QUALITY AND UPTAKE OF NUTRIENTS BY COWPEA (*Vigna unguiculata* L. Walp) IN A RHODIC HAPLUSTOX

By

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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM

2000

EFFECT OF SULPHUR ON YIELD, QUALITY AND UPTAKE OF NUTRIENTS BY COWPEA (*Vigna unguiculata* L. Walp) IN A RHODIC HAPLUSTOX

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THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)

FACULTY OF AGRICULTURE,
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM

2000

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DECLARATION

I here by declare that this thesis entitled **"Effect of S on yield ,quality and uptake of nutrients by cowpea (*Vigna unguiculata* L Walp) in a Rhodic Haplustox"** is a *bonafide* record of 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 other similar title, of any other University or Society

Vellayani,
31.05.2000

V.I. BEENA

CERTIFICATE

Certified that the thesis entitled **"Effect of S on yield ,quality and uptake of nutrients by cowpea (*Vigna unguiculata* L Walp) in a Rhodic Haplustox"** is a record of research work done independently by Ms. V.I. Beena under my guidance and supervision and it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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ACKNOWLEDGEMENT

I pay my obeisance to God Almighty for showering His blessings upon me in this endeavour.

I extend my unbounded gratitude and sincere thanks to Dr. P.B. Usha, Assistant Professor, Dept of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani and Chairman of my Advisory Committee for her valuable guidance. I am deeply indebted to her for her keen interest, encouraging attitude and creative suggestions.

I wish to place on record my deep sense of gratitude towards Dr. V.K. Venugopal, Prof. And Head, Dept of Soil Science and Agricultural Chemistry, Dr. (Mrs) Kumari Swadija, O., Assistant Prof., Dept. of Agronomy, Dr. C.R Sudharmai Devi., Asst. Prof. Dept of Soil Science and Agricultural Chemistry who have served as members of my Advisory Committee. I remember with gratitude, their valuable suggestions in carrying out the investigation, critical scrutiny of the manuscript and their whole hearted technical and moral support given to me.

I extend my sincere thanks to Dr. Thomas Varghese, former Professor and Head, Dept. of Soil Science and Agricultural Chemistry for his timely help and critical suggestions in the conduct of study.

I am grateful to Dr Viji, Asst. Prof.. Dept of Plant Physiology, for her valuable suggestions in the chemical analysis. I extend my sincere thanks to teaching and non teaching staff of the Dept of Soil Science and Agricultural Chemistry for the timely assistance extended by each and every one of them.

I am extremely thankful to Sri C.E Ajith kumar, Computer programmer, College of Agriculture, Vellayani and Dr. Sreekumar of Sugarcane Research Station, Thiruvalla for their most valuable help in statistical analysis of the data.

Cooperation and encouragement of my friends will remain a pleasant and cherished memory for me.My heartiest thanks to Sailaja, Sudha, Lekshmi, Manju, Devi, Asha, Baiju, Meera, Beena,Reena,Bhadra, Sreekala, Aparna, and Archana who had offered valuable help .

during the course of research work. I am also thankful to Sujachechi, Syam.S,Indira teacher, Suja teacher and Sushma teacher for their timely help and valuable suggestions.

But for the effort and prayers of Gautham, Sreejith,Indira and Bindhu I could not have accomplished this strenuous work. Iam deeply obliged to my family members for helping me to make. this thesis a reality.

I accord my sincere thanks to Sri Anil, Computer Park, Kayamkulam for undertaking the DTP work. Iam grateful to Kerala Agricultural University for granting Junior Fellowship to pursue my studies.

V.I. BEENA

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LIST OF ABBREVIATIONS

DAS	- Days after sowing
DMP	- Dry matter production
FYM	- Farmyard manure
H	- Harvest stage
HI	- Harvest Index
KAU	- Kerala Agricultural University
LAI	- Leaf area index
MOP	- Muriate of Potash
MFS	- Maximum flowering stage
NRA	- Nitrate reductase activity
POP	- Package of Practices
SSP	- Single super phosphate

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INTRODUCTION

INTRODUCTION

In developing countries like India, in order to meet the alarming demand of food and fibre, the present agricultural production has to be enhanced. Since land area is limited , the only alternative is to expand the vertical growth by increasing the production per unit area per unit time. This necessitates the need for development of possible, location- specific and intensive cropping system. Significance of balanced fertilization in Indian agriculture is gaining importance with respect to yield and quality of crops. In recent years, due to intensification of agriculture with high analysis fertilizers and ever increasing demand for nutrients made by crops on the soil and fertilizer system, the traditional boundaries between primary and secondary nutrients are becoming narrower. Neglect in the use of secondary and micronutrients have led to deficiencies of these nutrients, particularly sulphur.

Sulphur is essential for growth and development of all plants and its essentiality was established in 1911 by Horstmann. Now, S is recognised as the fourth major nutrient after N, P and K because crops in general require S in an amount equal to that of P in terms of crop uptake and N in terms of protein synthesis. It is essential for the synthesis of S containing aminoacids, cystine, cysteine and methionine which are essential components of protein. It is also needed for the synthesis of co-enzymeA, biotine, thiamine, glutathion, ferredoxin, formation of chlorophyll and metabolism of carbohydrates, proteins and oils. Sulphur promotes nodulation and N fixation in legumes. It is also associated with production of crops of superior nutritional and market quality.

In India about 90 districts have been reported to have S deficiency, which forms about 30 million ha of cropped land. India being the largest producer and consumer of pulses, the significance of undertaking present study in cowpea is well understood. According to soil analysis reports, all districts of Kerala are found to be deficient in sulphur. In Kerala, fertilizer use pattern at present is dominated by S free fertilizers like urea, DAP, MOP and NPK complexes. Since the studies on S nutrition in soils of Kerala are meagre, this study is proposed to find out the effect of S on yield and quality of grain cowpea in red loam soils of Kerala.

Current estimates indicate that there is quite wide gap between S addition and its removal by crops.Intensive cropping sequence can remove about 30-72 kg S ha^{-1} y^{-1}. Unless and until this gap is bridged, S deficiency could develop into a serious constraint in crop production and even reduce efficiency of other nutrients.

This study is proposed with the following objectives.

1. To study the effect of S application on the yield of cowpea.
2. To assess the influence of S application on uptake of nutrients and quality of grain cowpea.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Significance of balanced fertilization in Indian agriculture is gaining importance with respect to yield and quality of crops. In recent years, due to intensification of agriculture with high analysis fertilizers, the use of secondary and micronutrients has been neglected. Crops can yield to their full potential only by adding S along with NPK fertilizers. Most of our soils are deficient in sulphur. Pulses, being the main protein source of Kerala people, studying the effect of sulphur on yield and quality of this crop is important. A review of various works on sulphur nutrition is attempted in this chapter.

2.1 Growth characters

2.1.1 Plant height and number of branches

According to Chatterjee *et al.* (1988) by application of S fertilizers, number of branches in Indian mustard increased. Growth of braccoli and chilli was increased by the application of S in calcareous soils (Fenn *et al.* 1988). Sulphur nutrition increased plant height in soyabean. High levels of P and S increased plant height of wheat crop. (Fazal and Sirodia, 1990).Muraleedharan and Jose (1993) observed that in rice cv Jyothi application of 10 kg S ha $^{-1}$ enhanced the plant height.

Singh *et al.* (1993) found that S application @ 30 kg ha $^{-1}$ in toria increased the growth of plant. Growth characters were expressed best at 90 kg S ha $^{-1}$ in lentil (Singh and Singh, 1994).

According to Singh *et al.* (1994) maximum increase in plant height was recorded at 60 kg ha $^{-1}$ in summer mung. Nair (1995) reported progressive and significant increase in plant height of rice variety, Jyothi upto 30 kg S ha $^{-1}$ in Kerala. Balasubramanian *et al.* (1996) found that application of S @ 40 kg S ha $^{-1}$ as gypsum increased plant height in green gram.

Bora (1997) observed an increase in the number of branches per plant in mustard by gypsum application. Plant height of black gram was increased by gypsum application at 40 kg S ha^{-1} under rainfed conditions (Ramamoorthy *et al.* 1997).Saraf *et al.* (1997) found no significant difference in plant heights due to different levels of S application in chickpea. Sharma *et al.* (1997) observed an increase in plant height and number of branches in green gram by S fertilization @ 40 kg ha^{-1}.

Plant height and primary branches of green gram increased significantly with increasing levels of S upto 80 kg ha^{-1}(Singh *et al.* 1997). According to Geethalakshmi and Lourduraj (1998) gypsum application @ 500 kg ha^{-1} resulted in maximum plant height in groundnut.

2.1.2. Number of leaves and leaf area index

According to Upasani and Sharma (1988) number of leaves per plant increased significantly with 30 kg N and 90 kg S ha^{-1} in mustard under dry land conditions. He also noticed an increase in LAI with 60 kg S ha^{-1} in mustard. George (1989) found higher LAI in rice with S application. Fazal and Sirodia (1990) noted an increase in number of leaves in soyabean by increasing the rate of S application.

Nair (1995) could observe a progressive and significant increase in LAI of rice upto 30 kg S ha^{-1}. Number of leaves per bush increased with increase in the application of S in *Camellia sinensis* (Sharma *et al.* 1995). In green gram Singh *et al.* (1997) observed an increase in the number of functional leaves with increasing levels of S up to 30 kg ha^{-1}.

2. 1. 3 Number and weight of effective nodules

Application of 30 to 75 kg ha^{-1} of S increased nodulation and leghaemoglobin contents in nodules (Singh *et al.* 1988). Scherer *et al.* (1996) found that number of nodules, weight of nodules and N fixation rates were increased by high S application rates. Naidu *et al.* (1996)

reported an increase in nodule mass as a result of S fertilization up to 60 kg ha^{-1} in greengram. According to Jogendra *et al.*(1997) maximum number and dry weight of nodules was obtained at 60 days of crop growth as well as 45 kg ha^{-1} of S application in summer mung. Dry weight of nodules per plant increased with increasing levels of S upto 30 kg ha^{-1} in greengram (Singh *et al.* 1997).

2.1.4. Chlorophyll content

Nanawati *et al.* (1973) observed that chlorophyll content of rice was significantly reduced under conditions of S deficiency. A deficiency of S in rice makes it chlorotic at tillering (Suzuki, 1978). Application of S significantly increased chlorophyll a, b and total chlorophyll in fresh mustard leaves up to 50, 100 and 150 kg S ha^{-1} respectively (Singh and Singh, 1983; Rathore and Manohar, 1989; and Khanpara *et al.* 1993)

Qui (1989) found that leaf chlorophyll was increased by S application in wheat and maize. According to Deng *et al.* (1990) application of phosphogypsum to paddy crops increased the chlorophyll content.

2.1.5. Nitrate Reductase activity (NRA)

Qui (1989) observed an increase in NRA in wheat and maize by S application. NRA in tea leaves was increased with S nutrition (Yong and Xiu, 1994).

2. 2. Quality attributes

2. 2. 1. Protein content

Aulakh *et al.* (1976) found that S application accelerated metabolic pathway of protein synthesis. Protein content of seed increased in sunflower due to application of S and Zn (Badiger *et al.* 1985).According to Sagare and Bhalkar (1986) protein content in groundnut correlated significantly with S uptake.

According to Rathore and Manohar (19[illegible]) seed protein content increased with increasing levels of S.Seed protein content of mustard was maximum at 60 kg S ha^{-1} (Sharma *et al.* 1991). Mahopatra *et al.* (1992) observed an increase in protein content with increasing levels of S up to 20 kg ha^{-1} in rape seed. Gypsum significantly increased methionine and tryptophan per cent in chick pea (Hariram and Dwivedi,1992; Dwivedi and Singh, 1982 and Chauder *et al.* 1984)

Naidu *et al.* (1996) reported that an increase in protein content of seed was brought about by application of 40 kg S ha^{-1} in green gram.Since S is an integral part of S containing amino acids (cystine, cysteine and methionine) it improved protein and oil synthesis in seeds (Tamak *et al.* 1997).

Tripathi *et al.* (1997) found a positive effect of sulphur on protein and S containing amino acids in chickpea.According to Bhadoria *et al.* (1997) the protein content of grain increased significantly with P and S in clusterbean.Singh *et al.* (1997) reported that application of S increased the seed protein content in green gram. Shri Krishna (1995) found that seed protein content in green gram was increased by application of S and Zn.

2. 2. 2. Other nutritional qualities

Nutritional quality of chickpea was best at 40 kg S ha^{-1} applied as gypsum (Hariram and Dwivedi, 1992). Bhadoria *et al.* (1997) observed an increase in gum content of grain in clusterbean by P and S application.

2.3.Yield and yield attributes

2. 3. 1. Grain yield

The yield contributing characters of sulphur treated plants were significantly higher over control (Dube and Mishra, 1970). Nambiar(1985) reported 27 percent increase in rice grain yield due to sulphur incorporation over NPK.. Grain yield of black gram was increased by S application (Bapat ,1986).Rice yield showed an increase with S application at 25 kg ha^{-1} in three plots and 50 kg ha $^{-1}$ in the fourth plot (Hoque,1986). Rahman *et al.* (1986) observed higher yield of cane and sugar in sugarcane by application of S fertilizers.

Hossain *et al.* (1987) reported increased grain yield of rice with 30 kg S ha^{-1} . Seed yield of groundnut was increased significantly by S application (Hago *et al*,1987; Jangir,1992; Patel and Patel,1985). Fenn *et al.* (1988) found that yields of dry red chillies were highest with 16.5 kg S and then decreased with higher rates. According to Tiwari (1989) an increase in grain yield of chickpea was brought about by S fertilization.

Application of 30 kg S ha^{-1} maximised the grain yield in linseed (Aulakh *et al.* 1990) and application of 40 kg S ha $^{-1}$ resulted in a significant increase in seed yield of soyabean. Hundal and Arora (1990) observed that application of gypsum with urea produced a significantly higher yield of wheat grain over addition of urea alone. A field study designed to investigate S nutrition of cow pea (*Vigna unguiculata*)in the rain forest and savannah zones of Nigeria showed that S fertilization significantly increased seed yields in the savannah and in old forest fields where as yield was significantly influenced in newly opened rain forest fields. Application of 10 kg S ha^{-1} was adequate for cowpea production in the two zones (Kayode, 1990). Sulphur application increased seed yield in chickpea (Singh and Ram, 1990).

Chitkaladevi and Reddy (1991) reported an improved pod yield in groundnut with split application of gypsum. Grain yield of mustard in calcareous soil was highest by gypsum (Jain and Sexena,1991). Sulphur had no effect on grain yield in mustard (Joshi *et al.* 1991). In field trials with *Raphanus sativus var oleiformis,* application of 60 kg S ha^{-1} gave high yield than NPK only (Sinelnik and Vlasyuk, 1991). Sagar *et al.* (1991) found that application of 40 kg S ha^{-1} increased the seed yield in sunflower.Sharma *et al.*(1991) observed seed yield of mustard was maximum at 60 kg S ha^{-1}

Hariram and Dwivedi (1992) observed that gypsum @ 40 kg S ha^{-1} gave higher grain yield. According to Jaggi and Sharma (1992) application of S showed only negative levels in grain yield of black gram. Seed yield of sesamum was increased by S application (Chaplot *et al.* 1992). He also observed that plots treated with 60 kg S ha^{-1} during preceeding season gave significantly higher grain yield of wheat compared to plots not treated with S. According to Singh and Singh (1994) maximum yield in lentil was reported at 90 kg S ha^{-1}. Singh *et al.* (1994) found that increasing level of S enhanced the yield of summer mung bean and maximum yield was obtained at 60 kg S ha^{-1}.

Maximum pod yield was obtained with 30 kg S ha^{-1} in groundnut under dry land conditions.(Mishra, 1995). According to Sharma *et al.* (1995) highest leaf yield in tea was produced by S application @ 45 kg ha^{-1} .Shrikrishna (1995) reported an increase in yield of green gram by S application up to 40 kg S ha^{-1}. But at higher S rates decreased yields.

S fertilizer application at 45 kg S ha^{-1} in sunflower increased seed yield (Krishnamoorthy *et al.* 1996).S application at 40 kg S ha^{-1} produced greater grain yield in green gram (Naidu *et al.* 1996).

Grain yield of cluster bean was increased by P and S fertilization (Bhadoria *et al.* 1997). According to Bora (1997), application of gypsum in Brassica varieties increased seed yield significantly.Kachroo *et al.* (1997) observed an increase in seed yield of Indian mustard by S fertilization up to 40 kg S ha^{-1} .Maximum grain yield in summer mung was possible at

45 kg ha $^{-1}$ (Jogendra *et al.* 1997). Seed yield in toria was increased due to application of S at 50 kg ha $^{-1}$(Mahal *et al.* 1997).

According to Ramamoorthy *et al.* (1997) application of gypsum up to 40 kg S ha^{-1} enhanced the grain yield in blackgram.In sunflower, seed yield per plant and total seed yield ha^{-1} increased due to S fertilization (Tamak *et al.* 1997). Grain yield of Indian mustard was increased by increasing levels of S up to 80 kg S ha^{-1} (Singh *et al.* 1997). Sahu and Nanda (1997) reported that grain yield in blackgram increased up to 3.06 t ha^{-1}and 4.26 t ha^{-1} in black and laterite soil respectively with S application @ 40 kg S ha^{-1} for black soil and 60 kg S ha^{-1} for laterite soil.Saraf *et al* (1997) found that highest grain yield in chick pea was at 40 kg S ha^{-1} .

Gypsum was the most effective and cheapest source in groundnut. Application of gypsum at pegging stage is beneficial over basal application. Upto 14 % increase in pod yield was noticed by gypsum application. A linear response in yield was noticed when gypsum application increased from 200 to 500 kg S ha^{-1} (Geethalakshmi and Lourduraj, 1998). Jaggi (1998) observed an increase in seed yield in Indian mustard by the application of 60 kg S ha^{-1} . Seed straw ratio in Indian mustard increased with S application at 30 kg S ha^{-1} . A field experiment conducted in the Kharif seasons of 1996 and 1997 at RARS, Jammu revealed that application of 10, 20, 30 and 40 kg S ha^{-1} resulted in increased yield of rice by 14.2, 24.2, 25.6 and 20.1 per cent respectively over control (Gupta *et al.* 1998).

2. 3. 2. Number of pods per plant

Application of gypsum at the rate of 20 kg S ha $^{-1}$ gave largest number of siliqua per plant in rapeseed (Mahapatra *et al* 1992). According to Singh *et al* (1994) number of pods per plant increased significantly with increasing levels of S up to 40 kg S ha $^{-1}$ in summer mung.

Application of S at 40 kg S ha $^{-1}$ as gypsum increased the number of pods per plant and pod length in greengram (Balasubramanian *et al.* 1996). Naidu *et al.* (1996) noted that S at 40 kg ha $^{-1}$ produced higher number of pods per plant in green gram. Mishra (1996) observed an increase in number of pods per plant by application of S up to 30 kg ha $^{-1}$ to groundnut. Kachroo *et al* (1997) observed an increase in number of siliqua in Indian mustard by the application of 40 kg S ha $^{-1}$

Phosphorus and S enhanced number of clusters per plant and pods per plant in cluster bean. (Bhadoria *et al* 1997). Mahal *et al.* (1997) observed an increase in number of siliqua per plant by S application at 50 kg ha^{-1}. Ramamoorthy *et al.* (1997) found that number of pods increased by gypsum application in blackgram under rainfed conditions. Saraf *et al.* (1997) observed that application of S at 80 kg ha $^{-1}$ resulted in significantly higher number of pods per plant. Sharma *et al.* (1997) found out an increase in number of pods per plant in greengram by S fertilization. In mustard, number of pods per plant was enhanced with increasing levels of S up to 80 kg ha $^{-1}$ (Singh *et al.* 1997). Geethalakshmi and Lourduraj (1998) observed an increase in number of mustard pods per plant when gypsum was applied at 500 kg ha $^{-1}$

2. 3. 3. Number of seeds per pod

Application of gypsum at the rate of 20 kg S ha $^{-1}$ gave largest number of seeds per siliqua in rapeseed (Mahopatra *et al.* 1992). Singh *et al.* (1995) reported maximum number of grains per pod at 60 kg S ha^{-1} in summer mung. According to Balasubramanian *et al.* (1996) application of S at 40 kg ha $^{-1}$ as gypsum increased number of grains per pod in greengram. Bhadoria *et al.* (1997) observed an enhanced number of seeds per pod in cluster beans. Kachroo *et al* (1997) observed an inrcase in number of seeds per pod in Indian mustard by application of 40 kg ha^{-1}.Ramamoorthy *et al.* (1997) found out an increase in number of grains per pod in blackgram under rainfed conditions with application of gypsum. Saraf *et al.* (1997) found that application of S at 80 kg ha $^{-1}$ did not influence the number of seeds per pod.

2. 3. 4. Hundred seed weight

In Indian mustard seed weight per plant and thousand seed weight showed an increase with S fertilization upto 40 kg ha $^{-1}$ (Chatterjee *et al.* 1988). In clusterbeans the hundred seed weight increased significantly with application of P and S (Bhadoria *et al.* 1997).

According to Ramamoorthy *et al.* (1997) hundred seed weight of blackgram under rainfed conditions was increased by gypsum application. Application of S at 80 kg ha $^{-1}$ resulted in higher hundred seed weight than no S (Saraf, 1997). Tamak *et al.* (1997) found an increase in hundred seed weight of sunflower by S fertilization. Singh *et al.* (1997) found that thousend seed weight of mustard increased significantly with increasing levels of S up to 40 kg ha $^{-1}$ in green gram. Gypsum application at 500 kg ha $^{-1}$ in groundnut caused an increase in hundred kernel weight (Geethalakshmi and Lourduraj, 1998).

George (1989) found that S application could increase the thousand grain weight in rice. Sharma *et al.* (1997) observed that thousand seed weight of greengram was highest with the application 40 kg S ha $^{-1}$

2. 3. 5. Bhusa yield

Increased straw yield was reported by Hossain *et al* (1987) with 30 kg S ha $^{-1}$ in rice. Addition of 50 kg S ha $^{-1}$ as ammonium phosphate sulphate increased straw yield of rice by 27 per cent (Vijayachandran,1987). Application of gypsum with urea produced significantly higher yield of straw over the addition of urea alone (Hundal and Arora,1990). Increasing levels of S resulted in successive increase in straw yield of rice irrespective of the S source and the maximum yield was obtained by application of S sludge @ 100 kg ha $^{-1}$ (Malarvizhi *et al.* 1990). Rice straw yield showed an increase due to S application (Patel *et al.* 1991).

Sulphur has no effect on haulm yield in mustard (Joshi *et al.* 1991). Chaplot *et al.* (1992) observed that straw yield of sesamum was increased by S application. Stalk yield of sunflower was increased by S application (Prabhuraj *et al.*1993; Aulakh *et al.* 1990).

Straw yield of rice significantly increased with S application irrespective of the source and dose (Chowdhary and Majumdar,1994). Maximum straw yield in lentil was reported at 90 kg S ha^{-1} (Singh and Singh, 1994). Singh *et al.* (1995) reported that in summer mung continuous and significant increase in straw and biological yield was observed with increasing S levels up to 40 kg ha^{-1}.

Application of 30 kg S ha^{-1} gave significantly higher haulm yield in groundnut under dry land conditions (Mishra,1996). Zia *et al.* (1995) identified ammonium sulphate was superior to urea in increasing straw yield of rice.

