contributions of fertilizer and soil sulphur to the total plant sulphur are presented in Tables 33 and 34. The percentage sulphur derived from fertilizer

Table 32. Specific activity (cpm/ µg S)

Treatment	Leaves	Culm	Inflore-scence stalk	Grain	Whole plant
S_{20} FBL	28.94	43.36	34.18	55.07	42.66
S_{40} FBL	39.78	62.42	54.81	79.35	59.88
S_{60} FBL	61.69	69.33	67.92	92.27	73.36
S_{20} HBL + HTUL	12.79	16.87	25.45	25.19	17.03
S_{40} HBL + HTUL	25.14	27.97	19.64	36.27	29.10
S_{60} HBL + HTUL	37.49	40.3	49.51	33.20	36.46
S_{20} HBUL + HTL	9.34	14.7	11.43	14.72	13.04
S_{40} HBUL + HTL	14.79	15.54	8.49	15.03	14.70
S_{60} HBUL + HTL	29.04	32.68	25.06	23.21	26.20

FBL - Full basal labelled
HBL - Half basal dressing with labelled fertilizer
HTL - Half top dressing with labelled fertilizer
HBUL - Half basal dressing with unlabelled fertilizer
HTUL - Half top dressing with unlabelled fertilizer

(% Sdff) increased significantly with increasing levels of single basal application. A reverse trend was observed in the case of percentage sulphur derived from soil (% Sdfs). An increase in % Sdff was also observed with increasing levels of basal split dose although the difference between S_{40} HBL + HTUL and S_{60} HBL + HTUL was not significant. In the case of second split (top dressing) the increase in % Sdff was significant only at the highest level of application.

When the % Sdff for the two splits taken together were compared, the % Sdff was found to increase significantly with increasing levels of added sulphur (Table 34). Thus the highest value for % Sdff was recorded for the level of 60 kg S ha^{-1} (69.4%) and the lowest for 20 kg S ha^{-1} (32.3%). A reverse trend was observed in the case of % Sdfs.

A-value was found to differ depending on the method of application. A-value was relatively more when sulphur was applied in two splits (about 20 ppm) than when it was applied in a single basal dose (about 10 ppm) especially at lower levels of sulphur (S_{20} and S_{40}) (Table 34).

The percentage utilisation of applied fertilizer decreased significantly at the highest level of basally applied sulphur in single dose (Table 33). When applied in two split doses there was no significant differences in

Table 33. Utilisation of native and applied sulphur

Treatment	% Sdff*	Per cent utilisation of applied fertilizer	Quantity S in the plant taken up from the fertilizer (mg)
S_{20} FBL	45.8	17.0	4.56
S_{40} FBL	64.2	16.3	8.73
S_{60} FBL	78.7	10.4	9.51
S_{20} HBL + HTUL	18.3	16.9	2.26
S_{40} HBL + HTUL	31.2	15.8	4.24
S_{60} HBL + HTUL	29.1	15.0	6.07
S_{20} HBUL + HTL	14.0	15.0	2.02
S_{40} HBUL + HTL	15.8	7.4	1.98
S_{60} HBUL + HTL	30.2	8.7	3.52
SEm±	1.6	1.2	0.35
CD (0.05)	4.7	3.4	1.01

* - Sulphur derived from applied fertilizer

FBL - Full basal labelled

HBL - Half basal dressing with labelled fertilizer

HTL - Half top dressing with labelled fertilizer

HBUL - Half basal dressing with unlabelled fertilizer

HTUL - Half top dressing with unlabelled fertilizer

Table 34. Sulphur uptake and rice yield as influenced by single and split applications of ^{35}S labelled ammonium sulphate

Treatment	%Sdff*	%Sdfs**	A-value (ppm)	Per cent utilization of applied fertilizer	Quantity of S in the plant taken up from the fertilizer (mg/pot)	Total dry matter (g/pot)	Grain yield (g/pot)	Straw*** yield (g /pot)	Total grain-S (mg/pot)	Total straw-S (mg/pot)	Total S uptake (mg/pot)	S content of the plant (%)
S_{20} FBL	45.8	54.2	10.7	17.0	4.56	8.00	3.88	4.14	3.45	6.54	9.99	0.13
S_{40} FBL	64.2	35.8	10.1	16.3	8.73	8.60	4.00	4.60	4.09	9.60	13.69	0.16
S_{60} FBL	78.7	21.3	7.4	10.4	9.51	6.85	3.03	3.82	3.13	7.44	10.57	0.16
S_{20} HBL + HTUL + S_{20} HBUL + HTL	32.3	67.8	18.8	16.0	4.28	7.61	3.43	4.19	4.18	9.27	13.46	0.18
S_{40} HBL + HTUL + S_{40} HBUL + HTL	47.0	53.0	20.3	11.6	6.22	7.65	3.46	4.20	4.08	9.15	13.23	0.17
S_{60} HBL + HTUL + S_{60} HBUL + HTL	69.4	30.6	11.9	11.9	9.57	7.90	3.55	4.52	5.00	8.62	13.62	0.18
SEm±	1.2	1.8	0.9	0.9	0.46	0.60	0.38	0.35	0.42	0.73	0.95	0.01
CD (0.05)	5.3	5.3	2.7	2.7	1.35	NS	NS	NS	NS	NS	2.83	0.02

* - Sulphur derived from applied fertilizer
** - Sulphur derived from soil
*** - Oven-dry basis
FBL - Full basal labelled
HBL - Half basal dressing with labelled fertilizer
HTL - Half top dressing with labelled fertilizer
HBUL - Half basal dressing with unlabelled fertilizer
HTUL - Half top dressing with unlabelled fertilizer
NS - Not significant

per cent utilization among the three basal split levels. However, a marked decrease was observed in per cent utilization of the fertilizer at higher level of application in the second split (top dressing). A comparison of the per cent utilization of applied fertilizer between basal dressing in single dose and the total quantity of fertilizer in two splits showed a reduction in per cent utilization when applied in two splits especially at lower levels of applied sulphur (S_{20} and S_{40}) (Table 34). At the highest level of application (S_{60}) the per cent utilization of applied fertilizer was same irrespective of whether the total quantity was applied in a single dose (full basal) or in two equal splits (half basal + half top dressing).

The main effect of applied sulphur and method of application on sulphur uptake from the added sulphur by rice plant were significant (Table 33 and 34). In the case of application of sulphur in a single basal dose, the quantities of sulphur derived from the labelled fertilizer increased with increasing levels. The highest value (9.51 mg/pot) was recorded for the treatment S_{60} FBL which was on par with the quantity of sulphur derived from the fertilizer (8.73 mg/pot) at an applied level of 40 kg ha^{-1} (S_{40} FBL). The lowest uptake of sulphur (4.56 mg/pot) occurred at the lowest level of sulphur application (S_{20} FBL).

In the case of split applications increased uptake of sulphur from the applied fertilizer was observed with increasing levels of basally applied split dose. Thus the lowest uptake occurred from basally applied one-half of the lowest dose (S_{20} HBL + HTUL) and highest uptake from the basally applied one-half of the highest level of sulphur application (S_{60} HBL + HTUL). The uptake from the one half of the intermediate dose (S_{40} HBL + HTUL) came in between. On the other hand the uptake of sulphur from the second split application (top dressing) increased only at the highest level (S_{60} HBUL + HTL). Of the two splite (basal and top dressing) the quantity of sulphur taken up by the plant from the applied fertilizer was more for the basal applications.

When the total quantities of sulphur derived from the applied fertilizer were compared, the basal application in single dose as well as the application in two splits combined were found to be on par (Table 34).

4.2.3. Total Uptake of Sulphur

Total sulphur taken up by the plant was found to be significant with increasing levels of applied sulphur in single basal dressing (Table 34). This increase was only upto the level of 40 kg S ha^{-1} (from 9.99 to 13.69 mg/pot) beyond which the uptake of sulphur decreased. There were splits, the sulphur contents of plant parts were generally higher when the fertilizer was applied in two splits than in a single basal dose. The sulphur contents of leaf, culm, inflorescence stalk and grain were 0.20, 0.18, 0.18 and 0.10% respectively for the single dose treatment while these were 0.23, 0.21, 0.18 and 0.12% respectively in the split dose treatments. There was a general increase in sulphur content of leaf, culm and grain at higher levels of applied sulphur (40 and 60 kg ha^{-1}) compared to the lowest level (20 kg ha^{-1}) tried when the application was done in single dose (Fig. 7). On the other hand there was a sharp decline in sulphur content of inflorescence stalk when sulphur application was done in two equal splits. A more or less similar trend was observed only in the sulphur contents of inflorescence stalk and grain as obtained for single basal application. But for leaf and culm almost a reverse trend was observed showing a decrease with increasing levels of applied sulphur.

