

**RESIDUAL MANAGEMENT OF SULPHUR ON YIELD
AND QUALITY OF SAFFLOWER IN
SUNFLOWER-SAFFLOWER CROPPING SYSTEM**

(Carthamus tinctorius L.)

BY

VIJAY PIRAJIRAO JONDHALE

B. Sc. (Agri.)

DISSERTATION

T4044

*Submitted to the
Marathwada Agricultural University
in partial fulfilment of the requirement
for the degree of*

**MASTER OF SCIENCE
(Agriculture)**



IN

AGRICULTURAL CHEMISTRY AND SOIL SCIENCE

**DEPARTMENT OF AGRICULTURAL CHEMISTRY
AND SOIL SCIENCE,
MARATHWADA AGRICULTURAL UNIVERSITY,
PARBHANI - 431 402 (M.S.) INDIA**

2001.

CANDIDATE'S DECLARATION

*I hereby declare that the dissertation or part
thereof has not been submitted by
me to any other university or
institution for a degree
or diploma.*

Place: Parbhani.

Date: 24/6 / 2001.

V.P. Jondhale
(V.P. JONDHALE)



AFFECTIONATELY

DEDICATED

TO My

Beloved Parents

PROF. A.N. PHADNAVIS

M.Sc. (Agri.)

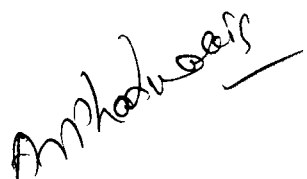
Assistant Professor,
Department of Agricultural Chemistry
and Soil Science,
College of Agriculture,
Marathwada Agricultural University,
Parbhani - 431 402 (M.S.).

CERTIFICATE – I

This is to certify that this thesis entitled "RESIDUAL MANAGEMENT OF SULPHUR ON YIELD AND QUALITY OF SAFFLOWER IN SUNFLOWER-SAFFLOWER CROPPING SYSTEM [Carthamus tinctorius L.] " embodies the result of investigation carried out by Shri. VIJAY PIRAJIRAO JONDHALE under my supervision and guidance. The best of my knowledge and belief, the data presented in this investigation are original and genuine and they have not been utilized for the award of any other degree or diploma. The assistance and help rendered during the course of investigation and source of literature have duly been acknowledged.

Place : Parbhani.

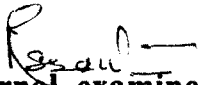
Date : 28/6 /2001.

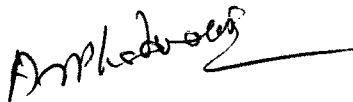

(A. N. PHADNAVIS)

Research Guide

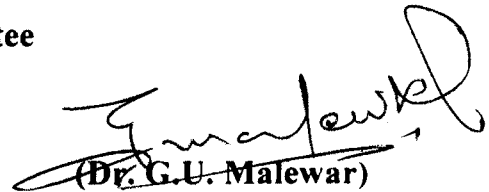
CERTIFICATE - II

This is to certify that the dissertation entitled, "RESIDUAL MANAGEMENT OF SULPHUR ON YIELD AND QUALITY OF SAFFLOWER IN SUNFLOWER-SAFFLOWER CROPPING SYSTEM [Carthamus tinctorius L.] ", submitted by Shri VIJAY PIRAJIRAO JONDHALE to the Marathwada Agricultural University, Parbhani in partial fulfilment of the requirement for the degree of MASTER OF SCIENCE (Agriculture) in the subject of AGRICULTURAL CHEMISTRY AND SOIL SCIENCE has been approved by the student's advisory committee after viva-voce examination in collaboration with external examiner.



(External examiner)
(R.S. KAUT)


(A.N. PHADNAVIS)
Research Guide

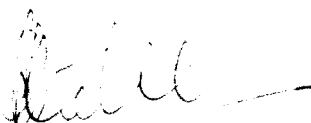
Advisory Committee


(Dr. G.U. Malewar)


(Prof. U.N. Karad)


(Prof. P.R. Waghmare)


(Dr. P.K. Joshi)


Associate Dean (P.G.)
College of Agriculture,
M.A.U., Parbhani.

ACKNOWLEDGEMENT

Indeed the words at my command are not adequate either in form or spirit to convey the depth of my feelings of gratitude to my esteemed Research Guide, **Prof. A.N. Phadnavis**, Assistant Professor, Department of Agriculture Chemistry and Soil Science, Marathwada Agricultural University, Parbhani, without whose scholastic guidance and constructive criticism this humble efforts would not have seen day light of today.

With profound respect, I acknowledge the indebtedness to **Dr. R.S. Raut**, Head of the Department of Agriculture Chemistry and Soil Science, M.A.U., Parbhani for his all the possible and valuable help in completion of this research work.

I equally grateful to my advisory committee members **Dr. G.U. Malewar**, Ex-Head of the Department of Agricultural Chemistry and Soil Science, **Prof. U.N. Karad**, Assistant Professor, Department of Agricultural Chemistry and Soil Science, **Prof. P.R. Waghmare**, Assistant Professor, Department of Agriculture Economics, **Dr. P.K. Joshi**, Associate Professor, Department of Agronomy, M.A.U., Parbhani, for ever willing advice, spiritual guidance and inspiration and full co-operation during my research work.

I am deeply indebted to **Dr. V.D. Patil**, Associate Dean (P.G.), College of Agriculture, M.A.U., Parbhani for his help and inspiration.

I am also thankful to all the staff members of the department of Agricultural Chemistry and Soil Science, M.A.U., Parbhani for time to time help they rendered.

I wish to place on record my personal thanks to class fellows and friends Limbraj Pholane, Arun Diwase, Rahul Hondalkar, Vinod Jondhale, Surendra Gaikwad, Mahendra Khandare, Jayesh Bhalerao, Feroz Khan, Vasim Khan and all the Departmental colleagues.

I have no words to express my feeling towards my respectful **Father Shri. Pirajirao Vithalrao Jondhale** and **Mother Sou. Kawshalya Pirajirao Jondhale**, My sister Mayadevi, Chhaya and Brother Sanjay who provided me all the facilities and encouragement during my life for doing better to the best. I will never forgot the share of sacrifice of my family members in my educational career.

Lastly, I am also thankful to Pravin Kapse and Rajesh Kapse (**Om Computer Point**), New Mondha, Parbhani for their patience and skill in computer typing, drawing in my research work successfully.

Place : Parbhani.

Date : / / 2001.


(V.P. JONDHALE)

CONTENTS

Sr. No.	Title	Page No.
1.	Introduction	1 – 2
2.	Review of literature	3 – 16
3.	Materials and methods	17 – 26
4.	Results	27 – 59
5.	Discussion	60 – 64
6.	Summary	65 – 66
	Literature cited	I – XIII
	Appendix – I	

LIST OF TABLES

Table No.	Title	Page No.
1)	Initial physico-chemical properties of experimental soil.	18
2)	Meteorological weekwise data recording during experimental period 1998-99.	20
3)	Cultural practices and other operations carried out during experiment	22
4)	Effect of residual sulphur on grain and dry matter yield (kg ha ⁻¹) of safflower.	29
4a)	Interaction effect of residual sulphur on grain and dry matter yield (kg ha ⁻¹) of safflower.	30
5)	Effect of residual sulphur on the content of crude protein, oil percentage and oil yield (kg ha ⁻¹) in safflower.	32
5a)	Interaction effect of residual sulphur sources and levels on oil yield (kg ha ⁻¹) of safflower.	33
6)	Effect of residual sulphur on N, P, K and S content (%) in plant at flowering and harvest stage of safflower.	34
6a)	Interaction effect of residual sulphur on the content of potassium (%) in the plant of safflower at flowering and harvest stage.	37
7)	Effect of residual sulphur on uptake of nitrogen (kg ha ⁻¹) by safflower.	40
7a)	Interaction effect of residual sulphur on uptake of nitrogen (kg ha ⁻¹) by safflower.	41
8)	Effect of residual sulphur on uptake of phosphorus (kg ha ⁻¹) by safflower.	43
8a)	Interaction effect of residual sulphur on uptake of phosphorus (kg ha ⁻¹) by safflower.	44

Table No.	Title	Page No.
9)	Effect of residual sulphur on uptake of potassium (kg ha^{-1}) by safflower.	46
9a)	Interaction effect of residual sulphur on uptake of potassium (kg ha^{-1}) by safflower.	47
10)	Effect of residual sulphur on uptake of sulphur (kg ha^{-1}) by safflower.	49
10a)	Interaction effect of residual sulphur on uptake of sulphur (kg ha^{-1}) by safflower.	50
11)	Residual effect of different sources and levels of sulphur on fractions of sulphur in soil (mg kg^{-1}) at flowering stage of safflower.	52
11a)	Interaction effect of sources and levels of sulphur on fraction of sulphur in soil (mg kg^{-1}) at flowering stage of safflower.	54
12)	Residual effect of different sources and levels of sulphur on fractions of sulphur in soil (mg kg^{-1}) at harvest stage of safflower.	56
12a)	Interaction effect of sources and levels of sulphur on fraction of sulphur in soil (mg kg^{-1}) at harvest stage of safflower.	57
13)	Residual effect of different sulphur fraction and their relationship with yield parameters of safflower.	59

LIST OF FIGURES

Fig. No.	Title	In between page number
1.	Layout experimental design	20 – 21
2.	Residual effect of sulphur sources and levels on Grain yield and dry matter yield	32 – 33
3.	Residual effect of sulphur sources and levels on crude protein and oil percent	32 – 33
4.	Residual effect of sulphur sources and levels on sulphur fractions in soil at flowering stage	57 – 58
5.	Residual effect of sulphur sources and levels on sulphur fractions in soil at harvest stage	57 – 58



Introduction

INTRODUCTION

Sulphur is categorized as a secondary essential nutrient for plant growth. In recent years sulphur has been receiving increasing attention throughout the world and India is no exception. Its significance is increasing many folds under irrigated, intensive and high-tech agriculture. Now the time has come to include sulphur, the forth major nutrient into the main stream of balanced fertilizer use (TSI, 1982 and FAO-FIAC, 1992),

Large number of factors have been identified for sulphur deficiency i.e. continuous use of high yielding varieties, restricting the concept of balanced fertilizer use in fertilizer planning, increasing removal of soil sulphur through high yielding hybrids, intensive cropping system, inadequate recycling of crop residues, losses of S-through leaching and erosion were led to a marked increase in area of sulphur deficiency in soils.