Kachroo and Kumar. (1997) found that straw yield of Indian mustard was increased due to S application @ 40 kg ha^{-1}. Application of S progressively increased straw yield in mustard up to 40 kg S ha^{-1} (Jaggi *et al.* 1997). Jogendra *et al* (1997) observed maximum straw yield in summer moong @ 45kg S ha^{-1}. According to Naidu *et al.* (1996) haulm yield at harvest was enhanced with S application in green gram. Haulm yield in groundnut was increased due to S application (Panda *et al.*1997).

According to Sharma *et al.* (1997) application of S @ 40 kg ha^{-1} increased straw yield in greengram. In Indian mustard straw.yield increased significantly with increasing levels of S at 30 kg ha^{-1}(Singh *et al.* 1997). Tamak *et al.* (1997) observed an increase in stalk yield of sunflower due to S application.. According to Jaggi (1998) straw yield in Indian mustard was increased by S application @ 30 kg S ha^{-1}. Increased straw yield of rice with S application has been reported with 40 kg S ha^{-1} as optimum level (Sakal *et al.* 1999).

2. 3. 6. Total dry matter production

In soyabean dry matter production increased with increasing levels of S (Kumar and Singh,1980). Higher dry matter production has been reported in upland rice by the application of S @ 20 ppm (Gupta and Otoole,1986). Dry matter yield of rice increased by 47.1per cent with S application when the total S in plant was less than 30 per cent (Islam and Buiyan,1988). In an experiment conducted at Mannuthy with the rice cv.Jaya, George (1989) observed higher dry matter production with S application. According to Fazai and Sirodia (1990) increasing levels of P and S increased the dry matter yield of rice. Nair (1995) reported significantly higher dry matter production with higher S levels up to 30 kg S ha $^{-1}$.

Singh *et al.* (1994) observed an increase in dry matter accumulation of summer mung at 60 kg S ha $^{-1}$. In legumes, dry matter yield was highest with high S supply (Scherer *et al.* 1996). According to Naidu *et al.* (1996) dry matter production at flowering stage was enhanced significantly with S application in greengram. Krishnamoorthy *et al.* (1996) found that S application in sunflower substantially increased dry matter production by about 32.8 per cent over control.

Singh *et al.* (1997) observed an increase in dry matter accumulation per plant in mustard by application of 80 kg S ha $^{-1}$. According to Tamak *et al.* (1997) dry matter production of sunflower increased due to S fertilization. Ramamoorthy *et al.* (1997) observed an increase in plant dry weight due to gypsum application in blackgram under rainfed conditions.

2. 3. 7. Harvest Index

According to Singh *et al.* (1994) HI was maximum at 60 kg ha $^{-1}$ of S level in summer mung. Nair (1995) studied response of rice to S application and reported higher HI for control plots, which could be due to the low straw yield. Levels of S did not influence HI in chickpea (Saraf *et al.* 1997).

According to Kachroo *et al.* (1997) HI of Indian mustard was increased due to application of 40 kg S ha^{-1}. The HI was highest with 400 kg ha^{-1} of gypsum at pegging stage in ground nut (Geethalakshmi and Lourduraj,1998). Kushwaha and Prasad (1998) observed significant enhancement in HI of wheat with S dose up to 30 kg ha^{-1}.

2. 4. Soil nutrients

Increase in N content in soils due to S application was reported by Tisdale *et al.* [1985]. Fenn *et al.* [1988] observed that addition of S increased water extractable and desorbable Ca , Mg and P content of soil.

Singh *et al.* [1994] observed maximum S availability in soil due to the application of 60 kg S ha^{-1}. The increasing levels of elemental S and pyrates increased the available and total S content of soil significantly. The available N and P also increased with increasing levels of S application in the soil.

Sakal *et al.* [1999] reported that continous application of SSP raised the soil available S status from deficiency to sufficiency level.

2. 5. Nutrient contents in plants

2. 5. 1. Nitrogen

The increasing levels of sulphur concomittantly increased N content in plant tissue (Tiwari,1989). Such synergestic relationship between N and S has been reported by several workers. (Sachdev and Deb,1990; Singh *et al.*1994). According to Nair (1995), the N content in grain and straw of rice increased with the application of higher levels of S. Sakal.*et al* (1999)studied the effect of S on plant nutrient concentration and reported that S application could significantly increase the N concentration in grain and straw of rice and wheat for three consecutive years of study.

In rice, the highest N content was observed with 120 ppm N and 60 ppm S (Ahmed *et al.* 1989). In field experiments, Aulakh *et al.* (1990) observed a synergestic effect for P and S when both were applied at low levels. However at a high level of 52.5 kg P ha^{-1} antagonistic effect between P and S was noticed.

According to Joshi *et al.* (1991) N content in haulm was observed upto 25 kg ha^{-1}. The concentration of P in rice significantly increased with increasing S levels up to 60 kg ha^{-1} (Singh *et al.* 1994). Scherer *et al.* (1996) found that high S application resulted in a significantly higher N accumulation in legumes.Nitrate N concentration was greatest in plants grown in soils that was not supplied with S (Nesheim,1997).

2. 5. 2. Phosphorus

S application decreased P content in grain as well as in straw of rice (Tiwari,1989). Muraleedharan and Jose (1993) recorded antagonism of P in rice var Jyothi with the application of S . P content in grain and straw decreased with S application non-significantly at lower levels of S and significantly at higher levels (Nair,1995).Fenn *et al.* (1988) observed that as the rate of S increased in pot grown chillies, the P content decreased.In mustard P content in straw increased progressively with the level of S addition (Jain and Saxena,1991).P content of grain in cluster beans increased by P and S fertilization (Bhadoria *et al* 1997)

2. 5. 3. Potassium

Application of S was found to increase the concentration of K in rice (Dev and Kumar, 1982; Singh,1986; Singh *et al.* 1990). According to Nair (1995) K content in grain and straw of rice increased by S application upto 40 kg ha^{-1}.

2. 5. 4. Sulphur

Rahman *et al* (1986) found high S content in cane leaves by S fertilization. Application of S significantly increased the S content in cowpea (Kayode,1990). S application in wheat caused an increase in S concentration (Mullins and Mitchell *et al.* 1990). Kochar *et al.*(1990) observed that plant S content increased with increasing S rates in maize crop. According to Deng *et al.* (1990)application of phosphogypsum increased S content in rice plant.

Joshi *et al.*·(1991) observed that in mustard S application significantly increased S content in seed and haulm. According to Jain and Saxena (1991) the S content in straw increased progressively with S addition in mustard. According to Hundal and Arora (1990) application of gypsum and urea-S significantly enhanced the S content in grain and straw and its total removal by wheat over control as well as over urea fertilization alone. S fertilization up to 25 kg ha^{-1} in rice tended to increase S content in leaf and straw (Hoque, 1986). According to Shri Krishna (1995) content of S in seed and straw were increased by S application in green gram. S content in grains of clusterbean increased with P and S fertilization (Bhadoria *et al.*1997).Buchholz *et al* .(1998) reported an increase in S content of plant material in all soils by S addition

2. 5. 5. Other nutrients

Mg absorption in SO_4 dominated salinity by chickpea was increased with increase in salt content of soil (Lauter and Munns,1986).In mustard Jain and Saxena(1991) observed a progressive increase in Mg content of straw by S addition.S application progressively increased copper and manganese content in seed and straw being maximum at 120 kg S ha^{-1} in chickpea (Shri Krishna and Yadav, 1997). In mustard, minimum, Ca content was observed with lower levels of S application (Jain and Saxena, 1991) .

2. 6. Uptake of nutrients

According to Potty (1991) S application in safflower tended to decrease the uptake of Ca and Mg but increased significantly the uptake of N,P,K and S.

According to Ahmed *et al.* (1989) highest N and S uptake in rice was observed with 120 ppm N and 60 ppm S. Kochar *et al.* (1990) observed that S uptake by plant was enhanced with increasing S rates in maize crop. Application of 30 kg S ha $^{-1}$ maximised the uptake of S by linseed (Aulakh *et al.* 1990). S fertilization enhanced the uptake of N,P and K by sunflower (Sagare *et al* 1990)

Joshi *et al.* (1991) found that in mustard total uptake of sodium was increased up to 25 kg S ha $^{-1}$ S uptake of rapeseed increased with increasing levels of S upto 25 kg S ha $^{-1}$ (Mahopatra *et al.* 1992).Muraleedharan and Jose (1993) recorded antagonism of P in rice var Jyothi with the application of S . Higher uptake of N, P,K and S was recorded when S fertilizers were used for rice nutrition (Mondal,1994). Synergestic relationship between N and S has been reported by several workers (Tiwari, 1989; Sachdev and Deb. 1990; Singh *et al.* 1994).

Sulphur uptake both by straw and grains were better with ammonium sulphate than with urea in rice (Zia *et al.*1995).Higher S levels enhanced the uptake of N,K,and S in rice (Nair,1995) and also noticed that the increase in P uptake with S application was only upto 20 kg ha $^{-1}$ of S and higher S levels significantly reduced the P uptake.

Uptake of S in seed and straw was increased by S application in greengram (Shri Krishna,1995).According to Krishnamoorthy. *et al.* (1996) S application resulted in higher N,P,Kand S uptake in sunflower. S and Zn uptake increased significantly with increasing levels of S upto 30 kg ha $^{-1}$ in green gram (Singh *et al.*1997).

Sulphur uptake by seed and straw consistently increased with each successive addition of S upto 90 kg ha $^{-1}$ (Jaggi *et al.* 1997).Increased level of S application in mustard caused an increase in the uptake of S by plants (Singh *et al.* 1997).Mahal *et al.*(1997) observed an increase of S uptake by each increment of S application up to 30 kg ha $^{-1}$ in toria.

Sakal *et al.* (1999) reported that increasing levels of SSP progressively increased P and S uptake by rice crop. In another experiment to study the effect of sulphur application on the yield and nutrient concentration in a rice-wheat cropping system for three consecutive years ,increasing

S levels increased total N uptake progressively, total K uptake upto 40 kg S ha^{-1} and total P uptake upto 20 kg S ha^{-1}.

2. 7. N : S ratio

For optimum protein production, one part S was needed for every 12-16 parts N depending on the culture (Dev and Sagar,1974). Shinde(1982) reported that soyabean plants with N: S ratio of 16.5 or more were found to be S deficient. According to Deng *et al.*(1990) application of phospho gypsum decreased the N:S ratio in rice crop.All sources of S decreased the N:S ratio. Increasing doses of S decreased the N:S ratio in mustard (Sharma *et al.* 1991).

Increasing levels of S decreased N:S ratio in grain and straw of rice from 13.17 to 9.68 and 4.95 to 4.31, respectively. At optimum S level of 40 kg ha^{-1} this ratio was found to be 10.34 in grain and 4.51 in straw. In case of wheat, N:S ratio decreased from 20.78 to 17.18 in grain and 11.13 to 6.71 in straw with increasing S levels and at optimum S level (60 kg ha^{-1}) this ratio was 17.80 in grain and 6.71 in straw (Sakal *et al.* 1999)

MATERIALS AND METHODS

MATERIALS AND METHODS

Field experiment to find out the effect of various sources and levels of sulphur on yield, quality and uptake of nutrients by cowpea was conducted in the Instructional farm, College of Agriculture, Vellayani. The details of the experimental site, season and weather conditions, materials used and methods adopted are presented in this chapter.

3.1 Experimental site

3.1.1 Location

The Instructional farm, Vellayani is located at 8 ^{o}30'N latitude and 76 ^{o}54' E longitude and at 29 m above MSL

3.1.2 Soil

The soil belongs to the family of Loamy Skeletal Kaolinitic Isohyperthermic Rhodic Haplustox. Physical and chemical properties of soil where the field experiment was conducted are given in Table 1

3.2 Season

The experiment was carried out during the summer season (February –May) of 1998.

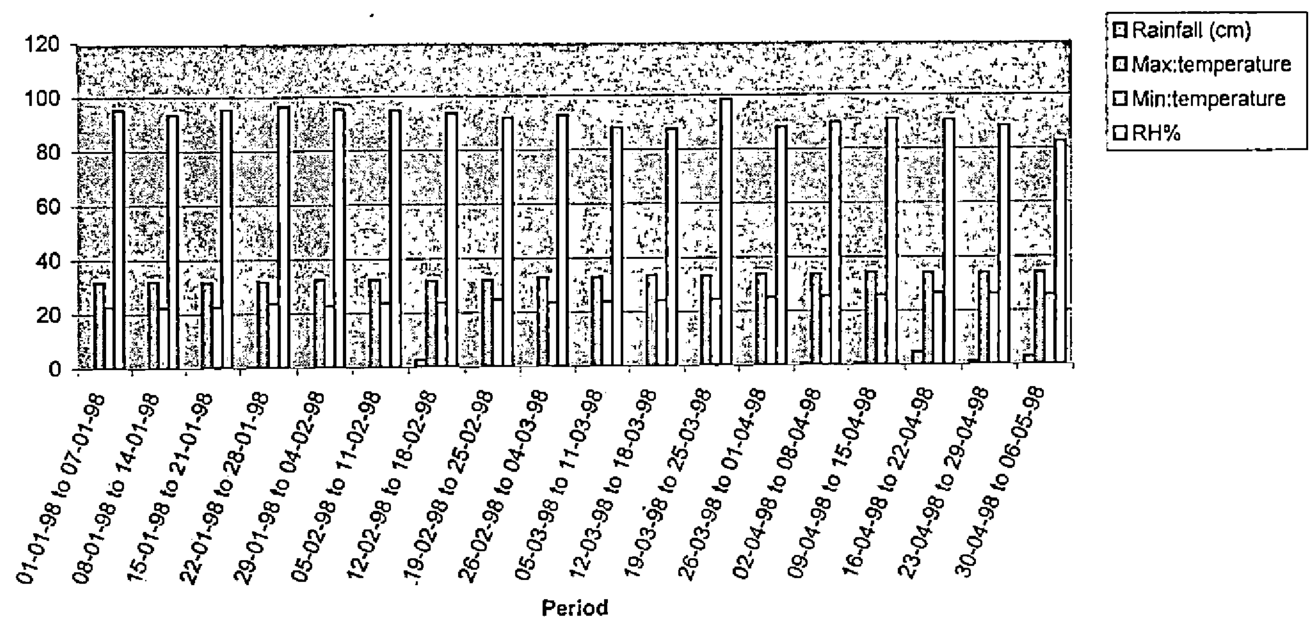
3.3 Weather conditions

The mean rainfall of the location was 1293 mm. The mean maximum and minimum temperatures prevailed during the cropping period were 32.26 ^{o}C and 24.46^{o} C respectively. Mean relative humidity was 91.87 per cent. Weekly distribution of rainfall and temperature prevailed during the crop period was collected from the agro-meterological observatory attached to the Dept. of Agronomy, College of Agriculture, Vellayani and is presented in Fig 1.

Table 1 Physical and chemical properties of the soil at experimental site

Parameter	Content
Mechanical composition:	
Coarse sand	14.20 %
Fine sand	33.10 %
Silt	27.50 %
Clay	24.60 %
Texture	Sandy loam
Bulk density	1.3 Mg m^{-3}
Particle density	2.145Mg m^{-3}
pH	5.1
EC	< 0.05 dS m^{-1}
CEC	5.4 cmol kg^{-1}
WHC	45.40 %
Organic carbon	0.62 %
Sesquioxides	12.8 %
Total nitrogen	0.03 %
Total phosphorus	0.04 %
Total potassium	0.09 %
Total sulphur	1029 ppm
Available N	220.25 kg ha^{-1}
Available P	13.22 kg ha^{-1}
Available K	149 kg ha^{-1}
Exchangeable Ca	0.79 cmol kg^{-1}
Exchangeable Mg	1.10 cmol kg^{-1}
Available S	7.87 ppm

Fig 1. Weather data during the cropping period.



3.4 Materials

3.4.1 Crop :- Cowpea cv.Ptb-1- It is a leguminous crop and can be cultivated either as an upland crop or as summer crop in rice fallows .

3.4.2 Variety

Seeds of Ptb-1(Kanakamoni), a dual purpose cowpea obtained from RRS, Kayamkulam were used for the experiment.

3.4.3 Manures and Fertilizers

Fertilizers used were urea, mussooriephos, gypsum, factamphos and muriate of potash. FYM was used as organic source. They were applied according to the treatments.

3.5 Design and lay out of the experiment

The experiment was laid out in Randomised Block Design.

The lay out plan of the experiment is given in Fig 2 .The details of the lay out are given below

Design	: Randomised block design
Number of replications	: 3
Spacing	: 25x 15 cm
Gross plot size	: 5 x 4 m
Crop variety	: Cowpea cv.Ptb-1 (Kanakamoni)
Treatments	: 10

T_1 POP recommendations without S

T_2 NPK alone

T_3 POP+15 kg S (source: factamphos)

T_4 POP+30 kg S (source : factamphos)

T_5 POP+15 kg S (source : gypsum)

T_6 POP +30 kg S (source : gypsum)

T_7 NPK alone +15 kg S (source : factamphos)

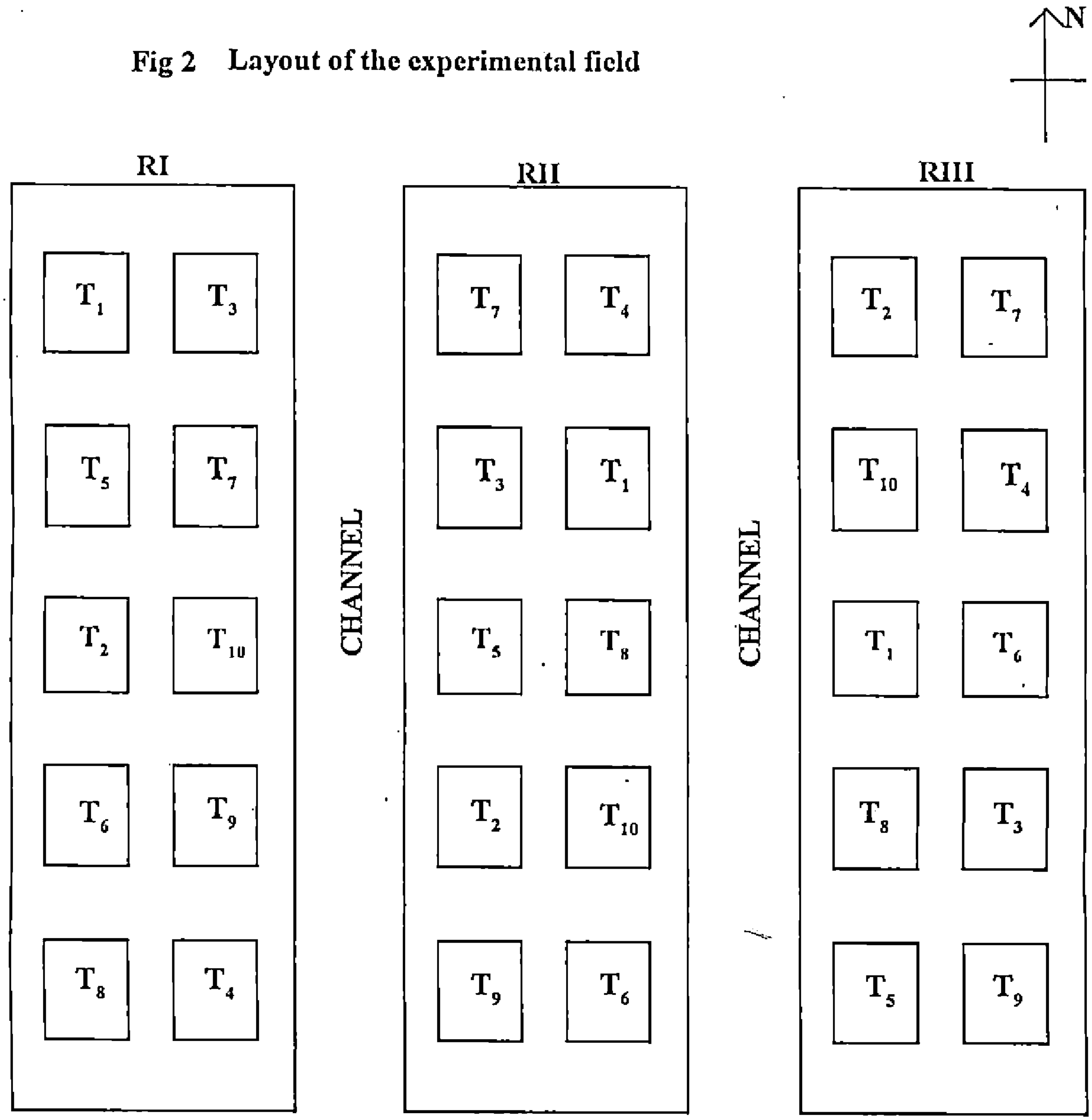
T_8 NPK alone + 30 kg S (source: factamphos)

T_9 NPK alone +15 kg S (source: gypsum)

T_{10} NPK alone +30 kg S (source : gypsum)

The POP recommendation for cowpea is 20 kg N ha^{-1}, 30 kg P ha^{-1} and 10 kg K ha^{-1} along with 20 t FYM ha^{-1}. Cultural operations were done as per POP of KAU [KAU, 1996]

Fig 2 Layout of the experimental field



3.6 Details of cultivation

3.6.1 Sowing

Seedsof cowpea var kanakamoni were sown in the field in the furrows. All cultivation practices as per POP recommendation of KAU were followed (KAU,1996)

3.6.2 Application of manures and fertilizers

Entire quantity of potash and phosphorus along with half the quantity of nitrogen were given as basal dose before sowing. Remaining half dose of nitrogen was applied 20 days after sowing.FYM and sulphur fertilizers were applied to different plots as basal dose according to different treatment combinations.

3.7 Biometric observations

3.7.1Height of the plant

Height of the plant was measured in cm from the scar of the first cotyledonous leaf of the plant to the top of the growing point at 30,60 and 90 days after sowing.

3.7.2Number of branches per plant

Number of branches were recorded from five observation plants at MFS and their average was calculated.

3.7.3 Leaf area index (LAI)

LAI was calculated at 30,60and 90 DAS. Area of all the leaves produced per plant was recorded using LI-COR-Model-3100 leaf area meter and LAI was worked out using the formula suggested by Watson(1952)

$$LAI = \frac{\text{Leaf area per plant } (cm^2)}{\text{Land area occupied by plant } (cm^2)}$$

3.7. 4 Days to maximum flowering

Number of days to reach maximum flowering stage was recorded from five observation plants and their average worked out.

3.7. 5 Number of effective nodules per plant and weight of nodules

Selected plants were uprooted carefully at maximum flowering stage. Root portion was washed and nodules were separated from the roots .Effective nodules were counted based on their size, shape and red colour .Weight of nodules was taken as g plant $^{-1}$.

3. 8 Yield and yield components

3. 8.1 Number of pods per plant

No of pods harvested from five observation plants were counted and average worked out

3. 8. 2 Number of seeds per pod

No of seeds/pod from five observation plants were counted and average was calculated.

3. 8. 3 Grain yield

Pods were collected and dried. Seeds were separated and weight of seeds from various harvests were added and per hectare yield in kg was found out.

3. 8. 4 Bhusa yield

The plants were uprooted after the harvest of pods, washed free of adhering soil ,air dried uniformly, weighed and is expressed in kg ha^{-1}

3. 8. 5 Total dry matter production

Total dry matter production was calculated by adding pod yield and bhusa yield and expressed in kg ha^{-1}

3. 8. 6 Harvest Index

Harvest Index was calculated using the formula

$$HI = \frac{\text{Economic yield /plant}}{\text{Biological yield / plant}}$$

where biological yield is total weight of all plant parts including grain and economic yield is the weight of grains.