4.2.5. Biomass Production and Yield

Biomass production, grain yield and straw yield were not found to be influenced by either the levels of applied sulphur or the method of application.

4.2.6. Distribution of ^{35}S in the plant

Autoradiograph of plants which received ^{35}S treatment is presented in Fig. 8. The absorbed ^{35}S was found to be translocated throughout the plant system. Leaves were found to accumulate more ^{35}S on dry matter basis (on an average 247 cpm/mg) than other parts. Grain and husk accumulated least quantities of ^{35}S (about 100 cpm/mg).

Discussion

5. DISCUSSION

The investigation was conducted to study the response of rice to applied sulphur through different fertilizer sources and the relative uptake and distribution of soil and fertilizer sulphur. The results of the study are briefly discussed in this section.

5.1. Experiment I

5.1.1. Growth and Yield

5.1.1.1. Dry matter production

The levels of sulphur, sources of sulphur and their interactions significantly influenced the dry matter production (Table 14, Fig. 2 and 3). The control plots where no sulphur was applied recorded the lowest dry matter production. The increase in dry matter production due to the application of graded doses of sulphur through different sources varied from 4 to 47 per cent. Sulphur application at the rate of 20 kg ha^{-1} resulted in higher dry matter production which was on par with 60 kg level. The intermediate level of 40 kg S ha^{-1} resulted in a reduction of the dry matter. Increase in dry matter production of rice with the application of sulphur was

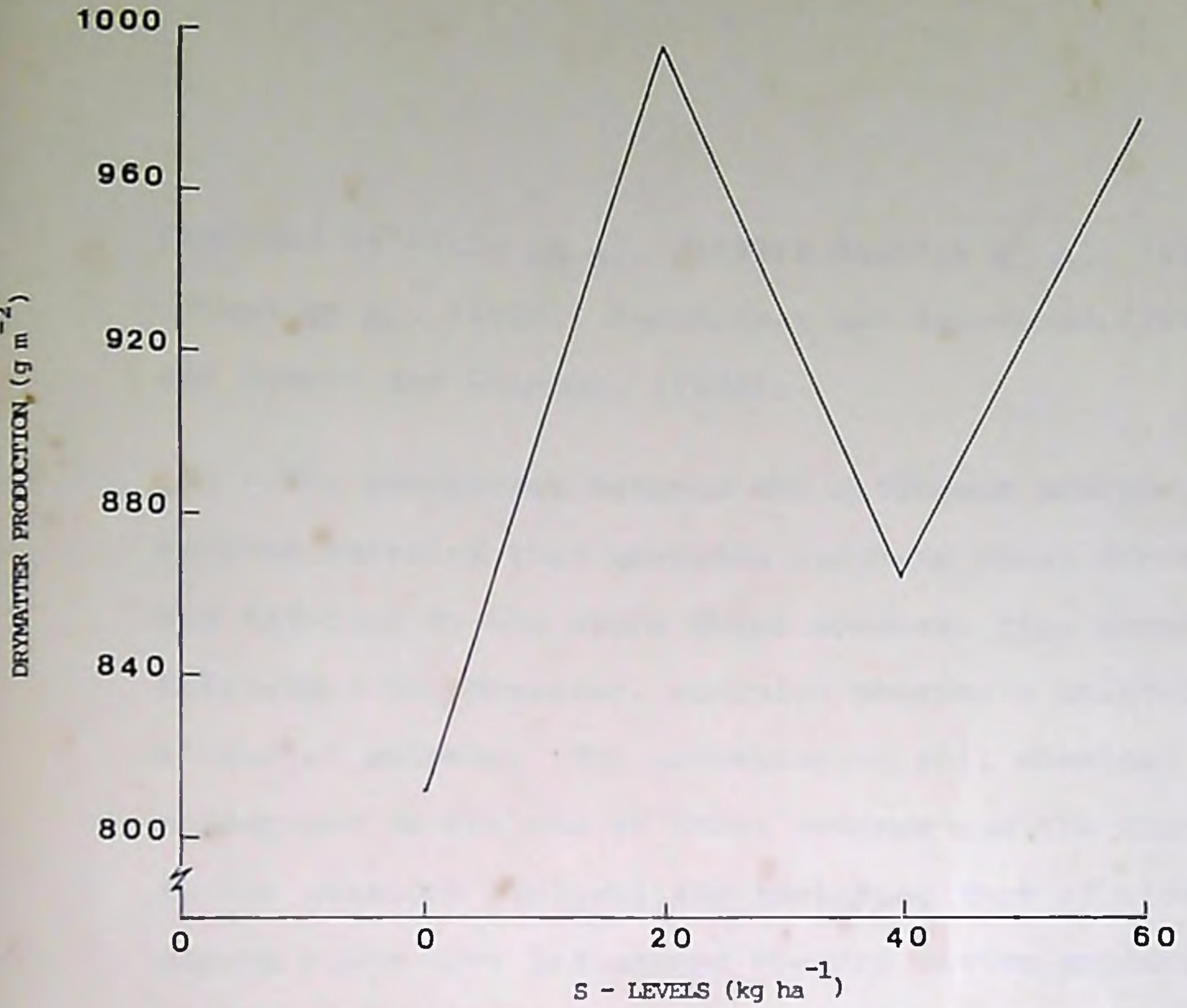


FIG.2 EFFECT OF LEVELS OF SULPHUR ON DRYMATTER PRODUCTION OF RICE AT HARVEST.