Sulphur requirement of oil seeds is 3-4 folds more than the cereals. Sulphur plays a multiple role in synthesis of sulphur containing amino acids, biosynthesis of proteins, nitrogen and carbohydrate metabolism, involved in biological nitrogen fixation by promoting nodulation in legumes and oil seed crops. Therefore, sulphur has been termed as master nutrient in oil seed production.

It is thought that sulphur containing fertilizers have little long residual effect as there is no strong mechanism for inorganic sulphate in soil (Sagare and Bhalkar, 1986). The direct fertilized crop contributed 33 to 82 per cent to the total rotational response to sulphur depending on the cropping system and the crop raised on residual sulphur contributed 18 to 67 per cent (Tiwari and Sakal, 1997). The widely observed residual response to sulphur shows that a significant amount of added sulphur remains in available form after harvest of first crop. The results on direct and residual effects of sulphur on yield revealed that sulphur expressed relatively low response to the succeeding crop (Sachdev and Deb, 1990). The residual value of sulphur application was mainly determined by plant uptake of

previous season and allowing plant residue to recycling in situ. The residual value was limited by the conversion of inorganic sulphur to organic forms (McLachlan and De Marco, 1975). It is also equally important to evaluate the residual value in totality rather than individual crops.

In soil sulphur occurs in sulphate ions in solution, adsorbed sulphate ions on exchange complexes. On oxidation, sulphides gives rise to sulphates. Since, sulphur exist in soil majorly in organic and inorganic combinations, the inter-relationship of these pools with one another would help in predicting the response of crops to its application (Patil *et al.*, 1981, Malewar and Ismail, 1997).

Considering recent scenario of residual sulphur response in vertisol of Maharashtra and also considerable response to added sulphur to the crops, and in adequate information in case of safflower with residual sulphur response. Safflower is grown as sole crop as well as taken as intercrop in various pulses and cereals in Maharashtra. It was felt necessary to evaluate residual sulphur response in vertisols of Maharashtra. Impact of the sulphur application on oil content is amply evident in oilseed crops. Further it is also proved fact that uptake of sulphur is more than phosphorus uptake in most of oilseeds.

Moreover, the sulphur aspects related to soil and crops are not dealt critically particularly in vertisols. Hence a comprehensive research project on ***“Residual management of sulphur on yield and quality of safflower in sunflower-safflower cropping system”*** was planned with following objectives.

1. To study the effect of residual sulphur on yield and quality of safflower.
2. To study the effect of residual value of sulphur on concentration and uptake of nutrients by safflower.
3. To study the sulphur fractions in soil and their relationship with yield parameters of safflower.



**Review of
Literature**

REVIEW OF LITERATURE

Safflower (*Carthamus tinctorius* L.) a source of high quality edible oil is a crop with much potential for Marathwada region and is adaptable for wide range of soil. The present study is aimed to assess the relative efficiency of different applied residual sulphur sources and their graded levels in relation to yield and quality attributes of safflower, concentration and uptake of nutrients and sulphur fraction. The pertinent literature on these aspects reviewed under the following heads :

- 2.1 Effect of residual sulphur on yield and quality of safflower.
- 2.2 Effect of residual value of sulphur on concentration and uptake of nutrients (N, P, K and S) by safflower.
- 2.3 Fractions of residual sulphur in soil.
 - 2.3.1 Available / sulphate sulphur.
 - 2.3.2 Organic sulphur.
 - 2.3.3 Non sulphate sulphur.
 - 2.3.4 Total sulphur.
- 2.4 To study the sulphur fractions and their relationship with quality attributes of safflower.

2.1 Effect of residual sulphur on yield and quality of crop.

The widely observed residual response to sulphur imply that a significant amount of added S remains in soil after its utilization by the proceeding crop which has a manurial value as residual effect for the succeeding crop.

Purvimath (1983). On vertisols of Bellary district of Karnataka. application of 10 ppm S with 150 kg ha⁻¹ each of N and P to safflower gave an extra seed yield of 6.16 q ha⁻¹ over control.

Takkar and Nayyar (1984) reported that an application of 50 kg S ha⁻¹ gave a response rate of 7.7 kg seed per kg added sulphur in safflower.

Beaton and Warger (1985) while reviewing the role of sulphur in the nutrition of safflower reported that sulphur is a vital component of maximum yield.

Sagare and Bhalkar (1986) reported that sulphur containing fertilizer have little long lasting residual effect, which significantly improves yield of succeeding oil seed crop. Also, reported that, elemental sulphur is slow acting and has long lasting effecting due to its least solubility.

Pasricha and Aulakh (1986). In the groundnut wheat cropping system, direct and residual effect were obtained regardless of which crop was fertilized, where direct response with groundnut were low, residual effect with wheat was more effective over control.

Singh and Tiwari (1989). In greenhouse study with sesame-mustard sequence, while sesame responded upto 20 kg S ha⁻¹, while, mustard raised on residual S responded upto 60 kg S ha⁻¹.

Bapat (1989) In wheat-soybean rotation in MP, soybean yield increased by 30 per cent when 30 kg S ha⁻¹ was added in wheat. Residual effect of 30 kg S ha⁻¹ found statistically significant over control in soybean.

Tiwari (1989) reported the highest seed yield (2264 kg ha⁻¹) of safflower, which was 23.30 per cent more over control when 30 kg S ha⁻¹ was applied in alluvial soils of Uttar Pradesh.

Bahl *et al* (1990) in loamy sand soil at Fatehpur Panjab, reported that, effect of Pyrite and gypsum on yield of mustard, but the highest response of S on yield was observed at 20 kg S ha⁻¹. However, both the sources achieved significant residual effect of S on wheat yield.

Gangadhara *et al* (1990) observed that application of elemental sulphur @ 10 kg ha⁻¹ alongwith N, P, K significantly increased the oil content, oil yield,

crude protein and test weight of sunflower but 5 kg S ha⁻¹ was relatively less effective.

Tiwari *et al.* (1990) results from Kanpur where wheat groundnut trial conducted showed that, groundnut crop benefited more with applied residual granulated elemental sulphur and achieved 22.00 per cent more yield over control.

Biswas and Tewatia (1991) reported significant residual effect of S application achieved more crop yield over control varied from 20.00 to 53.00 per cent in groundnut-groundnut and groundnut-wheat cropping systems.

Singh *et al.* (1991) in groundnut-mustard rotation on slightly alkaline soil, significant direct as well as residual sulphur responses were obtained. However, total grain yield for the rotation was 13 per cent more and oil yield was 19 per cent more when S was applied to groundnut when mustard on residual response.

Sharma and Gupta (1992) reported response of S application (0 to 100 kg S ha⁻¹) to soybean-safflower cropping system in vertisol at Indore. The highest yield was observed with 100 kg S ha⁻¹ + 22 kg P₅ treatment. The residual effect of S was significant on safflower and the highest yield of safflower was (1.92 t) obtained at applied residual S level 100 kg S ha⁻¹.

Tiwari *et al.* (1992) observed that, addition of 20 kg S ha as ammonium sulphate and 30 kg S ha⁻¹ as gypsum in mustard-rice cropping system, increased the yield of mustard from 686 to 1010 and 933 kg ha⁻¹ and their corresponding residual effect increased the rice grain yield from 2756 to 3466 and 2963 kg ha⁻¹ respectively.

Sreemannarayana and Sreenivasa Raju (1993) conducted a field experiment on Alfisols and Vertisols at Hyderabad on sunflower based cropping systems, which were sunflower-sunflower, sunflower-sorghum and sunflower-green gram. It was observed that the removal of S was highest in sunflower-sunflower cropping systems showed significant residual effect of applied sulphur at 40 to 60 kg S ha⁻¹ levels applied to safflower crop. Similar, result were obtained with vertisol too (Sreemannarayana *et al.*, 1994).

Abbas *et al.* (1995) reported that increasing level of sulphur increased seed yield and straw yield significantly upto 40 kg S ha⁻¹. Non significant difference existed between 40 kg and 60 kg S ha⁻¹ levels.

Tondon (1995) indicated that, application of 40 to 60 kg S ha⁻¹ per year in paddy-wheat cropping system. Paddy yield increased by 634 to 742 kg ha⁻¹ in cackreous soils of Northern Bihar. The residues of sulphur produced a further yield increases from 400 to 450 kg ha⁻¹ in wheat.

Tripathi and Sharma (1995) reported that oil and protein content in mustard seed increased significantly upto 40 and 80 kg S ha⁻¹ respectively.

Ganesh Murthy (1996) conducted field trial of soybean-wheat cropping system on vertisols, the residual effect of 60 kg S ha⁻¹, applied previously to soybean crop was found significant in increasing yield of wheat.

Singh *et al.* (1996) in maize-wheat cropping system, indicated that application of 40 kg S ha⁻¹ increased the maize grain yield from 2067 to 3340 kg ha⁻¹, also its residual effect increased wheat grain yield from 2450 to 3125 kg ha⁻¹.