3. 9. Chemical analysis

3. 9. 1 Chlorophyll content

Chlorophyll content (a, b and total) was determined by the colorimetric method as described by Arnon (1949)

3. 9. 2 Nitrate reductase activity

This was determined at maximum flowering stage and is expressed as mg g^{-1} leaf using the method suggested by Nason and Evans (1955) and expressed as $NO_2\ g^{-1}h^{-1}$

3. 9. 3 Crude fibre content

Crude fibre content of plants at maximum flowering stage (MFS) and harvest was estimated by acid and alkali digestion method.(Sadasivam and Manickam 1992) and expressed in per cent.

3. 9. 4 Soil analysis

Soil analyses were done at initial, MFS and harvest stages for estimation of organic carbon, N, P, K,Ca, Mg and S using standard procedures as given in Table 2.

3. 9. 5 Plant analysis for nutrient contents

Plant samples were collected at MFS and after harvest. The samples were oven dried at 70° C and powdered in a Willeymill and used for determination of N,P,K,Ca,Mg,S and protein content. Standard procedures adopted were given in table 3.

Table 2 Analytical methods followed in soil analysis

Character	Method	Reference
Mechanical composition	International pipette method	Piper,1966
Bulk density	Undisturbed core sample	Dakshinamurthy and Gupta,1968
pH	pH meter	Jackson, 1973
EC	Conductivity meter	Jackson,1973
CEC	Ammonium saturation using neutral normal ammonium acetate	Jackson, 1973
WHC	Undisturbed core sample	Hillel, 1980
Organic carbon	Walkley and Black Rapid Titration	Walkley and Black, 1934
Available N	Alkaline permanganate	Subbiah and Asija,1956
Available K	Flame photometry	Jackson,1973
Available P	Ascorbic acid reduced-molybdo phosphoric blue colour	Jackson,1973
Available S	Turbidimetry	Chesnin and Yien,1950
Exchangable Ca and Mg	Neutral normal ammonium acetate extraction and AAS	Jackson,1973
Total nitrogen	Modified microkjeldahl method	Jackson,1973
Total phosphorus	Vanado molybdo phosphoric yellow colour	Jackson,1973
Total potassium	Flame photometry	Jackson,1973
Total sulphur	Turbidimetry	FAO,1988

Table 3. Analytical methods followed in plant analysis

Element	Method	Reference
Nitrogen	Microkjeldahl digestion in sulphuric acid and distillation.	Jackson,1973
Phosphorus	Nitric-Perchloric-Sulphuric acid (10:4:1) digestion and colorimetry making use of vanado molybdo phosphoric yellow colour method	Jackson ,1973
Potassium	Nitric-Perchloric-Sulphuric acid (10:4:1) digestion and flame photometry.	Jackson,1973
Ca,Mg	Nitric-Perchloric -Sulphuric acid digestion and AAS	Piper,1966
Sulphur	Diacid mixture digest (nitric-perchloric acid 10:1) and turbidimetry	Tabatabai and Bremner 1970
Crude protein	% N x 6.25	Chopra and Kanwar 1976

3. 9. 6 Grain analysis

Seeds harvested from sample plants were dried and powdered in willey mill. Chemical analyses were carried out for the determination of N,P,K,Ca,Mg and S contents.Procedure adopted were same as that for plant analyses.

3. 9.7 Seed Protein content

Seed protein content in per cent was worked out by multiplying the seed N value by the factor 6.25 (Simpson *et al.* 1965)

3. 9. 8 Uptake of nutrients

Grain uptake and plant uptake were calculated .Nutrient contents in plant and grain multiplied by respective dry weights gave the uptake of nutrients.

3. 9. 9 N:S ratio

Ratio of nitrogen and sulphur contents in plant and grain was found out This was obtained by dividing N content in plant and grain by their respective S content

3.10 Scoring for pest and diseases

The pest and disease count was not significant to be scored.

3.11 Statistical analysis

The data was analysed statistically using RBD described by Cochran and Cox (1963) and significance was tested by F test (Snedecor and Cochran, 1967). Correlations were also carried out to draw definite conclusion (Snedecor and Cochran, 1967).

RESULT

4 RESULTS

An investigation was carried out in the Instructional farm, College of Agriculture, Vellayani to find out the effect of different sources and levels of S on yield, quality and uptake of nutrients by cowpea [*Vigna unguiculata* L.Walp]. The experiment was conducted during the summer season of 1998. The results obtained in the study are presented in this chapter.

4.1 Growth characters

4.1.1.Plant height

The effect of S on plant height is presented in Table(4).

Height of the plants at 30, 60 and 90 DAS were noted to be significantly enhanced by increased levels of S application. T_6 recorded maximum height at 30,60 and 90 DAP.At 30 DAS, height of the plant was significantly influenced by sulphur fertilization. T_6 [POP and 30 kg S ha^{-1} as gypsum] was found to be on par with T_8 and T_4 i.e. treatments with S application at 30 kg ha^{-1} produced significantly increased height. POP recommendation without S resulted in more height at 60 and 90 DAS when compared to treatment with NPK alone. Comparison of different sources revealed that gypsum was superior.

Table 4. Effect of S application on plant height and number of branches per plant

Treatments	Plant height of the plant(cm)			Branches per plant at MFS
	30 DAS	60DAS	90DAS	
T_1	14.20	37.73	67.33	5.47
T_2	16.26	37.46	59.93	4.53
T_3	19.60	53.06	82.00	6.26
T_4	21.40	62.26	89.86	7.20
T_5	20.63	57.06	85.60	6.93
T_6	23.23	66.20	100.40	5.53
T_7	20.76	52.13	71.86	6.40
T_8	22.40	56.60	90.00	6.27
T_9	11.96	57.26	88.26	6.93
T_{10}	19.86	62.20	94.50	7.13
$F_{9,18}$	11.94**	35.84**	21.04**	14.16**
SE	0.79	2.78	2.78	0.22
CD(0.05)	2.34	4.83	8.27	0.66

** Significant at 0.01 level

Sulphur at 30 kg ha^{-1} as gypsum along with FYM recorded maximum height of 23.23 cm. Treatments with S was found to be superior to treatments without S. Treatments applied with 15 kg S ha^{-1}. were found to be on par.

At 60 DAS, T_6 recorded maximum height of 66.20 cm. It was found to be on par with T_4 and T_{10}. S application significantly increased plant height. Treatments with S was found to be superior to treatments without S in enhancing the plant heights. T_1 and T_2 were on par.

At 90 DAS, T_6 gave maximum height of 100.4 cm. T_{10} [NPK alone and 30 kg S as gypsum] was on par with T_6.

4.1.2. Number of branches per plant

Observations on number of branches per plant revealed that it was significantly influenced by S fertilization (Table 4).Treatment with S @ 30 kg ha^{-1} along with FYM recorded maximum number of branches (7.20). The source used was factamphos [T_4]. This was on par with T_{10} and T_5. All the other treatments were found to be significantly superior to treatment with NPK alone.

4.1.3.Leaf Area Index

The LAI at 30,60 and 90 DAS were recorded. Sulphur application was found to have a significant influence on LAI at all the three stages (Table 5). Treatment with POP recommendation and S @ 30 kg ha^{-1} as gypsum [T_6] recorded highest mean value in all stages. At 30 DAS T_6 was found to be on par with T_5, T_9 and T_{10}. While at 60 and 90 DAS T_6 was significantly superior to all treatments. Treatments with NPK alone gave the lowest value in all the three stages. At 30 DAS and 60 DAS treatments without sulphur were found to be inferior to all other treatments. Comparing the sources, gypsum application was found to be better than factamphos at 30 DAS in enhancing the LAI, where as in other two stages, no such effect was noticed. Increasing levels of sulphur influenced the LAI at 30 DAS. But at 60 and 90 DAS similar trend was observed except at T_7 and T_8 [NPK application along with factamphos @ 15 and 30 kg ha^{-1} respectively].

Table 5. Effect of application of S on Leaf Area Index

Treatments	30DAS	60DAS	90DAS
T_1	0.03	1.20	1.27
T_2	0.26	1.25	1.21
T_3	0.35	1.31	1.27
T_4	0.37	1.36	1.34
T_5	0.41	1.39	1.35
T_6	0.42	1.46	1.45
T_7	0.40	1.38	1.34
T_8	0.38	1.34	1.30
T_9	0.40	1.31	1.30
T_{10}	0.40	1.40	1.37
$F_{9,18}$	53.6**	15.86**	19.45**
SE	0.01	0.02	0.15
CD(0.05)	0.02	0.05	0.04

** Significant at 0.01 level

4.1.4. Number of effective nodules per plant

Different levels and sources of sulphur produced significant positive effect on the number of effective nodules per plant (Table 6). Maximum number of nodules was recorded for T_6 i.e. treatment with 30 kg S ha^{-1} as gypsum along with POP which was on par with T_{10} and T_5. T_1 and T_2 [i.e. treatments without S] were found to be inferior to all other treatments. On comparing the sources of S fertilization, gypsum was found to be superior.

4.1.5. Weight of effective nodules per plant

From the results (Table 6) it can be inferred that weight of nodules was significantly enhanced by S fertilization. T_6 [Treatment with S @ 30 kg ha^{-1} as gypsum along with POP recommendations] was found to be significantly superior and recorded a maximum mean value of 0.396. Lowest value was recorded by treatment with POP recommendation, which was on par with NPK only. Treatments with POP recommendation and S had a significant effect on enhancing the nodule weight per plant..

4.1.6. Days to maximum flowering

The data on this is given in Table (6)

Sulphur application produced a significant effect on decreasing the days to maximum flowering. Minimum number of days was taken for maximum flowering in the case of treatment with S @ 30 kg ha^{-1} as gypsum and POP recommendation [32.7]. T_2 had taken maximum number of days [39.66] which was on par with T_7 and T_8. Treatments without S application differed significantly from other treatments and gave higher values compared to others.

4.1.7. Chlorophyll content

Observations on chlorophyll content revealed an increase in chlorophyll content with increasing levels of sulphur(Table7). Maximum chlorophyll content of 2.51 mg g^{-1} was recorded by the treatment with 30 kg S ha^{-1} and POP recommendation. But this was on par with T_4, T_8 and T_{10} indicating that sulphur application at 30 kg ha^{-1} was effective in enhancing the chlorophyll content. T_2 and T_1 [treatments without S] were on par and gave significantly lower chlorophyll

Table 6 . Effect of S application on number & weight of nodules and days to MFS

Treatments	No: of Nodules plant^{-1}	Wt: of Nodules plant^{-1}(gm)	Days to MFS
T_1	15.44	0.30	38.00
T_2	14.95	0.29	39.66
T_3	16.88	0.33	35.03
T_4	17.86	0.35	34.60
T_5	19.78	0.35	33.73
T_6	20.50	0.40	32.70
T_7	17.48	0.31	34.23
T_8	18.28	0.31	32.86
T_9	18.26	0.32	34.60
T_{10}	19.94	0.32	33.16
$F_{9,18}$	31.04**	7.723**	8.55**
SE	0.33	0.02	0.78
CD(0.05)	0.98	0.03	2.30

** Significant at 0.01 level

content compared to treatments with sulphur. Various sources of sulphur did not make any marked influence on the chlorophyll content.

4.1.8. Nitrate reductase activity

Sulphur application at different levels through different sources showed (Table 7) marked influence on NRA. S application @ 30 kg ha^{-1} along with POP recommendation was found to produce maximum value for NRA [0.0053]. This was on par with T_9 and T_{10} [Treatments with POP recommendations and S @ 15 kg ha^{-1} and 30 kg ha^{-1} respectively]. The NRA was significantly minimum at POP recommendations without S. This was found to be on par with treatment having NPK application only.

4.2 Quality attributes

4.2.1. Protein content

Protein content in plants at MFS and harvest stage was recorded (Table 8). S application could significantly influence the protein content at both stages. Protein content of the plants was found to be increased with increasing levels of S through different sources. At MFS , S fertilization @ 30 kg ha^{-1} was found to be superior among other treatments irrespective of the source used. Factamphos @ 30 kg S ha^{-1} along with POP recommendations [T_4] recorded maximum protein content of 22.54 % at MFS which was on par with T_5 and T_6. At harvest, maximum plant protein content was observed for T_8, the treatment with 30 kg S ha^{-1} through factamphos along with NPK application. T_4, T_5, T_6 and T_9 were on par with this. The lowest value was recorded for POP recommendations at MFS where as treatment with NPK alone had the minimum protein content at harvest stage.

Protein content in grain was significantly influenced by S fertilization (Table 8). POP recommendations along with S @ 30 kg ha^{-1} recorded significantly maximum protein content of

Table 7 Effect of S application on chlorophyll and NRA.

Treatments	Chlorophyll (mg g^{-1} leaf)	N R A (NO_2 g^{-1}h^{-1})
T_1	1.95	0.0018
T_2	1.96	0.0018
T_3	2.29	0.0032
T_4	2.46	0.0053
T_5	2.26	0.0041
T_6	2.51	0.0036
T_7	2.33	0.0034
T_8	2.51	0.0036
T_9	2.27	0.0050
T_{10}	2.45	0.0046
$F_{9,18}$	22.19**	22.77**
SE	0.05	0.0002
CD(0.05)	0.13	0.0007

** Significant at 0.01 level

Table 8.Effect of S application on protein and crude fibre content

Treatments	Plant Protein (%)		Grain Protein(%)	Crude Fibre (%)	
	MFS	H		MFS	H
T_1	19.08	13.54	21.04	1.75	2.72
T_2	19.60	12.70	20.83	1.64	2.82
T_3	20.01	13.33	21.08	1.95	2.75
T_4	22.54	15.18	24.79	2.16	2.93
T_5	21.85	15.05	23.39	2.12	2.91
T_6	22.26	15.05	26.12	2.22	2.93
T_7	19.73	13.81	20.94	2.16	2.95
T_8	20.91	15.54	21.14	2.16	2.99
T_9	20.10	15.02	21.23	2.18	2.97
T_{10}	21.15	14.93	22.87	2.20	3.03
$F_{9,18}$	58.3**	13.37**	23.62**	5.432**	1.41
SE	0.46	0.27	0.39	0.08	0.09
CD(0.05)	1.36	0.79	1.15	0.26	0:26

** Significant at 0.01 level

26.12 %. At increased levels of S application through various sources, grain protein content showed an increase.

Treatments with 30 kg S ha^{-1} and POP recommendations produced significantly higher grain protein content irrespective of the source used. Lowest grain protein content was noted for T_2 i.e. treatment without S and FYM.

4.2.2. Crude Fibre Content

Crude fibre content at MFS and harvest were noted. S application increased significantly the crude fibre content at MFS. But failed to produce any significant effect at harvest stage. At MFS, the maximum value of 2.22 was recorded for T_6 i.e. the treatment with30 kg S ha^{-1} along with POP. Lowest value (1.64) was obtained by T_2 (Table 8). T_1 [POP recommendation] recorded a lower fibre content. At harvest stage, different levels and sources of S addition could not produce any significant effect on fibre content of plants. However, the lowest fibre content was observed for POP recommendations(T_1).

4.3 Yield and yield attributes

4.3.1. Grain yield

Different levels and sources of sulphur significantly increased the grain yield. Maximum grain yield of 988.98 kg ha^{-1} was obtained from T_6 [gypsum at 30 kg S ha^{-1} and POP recommendations of NPK and FYM]. Comparing the yield from different levels of the same source an increasing trend was noticed with enhanced rate of sulphur application (Table 9). T_6 was found to be on par with T_5 [924.89 kg ha^{-1}] i.e. grain yield was significantly boosted by POP recommendation and gypsum application @ 15 kg ha^{-1} and 30 kg ha^{-1}. The lowest yield was for NPK treatment alone with no S fertilizer.

. 4.3.2. Number of pods per plant

There was significant effect of sulphur application on the number of pods per plants. At different sources of sulphur increase in sulphur levels up to 30 kg ha^{-1} increased the pod yield (Table 9). The maximum number of pods was recorded with T_6 [11.6] which was

Table 9. Effect of S application on yield and yield attributes

Treatments	Grain yield(kg ha^{-1})	Pods per plant	Seeds per pod	Bhusa yield(kg ha^{-1})	Dry matter (kg ha^{-1})	Harvest index
T_1	737.83	6.00	7.66	1830.40	2913.63	0.29
T_2	696.70	4.80	6.86	1781.93	2823.18	0.28
T_3	804.90	7.40	9.23	1888.06	3155.30	0.30
T_4	895.86	8.20	12.20	1955.32	3318.33	0.31
T_5	924.89	9.80	10.53	1986.96	3382.05	0.32
T_6	988.98	11.60	12.10	2070.40	3455.94	0.32
T_7	754.13	6.10	9.06	1941.45	3253.75	0.28
T_8	822.53	7.30	10.76	1951.80	3150.36	0.30
T_9	781.50	8.70	9.86	1921.70	3162.56	0.29
T_{10}	839.26	10.50	11.06	2016.60	3200.66	0.29
$F_{9,18}$	12.72**	73.62**	60.68**	6.036**	6.391**	4.7**
SE	25.32	0.25	0.23	34.63	77.10	0.01
CD(0.05)	75.24	0.74	0.67	102.92	229.11	0.02

** Significant at 0.01 level

found to differ significantly from all other treatments. While considering the two sources, gypsum was superior to factamphos in arising the number of pods. Significantly minimum pod yield was obtained from T_2 [treatment with NPK only].

4.3.3. Number of seeds per pod

Number of seeds per pod was significantly influenced by sulphur nutrition. With increased dose of S fertilizers, the number of seeds per pod showed an increase (Table 9). Maximum number of seeds was obtained with T_4 [12.2]. But T_6 was found to be on par with this [12.1]. Sulphur application @ 30 kg ha^{-1} was found to be superior in increasing the number of seeds per pod i.e.T_4,T_6.T_{10} and T_8 were found to be superior to all other treatments.But treatment with 15 kg S ha^{-1} through gypsum and POP recommendation was found to be on par with T_8. Treatment with NPK only [T_2] recorded significantly minimum number of seeds per pod [6.86].

4.3.4. Bhusa Yield

Bhusa yield (Table 9) was significantly enhanced by different levels and sources of sulphur application. Maximum yield was recorded with treatment having gypsum as the source of S @ 30 kg ha^{-1} along with POP recommendation [2070.40 kg ha^{-1}]. But this was on par with T_{10} and T_5 [2016.66 kg ha^{-1} and 1986.96 kg ha^{-1} respectively]. Considering the sources of S fertilizers, gypsum was found to be superior to factamphos in enhancing the bhusa yield. POP recommendations without S recorded higher yield over the treatment with NPK application only. But the effect was not significant.

4.3.5. Total dry matter production

Sulphur fertilization could significantly influence the total dry matter production. Maximum value [3455.94] was recorded in the case of treatment with 30 kg S ha^{-1} through gypsum along with POP recommendation (Table 9).This was found to be on par with T_5, T_4 and T_7 [3382.05 kg ha^{-1}, 3318.33 kg ha^{-1} and 3253.75 kg ha^{-1} respectively]. Lowest value was recorded for T_2 [NPK only], which did not differ significantly from T_1 [POP recommendation].

Table 9. Effect of S application on yield and yield attributes

Treatments	Grain yield(kg ha^{-1})	Pods per plant	Seeds per pod	Bhusa yield(kg ha^{-1})	Dry matter (kg ha^{-1})	Harvest index
T_1	737.83	6.00	7.66	1830.40	2913.63	0.29
T_2	696.70	4.80	6.86	1781.93	2823.18	0.28
T_3	804.90	7.40	9.23	1888.06	3155.30	0.30
T_4	895.86	8.20	12.20	1955.32	3318.33	0.31
T_5	924.89	9.80	10.53	1986.96	3382.05	0.32
T_6	988.98	11.60	12.10	2070.40	3455.94	0.32
T_7	754.13	6.10	9.06	1941.45	3253.75	0.28
T_8	822.53	7.30	10.76	1951.80	3150.36	0.30
T_9	781.50	8.70	9.86	1921.70	3162.56	0.29
T_{10}	839.26	10.50	11.06	2016.60	3200.66	0.29
$F_{9,18}$	12.72**	73.62**	60.68**	6.036**	6.391**	4.7**
SE	25.32	0.25	0.23	34.63	77.10	0.01
CD(0.05)	75.24	0.74	0.67	102.92	229.11	0.02

** Significant at 0.01 level

found to differ significantly from all other treatments. While considering the two sources, gypsum was superior to factamphos in arising the number of pods. Significantly minimum pod yield was obtained from T_2 [treatment with NPK only].

4.3.3. Number of seeds per pod

Number of seeds per pod was significantly influenced by sulphur nutrition. With increased dose of S fertilizers, the number of seeds per pod showed an increase (Table 9). Maximum number of seeds was obtained with T_4 [12.2]. But T_6 was found to be on par with this [12.1]. Sulphur application @ 30 kg ha^{-1} was found to be superior in increasing the number of seeds per pod i.e.T_4,T_6.T_{10} and T_8 were found to be superior to all other treatments.But treatment with 15 kg S ha^{-1} through gypsum and POP recommendation was found to be on par with T_8. Treatment with NPK only [T_2] recorded significantly minimum number of seeds per pod [6.86].

4.3.4. Bhusa Yield

Bhusa yield (Table 9) was significantly enhanced by different levels and sources of sulphur application. Maximum yield was recorded with treatment having gypsum as the source of S @ 30 kg ha^{-1} along with POP recommendation [2070.40 kg ha^{-1}]. But this was on par with T_{10} and T_5 [2016.66 kg ha^{-1} and 1986.96 kg ha^{-1} respectively]. Considering the sources of S fertilizers, gypsum was found to be superior to factamphos in enhancing the bhusa yield. POP recommendations without S recorded higher yield over the treatment with NPK application only. But the effect was not significant.

4.3.5. Total dry matter production

Sulphur fertilization could significantly influence the total dry matter production. Maximum value [3455.94] was recorded in the case of treatment with 30 kg S ha^{-1} through gypsum along with POP recommendation (Table 9).This was found to be on par with T_5, T_4 and T_7 [3382.05 kg ha^{-1}, 3318.33 kg ha^{-1} and 3253.75 kg ha^{-1} respectively]. Lowest value was recorded for T_2 [NPK only], which did not differ significantly from T_1 [POP recommendation].

4.3.6. Harvest index

Treatments with sulphur showed significant effect on harvest index. Considering each source, increased rate of sulphur application showed subsequent rise in HI of cowpea (Table 9). Maximum HI of 0.322 was recorded for treatment with 30 kg S ha^{-1} using gypsum as source along with POP recommendations, which was on par with T_5 and T_4. All other treatments recorded lower values for HI. Different sources failed to produce any significant effect on HI.

4.4 Soil Nutrients

4.4.1. Available Nitrogen

Available N status of the soil at MF and harvest stage was recorded. At both stages the N content in soil was found to be significantly influenced by sulphur fertilization. Maximum available N was found in T_3 at MFS (243.24 kg ha^{-1}) (Table 10). At harvest stage, T_1 [POP recommendation] recorded maximum value [225.52 kg ha^{-1}] which was on par with T_2 [225.51 kg ha^{-1}] The lowest value was noted in the case of T_{10} at both stages.

4.4.2. Available Phosphorus

Treatments with S produced significant influence on available P in soil at MFS (Table 10). But failed to produce any significant effect at harvest. POP recommendation recorded maximum value of 18.34 kg ha^{-1} and 14.2 kg ha^{-1} at MFS and harvest respectively. Lowest value was noticed in the case of POP recommendations with S @ 15 kg ha^{-1} as gypsum at both stages [15.32 kg ha^{-1} and 10.47 kg ha^{-1} at MFS and harvest stage respectively] .