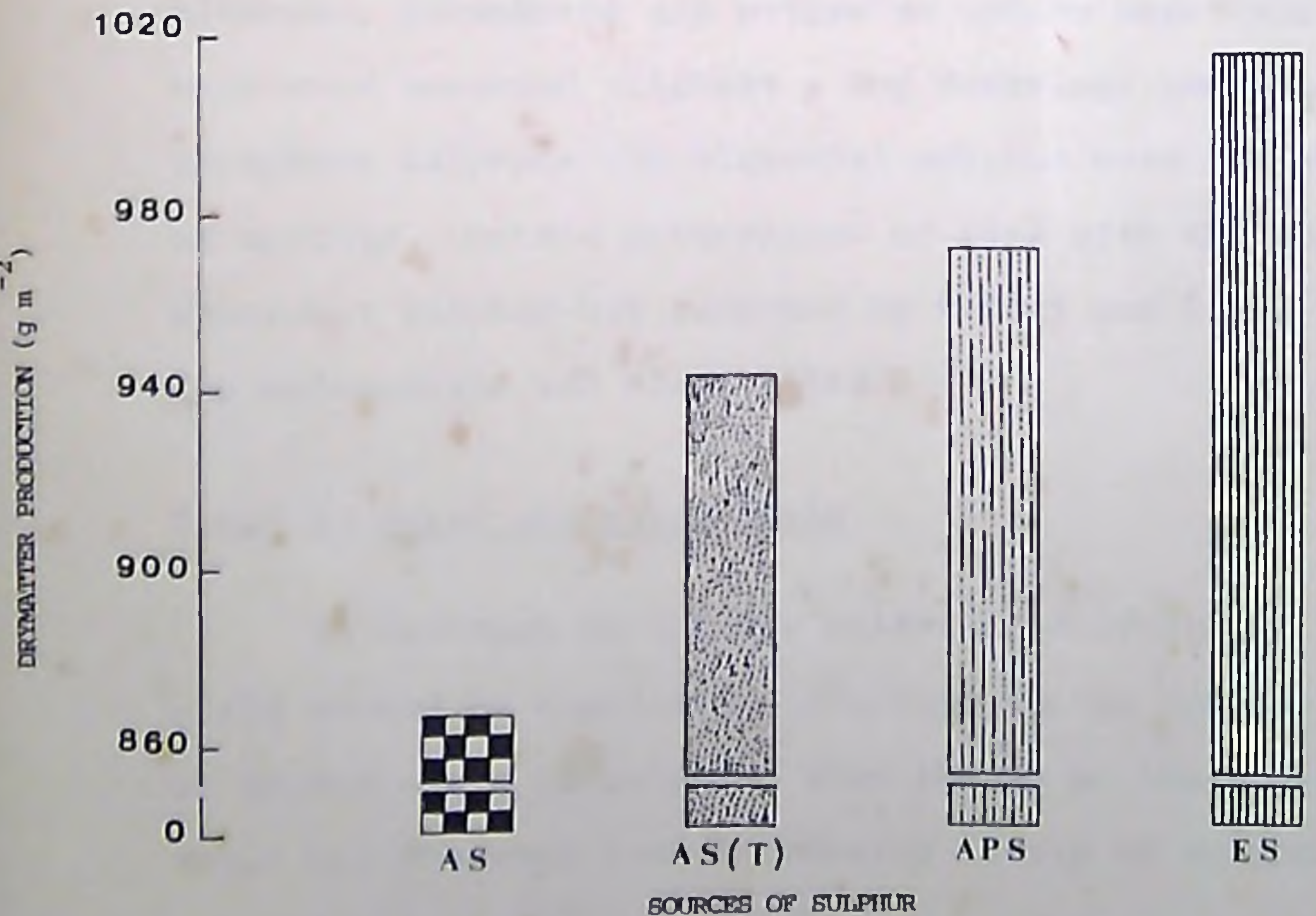


FIG.3 EFFECT OF SOURCES OF SULPHUR (AS = AMMONIUM SULPHATE, (T) TOP DRESSING, APS = AMMONIUM PHOSPHATE SULPHATE AND ES = ELEMENTAL SULPHUR) ON DRYMATTER PRODUCTION OF RICE AT HARVEST.

reported by Blair *et al*. (1979); Sachdev *et al*. (1982); Momuat *et al*. (1985); Ramanathan and Saravanan, (1985) and Russel and Chapman, (1988).

The comparison between the different sources of sulphur revealed that ammonium sulphate basal dressing was inferior to the other three sources, *viz*. ammonium sulphate - top dressing, ammonium phosphate sulphate and elemental sulphur. The accompanying soil chemical changes consequent to the use of these sources and the change in the nutrient availability including that of micronutrients might have influenced the dry matter production. It may be seen from the tables 25, 26 and 27 that the nitrogen, phosphorus and potassium uptake were relatively more when ammonium sulphate - top dressing, ammonium phosphate sulphate and elemental sulphur were the sources of sulphur. Better performance of rice with the use of elemental sulphur was reported by Pillai and Singh (1975) and Solosamosir and Blair (1983).

5.1.1.2. Grain and straw yield

In contrast to the dry matter production the grain yield showed no significant response to the application of graded doses of sulphur, even though an increasing trend was observed with increasing levels of sulphur

(Table 20, Fig. 4). Eventhough the main effects of sulphur levels and sources were not statistically significant, the interactions were significant. The highest grain yield of 2546 kg ha^{-1} was recorded with ammonium phosphate sulphate applied at a sulphur level of 60 kg ha^{-1}. Almost similar yield (2539 kg ha^{-1}) was secured with ammonium sulphate - top dressing at a sulphur level of 40 kg ha^{-1}. The other treatments which gave higher yield were ammonium sulphate basal dressed at 20 kg ha^{-1} (2276 kg ha^{-1}), ammonium sulphate - top dressing at 60 kg ha^{-1} (2327 kg ha^{-1}), ammonium phosphate sulphate at 40 kg ha^{-1} (2283 kg ha^{-1}) and elemental sulphur at 40 kg ha^{-1} (2373 kg ha^{-1}). The grain yield without sulphur application was only 2161 kg ha^{-1}. The difference in response observed with various sources of sulphur at different levels of sulphur indicate that the soil chemical changes and the availability of other nutrients may be influenced by the different sources and the response to applied sulphur varies with the changes in the availability of other nutrients consequent to the use of different sulphur sources. It may be noted that the high yield observed with ammonium phosphate sulphate was accompanied by a high uptake of phosphorus and potassium (Tables 26 and 27). Joshi and Seth (1975) observed that when phosphorus application rate was increased wheat responded to higher levels of sulphur. However, the high yield observed with

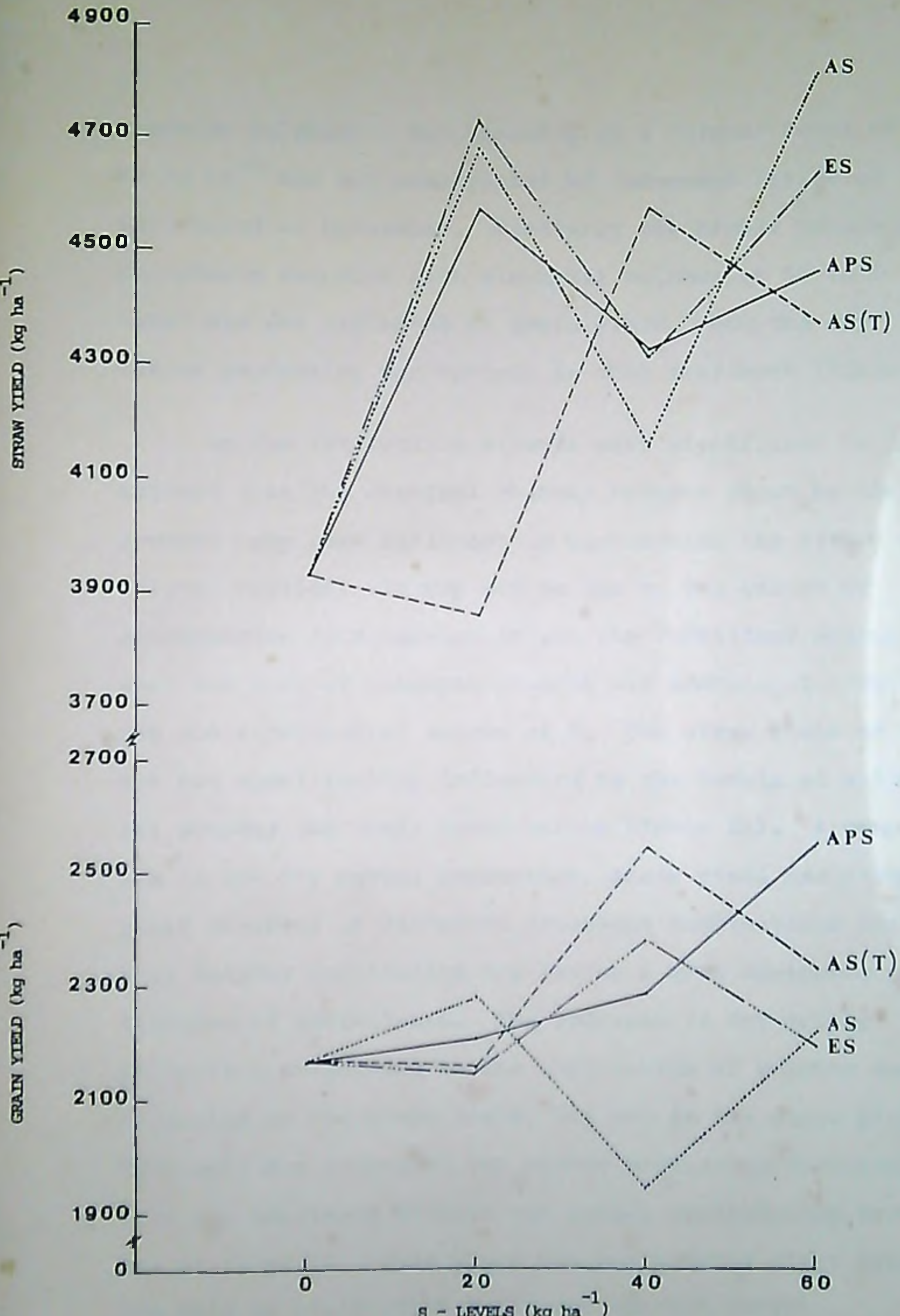


FIG. 4 EFFECT OF LEVELS OF SULPHUR AND ITS SOURCES (AS = AMMONIUM SULPHATE, (T) = TOP DRESSING, APS = AMMONIUM PHOSPHATE SULPHATE AND ES = ELEMENTAL SULPHUR) ON GRAIN AND STRAW YIELDS.

ammonium sulphate - top dressing at a sulphur level of 40 kg ha^{-1} was not accompanied by increased uptake of phosphorus or potassium. Similarly the higher uptake of phosphorus recorded with elemental sulphur at 60 kg S level was not reflected in grain yield. But the dry matter production was maximum in this treatment (Table 14).