Tiwari (1996) conducted field trials to evaluate carry over effect of applied S in rice-wheat, wheat-rice and sugarcane-ratoon cropping systems. He noted that the grain yield of the succeeding crops significantly increased at 40 to 60 kg S ha⁻¹ applied to preceeding crop.

Islam *et al.* (1997) reported the seed yield of mustard increase significantly but stalk yield showed non significant response with the applied residual sulphur to previous rice crop.

Yengade and Ghonsikar (1997) observed that application of 40 kg ha⁻¹ sulphur significantly increased oil content in seeds of sunflower.

Dwivedi and Bapat (1998) reported significant increase in seed yield, protein and oil content of soybean with successive application upto 50 kg dose of S and P in comparison to control.

Singh *et al.* (1998) reported that higher oil content of (38.8 per cent) and protein content (20.2 per cent) in seeds of mustard were recorded using gypsum as

the source of sulphur and the differences were statistically significant over pyrite and elemental sulphur.

Singh *et al.* (2000) reported that the mean oil content at 60 kg S ha⁻¹ application increased linearly by 3.7 per cent as compared to control and oil yield of niger increased with S application upto 40 kg ha⁻¹.

2.2 Effect of residual value of sulphur on concentration and uptake of nutrients (N, P, K and S).

It was observed that, sulphur fertilization increased the uptake of N, P, K and S in cereals, pulses and oilseed crops like sunflower, safflower, groundnut, soybean, mustard, sesamum, etc. The positive influence of sulphur on uptake of these nutrients has been reported by several workers.

Pathak and Pathak (1972) studied the response of S contained fertilizers on groundnut at Kanpur, uptake of S, N, K and Ca increased with increasing levels of sulphur, percent of S, N, and Ca were decreased with the advancement in the age of crop.

Aulakh *et al.* (1976) observed that with increasing rates of applied S, the concentration of total N, protein N, total-S protein S and total soluble S in the alfalfa plant increased.

Dhillan and Dev (1978) observed that application of sulphur to soybean grown on coarse textured soils of Punjab increased the sulphur uptake in the plant.

Shinde *et al.* (1982) studied the relationship between the contents of N, P, K and S in the soybean plant tissue with grain yield was better at 50 days growth than that at 25 days growth. The critical concentration of N, P, K and S in soybean plant tissue at 50 days growth was 2.38, 0.152, 1.982 and 0.138 per cent respectively.

Jain *et al.* (1984) noticed that application of elemental sulphur excelled all other sources in influencing sulphur uptake of different crops.

Aulakh *et al.* (1990) in three year field experiment on soybean showed a synergistic effect upto P @ 35 kg ha⁻¹ and S @ 40 kg ha⁻¹ after combine application of P and S. the antagonistic effect P + S on plant growth and on cross utilization was only observed when they were applied together at 52.2 kg ha⁻¹.

Rathor and Manohar (1990) observed that in mustard yield and N uptake increased with increasing S rates upto 160 kg ha⁻¹ and N rates upto 120 kg ha⁻¹. 180 kg N + 320 kg S ha⁻¹ gave the highest N uptake of 83.4 kg ha⁻¹ compared with 30.9 kg without N and S.

Tiwari (1990) results from Kanpur observed that wheat following groundnut benefited more from residual S (22 per cent yield increased). Also the increased the uptake of nutrients as compared to wheat.

Singh *et al.* (1991) noted in groundnut-mustard cropping system on sandy clay loam soils of Uttar Pradesh. Direct effect of pyrite was best on groundnut @ 500 kg ha⁻¹ and on mustard @ 400 kg ha⁻¹. But the residual effects were found best improving concentration on both the crops @ 400 kg ha⁻¹ pyrite.

Prasad *et al.* (1991) recorded that in soybean plant S concentration was 1069 ppm in control but the highest S concentration was observed with 75 kg ha⁻¹ S and 50 kg ha⁻¹ P₂O₅. Effect on oil concentration was not significant, but P and S generally increased their concentrations.

Sharma and Gupta (1992), In soybean and safflower sequence crops. N and S application increased uptakes of N, P, K and S of both the soybean and safflower crops.

Tiwari *et al.* (1992). FAO trials network conducted at Varanasi for two consecutive years inferred that residual effect of S applied @ 20 kg ha⁻¹ on mustard crops increased the N, P, K and S concentration in both the year.

Sreemannarayana and Sreenivasa Raju (1993) observed in sunflower safflower cropping sequence that, significant residual effect of applied S in increasing N, P, K and S concentration and uptake in both sunflower and safflower crops only @ 40 and 60 kg ha⁻¹ sulphur levels.

Tripathi *et al.* (1995) found that, S uptake in sorghum and cowpea cropping sequence increased significantly at residual level of sulphur @ 80 kg ha⁻¹ over control being highest with source elemental sulphur.

Islam *et al.* (1997) observed that, N and S uptake in mustard increased significantly with application of S to previous rice crop.

Anonymous (1998) In FAI-IGFRI collaborative project on Alfisols and vertisols, it was found in wheat-groundnut cropping sequence. The total uptake by wheat crop (grain + straw) were significantly increased with 45 kg ha⁻¹ sulphur application also the groundnut crop yield and total uptake were significantly increased with residual sulphur over control.

Jaggi and Sharma (1999) concluded pot culture experiment on mustard using different type of soils from Kangra district of Himachal Pradesh recorded that the application of S @ 30 and 60 mg kg⁻¹ consistently significant increase in S uptake in all that soils.

Paliya and Verma (1999) reported that the application of phosphorus lime and gypsum in acid soils (pH 5.8) increased the yield and phosphorus uptake by wheat-soybean cropping sequence.

Singh *et al.* (2000) reported the significant increase in S uptake by seed and straw of niger with increasing levels upto 45 kg S ha⁻¹.

2.3 Fractions of sulphur in soil.

2.3.1 Sulphate sulphur (Available sulphur) :

Plant absorbs S as SO₄ ions from the growth medium to meet its requirement. The SO₄-S pool comprises largely of water soluble, adsorbed and easily releasable sulphur from soil organic matter.

Patil *et al.* (1981) reported in the soil of Maharashtra that, SO₄-S ranged between 6 to 58 ppm.

Dev and Kumar (1982) reported that content of available S in soils of India varied widely and it is especially deficient either in light textured soils or in those areas, which are intensively cultivated under multiple cropping.

Singh and Singh (1994) found in soils of Madhya Pradesh, the content of available S in the soils varied from 4.9 to 43 mg kg⁻¹ in oil seed growing areas.

Singh *et al.* (1995) reported that SO₄-S is the most dominating fraction of S from the point of view of plant nutrition which ranged from 7.0 to 22.0 ppm in alluvial soil of Uttar Pradesh.

Tandon (1995) in a TSI-Funded project in sugarcane growing areas of Pune and Kholapur, only 8 per cent soil samples were S deficient in Maharashtra.

Bapat *et al.* (1997) reported that SO₄-S in soils varied from 1.4 to 21.5 mg kg⁻¹ (mean 10.3 mg kg⁻¹) in vertisols of Madhya Pradesh.

Naphade *et al.* (1997) reported that the available S status of soil after soybean crop was increased from 7.10 to 17.45 mg kg⁻¹ with increasing level of S application in Akola.

Malewar *et al.* (1998) collected 200 soil samples from oil seed growing area of Latur district of Marathwada region of Maharashtra which contained available S from 1.28 to 75.67 mg kg⁻¹ S. They further noted that 13.5 per cent of soil samples were deficient in available sulphur.

Malewar and Ismail (1998) indicated that 54 per cent of soils were found to be low in available S. It was ranged from 0.71 to 421.67 mg kg⁻¹ soil. They also noted that western Maharashtra soils are more prone to its deficiency (63 per cent).

2.3.2 Organic Sulphur :

Tanawada *et al.* (1976) reported that 55 per cent of total S was present as organic S in the black soils of Maharashtra.

Lande *et al.* (1977), noted in the black soils of Marathwada region of Maharashtra, the organic S were 39.95 and 46.03 per cent of the total sulphur.

Patil and Ghoniskar (1985) reviewed work on sulphur in Maharashtra and reported that organic sulphur was ranged from 54 to 265 ppm in the vertisols of Maharashtra.

Kanwar and Mudahar (1986) reported that, organic sulphur is the dominant fraction in most of the Indian soils. Organic S is a reserve for plants but it must undergo mineralization before becoming available to plants.

Takkar (1988) reviewed work on organic S in Indian soils which varied widely from 7 ppm in Ustochrepts in Punjab to 109 ppm in the fine textured soils of Bihar.

Kolape *et al.* (1991) In medium black soils of Konkan region of Maharashtra contained 75.2 to 263.2 ppm organic S and constituted on an are range of 55 to 57 per cent of total S.

Satpute and Malewar (1991) indicated organic S as 27 to 320 ppm in Jayakwadi command area. However, relatively lower values of 17.6 to 91.4 mg kg⁻¹ S in various soil series of the vertisols of Maharashtra.

Hariram and Dwivedi (1994) analysed ninety soil surface soil samples in the control alluvial tract of Uttar Pradesh and showed that organically bound sulphur ranged from 21.1 to 68.1 mg kg⁻¹ with mean value of 33.5 mg kg⁻¹ and on an average constituted 28 per cent of total S.

Ganesha Murthy *et al.* (1995) observed that, 90.4 per cent of organic S constitutes as total S and varied from 52 to 113 ppm with mean of 82 ppm, it was also indicated that organic S is mineralized by both biological and biochemical mineralization.