4.4.3. Available Potassium

S fertilization could not produce any significant effect on available K status of soil at MFS and harvest . Highest value was recorded (Table 11) for treatment with POP recommendation at both stages where as lowest value was for treatment with NPK only{T_2} at MFS and at harvest..

Table 10. Effect of S application on available N and P in soil

	Available nitrogen (Kg ha^{-1})		Available phosphorus (kg ha^{-1})	
Treatments	MFS	H	MFS	H
T_1	240.00	225.52	18.34	14.20
T_2	238.34	225.51	17.17	13.01
T_3	243.24	221.02	16.84	12.13
T_4	220.52	214.67	16.84	12.57
T_5	221.35	209.18	15.32	10.47
T_6	214.35	204.59	15.64	13.34
T_7	239.12	222.90	17.09	12.82
T_8	220.83	202.67	16.72	13.29
T_9	220.61	201.50	16.16	12.02
T_{10}	217.64	199.59	16.65	12.95
$F_{9,18}$	36.908**	16.48**	1.42**	3.048**
SE	1.82	2.57	0.71	0.57
CD(0.05)	5.42	7.64	2.09	1.69

** Significant at 0.01 level

4.4.4. Exchangeable Calcium

Sulphur application could significantly influence the exchangeable Ca content in soil at MFS and harvest. At MFS, maximum value of 1.33 c mol kg $^{-1}$ was recorded (Table 11) by the application of S fertilizers @ 30 kg ha $^{-1}$ along with POP recommendation [T_6] which was on par with T_5, T_{10}, T_9, T_8 and T_4. At harvest, maximum value of 0.823 c mol kg $^{-1}$ was recorded by treatments with 15 kg ha^{-1}, and 30 kg ha $^{-1}$ respectively through gypsum. T_5, T_6, T_9 and T_{10} were on par with this. Lowest value at MFS was observed for treatments without any S [T_1 and T_2].

4.4.5. Exchangeable Magnesium

Exchangeable Mg in soil at MFS and harvest stage was not significantly influenced by S fertilization (Table 12). However, highest value was recorded for T_6 [gypsum @ 30 kg ha $^{-1}$ along with POP recommendations] at MFS and NPK alone at harvest stage.

4.4.6. Available Sulphur

S fertilization at various levels and through different sources had significant effect on available S status of soil. At MFS and harvest stage, significantly maximum value was recorded (Table 12) by gypsum application @ 30 kg S ha^{-1} along with POP recommendations [21.38 and 20 ppm respectively]. With increase in the rate of S application using given sources, S levels of soil showed an increase. Various sources could not make any significant effect. The lowest value was recorded by POP recommendation at MFS and NPK alone at harvest.

4. 5 Nutrient content in plants

4. 5. 1. Nitrogen

S application showed significant influence on the N content in plant. It increased with increasing levels of sulphur through different sources. At MFS, S fertilization at 30 kg ha^{-1} was found to be superior among other treatments (Table 13). Treatment with S @ 30 kg ha^{-1} using factamphos as the source along with POP recommendations recorded maximum N content of 3.60 %. This was found to be on par with treatments with POP recommendations and gypsum @ 30

Table 11. Effect of S application on available K and exchangeable Ca in soil

Treatments	Available potassium (kg ha^{-1})		Exchangeable calcium(c mol kg^{-1})	
	MFS	H	MFS	H
T_1	169.33	157.54	1.21	0.73
T_2	154.15	145.92	1.21	0.69
T_3	158.05	148.30	1.22	0.73
T_4	164.98	152.65	1.28	0.79
T_5	163.59	151.03	1.32	0.82
T_6	163.49	149.98	1.33	0.82
T_7	168.48	151.90	1.23	0.73
T_8	157.45	143.00	1.28	0.68
T_9	160.07	148.38	130.00	0.80
T_{10}	161.39	145.88	1.32	0.82
$F_{9,18}$	1.63	1.02	5.436**	15.1**
SE	3.78	4.08	0.02	0.01
CD(0.05)	11.25	12.12	0.06	0.04

** Significant at 0.01 level

Table 12. Effect of S application on exchangeable Mg and available S in soil

Treatments	Exchangeable magnesium(c mol kg^{-1})		Available sulphur (ppm)	
	MFS	H	MFS	H
T_1	3.06	2.23	9.49	8.58
T_2	3.10	2.46	9.66	8.27
T_3	2.90	2.17	15.38	14.16
T_4	2.90	2.22	17.53	16.26
T_5	2.91	2.22	19.66	18.24
T_6	3.15	2.18	21.38	20.00
T_7	3.02	2.27	18.00	16.33
T_8	3.06	2.31	18.25	16.72
T_9	3.03	2.27	17.81	16.22
T_{10}	3.03	2.19	18.96	17.92
$F_{9,18}$	0.32	0.65	101.68**	98.67**
SE	0.16	0.11	0.40	0.39
CD(0.05)	0.46	0.32	1.18	1.17

** Significant at 0.01 level

and 15 kg S ha $^{-1}$ Lowest value was recorded for treatment with NPK only .At harvest , highest N content was obtained for T_8 [i.e.NPK and 30 kg S ha $^{-1}$ as factamphos] Factamphos application with S @ 15 kg ha^{-1} along with POP recommendation [T_3] was found to have lowest N content at harvest.

4. 5. 2. Phosphorus

The effect of sulphur could not significantly influence the plant P content (Table 13). However the highest values were obtained for treatments with 30 kg S ha $^{-1}$ as gypsum and NPK [T_{10}] in both stages.

4. 5. 3. Potassium

Plant K content was significantly influenced by S application through different sources and at various levels (Table 13). Maximum K content of 0.83 % was recorded by application of S @ 15 kg ha^{-1} along with POP recommendation at MFS. The source used was gypsum. This was on par with T_4,T_7, T_{10} and T_9 .At harvest also, the same treatment (T_5) recorded maximum value of 0.72 % whereas the lowest value was observed for treatment having NPK only in both cases. Different sources could not make any significant effect on plant K content.

4. 5. 4. Calcium

Different levels and sources of S produced significant effect on plant Ca content at both stages. Highest Ca content of 1.37% was recorded for treatment with POP recommendations along with S @ 15 kg ha^{-1} as gypsum [T_5]. T_6 and T_9 were found to be on par with T_5. While at harvest , the maximum value [1.25%] was recorded for treatment with POP recommendation and S @ 30 kg ha^{-1} as gypsum, which was on par with T_5,T_3,T_1 and T_9. At harvest, treatments without S were found to be significantly inferior to other treatments (Table 14). Lowest Ca content was observed for POP recommendation without S at MFS where as treatment with NPK alone recorded the minimum Ca content at harvest.

Table 13 Effect of S application on N,P, and K contents in plants

Treatments	Nitrogen%		Phophorus%		Potassium%	
	MFS	H	MFS	H	MFS	H
T_1	3.05	2.16	0.229	0.201	0.70	0.59
T_2	3.13	2.19	0.216	0.197	0.67	0.52
T_3	3.20	2.13	0.233	0.208	0.71	0.58
T_4	3.60	2.43	0.228	0.211	0.81	0.70
T_5	3.49	2.40	0.225	0.221	0.83	0.72
T_6	3.56	2.41	0.222	0.204	0.75	0.68
T_7	3.15	2.21	0.229	0.215	0.80	0.69
T_8	3.35	2.48	0.232	0.212	0.76	0.65
T_9	3.21	2.40	0.231	0.221	0.78	0.67
T_{10}	3.38	2.39	0.246	0.242	0.78	0.68
$F_{9,18}$	6.96**	3.19*	0.672	1.437	4.84**	8.42**
SE	0.07	0.07	0.010	0.010	0.02	0.02
CD(0.05)	0.22	0.22	0.028	0.032	0.07	0.06

** Significant at 0.01 level

*Significant at 0.05 level

4. 5. 5. Magnesium

At MFS and harvest, different levels and sources of S could not produce any significant impact on plant Mg content (Table 14). However highest value was obtained for treatment with factamphos containing S @ 15 kg ha^{-1} along with NPK at MFS. At harvest, POP recommendation with S @ 15 kg ha^{-1} as factamphos recorded the highest value (0.291)

4. 5. 6. Sulphur

Per cent of plant S at MFS and harvest stage was recorded. At both stages the S content was found to be significantly increased by different levels and sources of S (Table 14). Treatment with POP recommendation along with S @ 30 kg ha^{-1} using gypsum recorded maximum value of 0.22 % and 0.20 % respectively at MFS and harvest. At MFS T_6 was seemed to be on par with T_{10} [treatment with gypsum and NPK application, rate being 30 kg S ha^{-1}]. But at harvest , T_6 was found to be significantly superior. At both stages, gypsum @ 30 kg S ha^{-1} was found to be superior to all other treatments in raising the S content. A progressive enhancement in S content was noticed by increasing the rate of S application through different sources. Among different treatments combinations, NPK alone recorded the lowest value in both cases.

4. 6. Nutrient content in grains

4. 6. 1. Nitrogen

N content in grain was found to be significantly increased by S nutrition. Maximum value for grain N was observed for T_6 (4.18), treatment with S @ 30 kg ha^{-1} using gypsum along with POP recommendation .This was significantly superior to all other treatments . There was progressive increase in grain N content with increasing rates of S application through various sources (Table 15).Lowest value for grain N content was noticed for treatment with NPK application alone .

Table 14 Effect of S application on Ca,Mg and S contents in plants

Treatments	Calcium %		Magnesium%		Sulphur %	
	MFS	H	MFS	H	MFS	H
T_1	1.20	0.84	0.287	0.304	0.063	0.080
T_2	1.21	0.79	0.288	0.302	0.060	0.070
T_3	1.31	1.24	0.292	0.310	0.090	0.110
T_4	1.22	1.06	0.273	0.301	0.170	0.200
T_5	1.37	1.24	0.274	0.312	0.180	0.200
T_6	1.36	1.25	0.280	0.304	0.200	0.220
T_7	1.23	1.15	0.291	0.321	0.156	0.180
T_8	1.27	1.15	0.280	0.306	0.170	0.190
T_9	1.33	1.21	0.272	0.294	0.173	0.190
T_{10}	1.32	1.21	0.284	0.308	0.183	0.231
$F_{9,18}$	19.33**	85.12**	0.474	1.100	102.01**	79.13**
SE	0.01	0.02	0.011	0.007	0.005	0.006
CD(0.05)	0.04	0.05	0.032	0.020	0.010	0.019

** Significant at 0.01 level

Table 15 Effect of S application on nutrient contents in grain

Treatments	Nitrogen (%)	Phosphorus(%)	Potassium (%)	Calcium (%)	Magnesium (%)	Sulphur (%)
T_1	3.36	0.414	1.52	0.073	0.189	0.226
T_2	3.33	0.410	1.52	0.072	0.181	0.223
T_3	3.37	0.421	1.50	0.083	0.178	0.300
T_4	3.96	0.420	1.48	0.092	0.183	0.386
T_5	3.74	0.415	1.54	0.123	0.193	0.283
T_6	4.18	0.418	1.54	0.131	0.190	0.376
T_7	3.35	0.420	1.54	0.086	0.199	0.300
T_8	3.38	0.428	1.59	0.102	0.188	0.386
T_9	3.39	0.419	1.57	0.123	0.177	0.303
T_{10}	3.66	0.416	1.56	0.124	0.180	0.376
$F_{9,18}$	23.62**	0.256	1.002	4.15**	0.637	38.84**
SE	0.061	0.009	0.029	0.006	0.009	0.01
CD(0.05)	0.184	0.029	0.086	0.017	0.026	0.03

** significant at 0.01 level

4. 6. 2 Phosphorus

Different levels and sources of S could not make any significant impact on grain P content. Though not significant, maximum P content was recorded (Table 15) for treatment using factamphos @ 30 kg S ha^{-1} along with NPK .

4. 6. 3. Potassium

Observations on grain K content revealed (Table 15) that it was not significantly influenced by different levels of sulphur nutrition through various sources. Among the different treatments, treatment using NPK and factamphos, @ 30 kg S ha^{-1} [T_8] recorded highest grain K content .

4. 6. 4. Calcium

Effect of S application was significant in influencing the Ca content in grain. Among the different treatment combinations, POP recommendation along with gypsum @ 30 kg S ha^{-1} recorded the maximum value of 0.131% [T_6]. Treatments with gypsum was found to be superior (Table 15). T_6 was found to be on par with T_{10}, T_9 and T_5. The lowest grain Ca content was recorded for treatment with NPK only [T_2]. Progressive increase in Ca content was noticed with increased S rates through different sources.

4. 6. 5. Magnesium

No significant effect was noticed for grain Mg content by S application at various levels through different sources (Table 15). However, among different treatments, highest value for grain Mg was obtained for T_7 [0.199%], the treatment with 15 kg S ha^{-1} through factamphos along with NPK.

4. 6. 6. Sulphur

S content in grain was significantly enhanced by the application of different S fertilizers. An increasing trend was noticed (Table 15) at enhanced rate of S application through various sources. Maximum grain S content of 0.386% was recorded by T_4 and T_8, both having factamphos as source of S @ 30 kg ha^{-1} with and without FYM. T_6 and T_{10} were on par with this.

S application @ 30 kg ha^{-1} was found to be superior to all other treatments in rising the S content of grains irrespective of the source used. Treatment with NPK alone [T_2] had the lowest grain S content of 0.223%. Treatments without S were found to be inferior to all other treatments.

4. 7. Uptake of nutrients by plants

4. 7. 1. Nitrogen

Sulphur application showed marked influence (Table 16) on the uptake of the N at MFS and harvest. At MFS treatment with S @ 30 kg ha^{-1} through gypsum along with POP recommendation recorded significantly maximum uptake of 33.66 kg ha^{-1}. With different sources, increased rate of S application caused an enhancement in N uptake. Significantly minimum uptake was for treatment with NPK alone [20.99 kg ha^{-1}]. Treatments without sulphur were found to be significantly inferior to other treatments. While considering the harvest stage, highest uptake was for T_6 [49.89 kg ha^{-1}] and lowest value was for treatment with NPK alone [37.43 kg ha^{-1}].

4. 7. 2. Phosphorus

S nutrition could produce a significant effect on uptake of P at harvest. But failed to produce any impact at MFS (Table 16) At MFS, T_{10} recorded highest P uptake of 4.96 kg ha^{-1}. At harvest, maximum uptake was for treatment with NPK application along with S @ 30 kg ha^{-1} using gypsum as source. [i.e.T_{10} with an uptake of 4.87 kg ha^{-1}]. But it was on par with T_5 [treatment with S @ 15kg ha^{-1} using gypsum along with POP recommendation]. Lowest value for treatment with NPK only at both stages.

4. 7. 3. Potassium

At MFS and harvest, K uptake was noted. S application could significantly influence the uptake of K at both stages (Table 16). Maximum value was for treatment with gypsum @ 15 kg S ha^{-1} along with POP recommendation, the uptake being 16.90 kg ha^{-1}. This was on par with T_4, T_{10},T_6 and T_7. Lowest value was for NPK alone. This was significantly inferior to all sulphur applied treatments. At harvest, treatment with S @ 15 kg ha^{-1} along with POP recommendation

Table 16 Effect of S application on uptake of N P K by plant ($kg\ ha^{-1}$)

Treatments	Nitrogen		Phosphorus		Potassiun	
	MFS	H	MFS	H	MFS	H
T_1	22.16	39.63	4.20	3.67	12.80	10.79
T_2	20.99	37.43	3.85	3.50	11.92	9.31
T_3	26.01	40.27	4.40	3.93	13.47	11.06
T_4	32.27	47.50	4.47	4.13	15.91	13.69
T_5	32.24	47.84	4.48	4.40	16.90	14.42
T_6	33.66	49.89	4.60	4.23	15.68	14.15
T_7	23.74	43.40	4.16	4.31	15.52	12.98
T_8	27.56	48.85	4.53	4.14	14.84	12.69
T_9	25.13	46.21	4.45	4.26	14.99	12.95
T_{10}	28.39	48.22	4.96	4.87	15.86	13.85
$F_{9,18}$	139.49**	6.44**	2.18	4.74**	9.96**	12.12**
SE	0.35	1.71	0.20	0.18	0.50	0.48
CD(0.05)	1.11	5.09	0.59	0.52	1.48	1.43

** Significant at 0.01 level

using gypsum [T_5] recorded highest N uptake of 14.42 kg ha^{-1}. This was on par with T_6, T_{10} and T_4. Treatment with NPK only recorded an uptake of 9.31 kg ha^{-1} which was found to be inferior to all other treatments.

4. 7. 4. Calcium

S fertilization at different levels and through different sources could significantly increase the uptake of Ca at MFS and harvest (Table 17). T_6 i.e. gypsum application @ 30 kg ha^{-1} along with POP recommendations recorded the highest uptake at both stages. [The values being 28.54 kg ha^{-1} at MFS and 25 .91 kg ha^{-1} at harvest respectively]. At MFS, T_6 was found to be on par with T_5 where as at harvest T_5 and T_{10} were on par with T_6. Treatments without sulphur were found to be inferior to other treatments and had lowest Ca content in both cases. Uptake of Ca progressively increased with increasing level of S application through different sources except at T_3 and T_4.

4. 7. 5 Magnesium

Mg uptake by plant was significantly influenced by S nutrition at MFS whereas no significant effect was noticed during harvest stage. Maximum uptake of Mg was recorded (Table 17) for gypsum application @ 30 kg S ha^{-1} along with POP recommendations. This was found to be on par with T_7, T_{10} and T_5. Lowest uptake of Mg was for treatment without S and organic manure. Even though the effect was not significant at harvest, highest Mg uptake was for gypsum application at 30 kg S ha^{-1} along with POP recommendation.

4. 7. 6 Sulphur

S application at different rates and through different sources could significantly influence the uptake of S by plants at MFS and harvest stage (Table 17). Maximum uptake at both stages was noted for treatment with 30 kg S ha^{-1} as gypsum along with POP recommendation. T_6 was found to he significantly superior at harvest stage while at MFS T_{10} was on par with T_6.The maximum uptake being 4.67 kg ha^{-1} and 4.35 kg ha^{-1} at MFS and harvest stage respectively. Lowest value was obtained for T_2 in both cases, i.e. treatment with NPK only. Among different

Table 17 Effect of S application on uptake of Ca, Mg and S by plants (Kg ha $^{-1}$)

Treatments	Calcium		Magnesium		Sulphur	
	MFS	H	MFS	H	MFS	H
T_1	22.02	15.42	5.57	5.26	1.46	1.16
T_2	21.62	14.13	5.39	5.13	1.30	1.08
T_3	24.80	23.39	5.86	5.52	2.20	1.70
T_4	23.82	20.76	5.90	5.32	3.91	3.39
T_5	27.21	24.70	6.20	5.47	4.11	3.56
T_6	28.54	25.91	6.31	5.81	4.67	4.35
T_7	24.00	22.38	6.24	5.60	3.49	3.04
T_8	24.77	22.55	5.98	5.48	3.84	3.35
T_9	25.56	23.24	5.83	5.36	3.71	3.33
T_{10}	26.67	24.52	6.23	5.73	4.30	3.69
$F_{9,18}$	17.06**	61.37**	3.10*	1.15	59.64**	152.68**
SE	0.53	0.50	0.17	0.20	0.16	0.09
CD(0.05)	1.58	1.48	0.16	0.60	0.46	0.27

** Significant at 0.01 level

*Significant at 0.05 level

treatment combinations, treatments with S were found to have significantly superior effect to treatments without sulphur in the case of uptake of S by plants.

4. 7. 1. Grain uptake of nutrients

4. 7. 1. 1. Nitrogen

Uptake of N by grain was significantly influenced by S application at different levels and through different sources (Table 18). Gypsum application @ 30 kg S ha^{-1} along with POP recommendations had significantly maximum N uptake of 39.52 kg ha^{-1}. S application at high levels could cause an increase in N uptake. Lowest value was noted for T_2 [NPK alone]. A progressive increase in uptake was noticed with increasing rate of S application

4. 7. 1. 2. Phosphorus

Grain uptake of P was significantly influenced by sulphur nutrition (Table 18). Maximum uptake of 3.95 kg ha^{-1} was observed for T_6 [gypsum @ 30 kg S ha^{-1} along with POP recommendation]. At different sources, when the rate of S application was increased, an increase in grain uptake of P was noticed. T_5 and T_4 were found to be on par with T_6 [3.83 kg ha^{-1} and 3.75 kg ha^{-1} respectively]. Lowest grain P uptake was noticed for T_2 i.e. treatment without S and FYM.

4. 7. 1. 3. Potassium

S fertilization at different levels using different sources could significantly influence the grain K content. By increased rate of S application using different sources, enhanced uptake of grain K was noticed (Table 18). Maximum value was recorded for T_6 [14.61 kg ha^{-1}], the treatment with 30 kg S ha^{-1} as gypsum and POP recommendation. T_5 was on par with this [14.23 kg ha^{-1}]. Treatment having NPK application alone showed the lowest K uptake by grain {10.96 kg ha^{-1}].

4. 7. 1. 4. Calcium

Uptake of Ca by grain was significantly influenced by S fertilization through different sources and at different levels. Increased rates of S application through different sources could progressively increase the Ca uptake by grain (Table 18). Maximum uptake was for T_6 [gypsum @ 30 kg S ha^{-1} and POP recommendation]. T_5 was found to be on par with this. Factamphos @ 15 kg S ha^{-1} was found to be inferior to other treatments containing S. Minimum uptake was recorded for T_2, which was without organic manure and S.

4. 7. 1. 5. Magnesium

Uptake of Mg by grain was recorded (Table 18). A significant effect was noticed by S application. Increasing levels of S application through different sources significantly enhanced uptake. Lowest value was recorded for T_2 [1.3 kg ha^{-1}], the treatment with NPK alone. Maximum grain uptake was noticed for T_6 [1.79 kg ha^{-1}], which was on par with T_5, T_4 and T_8 [1.78, 1.64 and 1.54 kg ha^{-1} respectively]. POP recommendations with S @ 30 kg ha^{-1} using gypsum as source had the maximum uptake of Mg by grain.

4. 7. 1. 6. Sulphur

The effect of S application on grain uptake of S was noted (Table 18) . A significant influence was observed. Considering the different sources, a progressive increase in S uptake was noticed by increased rate of S application. Maximum S uptake of 3.56 kg ha^{-1} was noted for treatment with POP recommendation and gypsum @ 30 kg S ha^{-1}. T_4 was found to be on par with this [3.46 kg ha^{-1}]. S @ 30 kg ha^{-1} was found to be significantly superior to other S levels in enhancing the S uptake. Treatments without sulphur were found to be significantly inferior [i.e. T_1 and T_2] with an uptake of 1.71 kg ha^{-1} and 1.6 kg ha^{-1} respectively.

4. 8 N : S ratio

4. 8. 1. Plant N : S ratio

N:S ratio in plants at MFS and harvest were calculated (Table 20). At both stages significant effect was noticed by S application through different sources and at various levels. By progressive increase in S application, N: S ratio was found to be significantly decreased. Maximum value was recorded for treatment with NPK alone at MFS and differed significantly from other treatments. POP recommendation was found to be on par with NPK alone [T_2].