As the interaction effects were significant it is evident that the chemical changes brought about by these sources have some influence in manifesting the effect of sulphur applied. It may not be due to the effect of accompanying ions because in all the fertilizer sources used the form of nitrogen present was ammoniacal. Urea was the supplemental source of N. The straw yield of rice was not significantly influenced by the levels of sulphur, its sources and their interactions (Table 21). A comparison of the dry matter production, grain yield and straw yield observed at different treatment combinations indicates that sulphur application may favour a more desirable partitioning of assimilates. The increase in dry matter production consequent to the application of sulphur was reflected in the grain yield, but not in the straw yield. Obviously the increased dry matter production resulting from the treatment effects was mostly contributing towards the grain yield. This trend was not however clear from the data on grain straw-ratio and harvest index.

5.1.1.3. Growth and yield components

The growth characters recorded were height, number of tillers and leaf area index. Among these only LAI showed definite trend in response to the application of sulphur. Corroborating the results on dry matter production and grain yield, the interaction effects of sources of sulphur and levels of sulphur significantly influenced the LAI at 30, 45 and 60 DAP (Tables 10 - 12). At all these stages the leaf area index in sulphur fertilized plots were relatively more than that recorded in the plots where no sulphur was applied. The total leaf areaof the rice population is a factor closely related to the grain production. Especially the leaf area at flowering greatly affects the amount of photosynthates available to the panicle (De Datta, 1981). A study of the leaf area development in the plant revealed that the leaf area index increased from active tillering to panicle initiation, there was slight reduction by flowering followed by a drastic reduction by harvest (Tables 10 - 13, Fig. 5). The leaf area indices of the S fertilizer plots were superior to the control up to flowering. The Fig. 6 shows that ammonium sulphate basal dressing retained a higher leaf area index during all growth stages followed by ammonium phosphate sulphate and ammonium sulphate top

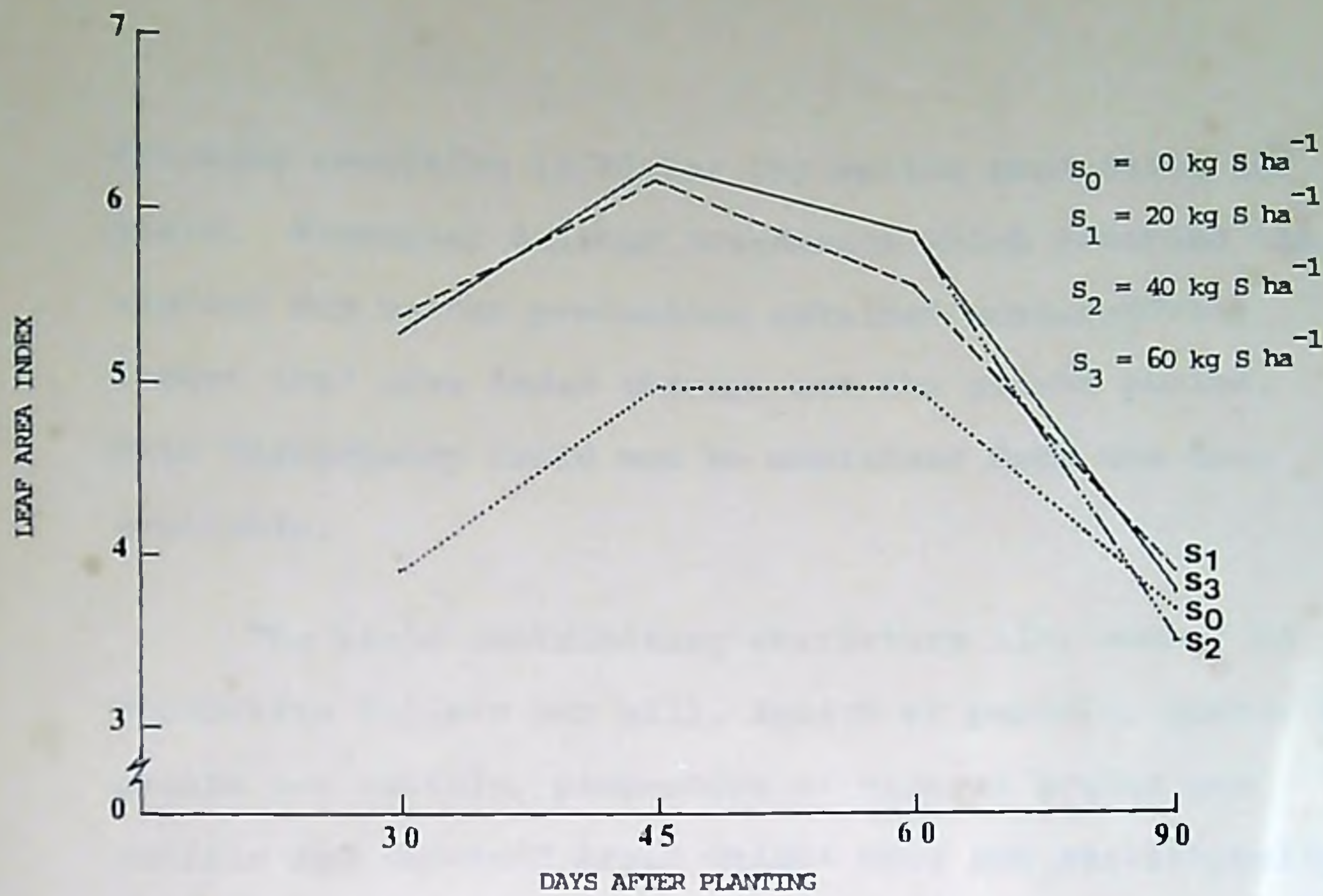


FIG.5 EFFECT OF LEVELS OF SULPHUR ON LEAF AREA INDEX OF RICE AT DIFFERENT GROWTH STAGES.