Sahoo *et al.* (1998) recorded that the lauser amount organic S (8.7 to 35.9 per cent of the total S) in respect of total S in the Sundarban soils which was due to the presence of higher amount of SO₄-S which contributed 60.7 per cent to the total S and also the presence of lower amount of organic matter in these soils.

2.3.3 Inorganic Sulphur (Non SO₄-S) :

Lande *et al.* (1977). In the vertisols of Maharashtra, found that non-SO₄-S ranged from 34.8 to 144.6 ppm with an average of 71 ppm in case of normal soils and from 158.8 to 558.8 ppm (mean 383.9 ppm) in case of saline soils of Marathwada region.

Dolui and Nayek (1981) indicated that non SO₄-S was varied from 13 to 70 ppm (average 29.14 ppm) in red and lateritic soils of West Bengal and accounted 24.6 to 64.4 per cent of the total-S.

Pandey *et al.* (1989) reported that non SO₄-S remains in the insoluble complex compound and could not be extracted by these chemicals and indicated that non SO₄-S varied from 53.9 to 86.7 ppm (75.7 ppm) which was about 50 per cent of the total-S.

Balanagoudar and Satyanarayana (1990) noted in vertisols and Alfisols of Karnataka that, non SO₄-S content in the soils varied from 404 to 3356 ppm with an average of 1136 ppm i.e. 75.4 to 98.7 per cent with an average of 89 per cent of total -S.

Kolape *et al.* (1991) showed non SO₄-S in the range of 76.92 to 195.15 ppm in lateritic, 18.57 to 168.07 ppm in medium black and 373.95 to 497.65 ppm in coastal saline soils with their mean contribution of 35.3, 35.4 and 44.1 per cent of total-S respectively, in the rice growing soils of Konkan region of Maharashtra.

Tondon (1991) reviewed sulphur work on Indian soils. Non sulphate sulphur fraction accounts for 2 to 71 per cent of total-S, this fraction is opposite of the organic sulphur fraction. On an average it constituted 22 per cent of total S in hill terai soils but 66 per cent in alluvial soil.

Hariram and Dwivedi (1994) observed non SO₄-S from 23.8 to 98.1 mgkg⁻¹ with a mean value of 72.1mg kg⁻¹ in the alluvial tracts of Uttar Pradesh, which constituted 61 per cent of total-S.

Pal and Singh (1994) showed significant increase in non SO₄-S content in soil from 28.1 to 156.7 ppm due to each level of sulphur application.

Dharkanath *et al.* (1995) observed non-SO₄-S content in soils varied from 1050 to 2432 mg kg⁻¹ with an average of 1616 mg kg⁻¹ in the series of vertisols of Maharashtra.

Mandal *et al.* (1997) reported mean content of non SO₄-S was 177.45 mg kg⁻¹ in mollisols of Uttar Pradesh.

Malewar and Ismail (1997) reported in review of non SO₄-S in the soils of Maharashtra that, non SO₄-S presence in the range of 28 to 558 ppm in surface soils and 1050 to 2432 ppm in sub-surface soil profiles of vertisols and Inseptisols of Maharashtra.

2.3.4 Total sulphur in soil :

Lande *et al.* (1977) reported that, total S ranged between 82.4 and 1057 mg kg⁻¹ in black soils of Marathwada region.

Ruhal and Paliwal (1978) indicated that total-S was in the range of 100 to 3250 mg kg⁻¹ with an average of 1577.9 mg kg⁻¹ in the soils of Rajasthan.

Dolui and Nayek (1981) studied total-S in some red and lateritic soil profiles of West Bangal which was ranged from 38 to 123 mg kg⁻¹ with an average of 60 mg kg⁻¹. They also noted that the total-S content declined with depth in the soil profiles.

Ganesh murthy *et al.* (1989) recorded wide variations in the content of total-S in coastal plain soils of Andaman and Nicobar, they also indicated that hill slop soils are generally contained less total-S as compared to coastal plain soils and followed a similar pattern of distribution of decreasing sulphur content with increase in the depth. Among, the coastal plain soils were acid sulphate in nature and S-accumulation was as high as 9750 mg kg⁻¹.

Satpute and Malewar (1991) worked in vertisols of Marathwada region of Maharashtra and found that the content of total-S varied from 68.5 to 1164.5 mg kg⁻¹.

Padmaja and Sreenivasa Raju (1992) noted in the red soils of Andra Pradesh, the mean contents of total-S in Patancheru-I, Pantancheru-II,

Devarkonda, Totikol and Denda series of Mahaboobnagar district were 199, 298, 232, 245 and 157 mg kg⁻¹ respectively.

Kher and Singh (1993) reported that total-S ranged from 139 to 226 mg kg⁻¹ with an average value of 183 mg kg⁻¹ in the mustard growing soils of North Kashmir.

Reddy *et al.* (1993) showed 608 mg kg⁻¹ total-S in red soils of Nagarjuna sugar project area of Andhra Pradesh.

Dongale *et al.* (1994) noted 843 to 952 mg kg⁻¹ total-S in coastal saline soils of Konkan region of Maharashtra.

Dharkanath *et al.* (1995) reported that total-S content in the vertisols of Maharashtra varied from 1125 to 2525 mg kg⁻¹ with an average of 1788 mg kg⁻¹. Total-S was highest in surface horizons and decreased with the increase in depth of soil in all profiles.

Singh (1995) noted that total-S varied from 23.1 to 369.6 mg kg⁻¹ in Niger growing areas of Ranchi district of Bihar.

Malewar and Ismail (1997) pointed out the fact that in soils of Western India, total-S increased with increasing depth of soil. Surface soil having 68.5 to 1164.5 mg kg⁻¹ and sub surface soil indicating 250 to 3835.6 mg kg⁻¹ total-S.

Tripathi *et al.* (1997) reported total S content in the range from 50 to 600 mg kg⁻¹ with mean value of 235 mg kg⁻¹ in Aridisols of Haryana and it was highest in surface horizon and decrease with depth of soil.

2.4 Sulphur fraction and their relationship with crop yield parameters.

Rawat and Srinivas (1979) reported that, SO₄-S extracted by 0.5M NaHCO₃ ($r = 0.815^{**}$) and 0.15 percent CaCl₂ solution was correlated with sulphur uptake by crop. Also, monopotassium phosphate, 500 ppm phosphorus solution was found to be significantly correlated with the dry matter yield ($r = 0.966^{**}$) of linseed crop.

Tiwari *et al* (1983) studied S-concentration in various parts of rice plant receiving to sulphur treatment and showed poor correlation with dry matter production and yield of grain and straw. But the values of correlation coefficient improved much when they were correlated with equivalent percentage yield. However, highest correlation coefficients ($r = 0.82^{**}$ to 0.97^{**}) were registered with percent S uptake in plants grain and straw grown in alluvial soils of Uttar Pradesh.

Patel and Marsonia (1985) reported that, heat soluble sulphur showed the highest significant and positive correlation with dry matter and seed yield of wheat, correlation coefficients were $r = 0.702^{**}$ and $r = 0.879^{**}$ respectively.

Singh *et al* (1990) observed that CaCl_2 extractable sulphur was significantly related with yield of control, relative yield and per cent S-uptake by mustard. Whereas, NH_4 OAC extractable S was not found to be significantly related with yield of mustard.

Satpute (1990) indicated that all the forms of sulphur has significant positive relationship with dry matter and grain yield of safflower. Soil SO_4 -S showed highest correlation coefficients $r = 0.913^{**}$ and $r = 0.999^{**}$ respectively with dry matter and grain yield of crop.

Patgiri and Baruah (1993) reported a positive but non significant correlation (0.38) between seed yield and S content of toria in acid soils of Aasam.

Subba Rao and Ganesha Murthy (1994) reported positive relationship of available sulphur (SO_4 -S) with Bray's per cent yield ($r = 0.767^*$) in vertisols of M.P. significant negative relationship was established between available sulphur and absolute response of soybean ($r = 0.641^{**}$) and per cent response of soybean ($r = -0.738^{**}$).

Gupta *et al* (1995) showed that, extracted S by various extractants correlated with Bray's per cent grain and straw yield and showed that the correlation obtained was relatively higher for 0.15 per cent CaCl_2 extractant than others. The

available S ($\text{SO}_4\text{-S}$) was significantly and positively correlated with wheat grain (0.81**) and straw (0.76**) yield.

Bapat *et al* (1997) reported that total sulphur and organic sulphur had a positive correlation with grain and straw yields, S-uptake and S-content in linseed crop. Also, adsorbed sulphur fractions had significant positive relationship with grain (0.674**) and straw yields (0.510*) of linseed crop. Similarly available sulphur ($\text{SO}_4\text{-S}$) has a significant positive correlation with all the plant characters except S-content in linseed grains.



Methodology

MATERIALS AND METHODS

The details about the material used and methods adopted during the course of present investigation are given in this chapter under appropriate heads.

3.1 Experimental material.

3.1.1 Experimental site:

Field experiment was conducted on experimental farm of Department of Agricultural Chemistry and Soil Science, College of Agriculture, Parbhani during rabi season of 1998-99. Topographically experimental plot was fairly leveled. The soil was well drained, calcareous, developed over weathered basaltic material. The initial physico-chemical properties of experimental soil are given in Table-1. The field used for the experiment was having soil identical to that of Typic Haplusterts (Vertisol) of Parbhani series as classified by Malewar (1976). On the basis of X-ray analysis. Malewar and Randhawa (1978) identified similar clay mineral assemblage in these soils which invariably dominant in montmorillonite followed by moderate amount of kaolinite and tracer illite. Further, these soils constitute bulk of iron ores along with epidote, augite, chlorite, hornblend, traces of zircon, tourmaine, feldspar, fiedspar, quartz, muscovite, pyrites and pyroxines (Maniyar, 1979).