Table 18 Effect of S application on uptake of nutrients by grain(kg ha^{-1})

Treatments	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulphur
T_1	27.18	3.13	11.57	0.55	1.43	1.71
T_2	24.05	2.94	10.96	0.52	1.30	1.60
T_3	26.73	3.34	11.90	0.67	1.41	2.37
T_4	35.53	3.75	13.30	0.82	1.64	3.46
T_5	34.70	3.83	14.23	1.14	1.79	2.61
T_6	39.52	3.95	14.61	1.25	1.80	3.56
T_7	25.91	3.36	11.61	0.67	1.50	2.26
T_8	27.88	3.52	13.09	0.84	1.55	3.18
T_9	27.25	3.27	12.26	1.01	1.38	2.37
T_{10}	30.72	3.49	13.04	1.05	1.51	3.16
$F_{9,18}$	22.98**	8.556**	9.16**	23.31**	3.50*	35.66**
SE	1.04	0.11	0.40	0.05	0.09	0.12
CD(0.05)	3.10	0.32	1.18	0.15	0.26	0.34

** Significant at 0.01 level

*Significant at 0.05 level

Table 19 Effect of S application on total uptake of nutrients by plants (kg ha^{-1})

Treatments	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulphur
T_1	66.81	6.80	22.36	15.97	6.69	1.24
T_2	61.48	6.44	20.27	14.65	6.43	1.15
T_3	67.00	7.27	22.96	24.06	6.93	1.81
T_4	83.03	7.88	26.99	21.58	6.96	3.59
T_5	82.54	8.23	28.65	25.84	7.26	3.76
T_6	89.41	8.18	28.76	27.16	7.61	4.57
T_7	69.31	7.67	24.59	23.05	7.10	3.22
T_8	76.73	7.66	25.78	23.39	7.03	3.54
T_9	73.46	7.53	25.21	24.25	6.74	3.52
T_{10}	78.94	8.36	26.89	25.57	7.24	3.92

Lowest ratio of 15.86 was observed for treatment with NPK and S @ 30 kg ha^{-1} through gypsum at MFS. Considering the harvest stage, NPK alone recorded maximum value for N:S ratio which was on par with POP recommendation. Treatment with S application @ 30 kg ha^{-1} as gypsum along with POP recommendations gave minimum N:S ratio.

4. 8. 2. Grain N : S

Grain N:S ratio was significantly influenced by S fertilization. Maximum value was observed for POP recommendations which was on par with NPK alone (Table 21). Treatment with 30 kg S ha^{-1} as factamphos along with NPK application recorded lowest N:S ratio [8.74]. Progressive decrease in N:S ratio was noticed with increase in the rate of S application.

Correlation Studies

Yield and growth characters

It is revealed from the data presented in Table (21) that yield was significantly and positively correlated with height of the plant at 30,60 and 90 DAP. Other growth characters like number and weight of effective nodules, chlorophyll content and NRA also significantly influenced the grain yield. Height of the plant at 60 DAP showed the highest degree of correlation with grain yield ($r = 0.762$) Days to maximum flowering showed significantly negative correlation with yield.

Yield and quality attributes

Protein content in plant and grain was positively and significantly correlated with grain yield. Crude fibre content at MFS was found to have significant positive correlation with grain yield (Table 22). A significantly negative correlation was seen in the case of N : S ratio. Maximum r value was seen in grain protein content (0.839)

Table 20 Effect of S application on N:S ratio

Treatments	N:S ratio in plants at MFS	N:S ratio in plants at H	N:S ratio in grain
T_1	38.62	35.44	14.89
T_2	42.93	36.55	15.10
T_3	27.86	23.94	11.25
T_4	18.03	14.30	10.25
T_5	16.28	13.41	13.24
T_6	16.26	12.10	11.10
T_7	17.58	14.19	11.19
T_8	17.04	14.39	8.74
T_9	16.70	13.86	11.23
T_{10}	15.86	13.05	9.92
$F_{9,18}$	58.30**	51.37**	14.77**
SE	1.33	1.29	0.542
CD(0.05)	3.96	3.85	1.613

** significant at 0.01 level

Table 21 Correlation between yield and growth charecters

Growth character		Grain yield
Height of the plant	30 DAP	0.621**
Height of the plant	60 DAP	0762**
Height of the plant	90 DAP	0.751**
Number of branches plant $^{-1}$		0.222
Number of nodules pod $^{-1}$		0.743**
Weight of nodules plant $^{-1}$		0.753**
Days to MFS		- 604**
Chlorophyll		0.650**
NRA		0.615**

Table 22.Correlation between Yield and quality attributes

Quality attributes		Grainyield
Protein		
Plant	MFS	0.577**
Plant	H	0.592**
Grain		0.839**
Crude fibre	MFS	0.523**
Crude fibre	H	0.09
N : S ratio		
Plant	MFS	- 0.604**
Plant	H	- 0.611**
Grain		- 0.343**

**Significant at .01 level

Table 23.Correlation between yield and yield attributes

	No of pods / plant	Bhusa yield	DMP	HI
Yield	0.798**	0.636**	0.701**	0.881**

**Significant at .01 level

Yield and yield attributes

It is evident from the Table(23) that number of pods per plant, seeds per pod, bhusa yield, dry matter production and HI were significantly and positively correlated with grain yield. The highest correlation was shown with HI (0.881).

Yield and uptake of nutrients (Table. 24)

Plant uptake of N ,Ca, K and S at both stages was found to be significantly and positively correlated with grain yield. Uptake of P and Mg by plants at MFS was also significantly and positively correlated with grain yield. Highest correlation was shown with N uptake by plant at MFS (0.906). Grain uptake of N, P, K, Ca, Mg and S was positively and significantly correlated with grain yield. Grain uptake of K showed highest correlation with grain yield (0.940). Uptake of nutrients at MFS and yield was found to be more correlated when compared to uptake of nutrients at harvest stage.

Table 24.Correlation between yield and uptake of nutrients

	Uptake	Grain yield
Plant		
	N at MFS	0.906**
	N at H	0.623**
	Pat MFS	0.495**
	Pat H	0.412*
	K at MFS	0.591**
	K at H	0.660**
	Ca at MFS	0.724**
	Ca at H	0.663**
	Mg at MFS	0.460*
	Mg at H	0.291
	S atMFS	0.731**
	S at H	0.714**
Grain		
	N	0.923**
	P	0.894**
	K	0.940**
	Ca	0.802**
	Mg	0.805**
	S	0.814**

**Significant at .01 level

DISCUSSION

5 Discussion

A field experiment was conducted during Feb-May, 1998 at the Instructional farm, College of Agriculture, Vellayani to study the effect of sulphur application on the yield, quality and uptake of nutrients by cowpea. A critical analysis of the results of the experiment revealed marked response of the crop to S nutrition.

5. 1 Growth Characters

5. 1. 1 Height of the plants

Observations showed that the plant height at 30, 60 and 90 DAS was significantly influenced by S fertilization (Fig. 3). Sulphur @ 30 kg ha^{-1}along with POP recommendation recorded maximum height at three stages. Gypsum was used as the source in all the cases. Treatments with sulphur were found to be superior to treatments without sulphur. . Increased plant height by sulphur nutrition might be due to effects of S in metabolism of growing plants, increased photosynthetic rate, chlorophyll content and uptake of nutrients.. It is directly related with cell division, enlargement and elongation of cell. Similar enhancement in plant height of greengram by gypsum @ 40 kg S ha^{-1} was reported by Balasubrahmanian *et al*. [1996].

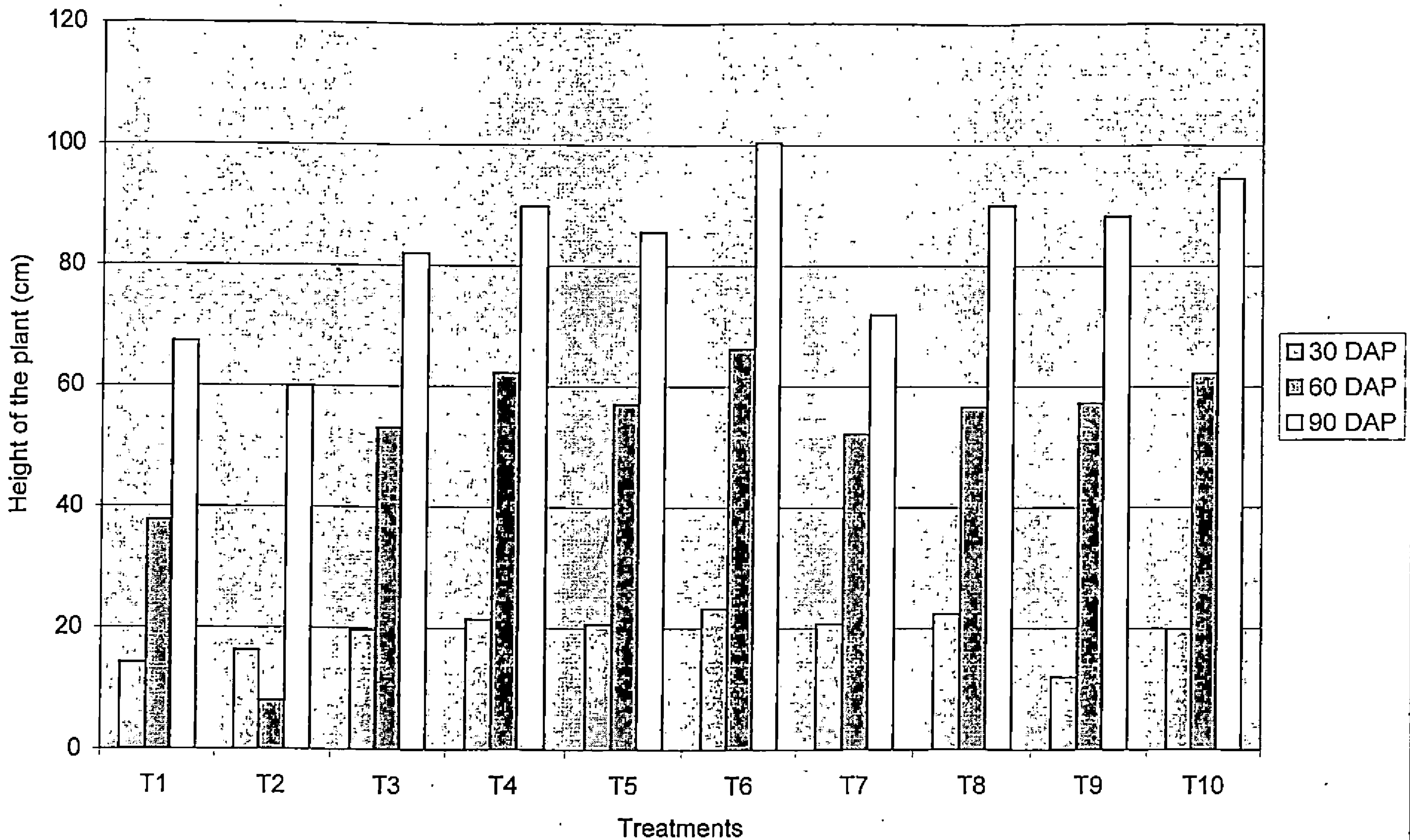
Continued application of organic manure along with S produced maximum plant height. Organic matter being a source of nutrients including S might have contributed to increased vegetative growth through out the growth period.

Increased plant height with 30 kg S ha^{-1} obtained in the present study is in accordance with results reported by Singh *et al.* [1997] in green gram. Application of 25 kg S ha^{-1} caused an increase in plant height in rice [Sudha, 1999].

5. 1. 2 Number of branches per plant

Results showed that highest number of branches per plant were recorded for treatment with S @ 30 kg ha^{-1} along with POP recommendation, the source being factamphos.. The increase in number of branches due to enhanced rate of S application was noticed byKachroo *et al.* [1997] in mustard and Bhadoria *et al* . [1997] in cluster bean. The significant positive

Fig.3 Effect of S application on height of the plants



influence of S application on S uptake and improvement in growth attributes might be the reason for increase in the number of branches. The increase in number of branches could also be attributed to over all improvement in plant vigour due to increased assimilation of photosynthates.

Treatment combination without OM and sulphur was found to be inferior to all other treatments. It is a well established fact that apart from the improvement in efficiency of applied mineral nutrients, organic manures ensure a steady supply of essential plant nutrients including secondary and micro nutrients throughout the growth period. This might have favoured increase in the number of branches by combined application of organic manure and sulphur.

5. 1. 3 Leaf Area Index

Sulphur fertilization produced significant positive effect on LAI at 30, 60 and 90 DAS(Fig 4). Maximum LAI at these three stages was recorded by the treatment with POP recommendations along with sulphur @ 30 kg ha^{-1}, the source being gypsum. S application @ 15 kg ha^{-1} could also influence the LAI. Combined application of sulphur and FYM also resulted in, significantly higher LAI over the control. Leaf area is a simple and appropriate measure of plant's photosynthetic potential. [Watson, 1952] A corresponding increase in size and number of leaves resulted in a subsequent increase in LAI. The higher S fertilizer @ 30 kg ha^{-1} has recorded maximum plant height and number of branches. Increased height and number of branches would cause an enhancement in the number of leaves. The increased trend in the number of leaves in greengram by S application was recorded by Singh *et al*. [1997]

Increased dose of S fertilizer along with FYM caused an increase in LAI. Organic manure helped in improving the efficiency of applied mineral nutrients and ensure a steady supply of primary and micronutrients required for vegetative growth. Increased LAI with 60 kg S ha^{-1} in mustard was reported by Upasani and Sharma [1988]. Sudha [1999] also reported an increase in LAI of rice by S application up to 25 kg ha^{-1}.

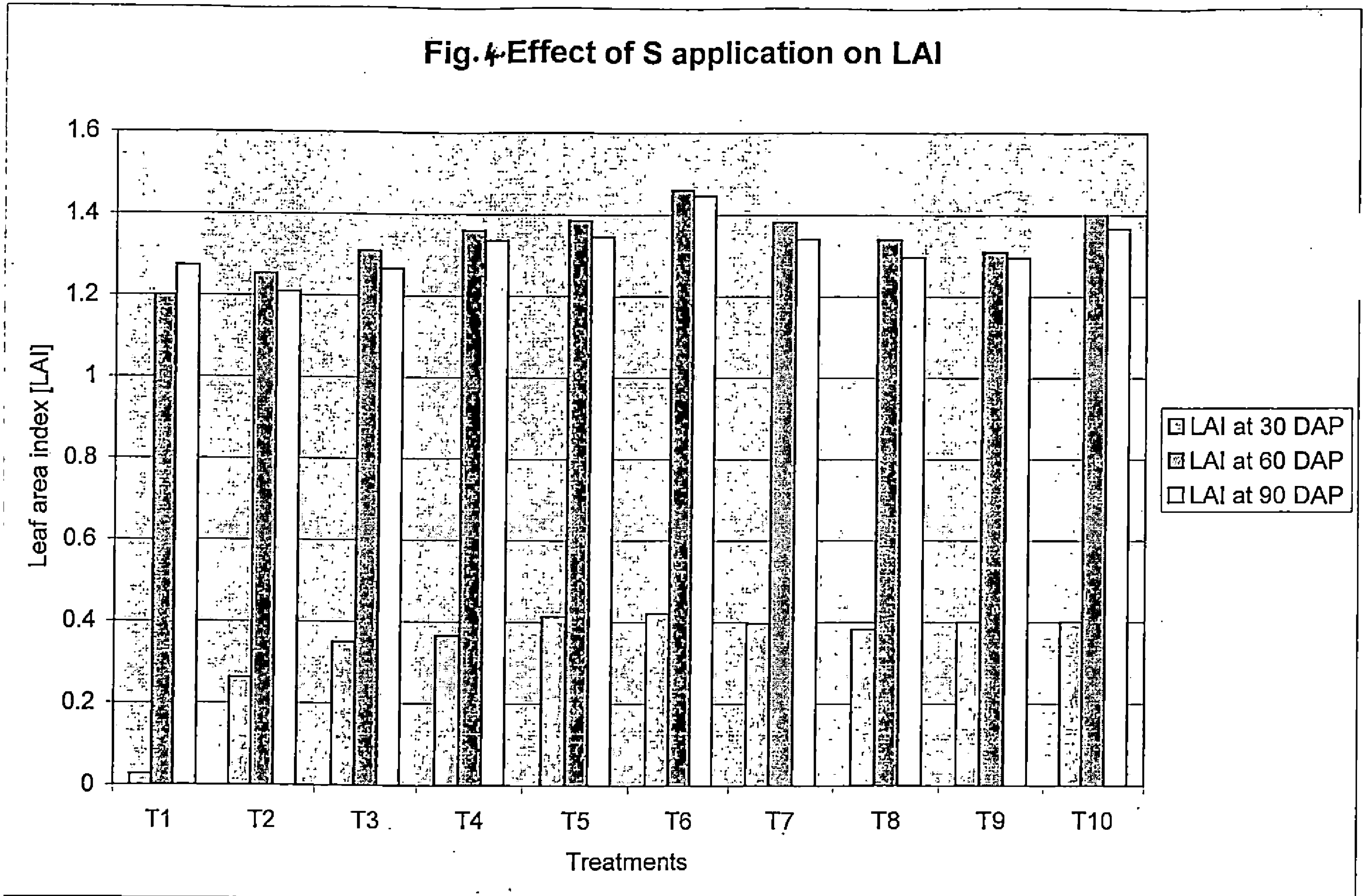


Fig. 4 Effect of S application on LAI
Leaf area index [LAI]
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
Treatments
LAI at 30 DAP
LAI at 60 DAP
LAI at 90 DAP

70

5. 1. 4. Number of effective nodules per plant

Maximum number of effective nodules was recorded by the treatment with 30 kg S ha^{-1} along with POP recommendations. Treatments with sulphur was found to be significant in influencing the number of effective nodules. While comparing the sources of sulphur application, gypsum was found to be superior to factamphos.. This helped in the production of large, branched and pinkish nodules High S application rate thus resulted in a significantly higher N accumulation, due to higher N fixation rate by nodules.

This observation of increased number of effective nodules per plant by application of S fertilizers is in conformity with the report of Shinde and Saraf. [1992], where S fertilizers up to 60 kg ha^{-1} resulted in an increase in number of nodules.

5. 1. 5. Weight of nodules per plant

Weight of nodules was maximum with the application of 30 kg S ha^{-1}. This was applied along with POP recommendations. This showed profound influence of S on increasing the weight of nodules. Higher dose of sulphur could promote number of effective nodules per plant there by increasing the weight of nodules. Nitrogen fixation is improved with sulphur application, which inturn helped in enhancing the nodule mass. High S application along with progressive increase in S uptake might have caused an increase in the production of more roots and nodule mass. This might also have contributed in increasing the dry weight of nodules.

Significantly higher weight of nodules was observed in treatments with S which indicates that an adequate level of S is required for N fixation by rhizobia. [Jogendra ,1997]. S is vital part of ferredoxins, a type of non haeme iron sulphur protein. Ferredoxin participates in oxidation - reduction reaction. It has a significant role in nitrate reduction and assimilation of N by root nodule bacteria. Among the two sources gypsum was found to be more effective in increasing the nodule dry weight . It is endorsed that gypsum is more effective in producing a favourable environment for the activity of nodule bacteria and helped in increasing the number and weight of nodules. Singh *et al*. [1997] reported similar increase in dry weight of nodules per plant with increased levels of S uptake up to 30 kg ha^{-1} in green gram. Scherer [1996] observed greater N fixation and nodule weight by high S application rate.

5. 1. 6 Days to maximum flowering

A decreasing trend was noticed in the case of days taken for maximum flowering with higher levels of S nutrition . Lesser number of days was taken for maximum flowering in the case of treatment with S @ 30 kg ha^{-1} as gypsum along with POP recommendation. This might be due to the fact that S application along with NPK and FYM caused an increased plant vigour. This would have helped the plants in reaching the reproductive phase earlier. With balanced fertilizer application, the vegetative growth was enhanced resulting in increased rate of photosynthesis. This might have helped in increased translocation of photosynthates thereby reaching the reproductive stage quite earlier. Treatments without S gave higher values compared to others .

5. 1. 7 Chlorophyll content

Chlorophyll content enhanced with increasing levels of sulphur. S application @ 30 kg ha^{-1} recorded significantly maximum chlorophyll content. (Fig. 5) Treatments with S gave higher chlorophyll content over control. This clearly indicates that S has a marked influence on the chlorophyll content of plant. This might be due to the increased availability of Fe by creating favourable cellular environment. S has got a synergestic effect on the uptake of iron. Adequate availability of Fe at the sites of porphyril biosynthesis may result in greater synthesis of chlorophyll. This was due to the high content of S in leaf at this stage, which might have made more Fe physiologically active for the synthesis of chlorophyll. Even though S is not a constituent of chlorophyll, it has been identified as essential for chlorophyll synthesis [Tisdale *et al.* 1985]. Similar increase in chlorophyll content of rice was found out by Sudha [1999]. Confirmatory results were reported by Qui [1989].

Treatment combination which recorded maximum chlorophyll content contained FYM also. The improvement in chlorophyll might have occurred due to enhancement in the availability

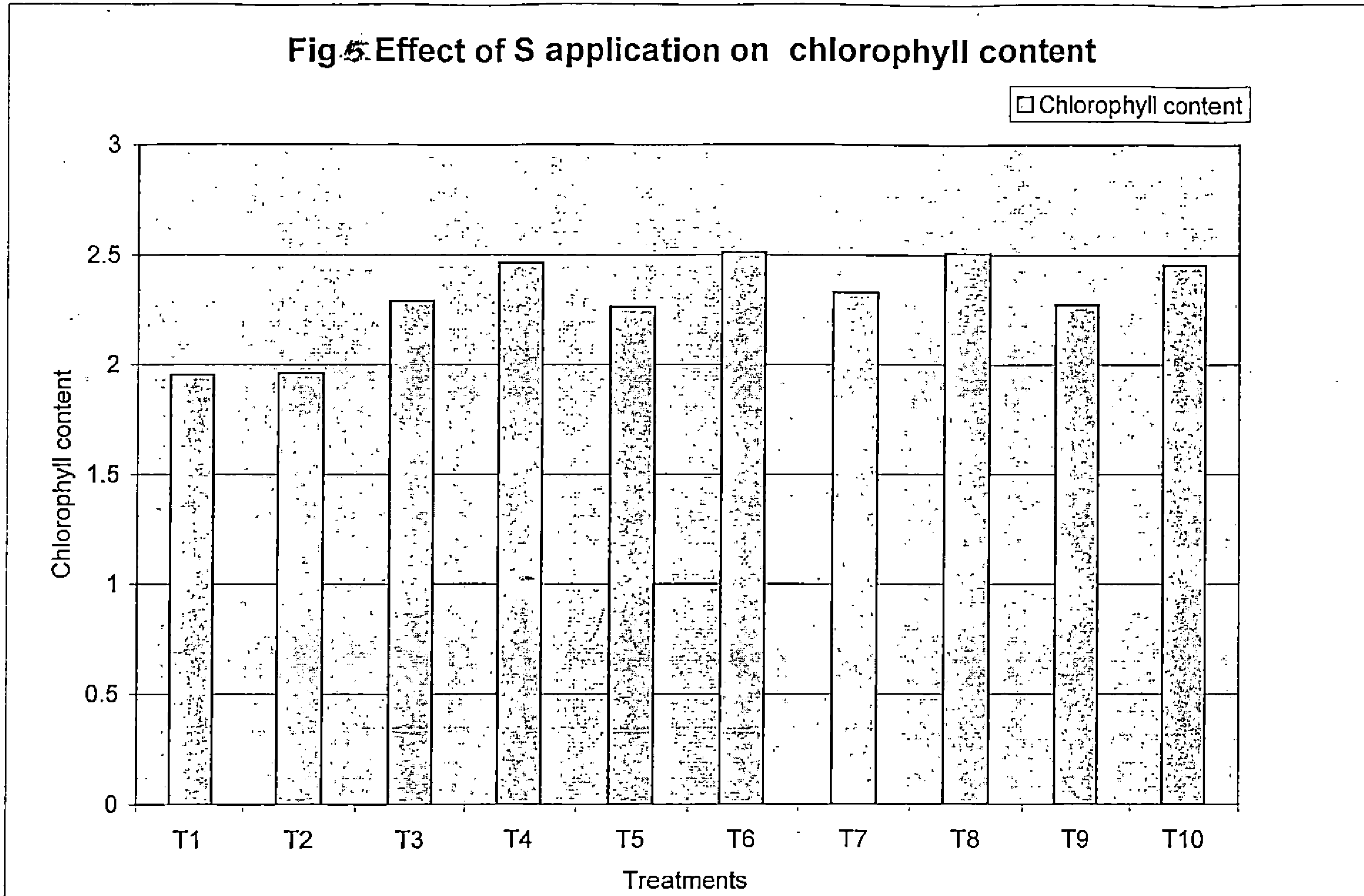


Fig 5 Effect of S application on chlorophyll content
Chlorophyll content
3
2.5
2
1.5
1
0.5
0
Chlorophyll content
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
Treatments

of micro and secondary nutrients including Fe and Mg respectively. Fe and Mg are known to have influence on chlorophyll synthesis.