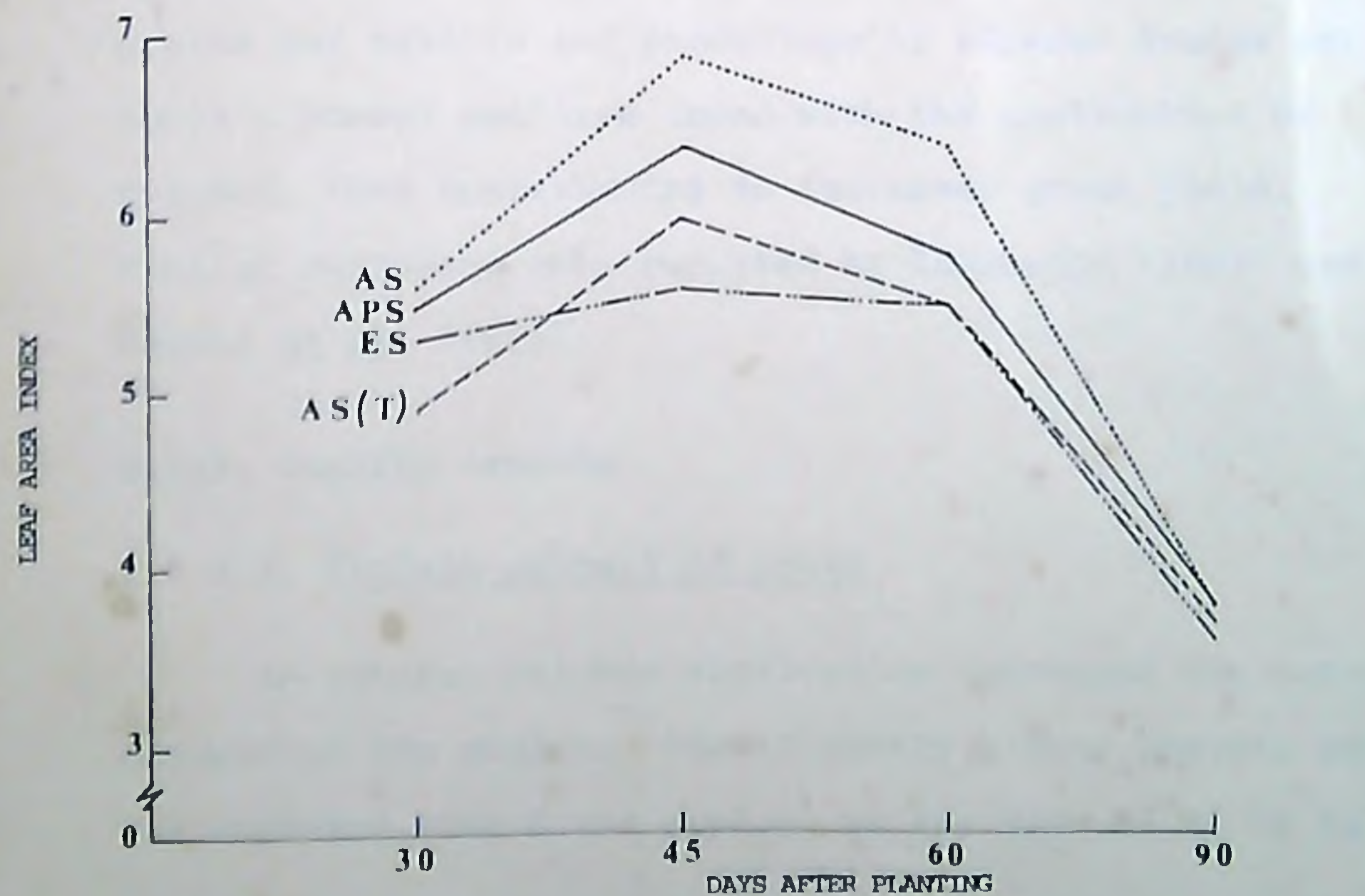


FIG.6 EFFECT OF SOURCES OF SULPHUR (AS = AMMONIUM SULPHATE, (T) = TOP DRESSING, APS = AMMONIUM PHOSPHATE SULPHATE AND ES = ELEMENTAL SULPHUR) ON LEAF AREA INDEX OF RICE AT DIFFERENT GROWTH STAGES.

dressing resulting in higher dry matter production and yield. Elemental sulphur treatments which recorded the highest dry matter production retained comparatively lesser leaf area index through out the growth period. This discrepancy could not be explained from the data available.

The yield contributing characters like number of productive tillers per hill, length of panicle, number of grains per panicle, percentage of ripened grains per panicle and thousand grain weight were not statistically influenced by the levels of sulphur, its sources and the interactions (Tables 15 - 19). However, the number of grains per panicle and percentage of ripened grains per panicle showed positive trend with the application of sulphur, thus contributing to increased grain yield. Similar responses were reported by Ismunadji (1985) and Momuat _et al_. (1985).

5.1.2. Quality Aspects

5.1.2.1. Protein content of grain

In general sulphur application increased the protein content of the grains. Significantly higher protein content was observed when S was applied at the rate of 20 kg ha^{-1}

in the form of elemental sulphur (Table 24). Increase in protein content of rice with the application of sulphur was reported by Das and Datta (1973) and Das et al. (1975).

5.1.2.2. Uptake of N, P, K and S

The uptake of the nutrients N, P and K followed almost the same trend as that of dry matter production. But sulphur uptake was found to increase with increasing levels of sulphur at all stages of growth (Tables 28 - 31). There was a decline in S uptake values when S was applied as ammonium sulphate at panicle initiation. Evidently as sulphur was applied only just before panicle initiation the uptake was less. Similar trends in the uptake of sulphur by rice was reported by Lathiff and Amarasiri (1982) and Islam et al. (1987). Randall (1988) observed that sulphate accumulates when sulphur supply is in excess of demand for growth acting as a reserve. Similar results were observed in this study also. Sulphur uptake increased at all stages of growth where higher levels of sulphur was applied although proportionate grain yield response was not obtained. Similar result was recorded from the pot culture experiment using ^{35}S labelled ammonium sulphate.

In brief the trend of the result shows that there is chance of getting response for applied sulphur in rice soils in Kerala. Effect of sulphur is not same when applied in different sources, the actual reason for which need to be established. The response trend observed by the present study needs confirmation by further field trialsbefore it is recommended. There is a tendancy for the rice crop to accumulate sulphur when higher levels are supplied even though it is not reflected in yield.

5.2. Experiment II

5.2.1. Specific Activity of ^{35}S in Different Parts of the Plant

Marked differences in specific activities of plant parts were observed. Further, the specific activities of only culm and inflorescence stalk were found to be similar to the specific activity of the whole plant (Table 32). These results indicate probable differences in the translocation of labelled nutrient to different plant parts and how the plant accumulates the labelled nutrient. Since the specific activity differs significantly among plant parts it follows that for the computation of quantities such as 'A'-value etc., whole plant specific activity must be considered. In view of the differences among specific activities of the plant parts determination of quantities requiring specific activities in their computation, from the specific activity of any plant part will lead to error. In the experiment reported herein, therefore, the whole plant specific activity was considered for computation of different parameters including 'A'-value.

5.2.2. Absorption of Soil and Fertilizer Sulphur

The alternate labelling technique employed in the experiment clearly revealed the relative contribution of fertilizer sulphur from basal and top dressings of split applications. The main effect of sulphur as well as the methods of sulphur application were found to influence the relative contributions from the applied source as well as the native soil source of sulphur towards plant uptake (Table 33). Thus when sulphur was applied in a single basal dose at increasing levels (from 20 to 60 kg S ha^{-1}) the contribution from the fertilizer towards sulphur uptake increased correspondingly from 45.8 to 78.7 % Sdff. This would mean that the dependence of plant on native sulphur decreased considerably (54.3 to 21.3%). Such a trend for basal application in split dose treatments was also evident though not to the same extent. The results further indicated that the contribution of fertilizer sulphur towards plant uptake from the top dressing was comparatively less than that from the basal dressing of the same level of application. Apparently most of the plant uptake of sulphur from the applied source had come from the first split application (one-half dose basal dressing). This was also evident from the per cent utilization figures as well as the quantity of sulphur taken up from each split. Between the methods of application basal application in single dose was found to be more efficient than application of the same quantity in two splits as far as the utilization of sulphur from applied fertilizer is concerned (Table 34). This superiority was noticed upto an application rate of 40 kg S ha^{-1} beyond which the difference in the utilization of applied sulphur was insignificant between the two methods of application. From these results it may be concluded that the dependence of the plant for sulphur will be more on the soil source than on the applied fertilizer when application is done as top dressing. In other words the plant does not utilize the applied fertilizer sulphur efficiently if the fertilizer is top dressed. Perhaps this preference for soil sulphur in the later stages of growth may be due to the initial increased availability of soil sulphur following flooding coupled with less quantity (one-half) of the applied fertilizer as basal dressing.

Eventhough the available sulphur in soil was found to be 40 ppm by chemical method (Table 1) the 'A'-value obtained by radioisotope technique for sulphur was much less (Table 34). Further there was significant differences in A-values among levels of applied sulphur as well as between methods of application. 'A'-value was found to increase when the application of ^{35}S labelled ammonium sulphate was done in two split doses as compared to when the application was done in single basal dose. In either case, however, lower levels of applied sulphur increased the 'A'-value. In the light of these observations 'A'-value for sulphur does not seem to be a soil characteristic; rather it may be best considered as a measure of dependence of the plant on native soil source. The influence of applied sulphur level on A-value of sulphur in soil was also reported by Shinde _et al_. (1980). Jaggi _et al_. (1977) also observed an absorption of soil sulphur by maize in preference to applied sulphur at increasing rate of application.

5.2.3. Biomass Production and Yield

Responses to added levels of sulphur or to the methods of application in terms of dry matter production, grain yield and straw yield were not obtained in the present study. This result is slightly different from that observed in the field trial, where dry matter production and grain yield showed significant variation due to the interaction effects of various sulphur sources and the levels of sulphur. Probably the sulphur requirement of the crop might have been met from the native available sulphur pool. This would mean that the available sulphur content (40 ppm S extractable with Morgan's acetic acid - sodium acetate solution, pH 4.5) is at or above the critical soil sulphur level. This contention agrees well with the reports of several other workers (Tandon, 1984; Tiwari et al., 1983b) who showed an available sulphur content of 10 ppm was the critical limit in several soils beyond which response was not generally expected. As there was no different sources, the accompanying variation in soil properties and availability of other nutrients are not expected in this trial.