The experimental soil was Vertisol (Typic Haplusterts) clay in texture, moderately calcareous and alkaline in nature, normal in salt content. Available N, P₂O₅ and K₂O were in moderate range. However, 0.15 per cent CaCl₂ extractable (SO₄-S) Sulphur.

Table-1: Initial physico-chemical properties of experimental soil.

Sr. No.	Soil characteristics	Unit	Value
A.	Mechanical composition		
	Coarse sand	%	8.85
	Fine sand	%	4.62
	Silt	%	32.17
	Textural class	-	Clayey
	Field capacity	%	34.38
B.	Chemical composition		
	PH	-	7.86
	EC	dSm ⁻¹	0.35
	Organic carbon	g kg ⁻¹	5.51
	Free CaCO ₃	g kg ⁻¹	5.78
C.	Fertility analysis		
	Available N	Kg ha ⁻¹	206.32
	Available P ₂ O ₅	Kg ha ⁻¹	10.98
	Available K ₂ O	Kg ha ⁻¹	339.81
	Available S (0.15% CaCl ₂ extractable)	Mg kg ⁻¹	32.91
	Exchangeable Ca	Cmol (p) kg ⁻¹	37.21

3.1.2 Climate and weather conditions :

Parbhani falls under semi-arid tropics, geographically situated at 19°60' North latitude and 76°47' East longitude with an elevation of 423.46 meters above mean sea level. The average rainfall on the basis of annual rainfall of the region is 830 mm and region comes under assured rainfall zone. The precipitation during 1998-99 was 859.3 mm in the period from Aug. 98 to Apr. 99. The rainfall mostly concentrated during the rainfall monsoon month from June to October. The daily mean maximum and minimum temperature ranged from 16.5 to 31.48°C and 7.7 to 17.3°C respectively during crop growth period. The variations in rainfall distribution, temperature and atmospheric humidity recorded at Agricultural Meteorological Observatory, MAU, Parbhani during the period of experiment is given in Table-2.

3.1.3 Cropping history of the experimental plot :

Year	Kharif	Rabi
1997-98	Cotton	Groundnut
1998-99	Sunflower	Safflower

3.1.4 Experimental layout :

The experiment was laid out in a factorial randomized block design with twelve treatment combinations, which were replicated thrice. The treatments consist of four applied residual sulphur sources and their three graded levels. Recommended N, P₂O₅ and K₂O (60:30:30 kg ha⁻¹) was applied at the time of sowing through urea, single super phosphate and Murate of potash respectively.

3.1.5 Treatment details :

Sources of residual sulphur

- S₁ : Residual elemental sulphur (RES)
- S₂ : Residual Acidam – 90 (RAS)
- S₃ : Residual Mahadhan Na – 90 (RMNa)
- S₄ : Residual Mahadhan Ca – 90 (RMCa)

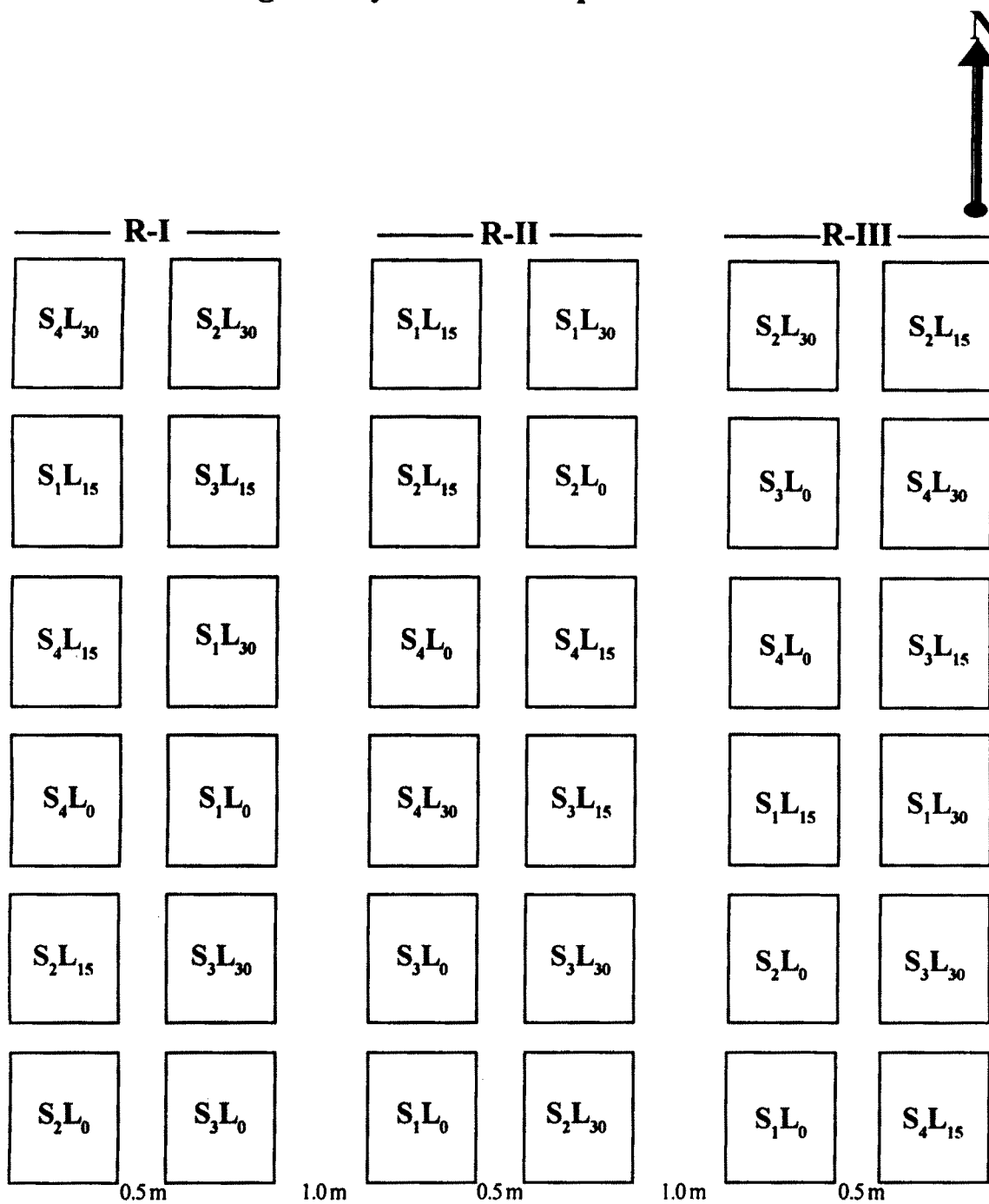
Levels of residual sulphur

- L₀ : 0 kg S ha⁻¹ (control)
- L₁₅ : 15 kg S ha⁻¹
- L₃₀ : 30 kg S ha⁻¹

Table-2: Meteorological data, Parbhani (1998-99).

Month	Meteorological week No.	Rain fall (mm)	Rainy days	Temperature °C		Relative humidity (%)	
				Max.	Min.	A.M.	P.M.
Aug.	32	116.6	5	29.5	23.4	91	77
	33	18.0	3	30.5	23.2	85	68
	34	133.9	4	31.2	22.7	92	76
	35	28.4	1	30.6	23.0	84	64
Sept.	36	124.7	2	30.8	23.0	90	71
	37	24.5	4	29.2	22.8	87	73
	38	124.0	3	30.2	22.0	90	68
	39	27.0	3	30.6	22.0	89	70
Oct.	40	32.6	2	32.0	22.1	84	64
	41	86.0	5	30.8	22.3	91	75
	42	107.0	2	29.3	19.2	91	63
	43	1.0	0	29.2	19.6	83	66
	44	4.6	1	29.8	19.6	76	58
Nov.	45	22.0	1	30.8	20.5	78	58
	46	0.0	0	29.3	15.4	75	41
	47	0.0	0	29.6	13.0	78	57
	48	0.0	0	29.0	10.5	77	29
Dec.	49	0.0	0	29.5	8.8	74	27
	50	0.0	0	28.0	8.7	76	28
	51	0.0	0	27.8	7.9	77	30
	52	0.0	0	27.2	6.7	78	28
Jan.	1	0.0	0	28.0	7.8	80	30
	2	0.0	0	26.2	6.9	71	30
	3	0.0	0	28.7	9.0	78	29
	4	0.0	0	30.6	11.0	74	28
Feb.	5	0.0	1	30.5	11.7	74	28
	6	9.0	0	30.5	15.6	83	38
	7	0.0	0	32.0	14.7	77	36
	8	0.0	0	34.5	14.7	66	31
Mar.	9	0.0	0	35.5	15.8	69	29
	10	0.0	0	36.2	16.5	60	28
	11	0.0	0	36.7	17.8	51	24
	12	0.0	0	37.4	18.0	47	24
April.	13	0.0	0	39.5	16.0	47	17
	14	0.0	0	40.3	19.7	46	14
	15	0.0	0	42.0	21.4	42	17
	16	0.0	0	40.8	19.1	44	18
	17	0.0	0	41.8	24.5	41	17
	18	0.0	0	43.0	24.0	44	18
Mean		859.3	37	31.48	16.52	71	41.18

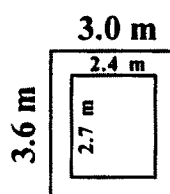
Fig 1 : Layout of the experimental field.