5. 1. 8 Nitrate reductase activity

An increasing trend in NRA was noticed with higher levels of S application (Fig. 6). This might be due to the influence of sulphur on NRA. Nitrate reductase is a soluble molybdo flavo protein occuring in the envelope of chloroplasts. One of the main functions of S in proteins is the formation of disulphide bonds between poly peptide chains. S application @ 30 kg ha^{-1} along with POP recommendation recorded maximum value. Comparable effect was observed in the case of treatment with 15 kg ha^{-1}. This could be due to increased uptake of S by enhanced S addition which might have led to the enhancement in NRA. This is in agreement with increase in NRA reported by Qui [1989] due to S application.

Involvement of sulphur in NRA can be attributed to following reasons. S is a vital part of the ferredoxin, a type of non haem Fe – S protein occuring in the chloroplasts. Ferredoxin participates in oxido reduction processes by transferring electrons and has a significant role in nitrate reduction [Tisdale *et al.*1985]. Fe may also be capable of substitution for Mo as a cofactor necessary for the functioning of nitrate reductase.

5. 3 Yield and yield attributes

5. 3. 1 Grain yield

Different levels and sources of sulphur produced significant effect on grain yield (Fig. 7). S application at 390 kg ha^{-1} along with POP recommendations produced maximum grain yield. Within a given source, an increasing trend was noticed with higher rate of S application. Comparable yield was obtained with 15 kg S ha^{-1} using gypsum along with POP recommendations. The increase in yield might be due to S nutrition along with FYM. The increased availability of S in soil followed by increased plant uptake might have contributed to the improvement in the yield attributing characters which is reflected in enhanced grain yield. Tamak *et al.* [1997] observed that adequate supply of nutrients resulted in high production of

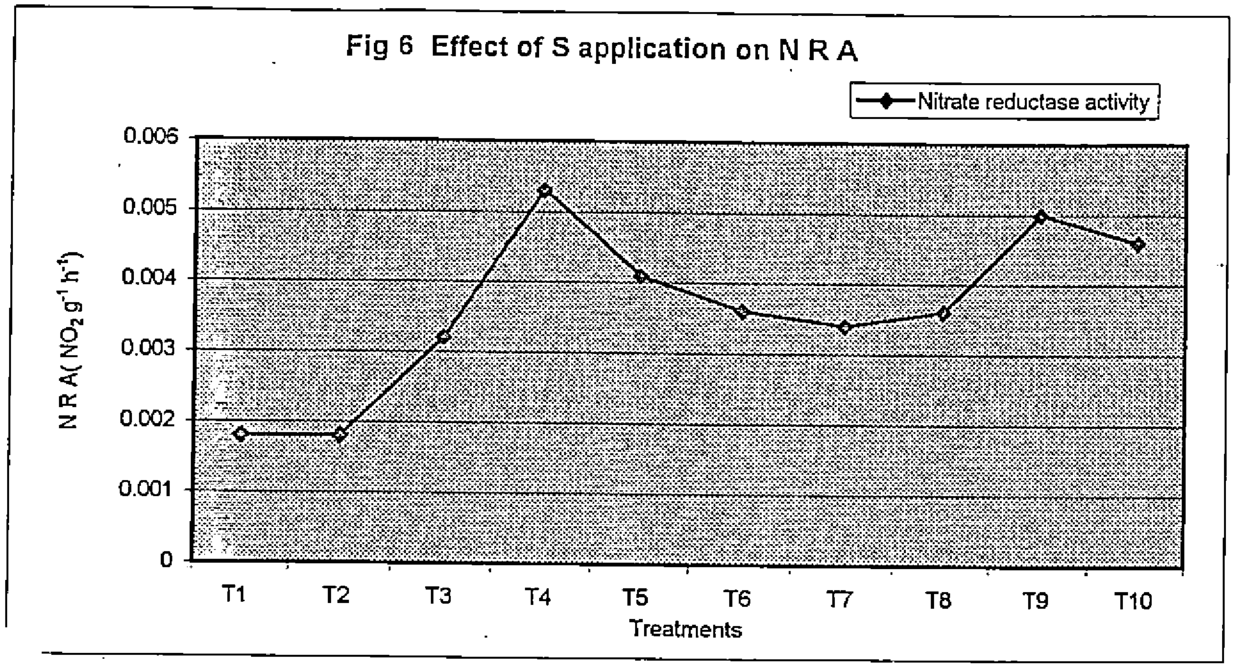


Fig 6 Effect of S application on N R A
Nitrate reductase activity
0.006
0.005
0.004
0.003
0.002
0.001
0
N R A(NO2 g-1 h-1)
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
Treatments

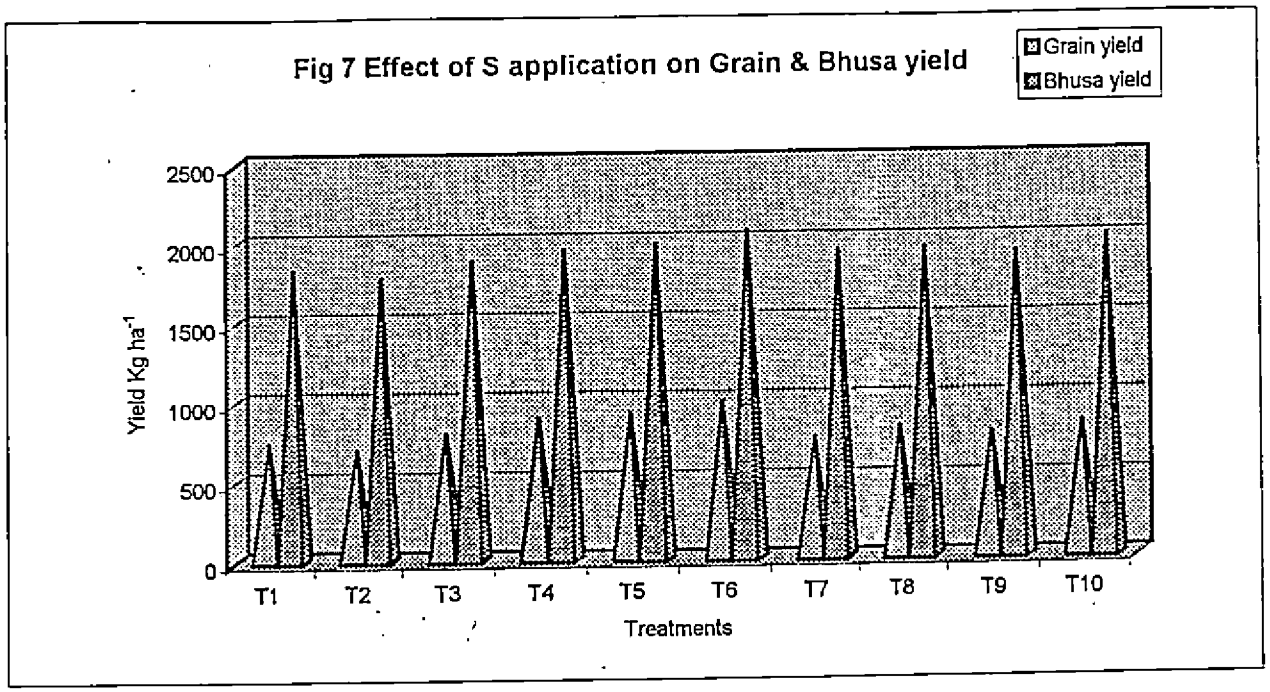


Fig 7 Effect of S application on Grain & Bhusa yield

photosynthates and their translocation to sink, causing an increase in leaf area and dry matter production ultimately resulting in high seed yield. It is also noticed that due to balanced nutrition, marked improvement in yield attributing characters was seen resulting in the production of greater number of pods, pod weight and heavier test weight. Efficient and greater partitioning of metabolites and adequate translocation of nutrients to the developing reproductive structures might have occurred.

Another factor responsible for yield increase might be improved S status in soil which resulted in bold grains and well filled pods, which inturn enhanced the grain yield.

Gypsum application produced significant effect on increasing the grain yield. This could be due to the fact that Ca present in gypsum might have reduced acidity and helped in maximum uptake of nutrients there by increasing the yield. High response to gypsum application might be due to readily available sulphate S in gypsum. Similar results by Sridhar *et al* [1985], Increased grain yield in cowpea due to S fertilization @ 10 kg ha^{-1} was also recorded by Kayode [1990].

Treatment combination which recorded highest yield contained FYM also. This might be due to the fact that FYM improves physical environment of soil and it is a source of almost all essential nutrients especially N and S which helped in improving the yield and yield attributes. The additional effect of FYM along with NPK in increasing the availability of nutrients to plants throughout the growth period resulted in superior yield.

5. 3. 2 Number of pods per plant

Number of pods per plant was significantly enhanced by S nutrition. Increasing levels of S enhanced the number of pods. The treatment combination which noticed the highest yield was for POP recommendation along with gypsum @ 30 kg S ha^{-1} . This was due to higher uptake and efficient utilization of nutrients by enhanced S application. S enhances fruit maturation and increase kernel weight Greater number of pods were produced because of balanced nutrition and efficient partitioning of metabolites there by adequate translocation of nutrients to the developing

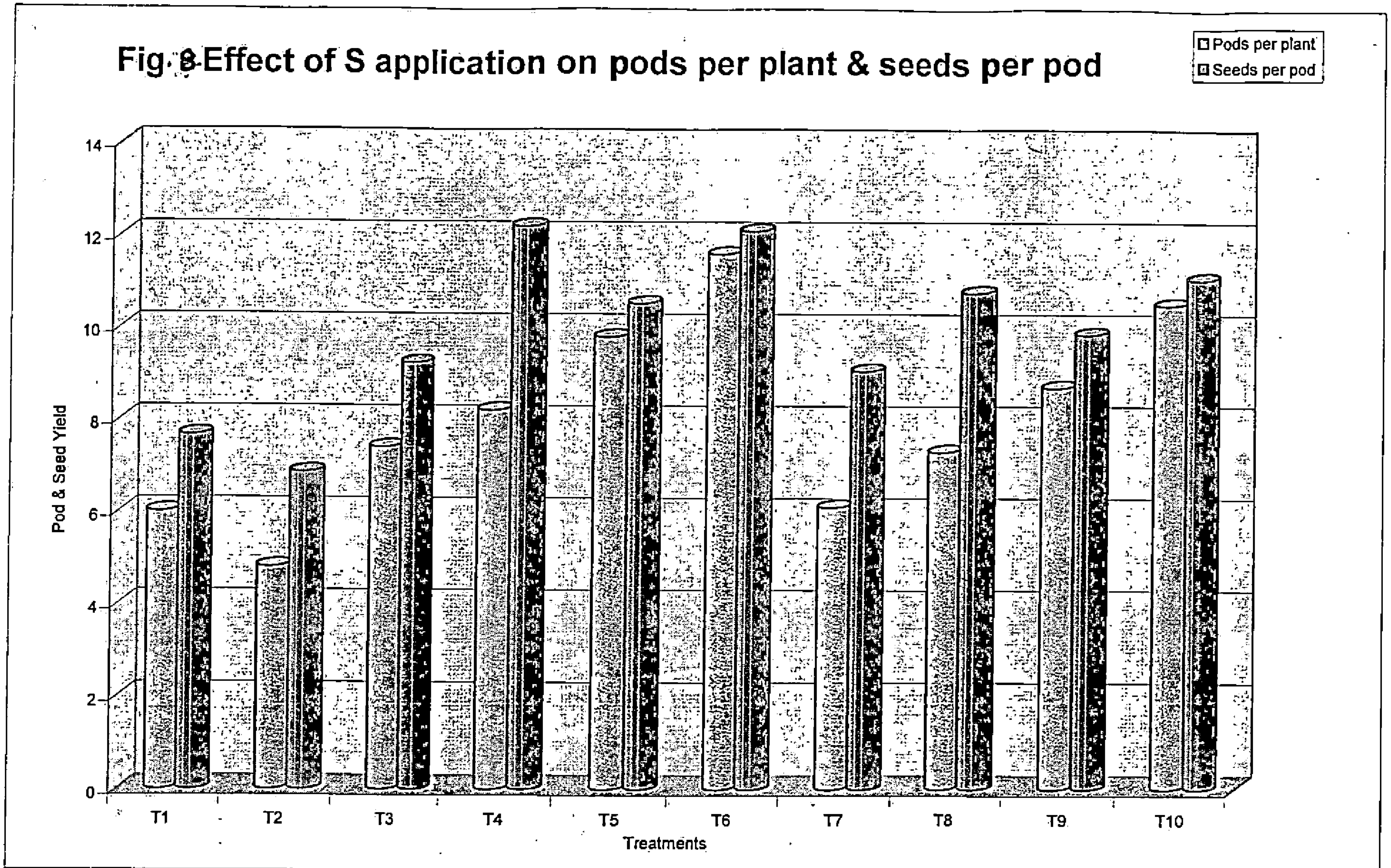


Fig. 8 Effect of S application on pods per plant & seeds per pod

reproductive structures. This might also be due to improved status of S in soil through different S fertilizers which resulted in bold grains and well filled pods.

It was found that the treatments containing OM and S was more effective than treatment without OM due to efficient utilization of nutrients While considering the two sources, the effect of gypsum is noteworthy. Improvement in yield attributes due to gypsum as a source of two major nutrients [S and Ca] contributed positively towards higher number of pods. Role of Ca in pod development is a well established fact. Similar enhancement of pod number by gypsum application was reported by Geethalakshmi and Lourduraj [1998].

Increased number pods as a result of increased S fertilization was reported by Saraf *et al.* [1997], Ramamoorthy *et al.* [1997] and Sharma *et al.* [1997].

5. 3. 3 Number of seeds per pod

An increasing number of seeds was noticed with S application at higher levels. Maximum number of seeds per pod was obtained with S fertilization @ 30 kg ha^{-1} along with POP recommendations. The source used was factamphos. This might have resulted from favourable conditions of nutrient availability in the soil system. The uptake of S was increased due to increased availability of this nutrient in the soil. [Table 14]. S fertilizers influenced chlorophyll synthesis and there by improving the photosynthetic activities. It increased nitrate reduction and synthesis of S containing amino acids like cystine, cysteine and methionine which are essential components of protein. Adequate supply of nutrients that resulted in higher production of photosynthates and their translocation to sink caused an increase in drymatter production ultimately resulting in high seed yield.

Combined application of sulphur and FYM recorded maximum number of seeds per pod. This might be due to favourable condition of nutrient availability in soil system through favourable effects of organic manure during the entire growing period. Sudha [1999] also observed higher grain content in rice due to S application @ 25 kg ha^{-1}. Similar results were obtained by Singh *et al* [1995] in green gram. Kachroo *et al.* [1997] observed an increasing number of seeds per siliqua in Indian mustard by 40 kg S ha^{-1}.

5. 3. 4. Bhusa yield

Observations on bhusa yield revealed that S fertilization produced marked influence on enhancement of bhusa yield. With increasing levels of S fertilization bhusa yield was significantly increased. Maximum yield was recorded by treatment having gypsum as source of S @ 30 kg ha^{-1} along with POP recommendation. The increased bhusa yield might be due to the fact that S enhances the photosynthesis and is involved in N fixation by nodule bacteria. Due to its active role in the formation of ferredoxin-a type of non haem iron sulphur protein that acts as an electron carrier in photosynthesis and N fixation. [Blair,1979; Tisdale *et al.* 1985]. Reduced form of ferredoxin is the ultimate source of reducing power for reduction of carbon dioxide in the dark reaction of photosynthesis. Greater N fixation added to greater vegetative growth. Vegetative characters like height, no of branches and leaf area were increased significantly which ultimately resulted in increased haulm yield. Due to increased availability of S in the soil S uptake by plants is increased. FYM the source of most of the essential plant nutrients, their steady supply throughout the growth period and creation of soil favourable physical environment in soil for the uptake of nutrients might have given an added advantage in increasing bhusa yield.

The data presented in table [4,5] clearly indicates that higher S levels had positive influence on plant height, LAI and DMP which have direct bearing on bhusa yield.

Comparing two S sources, gypsum was found to be more efficient in enhancing bhusa yield. This might be due to the fact that gypsum contributes to exchangeable Ca in soil. The increased availability of this nutrient along with enhanced rate of uptake contributed to higher bhusa yield. Increased haulm yield with S application was reported in green gram by Naidu *et al* [1996] and Jaggi [1998] in mustard.

5. 3. 5 Total dry matter production

S application had profound influence in total DMP. Increased rate of S application caused an increase in total DMP, height of plant, branches and LAI. S produced an overall vigour in plant causing an increased vegetative growth. S enhanced the photosynthesis and had a role in N fixation by nodule bacteria. Greater N fixation led to higher vegetative growth. This might have resulted in increased dry matter accumulation.

OM application had a profound influence on DMP. Similar enhancement in DMP was reported by Singh *et al.* [1997] in mustard and Ramamoorthy *et al.*[1997] in blackgram.

5. 3. 6 Harvest index

Treatments with sulphur showed significant influence on harvest index of cowpea. Maximum HI was recorded for the treatment having 30 kg S ha^{-1} as gypsum along with POP recommendation. This might be due to better partioning and translocation of photosynthates leading to more accumulation in seeds [Kachroo *et al.* 1997]. These were in conformity with Khanpara *et al.* [1993]. S application significantly increased grain yield in cowpea. Efficient and greater partitioning of metabolites and adequate translocation of nutrients to the developing reproductive structures caused an enhanced economic yield which reflected on HI of cowpea.

Combination of OM with NPK and S effected an increase in HI. This might be due to the effect of OM on physico chemical properties of soil and as a nutrient source. Maximum HI was for gypsum application. Gypsum contains sulphate, which is an easily available source for sulphur. Ca present in gypsum had a profound influence on pod development. These factors increased grain yield thus causing an increase in economic yield.

Singh *et al.* [1994] observed maximum HI for summer mung at 60 kg S ha^{-1}. Similar enhancement in HI was noted by Geethalakshmi and Lourduraj [1998] by the application of gypsum

5. 4 Soil nutrients

At MF and harvest stages, higher sulphur level recorded a decreasing trend in soil N content. N accumulation was significantly increased due to the enhanced rate of N fixation caused by S fertilization. S has got synergestic effect on the uptake of N. This results in high N uptake and low soil N status [Table 10] Confirmatory results were reported by Sudha [1999]. Treatment without sulphur was found to have higher soil N status, where the uptake of N was also less. At the harvest stage, POP recommendations without S recorded the maximum value for soil N. This might be due to the fact that organic manure addition helps in supplying more N to soil, N uptake was also lower in this case.

Treatments with S produced significant effect on available P status of soil at MF stage only. At MF and harvest stage, POP recommendations without S produced maximum content of available P in soil. With increased S levels a reduction in P status was recorded. This might be due to the fact that, with increased S application,uptake of P by grain and plant was increased due to the synergestic effect of P and S. Singh *et al.* [1994] observed a similar reduction in P content of soil with S @ 20 kg ha^{-1} With increased S levels a reduction in P status in soil was also recorded by Sudha [1999]. Treatment combination with OM recorded highest P status of soil at MF and harvest. The solubilising action of organic acid produced during the decomposition of organic materials might have resulted in an enhanced P status of soil.

Highest value for available K content in soil was recorded for treatment with POP recommendation without S at MF and harvest stages. This increased K uptake with S addition might have resulted in a reduction in soil K content. Sudha [1999] observed a synergestic relationship between K uptake and S application. Similar results by Sakal *et al.* [1999]. Highest K status was for treatment with organic manure [FYM]. FYM contains K, which might be the reason for improved K status in soil by the FYM application.