5.2.4. Uptake and Distribution of Sulphur

Notwithstanding the results obtained for dry matter production and yield, it was found that the plant tended to absorb more sulphur with increasing levels of applied sulphur in single basal dose up to an application level of 40 kg ha^{-1} (Table 34). Although this tendency was not evident with increasing levels of split application, the

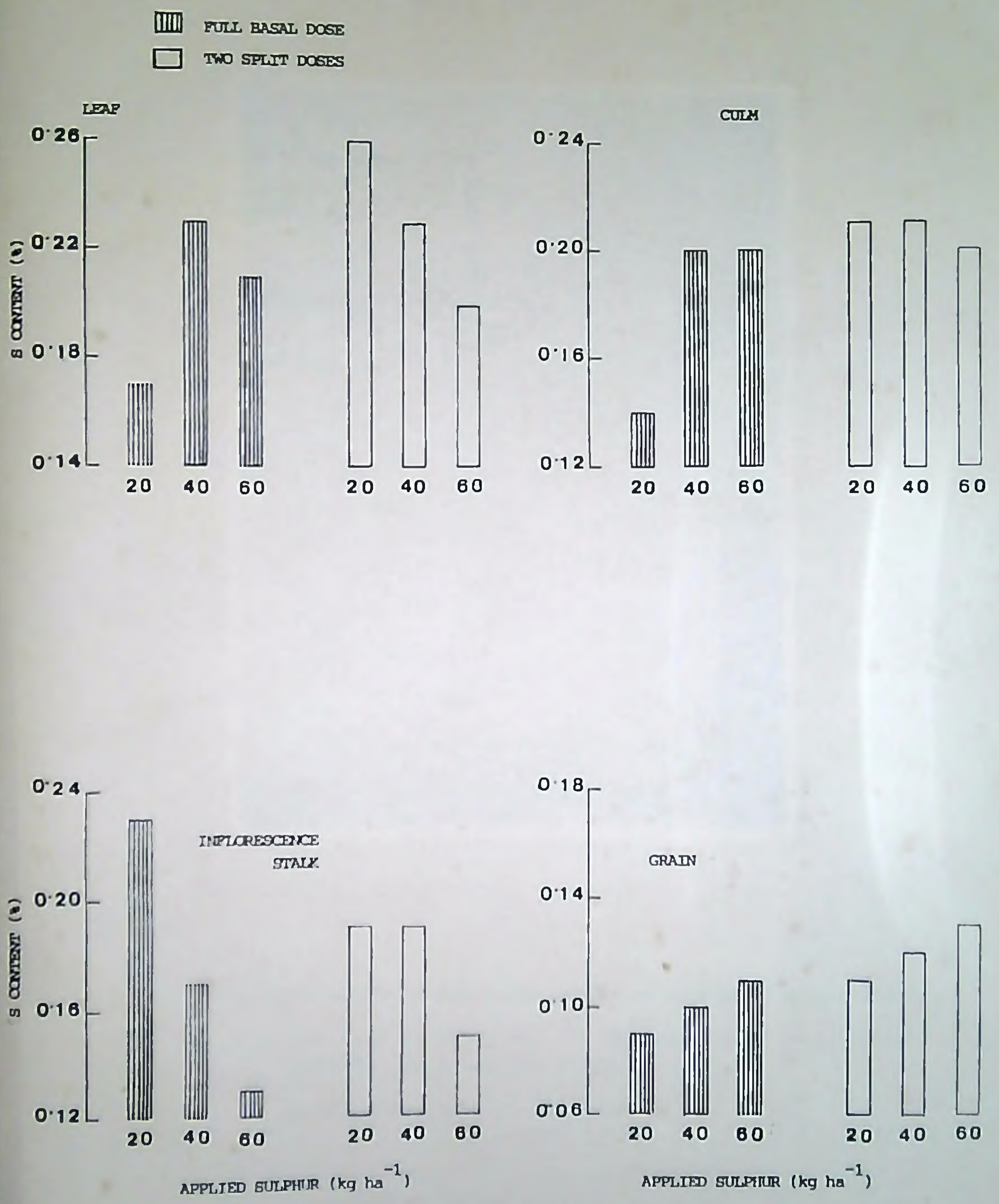
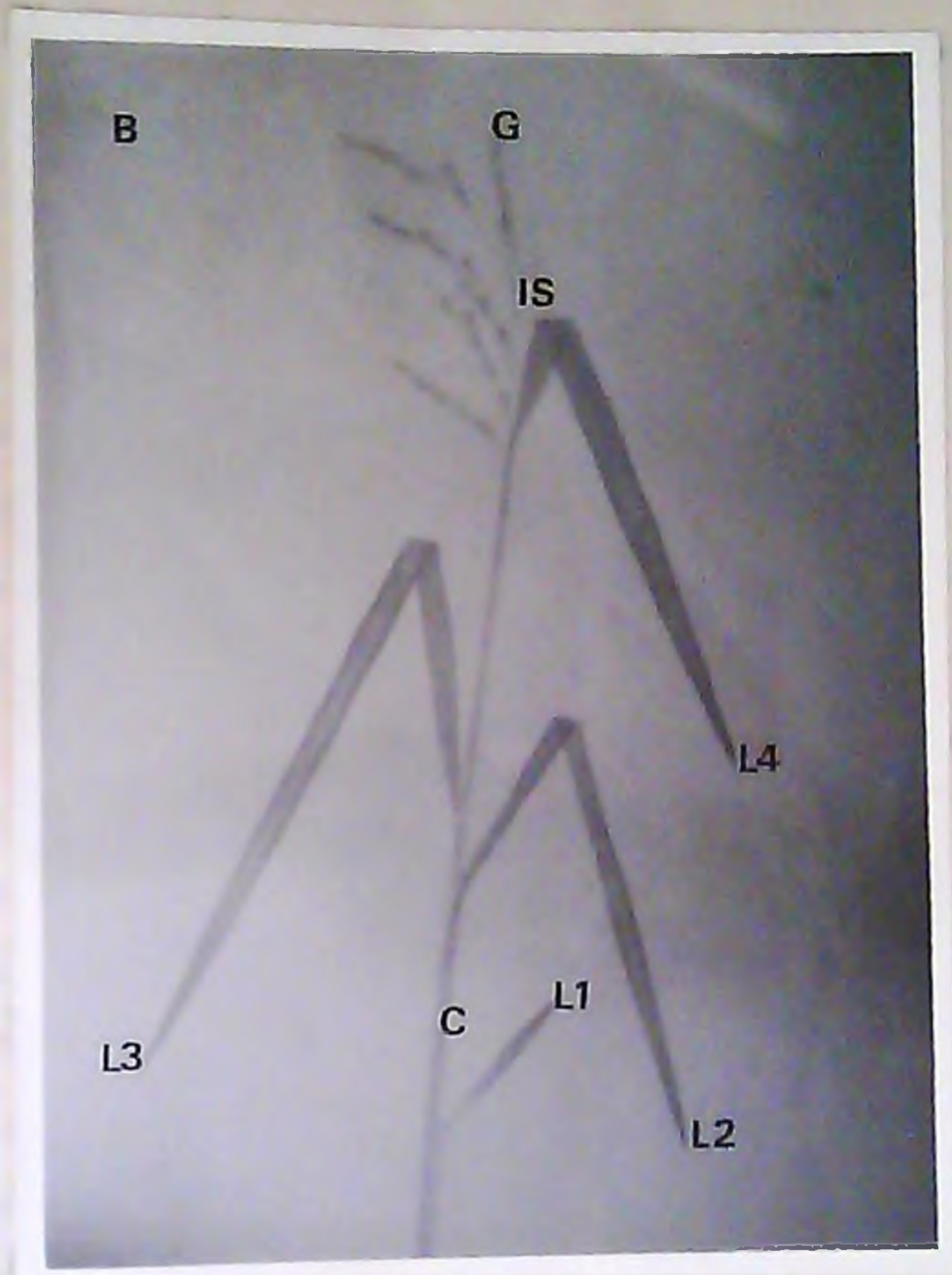


FIG.7 SULPHUR CONTENT OF PLANT PARTS

FIG.8: AUTORADIOGRAPHS OF RICE PLANTS SHOWING THE DISTRIBUTION PATTERN OF ^{35}S.

A. RICE PLANT WITHOUT PANICLE. ^{35}S CONTENTS EXPRESSED AS cpm/mg DRY-MATTER FOR LEAF (L) AND CULM (C) ARE:

L1-205; L2-304; L3-241; L4-246; C-112



B. RICE PLANT WITH PANICLE

L1-191; L2-353; L3-247; L4-196; C-108; IS (INFLORESCENCE STALK)-150; G (GRAIN) -98.

plants receiving sulphur in two splits accumulated more sulphur per unit weight of dry matter produced compared to those receiving sulphur in single basal dose. In as much as the uptake of sulphur by the plant has not reflected in increased production of dry matter or yield it has to be inferred that there was considerable accumulation of sulphur in the plant tissue over and above its requirement and/or what is required for the dry matter produced. Sulphate accumulation in excess of demand in plants has been observed (Randall, 1988). Perhaps as in the case of K there may be luxury consumption of sulphur also by the plant. The distribution pattern of sulphur in the plant system indicated that the accumulation of sulphur was mainly in the leaves and culm and is least in the grain (Fig. 7). Autoradiograph of ^{35}S absorbed plant also indicated a similar distribution pattern (Fig.8A&B). Such a distribution pattern confirms the role of leaf tissues as sulphur sink.