Plot Size :

Gross : 3.6 x 3.0 m²

Net : 2.7 x 2.4 m²



3.1.6 Other details of the experiment :

1.	Experimental design	Factorial Randomized Block Design.
2.	Treatment combinations	Twelve.
3.	Number of replication.	Three.
4.	Crop.	Safflower.
5.	Variety.	Sharda.
6.	Plot size	
	<i>Gross</i>	3.4 × 3.0 m ²
	<i>Net</i>	2.7 × 2.4 m ²
7.	Spacing.	45 × 20 cm ²
8.	Total number of plots	Thirty six.
9.	Recommended dose of fertilizers.	60 : 30 : 30
10.	Date of sowing.	24-11-1998
11.	Date of harvesting.	29-03-1999

3.1.7 Seed and sowing :

Sharda variety of safflower, selected for present investigation was released for its cultivation in the State of Maharashtra by Marathwada Agricultural University, Parbhani and having following characters; it matures in 120-125 days. It is resistant to wilting and aphids having heavy tillering habit, the flower colour is reddish yellow and grains are bold white.

The germination test was carried out in the laboratory before sowing. The average germination percentage was 92.0. The sowing was done by dibbling two seeds at each spot spaced at 15cm × 45cm apart and seed was covered with soil. Periodical operations like thinning to keep one plant at each dibble were carried out to maintain plant population. Due care was taken against insect and pests. The dates of various cultural operations are given in Table-4.

3.2 Pre-harvest studies :

Five plants from each net plot were randomly selected and labeled with alumina foil tag. Number of branches/plant and number of capsules/plant were counted from same tagged plants at flowering (72days) and at harvest stage and averaged. At the same stages two plants from each net plot were drawn for uptake studies. Simultaneously soil sample from each plot was also collected at 72 days after sowings and at harvest for the analytical purpose.

Table-3 : Cultural practices and other operations carried out during experiment.

Sr. No.	Cultural operations	Date
1.	Land preparation.	04-10-98
2.	Land layout.	05-10-98
3.	Sowing (dibbling) and with fertilizer application (N, P and K).	24-11-98
4.	Germination count.	08-12-98
5.	Thinning/gap fillings.	09-12-98
6.	Spraying of rogar.	03-01-98
7.	Hand weeding.	08-01-98
8.	Harvesting (Cutting)	29-03-98
9.	Threshing.	06-04-99

3.3 Post harvest studies :

3.3.1 Harvesting :

The experimental net plots of each treatment from three replications were harvested separately and kept for sun drying for eight days. After complete drying the weight of dry matter/plot along with grains and capsules was recorded with spring balance. Threshing was done manually by beating the capsules with wooden stick and grain weight per net plot was taken on top pan electrical balance. Finally, for dry matter yield per plot was calculated by its subtraction from green matter yield per plot and both were calculated for per hectare yield.

3.4 Soil analysis.

Soil samples were collected at flowering and harvest stage of the crop treatment wise randomly from 0-30 cm depth from each net plots and were analysed for pH, EC, organic carbon, free calcium carbonate, available N, P₂O₅, K₂O and available sulphur.

3.4.1 Soil sample preparation :

The already collected bulk soil sample and samples collected at various growth stages were air dried, cleaned and filled in polythene bags with proper labelling for further analytical purpose.

3.4.2 Mechanical analysis of soil :

The various mechanical fractions from the initial soil sample were determined by international pipette method as described by Piper (1966).

3.4.3 soil reaction (pH) :

This was determined in 1:2.5 soil: water suspension using digital pH meter (Jackson, 1973).

3.4.4 Electrical conductivity (EC) :

It was estimated in (1:2.5) soil: water suspension using direct read type conductivity meter (Jackson, 1973).

3.4.5 Organic carbon :

Walkley and Black's rapid titration method was used for the determination of organic carbon from soil (Black, 1965).

3.4.6 Free calcium carbonate :

Free calcium carbonate was determined by Rapid titration method using bromothymol blue and bromocresol green indicators (Puri, 1949).

3.4.7 Available soil nitrogen :

It was determined by using hot alkaline potassium permagnet method as described by Subbiah and Asija (1956).

3.4.8 Available soil phosphorus :

Phosphorus was extracted from the soil with 0.5 M sodium bicarbonate at a constant pH 8.5 and phosphorus thus extracted was determined by Olsen's method (Olsen *et al*, 1954).

3.4.9 Available soil potassium :

It was determined by using neutral normal ammonium acetate as an extractant using flame photometry (Jackson, 1973).

3.4.10 Sulphur fractions in soil.

3.4.10.1 Total sulphur :

Total-S in soil was determined in diacid digest Chapman and Pratt, (1961). Total-S in all the extract was determined by turbidimetrically as described by Chesnin and Yein (1951). Transfer 2g of soil in 100 ml conical flask and add 20ml of diacid (HNO_3 : HClO_4) mixture in 9 : 4 ratio, put a funnel on the mouth of the conical flask and heat for an hour on hot plant. Then increase the temperature until the residue is white, cool and filter in 100 ml volumetric flask, wash the residues with distilled water until became volume upto the mark. Take 5ml of extract in 25ml of volumetric flask. Then add 1 g of BaCl_2 powder and shake well for 1 minute. Add 1 to 2 ml of gum acacia solution and make volume upto the mark, shake well and take the turbidity reading between 5 to 20 minutes on spectrophotometer at $440\mu\text{m}$ wavelength. Standard curve was prepared using A.R. grade K_2SO_4 .

3.4.10.2 Available sulphur (sulphate sulphur) :

In this method. S is extracted with 0.15 per cent CaCl_2 (Williams and Steinberg's, 1959) and the soluble sulphate sulphur is to be estimated turbidimetrically on a colorimeter using blue filter or spectrophotometer at $440\mu\text{m}$. Transfer 5g soil upto conical flask and add 25 ml of 0.15 per cent CaCl_2 solution into it. Shake for 30 minutes on reciprocating shaker, filter the suspension through whatman No. 42 filter paper. Pipette out 10 or 20ml extract in 150ml conical flask and add 20ml of distilled water. Thus bringing the volume to 30ml add 2.5 ml of stabilizing solution and 0.2 to 0.3 g of BaCl_2 powder, shake the flask for 1 minute each at concentrate. After 1-3 minutes, measure the turbidity on spectrophotometer at $440\mu\text{m}$.

3.4.10.3 Organic sulphur :

Organic S in soil was estimated by the procedure described by Evan's and Rost (1945). Take 5 or 10g of soil depending upon the amount of organic matter, leach with distilled water until free of chloride. Transfer the soil to a beaker and oxidize with hydrogen peroxide, filter through filter paper and precipitate S with barium chloride and shake for one minutes, add one ml of 0.25 per cent gum acacia solution. Measure the turbidity on spectrophotometer at 440 μ m wavelength.

3.4.10.4 Non sulphate sulphur :

This was determined by subtraction of organic sulphur and sulphate sulphur from total sulphur as given by Chesnin and Yein (1951).

3.5 Plant analysis.

3.5.1 Preparation of samples :

For the determination of nutrient contents in plant samples, the samples were drawn at flowering (72 DAS) and at harvest (120 DAS). First of all the plant was washed with tap water and roots were discarded, the plant further rinsed in detergent solution followed by distilled water. After cleaning plants were dried in shade and subsequently in oven at 70⁰ for 12 hrs. The oven dried samples were ground in electrically operated grinder with stainless steel blades upto maximum fineness. The powdered samples were stored in polythene pockets with proper labeling and these were further used for nutrient analysis.

However, defatted grain samples (residue left after oil extraction in soxhlet thimble) were used for nutrient analysis.

3.5.2 Digestion :

One g of fine powdered plant per grain sample was taken in 100 ml conical flask. 5 ml of concentrated nitric acid was added to it and kept for over night. On next day 10 ml of diacid mixture (HNO₃ and HClO₄ in 10:4) was added and digested on hot plate as described by Piper (1966). After digestion known volume was prepared with glass distilled water and filtered. The same extract was used for the estimation of P, K, and S

3.5.3 Nitrogen :

The plant and grain nitrogen content was determined by Microkjeldahl's method as described in A.O.A.C. (1975).

3.5.4 Phosphorus :

The plant and grain phosphorus was estimated by Vanadophosphomolybdate yellow colour method as given by Piper (1966).

3.5.5 Potassium :

It was determined by the method described by Jackson (1973). The acid extract was used for potassium determination by flame photometer.

3.5.6 Sulphur :

Sulphur in plant and grain samples was estimated by turbidimetric method on spectrophotometer as described by Tabatabai and Bremner (1970). The turbidity was measured on spectrophotometer.

3.6 Analysis of safflower seed for quality aspects.

3.6.1 Oil content :

Oil content from the safflower seed was determined by soxhlet apparatus using petroleum ether as an extractant (Plummer, 1988).

3.6.2 Oil yield :

Oil yield (kg ha^{-1}) was calculated by multiplying the respective oil content with respective grain yield.

3.6.3 Protein content :

The nitrogen content from the grain samples was estimated by Microkjeldhals method (A.O.A.C., 1975) and N content was multiplied by 6.25 to get per cent crude protein.

3.6.4 Uptake of nutrients :

Nutrient uptake i.e. uptake of N, P, K, and S was calculated by considering grain and dry matter yield at harvest in particular plot in relation to concentration of the particular nutrient in respective plot.

3.7 Statistical analysis :

Results obtained were statistically analysed as per the method given by Panse and Sukhatme (1985).