At MF and harvest, exchangeable Ca present in soil was observed to be significantly influenced by S application through different sources. At MF S, maximum value was for

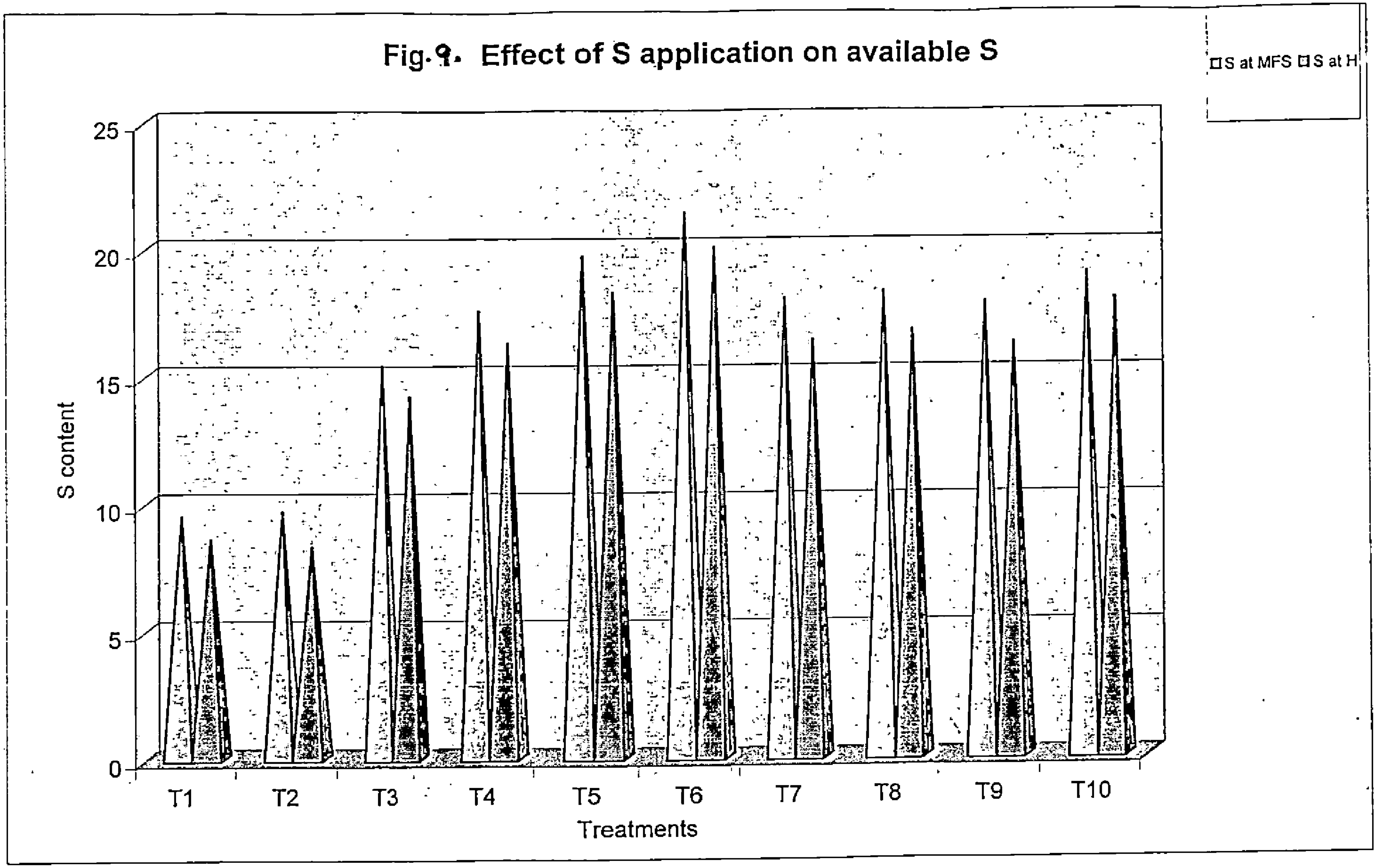


Fig.9. Effect of S application on available S

treatment with S @ 30 kg ha^{-1} along with POP recommendation, the source being gypsum. Where as at harvest, highest value was recorded for treatments with 15 kg S ha^{-1}.and 30 kg S ha^{-1} through gypsum along with POP recommendations. S application at 15 kg ha^{-1} without FYM also gave highest value. Gypsum application was found to have a positive effect on available Ca content in soil. Gypsum was found to increase exchangeable Ca in soil. This might be the reason for increased Ca content in soil by gypsum application. These results were in conformity with the reports by Patel *et al*. (1985)

Available S status of soil at MF and harvest stage was significantly influenced by S fertilization at different levels and through different sources. (Fig.9) At both stages, significantly maximum value was recorded by gypsum application @ 30 kg ha^{-1} along with POP recommendation. S application at higher levels obtained high levels of available S status in soil. This might be due to the higher dose of S fertilization to the crop. Increased application resulted in enhanced S availability in soil. Treatment combinations which recorded maximum content of available S in soil include FYM also. Major source of sulphur in soil is organic sulphur contributed by OM. This would have accounted for the increased amount of sulphur in soil through out the growing period. The source which recorded highest available S status was gypsum. The sulphate S present in gypsum is in readily available form, which might have contributed to increased S status in soil. Similar result was reported by Sudha [1999] ,who observed that increased S levels upto 25 kg ha^{-1} could increase the S status of soil. This finding is in agreement with the reports of Singh *et al.* [1994]. Sakal *et al.* [1999] reported that continuous application of SSP could raise the available S status of soil from deficiency to sufficiency.

5. 5 Nutrient content in plants

Plant N content was significantly enhanced with increasing levels of S application at MFS and harvest. Maximum N content at MF was recorded by the treatment with 30 kg S ha^{-1} using factamphos along with POP recommendation. But at harvest stage, NPK and 30 kg S ha^{-1} as factamphos recorded maximum value. Sudha [1999] reported an increase in N content of rice

OM facilitates the crop roots to absorb more nitrogen which is translocated to grain. Synergestic effect of S on N content was previously identified by Singh *et al.* [1994] and Sudha [1999].

Highest value for grain P content was observed for treatment with 30 kg ha^{-1} as gypsum along with POP recommendation., though not significant . Similar results was reported by Beaton and Wagner [1985], Singh *et al.* [1994]. A strong synergistic relationship between P and S in wheat was observed by Kumar and Singh [1980]. This increased P availability coupled with enhanced uptake contributed towards the grain P content.

Although grain K content was not significantly influenced by S fertilization, highest value for grain K was recorded for treatment with 30 kg S ha^{-1} as factamphos along with NPK only. With increased dose of S fertilization grain K content recorded higher value. This may probably due to the synergistic interaction of S and K contents. Sudha [1999] reported similar increase in K content of rice by S application up to 25 kg ha^{-1}.

Grain Ca content was significantly influenced by S fertilization. S application upto 30 kg ha^{-1} was found to increase the Ca content in grain. The source of application which recorded the highest content of grain Ca was gypsum. Gypsum as a source of S and Ca helped in increasing in the amount of Ca in soil. The availability of Ca was also increased, which in turn enhanced Ca uptake by grains. Gypsum might have helped in increasing efficiency of absorption of Ca by plants

Increased dose of S fertilizer @ 15 kg ha^{-1} caused an enhanced grain Mg content, even though not significant. S fertilization might have helped in producing a favourable environment for absorption of Mg by plants. This would have resulted in increased absorption of Mg along with enhanced rate of uptake. The increased level of S fertilization resulted in enhanced absorption of all nutrients in general. These results were in conformity with Jain and Saxena [1991]

S fertilization at high doses was found to increase S content in grains significantly. Maximum amount of grain S was recorded by the treatment with 30 kg S ha^{-1}. This might have resulted from increased S availability coupled with enhanced S uptake by grain [Table 15]. The treatment combination which recorded maximum value included application of OM. OM is the major source of organic S in soil. S uptake was more in the presence than in the absence of OM because of its effects on physio-chemical properties of soil.

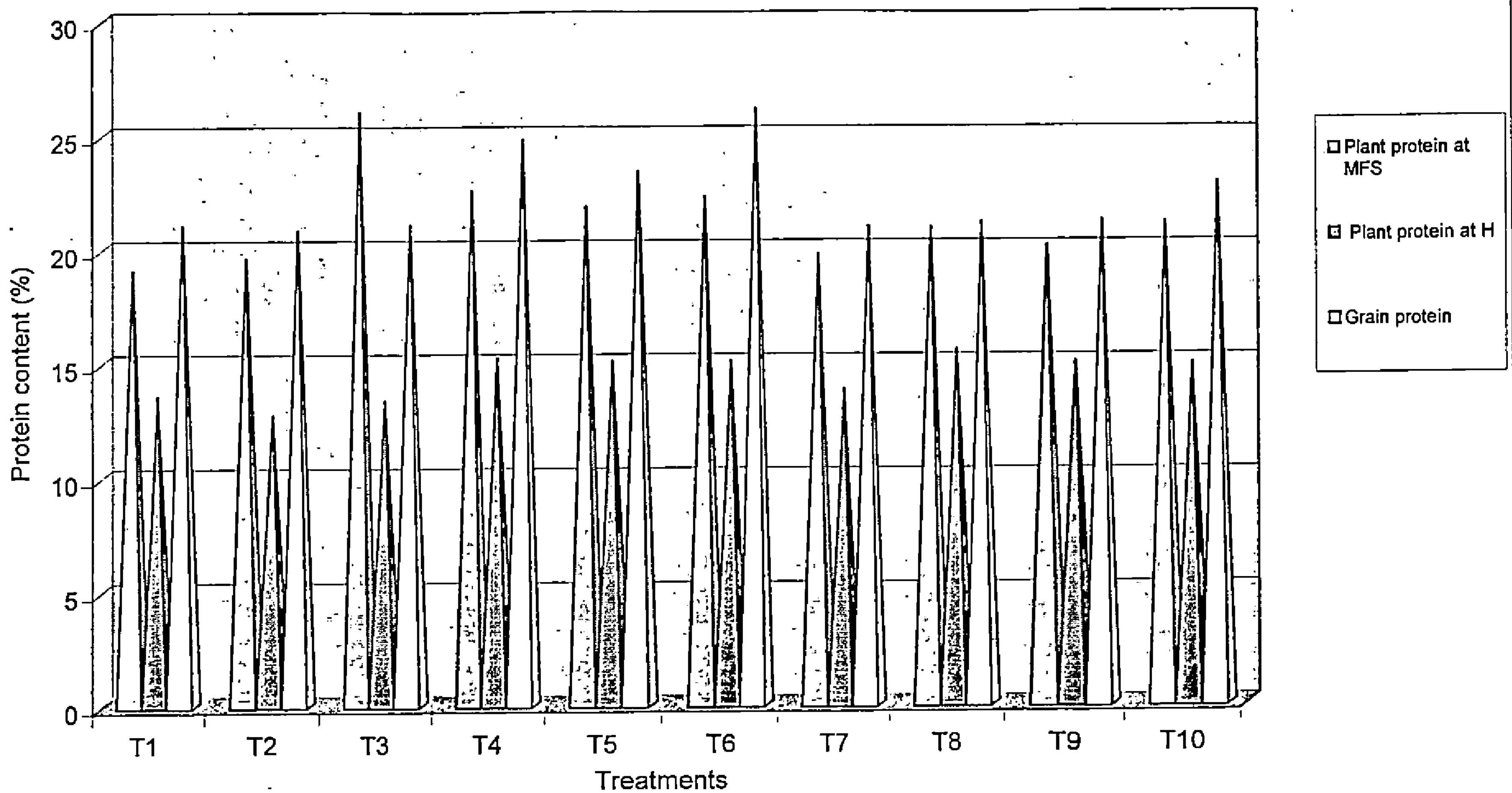
5. 2 Quality attributes

5. 2. 1 Protein content

S fertilization could significantly influence protein content at MFS and harvest stages (Fig.). Maximum protein content was obtained with 30 kg S ha^{-1} through factamphos. This shows active involvement of S in protein synthesis. S is a constituent of amino acids like methionine, cystine, cysteine which are building blocks of protein. High S application rate resulted in higher N accumulation [Table 13]. This was mainly caused by enhanced rate of N fixation which ultimately resulted in protein synthesis. Kayode [1990] reported a significant increase in protein content of cowpea by S application. The results obtained were in conformity with results obtained by Qui [1989] in wheat and maize.

Treatments with POP recommendations along with S @ 30 kg ha^{-1} recorded maximum content of grain protein. Increasing levels of S application showed an increase in grain protein content. S is essential for the formation of disulphide bonds in polypeptide chains. Disulphide bonds are important in stabilizing and determining the configuration of protein. The sulftydyl group (-SH) of cystein is involved in the catalytic function of enzymes. S fertilization resulted in increased accumulation of N in grains [Table 13]. Increased protein content in grains may be due to the fact that S, as an essential plant nutrient promoted npdulation in legumes, there by enhanced N fixation and ultimately led to higher protein production. Confirmatory results were obtained by, Dwivedi *et al.* [1988], Singh and Ram [1990] Combined application of FYM and S resulted in maximising the protein content. FYM, being the source of S and other essential nutrients might have helped in increased accumulation of N and S in plants.

Fig. 10 Effect of S application on protein content in plant & grain



5. 7 Uptake of nutrients

5. 7. 1 Nitrogen

S fertilization showed marked influence on the uptake of N at MFS and harvest stages (Fig.11). At MFS and harvest stages, treatment with S @ 30 kg ha^{-1} through gypsum along with POP recommendation showed maximum N uptake. Treatments with sulphur were found to be significantly superior to other treatments. With different sources, increased rate of S application caused an enhancement in N uptake. Grain N uptake was significantly maximum for treatment with 30 kg S ha^{-1} as gypsum along with POP recommendation.

The increase in N uptake due to high levels of S application might be due to the increased N availability in soil [Table 10]. This synergistic relation between N and S is a well established fact. Confirmatory reports by Sakal *et al.*[1999] prove this relationship. The S application significantly improved DMP, bhusa yield and grain yield [Table 9]. This also contributed to the enhanced N uptake. The N content of grain and straw was also improved by S fertilization, which ultimately led to higher N uptake.

Sudha (1999) and Krishnamoorthy *et al.* (1996) observed similar enhancement of N uptake by S application. The increased uptake due to organic manure addition may be probably due to improvement of soil environment, which encouraged root proliferation and maximum nutrient uptake by plants. Gypsum was found to be the best source, which might be due to readily availability of sulphate S.

5. 7. 2 Phosphorus

Maximum P uptake was for treatment with NPK application along with S @ 30 kg ha^{-1} using gypsum as the source at both stages. Sulphur application produced synergestic effect on P content. Similar results by Sakal *et al.* [1999] in wheat. Increased dose of sulphur could enhance the availability of this nutrient in soil by dissolution. S fertilization had a positive effect on straw yield, grain yield and contents of nutrients in plant and grain. This might have contributed towards increased P uptake by grain and straw.

Combined application of organic manure with sulphur fertilizers helped in higher uptake. The organic acids produced during the degradation of organic materials might have resulted in the solubility and release of native and applied P, which in turn resulted in higher P uptake.

In the case of grain, the highest uptake of P was for treatment with 30 kg S ha^{-1} as factamphos along with NPK application. S application enhanced nutrient content and yield resulting in higher grain uptake.

5. 7. 3 Potassium

K uptake in plant was significantly influenced by S application at MFS and harvest. Maximum value was for treatment with gypsum @ 15 kg S ha^{-1} along with POP recommendations at both stages. The increased uptake of K might be due to its enhanced availability in soil. This could be attributed to increased dry matter production by S fertilization. The increased absorption of K by plants was resulted by S application. The increase in K uptake with S nutrition could be due to the synergestic effect of S on K. Sakal *et al.* [1999] observed similar enhancement in K uptake by rice with the addition of 40 kgS ha^{-1}. Grain uptake of K was maximum in the case of treatment with gypsum containing S @ 30 kg ha^{-1} along with POP recommendations. Increased grain yield and high K content in grain might be the reason for increased uptake. The treatment combination which recorded highest K uptake included FYM also. The higher uptake was mainly associated with increase in drymatter as a result of OM application.

The source used for application was gypsum. The sulphate present in gypsum is in readily available form, resulting in increased content of particular nutrient in plant and grain. This might have resulted in increased uptake.

5. 7. 4 Caicium

S fertilization at different levels and through different sources could significantly influence the uptake of Ca by plants. Increased rates of S application through different sources

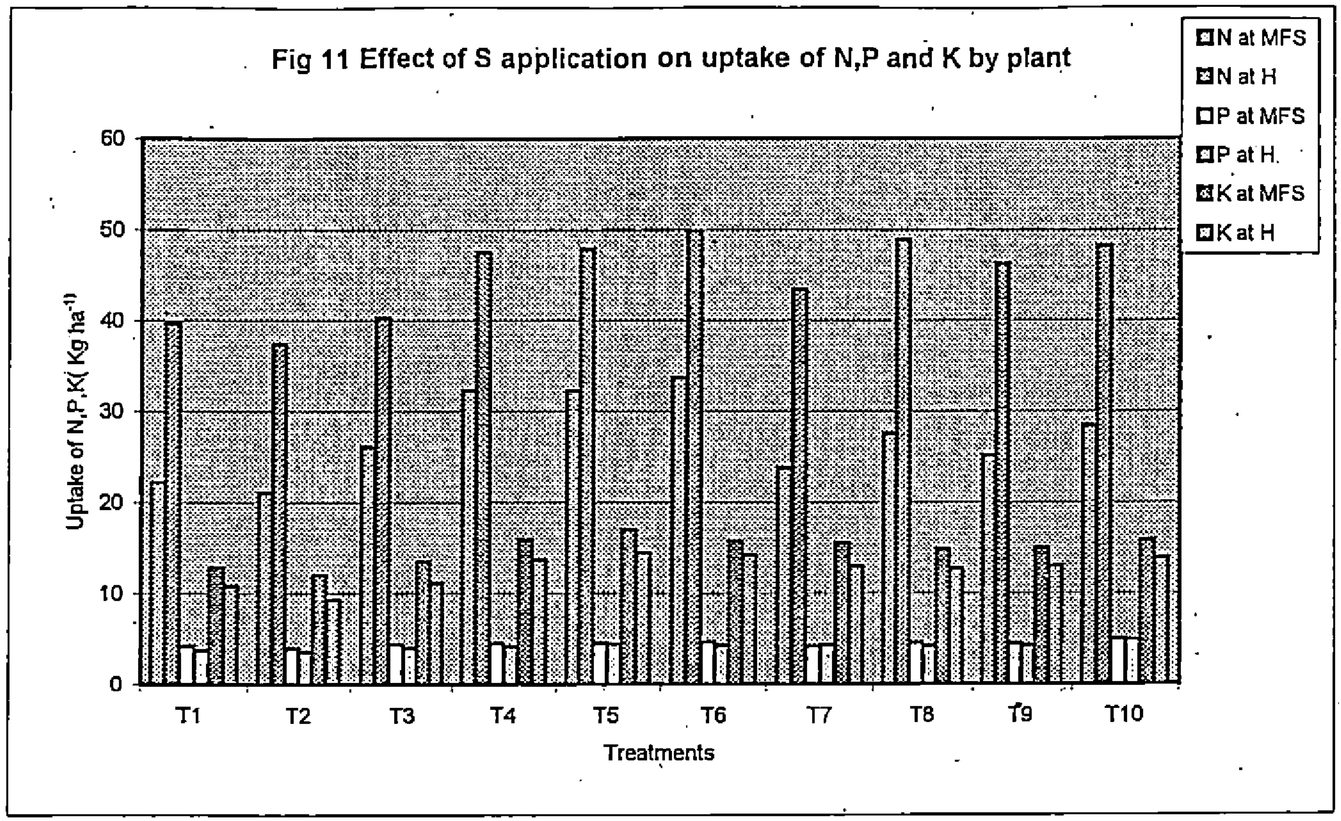
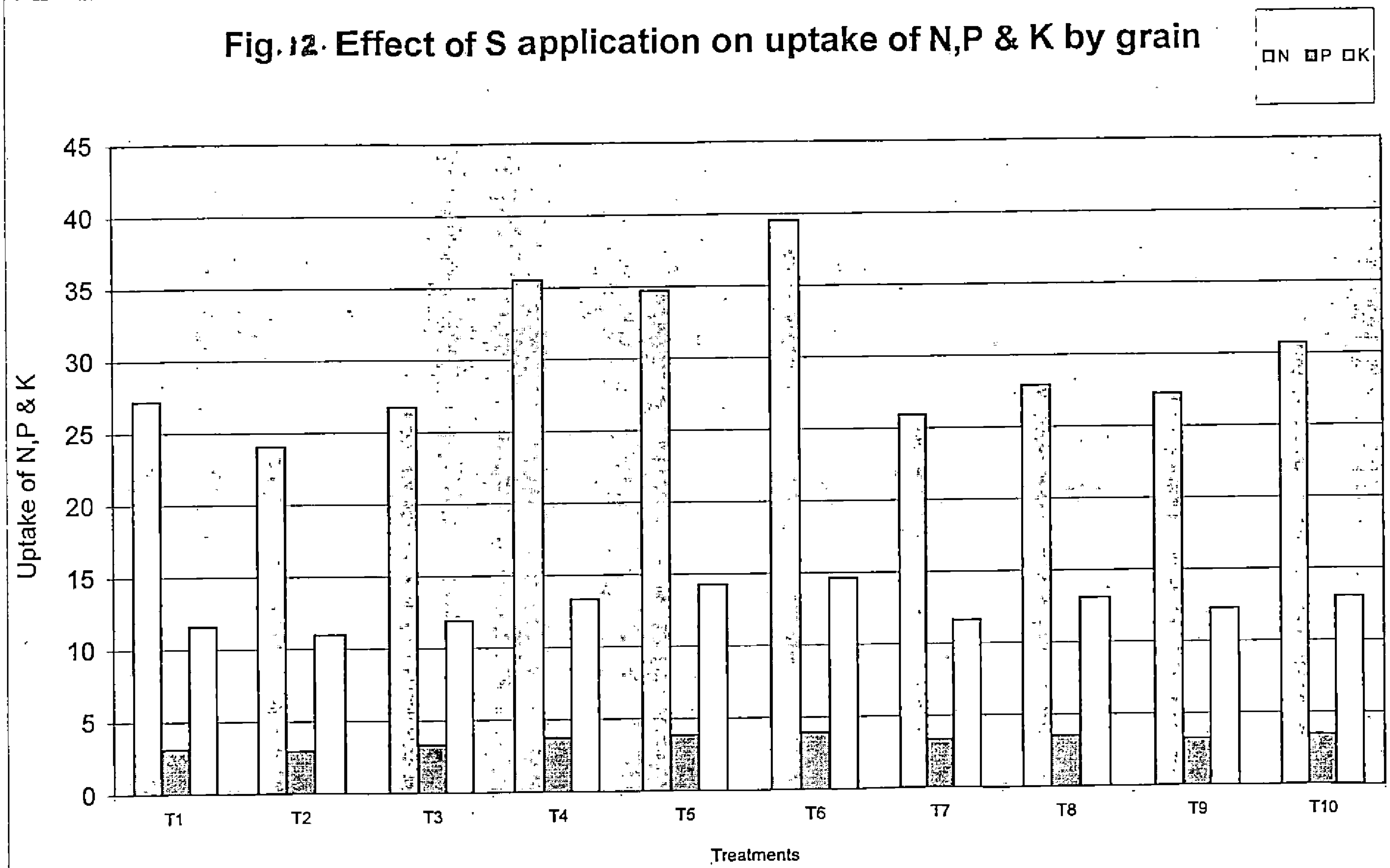


Fig 11 Effect of S application on uptake of N,P and K by plant
N at MFS
N at H
P at MFS
P at H.
K at MFS
K at H
Uptake of N,P,K(Kg ha-1)
60
50
40
30
20
10
0
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
Treatments

88

Fig. 12. Effect of S application on uptake of N,P & K by grain



could progressively increase the Ca uptake by grain. The maximum Ca uptake was for treatment with 30 kg S ha^{-1} as gypsum along with POP recommendations.

S fertilizers might have helped in enhanced availability of Ca in soil. This resulted in increased Ca content in grain and straw, which helped in increased uptake. Further, the increased grain yield and straw yield also contributed to the enhanced rate of Ca uptake by grain and plant.

The source of application of S which gave highest uptake in all the three cases was gypsum. Gypsum containing the element Ca might have a favourable effect on increasing the Ca content in soil, there by enhancing the availability of this nutrient.

Combined application of FYM along with S fertilizers enhanced the uptake. FYM containing essential nutrients might be favourable for enhancing the nutrient availability. It also improved the soil properties, there by making the nutrients more readily available to plant and helped in enhancing the Ca uptake.

5. 7. 5 Magnesium

Gypsum application @ 30 kg ha^{-1} along with POP recommendation recorded highest uptake of Mg by plant at MFS and harvest stages. The grain uptake also showed maximum value by this treatment. By sulphur fertilization, increased Mg content in plant and grain resulted. The increased grain yield and DMP along with increased Mg content in plant and grain have favoured maximum uptake of Mg. The treatment combination which gave highest value was one with FYM also. This would have improved the soil properties, there by enhancing the availability of nutrients along with their uptake.

5. 7. 6 Sulphur.