Summary

SUMMARY

Experiments were conducted at the Agricultural Research Station, Mannuthy and the Radiotracer Laboratory of the Kerala Agricultural University during the first crop season of 1988 to study the response of rice to applied sulphur and to assess the relative uptake and distribution of soil and fertilizer sulphur. There was a field experiment conducted with four levels of sulphur (0, 20, 40 and 60 kg ha^{-1}), four sources of sulphur (ammonium sulphate - basal dressing, ammonium sulphate - top dressing, ammonium phosphate sulphate and elemental sulphur). The experiment was laid out in RBD in plots of size 4.6 m x 4.5 m and replicated thrice. A pot culture experiment was conducted for studying the uptake and distribution of ^{35}S applied as labelled $(NH_4)_2SO_4$ at 20, 40 and 60 kg sulphur levels per hectare. The utilization of sulphur applied at planting and that applied at panicle initiation were also studied in this experiment.

The results of the experiments are summarised below.

The plant height and number of tillers were not significantly influenced by the levels of sulphur, sources of sulphur or their interactions. Leaf area index was relatively more in sulphur fertilized plots at all the growth stages. Ammonium sulphate - basal application resulted in relatively higher leaf area index.

The dry matter production showed that the main effect of sulphur, sources of sulphur and their interactions were significant. The increase in dry matter production due to the application of graded levels of sulphur varied from 4 to 47 per cent. Sulphur application at the rate of 20 kg ha^{-1} resulted in higher dry matter production which was on par with 60 kg level. The intermediate level of 40 kg showed a reduction in dry matter production. Among the sources elemental sulphur, ammonium phosphate sulphate and ammonium sulphate - top dressing were on par and were superior to ammonium sulphate - basal dressing. The maximum dry matter production was recorded by elemental sulphur applied at the rate of 60 kg S ha^{-1}.

The yield contributing characters like number of productive tillers per hill, panicle length, number of grains per panicle, percentage of ripened grains per panicle and thousand grain weight were not significantly influenced by the levels of sulphur, sources of sulphur or their interactions.

The grain yield was significantly influenced by the interaction effects of levels and sources but not by the main effects. Ammonium sulphate at 20 kg S ha^{-1} as basal dressing or ammonium phosphate sulphate and ammonium sulphate - top dressing at levels 40 and 60 kg or elemental sulphur at 60 kg ha^{-1} recorded significantly higher grain yields as compared to other treatments. The main effect of sulphur and sources of sulphur showed no significant influence on straw yield, grain-straw ratio and harvest indices of rice.

Protein content was significantly influenced by the sources of sulphur and the interactions. Elemental sulphur was superior over other sources and elemental sulphur at 20 kg S ha^{-1} recorded maximum protein content.

The uptake of N, P and K at harvest followed almost the same trend as that of the dry matter production. The sulphur uptake was found to increase with increasing levels of sulphur at all the growth stages.

The experiment with labelled ammonium sulphate revealed that the specific activity among plant parts differed significantly. Specific activity of grain was the highest followed by that of culm, inflorescence stalk and the leaf. Culm and inflorescence stalk had almost similar specific activities to that obtained for the whole plant. In general the fertilizer sulphur taken up by the plant increased with levels of sulphur applied. Rice derived more sulphur from the basal dose than from the top dressing. The contribution of native sulphur present in the soil towards plant uptake decreased with increasing levels of applied sulphur. 'A'-value determined at different levels of added sulphur remained more or less constant at 10 ppm upto the sulphur level of 40 kg ha^{-1} and decreased there after. 'A'-value was found to be affected by the method of application and was relatively more when sulphur was applied in two splits than when it was applied in a single dose. Seven to seventeen per cent of the applied sulphur was utilized by the rice plant. The per cent utilization of applied sulphur decreased with increasing levels of applied sulphur. Autoradiograph of the plant receiving labelled ammonium sulphate showed that the absorbed ^{35}S is translocated through out the plant system with relatively high accumulation in grain tips and leaf veins.

The study indicated that there may be response for the applied sulphur in paddy soils of Kerala. However, confirmative results have to be obtained before reaching any conclusion. Similarly the interaction effects of sources and levels observed needs further investigation for the reasons for such variation in response. Finally an economic analysis of the application of sulphur to rice is needed. This may be meaningfully done after the confirmation of the results.

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* Originals not seen

Appendices

Appendix-1

Mean weekly weather parameters for the entire crop period

Month and week		Temperature (°C) Maximum	Temperature (°C) Minimum	Relative humidity (%)	Total rainfall (mm)	No. of bright sunshine hours
1988						
June	28-3	31.7	24.3	83.0	292.6	2.7
	4-10	29.1	23.9	90.5	144.4	1.5
	11-17	30.4	23.9	85.0	58.0	6.3
	18-24	30.3	23.9	85.0	102.7	4.7
	25-1	29.7	22.6	84.5	154.3	3.9
July	2-8	30.4	23.1	82.5	19.7	6.6
	9-15	29.6	23.4	86.5	105.4	4.0
	16-22	28.2	22.8	93.0	245.9	0.3
	23-29	27.6	23.3	88.0	134.9	0.5
August	30-5	29.9	24.5	86.0	89.9	3.6
	6-12	28.9	23.9	87.5	61.2	2.9
	13-19	28.2	24.3	89.0	177.6	3.2
	20-26	29.7	24.6	83.5	72.1	5.1
September	27-2	29.6	23.6	84.0	200.8	3.9
	3-9	29.6	23.6	84.5	153.7	4.9
	10-16	30.5	23.4	85.0	113.7	6.0
	17-23	29.6	23.4	85.5	240.0	4.5
	24-30	29.7	22.4	85.0	123.2	4.3
October	1-7	30.4	23.4	77	29.8	6.5
	8-14	31.8	23.3	78	19.6	7.7
	15-21	31.8	27	78.5	6.8	7.6

Appendix-3

Abstract of ANOVA

Source	DF	Mean squares			
		Number of tillers per m^2			
		30 DAP	45 DAP	60 DAP	Harvest
Block	2	10833.8	8315.9	21765.8	21417.9
Treatment	12	544.1	491.7	775.4	644.8
Source	3	523.2	190.3	389.2	80.7
Levels	2	525.3	158.1	37.8	817.8
Interaction	6	632.6	832.9	1240.8	748.7
Control vs rest	1	113.5	16.0	617.0	1367.8
Error	24	749.7	790.4	1129.2	1019.5

* Significance at 5 per cent level

Appendix-2

Abstract of ANOVA

Source	DF	Mean squares			
		Plant height			
		30 DAP	45 DAP	60 DAP	Harvest
Block	2	51.5	20.6	9.2	22.4
Treatment	12	4.2	5.4	4.9	5.2
Source	3	0.8	1.4	8.8	11.0
Levels	2	10.4*	3.9	2.1	2.3
Interaction	6	3.1	8.3	4.5	4.1
Control vs rest	1	7.9	2.9	0.8	-0.03
Error	24	2.7	4.2	9.6	8.4

Appendix-4

Abstract of ANOVA

Source	DF	Mean squares			
		Leaf area index			
		30 DAP	45 DAP	60 DAP	Harvest
Block	2	0.09	1.4	1.1	0.2
Treatment	12	1.1	1.5	0.7	0.3
Source	3	0.8	2.7**	1.6**	0.1
Levels	2	0.06	0.08	0.2	0.4
Interaction	6	0.9	0.9	0.2	0.5
Control vs rest	1	5.7**	4.8**	2.0*	0.0
Error	24	0.6	0.4	0.3	0.5

Appendix-5

Abstract of ANOVA

Source	DF	Mean squares			
		Dry matter production	Number of productive tillers per hill	Panicle length	Number of grains per panicle
Block	2	30774.0	3.6	0.1	1008.8
Treatment	12	41603.0	0.4	1.1	144.2
Source	3	34378.7**	0.6	1.2	143.7
Levels	2	62657.0**	0.4	1.3	231.7
Interaction	6	36558.7**	0.3	1.1	107.8
Control vs rest	1	51434.0*	0.1	1.0	189.7
Error	24	7028.0	0.4	1.6	73.0