Results

RESULTS

Field studies on different residual sources of sulphur and their levels in safflower were conducted in order to evaluate response to residual effect on safflower crop. The experiment was conducted on well defined soil group (Typic Haplustert) during Rabi season of 1998-99 with crop safflower at departmental farm, College of Agriculture, Parbhani during the experimentation biometric and yield parameters were recorded. In addition, different soil properties and fractions of sulphur in soil were estimated at various critical growth stages of safflower. Data on yield, nutrient concentration, nutrient uptake by crop and nutrient availability in soil during the experiment were collected and subjected to statistical analysis.

From these experiments, large amount of data was obtained which were analyzed statistically compiled, properly and presented under the appropriate heads.

1. Residual effect of sources and levels of sulphur on yield parameters of safflower.
2. Residual effect of sources and levels of sulphur on quality of produce of crop.
3. Residual effect of sources and levels of sulphur on nutrient concentration at critical growth stages of safflower.
4. Residual effect of sources and their levels of sulphur on nutrient uptake at critical growth stages of safflower.
5. Residual effect of sulphur sources and their levels of sulphur on sulphur fractions in soil at critical growth stage of safflower.
6. Residual effect of different sulphur fractions and their relationship with yield parameters of safflower.

4.1 Grain and dry matter yield of safflower.

The data presented in Table 4 indicated that, the grain yield of safflower varied from 1360.70 to 1443.30 kg ha⁻¹ grain yield followed by S₃ (RMNa) recorded 1421.00 kg ha⁻¹ and S₄ (RMCa) noted 1384.80 kg ha⁻¹. Further, lowest grain yield was recorded in S₂ (RAS) i.e. 1360.70 kg ha⁻¹ statistically S₁ (RES) was recorded superior to all other sources.

Similarly, the dry matter yield of safflower at flowering and harvest stage ranged between 2897.00 to 3080.70 kg ha⁻¹ and 4491.00 to 4776.00 kg ha⁻¹ respectively. From all the residual sulphur sources S₁ (RES) recorded significantly higher dry matter yield at flowering and at harvest stage of safflower i.e. 3080.70 and 4776.00 kg ha⁻¹ respectively. Followed by S₃ (RMNa) at flowering (3031.70 kg ha⁻¹) and at harvest (4700.00 kg ha⁻¹) also in S₄ (RMCa) recorded at flowering (2954.00 kg ha⁻¹) and at harvest (4567.00 kg ha⁻¹) dry matter yield.

The residual effect of sulphur levels were significantly increased the safflower grain and dry matter yield. The grain yield increased varied from 1181.10 to 1568.50 kg ha⁻¹ and dry matter yield at flowering and harvest stage were increased from 2453.00 to 3406.20 kg ha⁻¹ and 3802.80 to 5280.80 kg ha⁻¹ respectively. It was noted that each incremental level of sulphur in soil increased the grain and dry matter yield of safflower. However, L₃₀ (30 kg S ha⁻¹) registered higher grain yield (1568.50 kg ha⁻¹) and dry matter yield at flowering stage (3406.20 kg ha⁻¹) also at harvest stage (5280.80 kg ha⁻¹) statistically L₃₀ (30 kg S ha⁻¹) was found to be superior to all other levels of sulphur.

The interaction effect of sources and levels of sulphur on grain and dry matter yield at flowering and harvest stage of safflower were found to be statistically significant. Compiled data (Table - 4a) revealed that, S₁L₃₀ recorded maximum grain yield (1660.00 kg ha⁻¹) and dry matter yield at both stages of safflower i.e. 3605.00 and 5589.00 kg ha⁻¹ respectively. Further, it was indicated

Table 4 : Effect of residual sulphur on grain and dry matter (kg ha⁻¹) yield of safflower.

Treatment	Grain yield (kg ha ⁻¹)	Dry matter yield (kg ha ⁻¹)	
		At flowering	At harvest
Residual 'S' sources			
S ₁	1443.3	3080.7	4776.0
S ₂	1360.7	2897.0	4491.0
S ₃	1421.0	3031.7	4700.0
S ₄	1384.8	2954.0	4567.0
S.E. ±	7.971	10.73	15.20
C.D. at 5%	23.34	31.43	44.52
Residual 'S' levels			
L ₀	1181.1	2453.0	3802.8
L ₁₅	1457.8	3113.0	4817.0
L ₃₀	1568.5	3406.2	5280.8
S.E. ±	30.90	9.29	13.16
C.D. at 5%	20.21	27.22	38.56
Interaction (S×L)			
S.E. ±	13.80	18.59	26.33
C.D. at 5%	40.48	54.44	77.12

Table 4a : Interaction effect of residual sulphur on grain and dry matter yield (kg ha⁻¹) of safflower.

Treatments	Residual sulphur sources			
	S ₁	S ₂	S ₃	S ₄
Residual sulphur levels	Grain (kg ha⁻¹)			
L ₀	1180.0	1163.0	1206.0	1175.3
L ₁₅	1490.0	1421.0	1468.0	1452.0
L ₃₀	1660.0	1498.0	1589.0	1527.0
S.E. ±	13.80			
C.D. at 5%	40.43			
	Dry matter yield (kg ha⁻¹) at flowering stage			
L ₀	2455.0	2403.0	2509.0	2445.0
L ₁₅	3182.0	3035.0	3135.0	3101.0
L ₃₀	3605.0	3253.0	3451.0	3316.0
S.E. ±	18.59			
C.D. at 5%	54.44			
	Dry matter yield (kg ha⁻¹) at harvest stage			
L ₀	3806.0	3725.0	3890.0	3790.0
L ₁₅	4933.0	4705.0	4860.0	4770.0
L ₃₀	5589.0	5043.0	5350.0	5141.0
S.E. ±	26.33			
C.D. at 5%	77.12			

that, S_1L_{30} was found to be statistically significant to all other treatment combinations.

4.2 Residual value of sulphur on quality parameter of safflower.

From the data (Table-5), it is showed that, the protein percentage in safflower increased from 15.28 to 15.66 per cent, due to different sources of sulphur. Sources of sulphur significantly improved the oil percentage and oil yield from 33.69 to 36.18 per cent and 487.02 to 524.87 kg ha⁻¹ respectively. Relatively, highest protein percentage was recorded under S_1 (RES) i.e. 15.66 per cent, followed by S_3 (RMNa) and S_4 (RMCa) giving 15.52 and 15.39 per cent respectively. Similarly, highest oil percent and oil yield were recorded in S_1 (RES) which were 36.18 per cent and 524.87 kg ha⁻¹ respectively. Followed by S_3 (RMNa) and S_4 (RMCa) the lowest values of oil per cent and oil yield were noted in S_2 (RAS) i.e. 35.39 percent and 487.02 kg ha⁻¹ respectively. In all the sources S_1 (RES) found to be statistically significant to all other treatments.

The residual effect of various levels of sulphur significantly affected the protein percentage, oil percentage and oil yield of safflower. Increasing levels of sulphur from 0 to 30 kg S ha⁻¹ increased the protein percentage, oil percentage and oil yield of safflower. Increased values of protein percentage, oil percentage and oil yield were noted in L_{30} (30 kg S ha⁻¹) levels i.e. 15.98 per cent, 36.82 per cent and 578.05 kg ha⁻¹ respectively. Whereas, the values of protein per cent and oil per cent due to various levels of sulphur were found on par with each other. Statistically, L_{30} (30 kg S ha⁻¹) level was found to be significantly superior to all other levels of sulphur in all the quality parameters of safflower.

The residual interaction effect of sources and levels of sulphur was found significant in influencing oil yield (kg ha⁻¹) except protein percentage and oil percentage.

T 4044

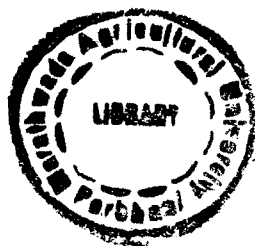


Table 5 : Effect of residual sulphur on the content of crude protein, oil percentage and oil yield (kg ha⁻¹) in safflower.

Treatment	Crude protein (percent)	Oil (per cent)	Oil yield (kg ha⁻¹)
Residual 'S' sources			
S ₁	15.66	36.18	524.87
S ₂	15.28	35.69	487.02
S ₃	15.52	35.59	507.55
S ₄	15.39	35.25	489.34
S.E. ±	0.036	0.216	5.437
C.D. at 5%	0.106	0.633	15.924
Residual 'S' levels			
L ₀	14.96	34.46	407.05
L ₁₅	15.45	35.76	521.49
L ₃₀	15.98	36.82	578.05
S.E. ±	0.031	0.187	4.709
C.D. at 5%	0.092	0.548	13.791
		0.374	9.418
Interaction (S×L)			
S.E. ±	0.063	0.374	9.418
C.D. at 5%	NS	NS	27.58

Fig 1 : Residual effect of sulphur sources and levels on Grain yield and dry matter yield