Higher uptake of S was noticed with S fertilizers at different levels and through different sources. Plant uptake at MFS and harvest was maximum for treatment with S @ 30 kg ha^{-1} as gypsum along with POP recommendations. S applications at 30 kg ha^{-1} could increase the availability of S in soil. [Table14]. This ultimately led to the increased content of this nutrient in

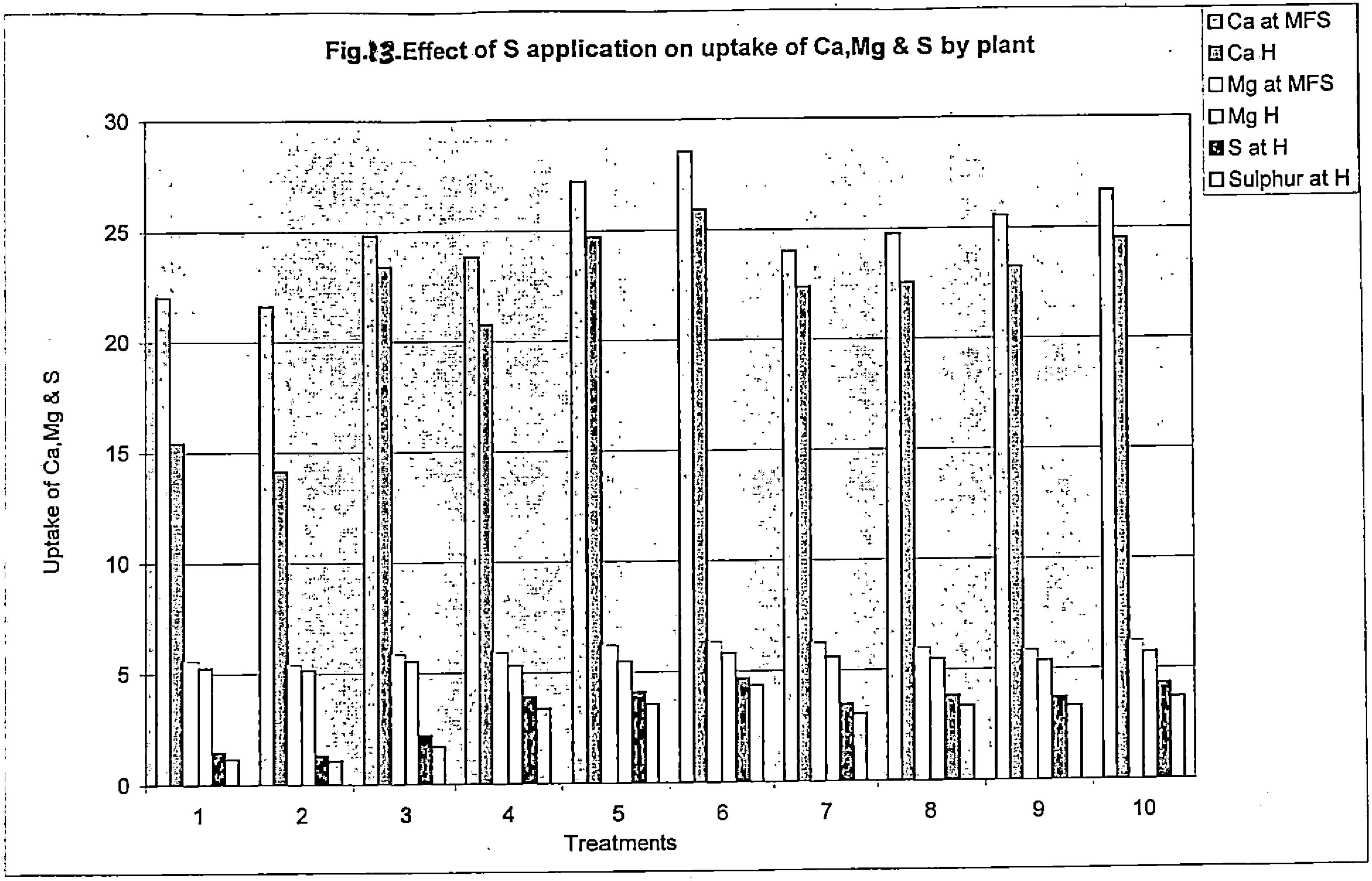
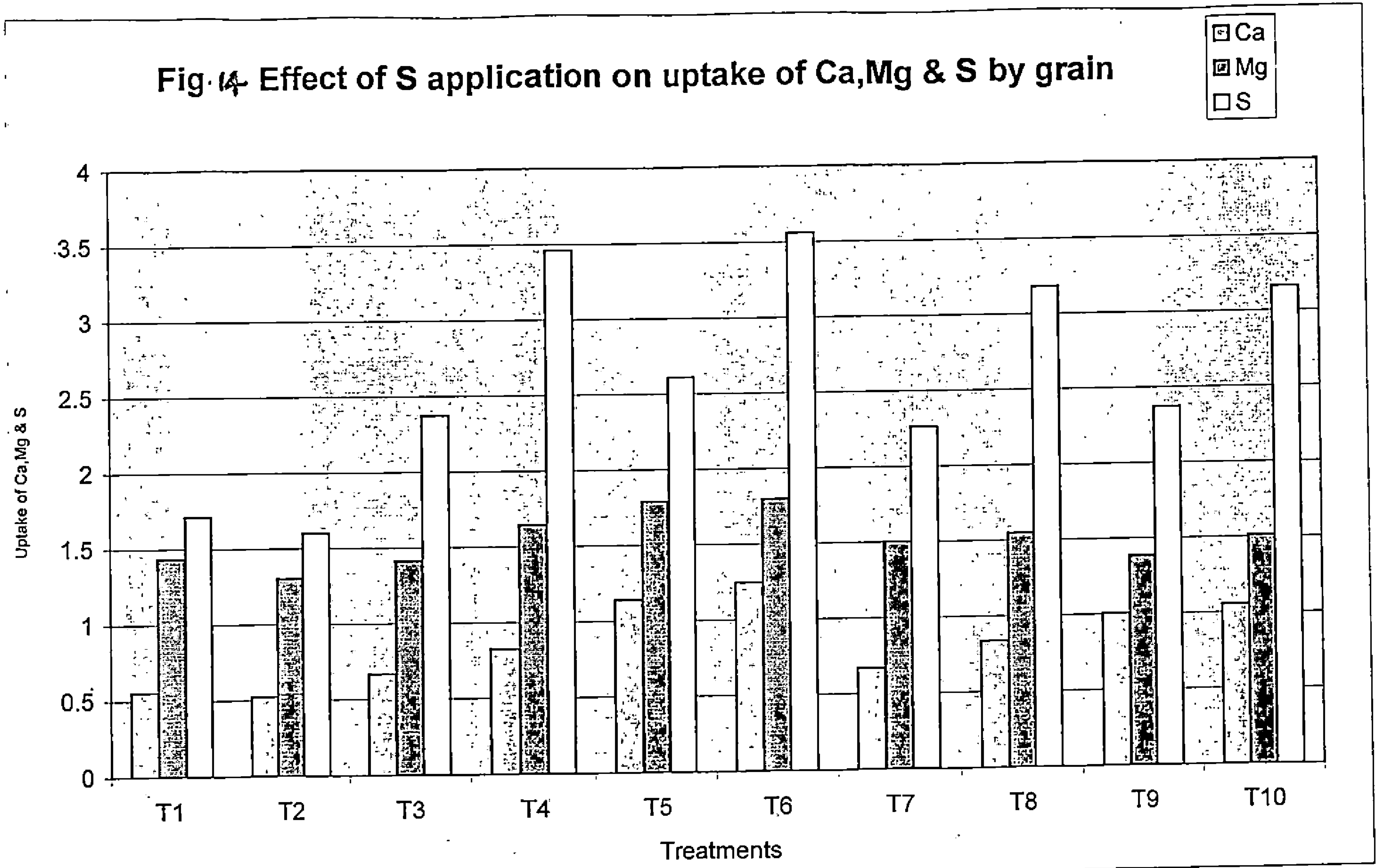


Fig.13.Effect of S application on uptake of Ca,Mg & S by plant

Fig. 14 Effect of S application on uptake of Ca,Mg & S by grain



plant. S addition also caused an increased DMP and yield. This might have made possible the increased S uptake by plant. Positive increase in S uptake with increased S level was reported by Sudha [1999]. Grain uptake was also found to be increased due to S fertilization.Gypsum @ 30 kg S ha^{-1} along with POP recommendation have favoured the uptake by grain. A general increase in growth attributes, grain yield and S uptake seemed to be associated with the increased S availability.This subsequently increased S uptake from applied sources as the experimental site had low S content. Similar increase in S uptake of seed was reported by Jaggi *et al.* [1992].

In all the three cases, the highest uptake was seen by using gypsum as source. This might be due to the increased availability of S when gypsum was used as source. Similar enhancement in uptake by gypsum was recorded by Raghuvanshi *et al.* [1997] in soyabean - wheat cropping system.

The highest value was recorded for the treatment with FYM. FYM is the main source of S in soil which would have contributed towards higher uptake. This in turn helped in enhancing growth characters.

5. 8 N : S ratio

At MF and harvest, this ratio was significantly influenced by S fertilization (Fig.16). By progressive increase in S application N : S ratio was found to be significantly decreased. For optimum protein production, one part S was needed for every 12-16 parts N depending on the culture. [Dev and Saggar, 1974]. Shinde [1982] reported that soyabean plants with N : S ratio 16.5 or more were a found to be S deficient. At both stages S @ 30 kg ha^{-1} recorded the lowest value. This treatment gave the highest DM, grain yield and protein content [Table 9]. The decrease in N : S ratio from 42.93 to 15.86 in plants can be achieved by S addition.

Grain N : S ratio was significantly influenced by S fertilization through different sources. Progressive decrease in N:S ratio was noticed with increase in the rate of S application. Lowest

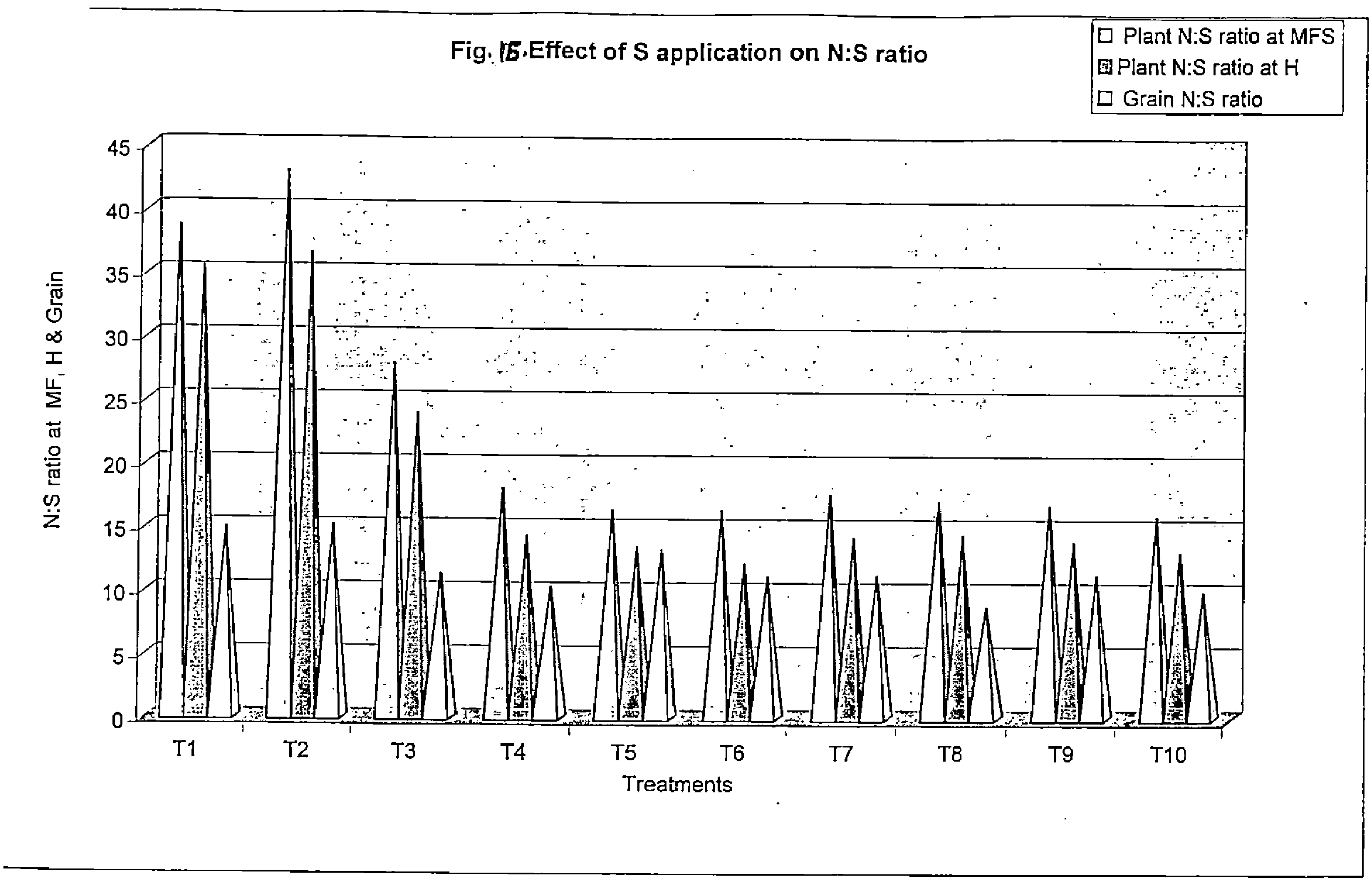


Fig. 15. Effect of S application on N:S ratio

value was for sulphur application @ 30 kg ha^{-1} as factamphos along with NPK application. The treatment with 30 kg S ha^{-1} enhanced S accumulation in grains [Table 15]. This might have contributed to decrease in N : S ratio of grain. Decrease in N:S ratio of rice grain from 13.17 to 9.68 by increasing level of S fertilization was reported by Sakal *et al.* [1999]. S nutrition @ 30 Kg as gypsum could increase the yield of cowpea by 41.96 % and protein content by 25.39% in a Rhodic Haplustox. From the present study it could be confirmed that S application has a favourable effect on all the growth characters, yield and quality attributes in cowpea.

SUMMARY

SUMMARY

An investigation was carried out to study the effect of S on yield, quality and uptake of nutrients by cowpea (*Vigna unguiculata* L Walp) in the Instructional farm, College of Agriculture, Vellayani.

The experiment was laid out in RBD with ten treatments and three replications. S fertilization was done through two sources. The treatments consisted of T_1 - POP recommendations without S, T_2 - NPK alone , T_3 - POP+15 kg S (source: factamphos),T_4 - POP+30 kg S (source : factamphos), T_5 - POP+15 kg S (source : gypsum) ,T_6 - POP +30 kg S (source : gypsum), T_7 - NPK alone +15 kg S (source : factamphos), T_8 - NPK alone + 30 kg S (source: factamphos), T_9 - NPK alone +15 kg S (source: gypsum), T_{10} -NPK alone +30 kg S (source : gypsum), The POP recommendations for cowpea is 20 kg N ha^{-1},30 kg P ha^{-1} and 10 kg K ha^{-1}along with 20 t FYM ha^{-1}. Urea,mussoriephos and murate of potash were used as sources of N,P and K respectively. Cultural operations were done as per POP of KAU. [KAU, 1996].

Results obtained are summarised below

All the growth charecters like height of the plant, number of branches, LAI, number and weight of effective nodules, chlorophyll content(a,b and total) and NRA were found to be significantly boosted by S application. POP recommendations along with 30 kg S ha^{-1} as gypsum recorded maximum value in all the cases except in the case of number of branches. Treatment with POP recommendations along with 30 kg S ha^{-1} as factamphos produced highest number of branches per plant.

In the case of treatment with 30 kg S ha^{-1} as gypsum and POP recommendations protein content was found to significantly ienhanced. At MFS S fertilization @ 30 kg ha^{-1} as factamphos along with POP recommendation gave maximum protein content in plant. At harvest stage, NPK along with factamphos @ 30 kg S ha^{-1} recorded highest value for protein content. Crude fibre content of cowpea was significantly increased by S

fertilization. Yield and yield components were significantly boosted by S nutrition. Grain yield was significantly enhanced by POP recommendation and gypsum application @ 15 kg ha^{-1} and 30 kg ha^{-1}. 42% increase in yield was obtained with 30 kg S ha^{-1} as gypsum over the treatment with NPK alone. Yield attributes like bhusa yield, number of pods per plant, harvest index and total dry matter production gave the highest values for treatment with 30 kg S ha^{-1} as gypsum along with POP recommendation. However, treatment with 30 kg S ha^{-1} as factamphos along with POP recommendation recorded maximum number of seeds per pod which was on par with treatment with 30 kg S ha^{-1} as gypsum along with POP recommendations.

Available N status of soil at both stages was found to be significantly influenced by S fertilization. Higher values were obtained for treatments without S. At MFS,available P in soil was significantly influenced by S application. POP recommendation without S fertilization recorded highest P status in both cases. Significantly maximum value for exchangeable Ca and available S status of soil was recoded by treatment with 30 kg S ha^{-1} as gypsum along with POP recommendations. The highest available K status of soil was for treatment with POP recommendations. Exchangeable Mg was maximum for treatment with gypsum @ 30 kg S ha^{-1} along with POP recommendation at MFS and NPK alone at harvwst stage.

The N, K ,Ca and S content in plant were found to be significantly increased by S fertilization at both MFS and harvest stage. Treatment with S @ 30 kg S ha^{-1} using gypsum along with POP recommendation gave the highest N at MFS. Whereas at harvest, maximum value was recorded by treatment with NPK and 30 kg S ha^{-1} as factamphos. Highest Mg content in plant was noticed for treatment with factamphos @ 15 kg S ha^{-1} along with NPK. Maximum S content in plants at both stages was for treatment with 30 kg S ha^{-1} as gypsum along with POP reommendations. At both stages, gypsum @ 30 kg S ha^{-1} was found to be superior to all other treatments in raising the S content.

The N, Ca and S contents in grain was found to be significantly influenced by S fertilization. Significantly maximum grain N content was observed for treatment with S @ 30 kg ha^{-1} using gypsum along with POP recommendations. Treatments with gypsum was superior in enhancing the Ca content in grain. The highest value was recorded for treatment with 30 kg S ha^{-1} as factamphos with and without FYM. S fertilization @ 30 kg ha^{-1} was superior in enhancing the grain content.

Uptake of N,K,Ca and S by plants was significantly enhanced by S application at both stages. P uptake at harvest and Mg uptake at MFS were also significantly influenced by S fertilization. N, Ca, Mg and S uptake was highest for treatment with 30 kg S ha^{-1} as gypsum along with POP recommendations. P uptake was highest for treatment with NPK application along with S @ 30 kg ha^{-1} using gypsum. Treatment with 15 kg S ha^{-1} as gypsum along with POP recommendation gave highest K content at both stages.

Grain uptake of N,P,K,Ca, Mg and S was significantly influenced by S fertilization. Gypsum application @ 30 kg S ha^{-1} along with POP recommendations gave highest value in all cases. The synergistic effect of S on the uptake of N,P,K, Ca and Mg was well established in this experiment. N : S ratio was significantly decreased by S fertilization. In plants minimum N : S ratio was obtained for treatment with 30 kg S ha^{-1} as gypsum due to higher uptake of S. Lowest grain N : S ratio (9.92) was for treatment with 30 kg S ha^{-1}as factamphos.

Correlation studies revealed positive correlation between yield and growth characters like height, number of branches, number and weight of effective nodules, chlorophyll content and NRA. All yield attributes were positively correlated with grain yield. Protein content was also correlated positively with yield. Grain uptake of N,P,K,Ca,Mg and S and plant uptake of N,Ca,K and S were positively correlated with yield. Uptake of nutrients at MFS was found to be more correlated with yield than uptake of nutrients at harvest.

The study revealed the favourable effect of S on yield, quality and uptake of nutrients by cowpea. The POP recommendation for cowpea should include 30 kg S ha^{-1} as gypsum to get higher yield.

ABSTRACT

EFFECT OF SULPHUR ON YIELD, QUALITY AND UPTAKE OF NUTRIENTS BY COWPEA (*Vigna unguiculata* L. Walp) IN A RHODIC HAPLUSTOX

By

V. I. BEENA

ABSTRACT OF THE THESIS

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURE (SOIL SCIENCE AND AGRICULTURAL CHEMISTRY)

FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM

2000

ABSTRACT

The proposed piece of research work entitled " Effect of sulphur on yield, quality and uptake of nutrients by cowpea (*Vigna unguiculata* L Walp) in a Rhodic Haplustox" was conducted at Instructional farm,College of Agriculture, Vellayani. The study was undertaken to evaluate the effect of different levels and sources of sulphur application on yield, quality and uptake of nutrients by cowpea using the var Kanakamoni.

The experiment was laid out in RBD with three replications. Combination of three factors, organic manures (FYM), NPK fertilizers and sulphur constituted the ten treatments. Sulphur was applied through two sources viz gypsum and factamphos. Different levels of S application were 1) no sulphur 2) S @ 15 kg ha^{-1} and 3) S @ 30 kg ha^{-1}. All treatments included normal NPK applied through urea,mussooriephos and MOP at the rates of 20:30:10 kg ha^{-1}. FYM application was also done at two levels i.e.treatments with FYM and without FYM.

Growth characters like height of the plants, number of branches per plant , number and weight of effective nodules, chlorophyll content and NRA were significantly enhanced as a result of S fertilization.The treatment combination with 30 kg S ha^{-1} along with POP recommendation recorded the maximum value in all these cases. Gypsum was found to be superior in all these cases except in the case of number of branches per plant. Treatment with 30 kg S ha^{-1} as gypsum along with POP recommendation recorded significantly minimum value for days to maximum flowering and N:S ratio.

A 42 per cent increaese in yield over control was recorded by 30 kg ha^{-1} as gypsum along with POP recommendations. A significant increase in yield attributes and protein content (25.39%) was also noticed through S fertilization. Uptake of N,P,

K, Ca, Mg and S was increased due to S fertilization indicating a synergistic effect. All the growth characters and yield attributes were best correlated with yield . Uptake of nutrients showed positive and significant correlation with yield, the best correlation being obtained at MFS. Yield is decided by the uptake of nutrients at MFS. N:S ratio and days to maximum flowering showed significantly negative correlation with yield.

Field experiment revealed that S as well as combination of S with organic manures exerted significant effect on most of growth and yield attributing charecters of cowpea. The treatment combination with normal level of NPK and FYM along with S @ 30 kg ha^{-1} was found significantly superior to other treatments. Gypsum as the source was found to be superior to factamphos.

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APPENDIX

Table 1 Weather data during the cropping period

Period (Std:week)	Rainfall (cm)	Max temp °C	Min temp °C	RH (%)
01-01-1998 to 07-01-1998	0	31.68	22.60	95.26
08-01-1998 to 14-01-1998	0	31.84	22.36	93.30
15-01-1998 to 21-01-1998	0	31.68	22.60	95.26
22-01-1998 to 28-01-1998	0.29	31.76	23.79	96.29
29-01-1998 to 04-02-1998	0	32.39	22.73	95.14
05-02-1998 to 11-02-1998	0	32.26	23.61	94.60
12-02-1998 to 18-02-1998	2.63	31.83	23.71	93.57
19-02-1998 to 25-02-1998	0.06	31.86	24.79	91.87
26-02-1998 to 04-03-1998	0	32.80	23.53	92.43
05-03-1998 to 11-03-1998	0	33.00	23.73	88.00
12-03-1998 to 18-03-1998	0	33.60	24.11	87.43
19-03-1998 to 25-03-1998	0	33.23	24.46	98.43
26-03-1998 to 01-04-1998	0	33.70	25.11	88.00
02-04-1998 to 08-04-1998	0.43	33.70	25.44	89.71
09-04-1998 to 15-04-1998	0.69	34.30	25.84	90.86
16-04-1998 to 22-04-1998	4.71	34.17	26.60	90.52
23-04-1998 to 29-04-1998	1.21	34.21	26.23	88.29
30-04-1998 to 06-05-1998	2.91	34.07	25.66	82.29