* Significance at 5 per cent level

** Significance at 1 per cent level

Appendix-6

Abstract of ANOVA

Source	DF	Mean squares			
		Percentage of ripened grains per Panicle	Thousand grain weight	Grain yield	Straw yield
Block	2	316.0	0.4	2033176.0	665440.0
Treatment	12	25.6	1.0	81348.0	270000.0
Source	3	26.7	1.1	81525.3	168362.7
Levels	2	22.4	1.4	51064.0	159264.0
Interaction	6	24.5	0.7	99848.0*	272309.4
Control vs rest	1	35.5	1.9	30384.0	782528.1
Error	24	19.7	0.8	37933.3	354906.7

Appendix-7

Abstract of ANOVA

Source	DF	Mean squares			
		Grain-straw ratio	Harvest index	Protein content	N-uptake
Block	2	0.01	0.004	0.1	942.3
Treatment	12	0.01	0.002	0.9	1174.9
Source	3	0.02	0.003	1.6**	833.9*
Levels	2	0.03	0.003	0.3	1855.1**
Interaction	6	0.01	0.002	0.9*	1111.8**
Control vs rest	1	0.00	0.002	0.2	1215.8*
Error	24	0.01	0.001	0.3	183.7

* Significance at 5 per cent level

** Significance at 1 per cent level

Appendix-8
Abstract of ANOVA

Source	DF	Mean squares	
		P-uptake	K-uptake
Block	2	22.4	504.1
Treatment	12	27.6	1415.9
Source	3	14.9*	985.2**
Levels	2	39.7**	1469.7**
Interaction	6	27.5**	1766.7**
Control vs rest	1	41.5**	495.8
Error	24	4.4	140.1

Appendix-9
Abstract of ANOVA

Source	DF	Mean squares			
		S-uptake			
		30 DAP	45 DAP	60 DAP	Harvest
Block	2	.2	10.0	0.9	3.2
Treatment	12	6.4	11.5	30.6	29.3
Source	3	11.2**	1.0	1.1	20.6**
Levels	2	10.2**	52.6**	104.6**	60.1**
Interaction	6	1.7	2.1	9.2	14.5**
Control vs rest	1	13.0**	16.8**	99.3**	82.9**
Error	24	0.9	1.8	4.5	2.1

* Significance at 5 per cent level
** Significance at 1 per cent level

Appendix-10
Abstract of ANOVA

Source	DF	Mean squares		
		% Sdff	Per cent utilization of applied fertilizer	Quantity of S in the plant taken up from the fertilizer
Treatment	8	1984.7**	55.6**	31.7**
Error	27	10.6	5.5	0.5

Appendix-11
Abstract of ANOVA

Source	DF	Mean squares		
		% Sdff	% Sdfs	A-value
Treatment	5	1208.6**	1208.6**	106.8**
Error	18	12.9	12.9	3.4

Appendix-12
Abstract of ANOVA

Source	DF	Mean squares		
		Per cent utilization of applied fertilizer	Quantity of S in the plant taken up from the fertilizer	Total dry matter
Treatment	5	32.8**	23.8**	1.3
Error	18	3.2	0.8	1.5

** Significance at 1 per cent level

Appendix-13
Abstract of ANOVA

Source	DF	Mean squares		
		Grain yield	Straw yield	Total grain-S
Treatment	5	0.5	0.3	1.7
Error	18	0.6	0.5	0.7

Appendix-14
Abstract of ANOVA

Source	DF	Mean squares		
		Total straw-S	Total S uptake	S-content of the plant
Treatment	5	5.7	11.33*	.002**
Error	18	2.1	3.63	.0002

* Significance at 5 per cent level
** Significance at 1 per cent level

Appendix-15

Result of paired t-test on specific activity in leaf, culm, inflorescence stalk, grain and whole plant calculated t-value, t-value from the table and their significance

Comparisons	t-value	
	Calculated	Table
Leaf and culm	4.85*	1.96
Leaf and inflorescence stalk	2.74*	1.96
Leaf and grain	4.73*	1.96
Culm and inflorescence stalk	1.97*	1.96
Culm and grain	3.06*	1.96
Inflorescence stalk and grain	3.23*	1.96
Whole plant and leaf	4.58*	1.96
Whole plant and culm	1.59	1.96
Whole plant and inflorescence stalk	1.21	1.96
Whole plant and grain	4.6*	1.96

* _ Significance at 5 per cent level

RESPONSE OF RICE TO APPLIED SULPHUR

By

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ABSTRACT OF A THESIS

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ABSTRACT

Experiments were conducted at the Agricultural Research Station, Mannuthy and the Radiotracer Laboratory of the Kerala Agricultural University during the first crop season of 1988 to study the response of rice to applied sulphur and the relative uptake and distribution of soil and fertilizer sulphur. There was a field experiment conducted with four levels of sulphur (0, 20, 40 and 60 kg ha^{-1}) and four sources of sulphur (ammonium sulphate-basal dressing, ammonium sulphate-top dressing, ammonium phosphate sulphate and elemental sulphur). The experiment was laid out in RBD in plots of size 4.6 m x 4.5 m and replicated thrice. A pot culture experiment was conducted for studying the uptake and distribution of ^{35}S applied as labelled $(NH_4)_2SO_4$ at 20, 40 and 60 kg ha^{-1} levels of sulphur application. The utilization of sulphur applied at planting and that applied at panicle initiation were also studied in this experiment. The results showed that plant height and number of tillers were not significantly influenced by the levels of sulphur, sources of sulphur and their interactions. The leaf area index increased due to the application of sulphur at all the growth stages. The dry matter production increased with sulphur application. The increase in dry matter production due to the application of graded levels of sulphur was

found to vary from 4 to 47 per cent. The grain yield was influenced by interaction effects only and not by the main effects. Ammonium phosphate sulphate at 60 kg sulphur level recorded the highest grain yield which was on par with ammonium sulphate at 20 kg sulphur level as basal dressing, ammonium sulphate top dressing at sulphur levels 40 and 60 kg, ammonium phosphate sulphate at 40 kg sulphur level, and elemental sulphur at 60 kg sulphur level. However, the yield contributing characters like number of productive tillers per hill, panicle length, number of grains per panicle percentage of ripened grains per panicle and thousand grain weight were not influenced by either the levels, sources or their interactions. The sulphur levels, its sources and their interactions showed no significant influence on the straw yield, grain-straw ratio and the harvest indices. The uptake of N, P and K followed the same trend as that of the dry matter production. The uptake of sulphur increased with increasing levels of sulphur at all the stages of growth.

The experiment with labelled ammonium sulphate revealed that the specific activity among plant parts differed significantly. Specific activity of grain was the highest followed by that of culm, inflorescence stalk and the leaf. Culm and inflorescence stalk had almost similar specific activities to that obtained for the whole plant. In general the fertilizer sulphur taken up by the plant increased with levels of sulphur applied. Plant derived more sulphur from the basal dose than from the top dressing. The contribution of native sulphur present in the soil towards plant uptake decreased with increasing levels of applied sulphur. 'A'-value determined at different levels of added sulphur remained more or less constant at 10 ppm upto the sulphur level of 40 kg ha^{-1} and decreased there after. 'A'-value was found to be affected by the method of application and was relatively more when sulphur was applied in wo splits than when it was applied in a single dose. Seven to seventeen per cent of the applied sulphur was utilized by the rice plant. The per cent utilization of applied sulphur decreased with increasing levels of applied sulphur. Autoradiograph of the plant receiving labelled amonium sulphate showed that the absorbed ^{35}S is translocatd through out the plant system with relatively high accumlation in grain tips and leaf veins.

It is found that A-values of soil sulphur increase with the application of sulphur and the per cent utilization of applied sulphur decreases with an increase in the rate of application. However, the results are inconsistent and needs further confirmation.

2.7. Relative Effectiveness of Various Sources

Pillai and Singh (1975) reported that out of the four sources of soil applied sulphur, elemental sulphur was the best for preventing chlorosis and increasing rice grain yields in calcalcareous soils. Solosamosir and Blair (1983) observed that sulphur uptake in rice was not significantly different between gypsum, elemental sulphur and ammonium sulphate sources confirming the suitability of fine (100 per cent 60 mesh) elemental sulphur as a source for rice, whereas Paulraj et al. (1985) reported that gypsum was an easily available and cheaper source of sulphur than elemental sulphur. Chien et al. (1987) compared the relative agronomic effectiveness (RAE) of powdered elemental sulphur to that of gypsum and found that the RAE value for powdered elemental sulphur was superior to gypsum. However, Chien et al. (1988) reported that elemental sulphur and gypsum incorporated with urea were equally effective in increasing the rice grain yield.