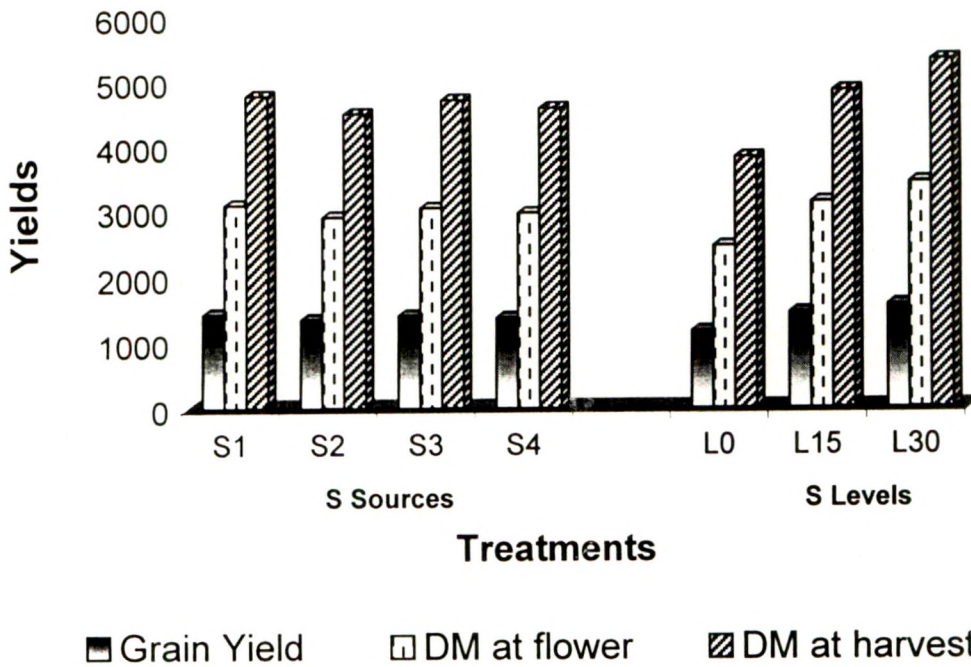


Fig 2 : Residual effect of sulphur sources and levels on crude protein and oil percent

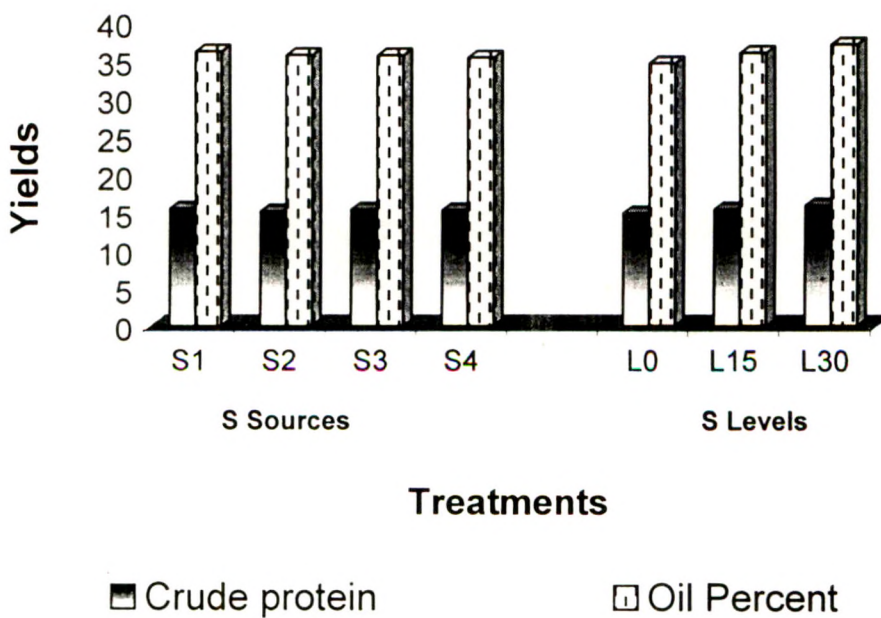


Table-5a : Residual interaction effect of sources and levels of sulphur on oil yield (kg ha⁻¹) of safflower.

Treatments	Residual sulphur sources			
	S ₁	S ₂	S ₃	S ₄
Residual sulphur levels				
L ₀	408.49	402.03	413.31	404.39
L ₁₅	540.56	509.95	523.28	512.15
L ₃₀	625.56	549.09	586.07	551.49
S.E. ±	9.41			
C.D. at 5%	27.58			

However, statistically S₁L₃₀ found superior to all other treatment combinations.

4.3 Residual effect of sources and levels of sulphur on N, P, K and S concentration safflower at flowering and harvest stage.

Sulphur was applied to sunflower crop in kharif and its residual effect was tested in safflower. Here, residual effect of sulphur on nutrient content in safflower is presented in detail.

4.3.1 Nitrogen concentration :

The results from Table-6 indicated that the nitrogen concentration in safflower at flowering stage ranged between 1.85 to 1.91 per cent. Similarly nitrogen percentage in grain and straw at harvest stage varied from 2.44 to 2.50 per cent and 1.32 to 1.36 per cent, respectively. Sources of residual sulphur had brought significant changes in the nitrogen concentration in safflower at flowering and harvest stage. However, differences among sources were found to be in a very

Table 6 : Effect of residual sulphur on N, P, K and S content (%) in plant at flowering and harvest stage of safflower.

Treatment	N %			P %			K %			S %		
	At flowering	At harvest		At flowering	At harvest		At flowering	At harvest		At flowering	At harvest	
		Seed	Straw		Seed	Straw		Seed	Straw		Seed	Straw
Residual 'S' sources												
S ₁	1.91	2.50	1.36	0.20	0.23	0.12	1.52	1.92	1.07	0.346	0.45	0.26
S ₂	1.85	2.44	1.32	0.18	0.21	0.10	1.48	1.75	0.93	0.323	0.42	0.23
S ₃	1.90	2.48	1.34	0.19	0.24	0.11	1.51	1.86	1.00	0.343	0.44	0.25
S ₄	1.87	2.46	1.33	0.19	0.23	0.11	1.49	1.82	0.98	0.340	0.43	0.24
S.E. ±	0.01	0.005	0.009	0.004	0.004	0.003	0.005	0.006	0.003	0.004	0.003	0.004
C.D. at 5%	0.03	0.016	0.027	0.012	0.012	0.008	0.014	0.018	0.01	0.013	0.01	0.12
Residual 'S' Levels												
L ₀	1.76	2.39	1.19	0.17	0.20	0.09	1.43	1.63	0.81	0.28	0.40	0.20
L ₁₅	1.89	2.47	1.35	0.19	0.21	0.11	1.49	1.77	0.98	0.34	0.44	0.24
L ₃₀	1.99	2.55	1.47	0.21	0.24	0.13	1.57	2.11	1.20	0.38	0.47	0.29
S.E. ±	0.01	0.004	0.008	0.003	0.003	0.002	0.004	0.005	0.003	0.003	0.003	0.003
C.D. at 5%	0.03	0.014	0.023	0.01	0.01	0.006	0.012	0.015	0.009	0.011	0.009	0.01
Interaction (S×L)												
S.E. ±	0.02	0.009	0.001	0.007	0.007	0.004	0.008	0.01	0.006	0.007	0.006	0.007
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	0.031	0.018	NS	NS	NS

narrow range. The highest nitrogen concentration in safflower at flowering stage also in seed and straw yield at harvest stage was recorded. In S_1 (RES), indicating values 1.91 per cent, 2.50 per cent and 1.36 per cent respectively. Followed by S_3 (RMNa) and S_4 (RMCa). The lowest values of nitrogen concentration were recorded in S_2 (RAS) at flowering and harvest stage of safflower.

The residual effect of levels of sulphur significantly improved the nitrogen concentration in safflower at flowering stage also in seed and straw at harvest stage. At flowering stage, the nitrogen concentration ranged from 1.76 to 1.99 per cent. Whereas, in seed and straw at harvest stage it varied from 2.39 to 2.55 per cent and 1.19 to 1.47 per cent respectively significantly higher values of nitrogen concentration in safflower at flowering stage also in seed and straw at harvest stage were observed L_{30} (30 kg S ha⁻¹) level, indicating 1.99 per cent at flowering stage, 2.55 per cent in seed and 1.47 per cent in straw at harvest stage of safflower.

The residual interaction effect of sources and levels of sulphur failed to reach the level of significance to nitrogen concentration in safflower.

4.3.2 Phosphorus concentration :

The data presented in Table-6 indicated that the phosphorus concentration in safflower at flowering stage varied from 0.18 to 0.23 per cent, also, that in seed and straw at harvest stage, it ranged between 0.21 to 0.23 per cent and 0.10 to 0.12 per cent. Sources of sulphur had brought significant changes in phosphorus percentage at both the growth stages of safflower. But the differences among sources were found to be in a very narrow range. The higher phosphorus concentration in safflower at flowering stage that also in seed and straw at harvest stage, were recorded under S_1 (RES) indicating values 0.20 per cent, 0.23 per cent and 0.12 per cent respectively. Comparing the other sources, S_3 (RMNa) was on par with S_4 (RMCa). Lowest phosphorus concentration in safflower at flowering stage (0.18 per cent), in grains (0.21 per cent) and straw (0.20 per cent) at harvest stage, were recorded in S_2 (RAS) source. Statistically S_1 (RES) was recorded superior to all other sources.

The residual effect of levels of sulphur significantly improved the phosphorus concentration in safflower. At flowering stage, phosphorus concentration ranged from 0.17 to 0.21 per cent. Whereas in seed and straw at harvest stage it varied from 0.20 to 0.24 per cent and 0.09 to 0.13 per cent respectively. Significantly maximum value of phosphorus concentration was observed in L₃₀ (30 kg S ha⁻¹) level indicating values at flowering (0.21 per cent), in seed (0.24 per cent) and in straw (0.13 per cent), followed by L₁₅ (15 kg S ha⁻¹) and L₀ (Control). Statistically L₃₀ (30 kg S ha⁻¹) noted significantly superior to all other levels.

The residual interaction effect of sources and levels of sulphur failed to reach the level of significance.

4.3.3 Potassium concentration :

The potassium concentration in safflower at flowering stage ranged from 1.48 to 1.52 per cent, also at harvest stage, in seed it was ranged between 1.75 to 1.92 per cent and in straw yield it was found to be 0.93 to 1.07 per cent (Table 6). Among the all residual sulphur sources S₁ (RES) noticed higher values of potassium concentration in safflower at both the growth stages and that values were at flowering (1.52 per cent), in seed (1.92 per cent) and in straw at harvest stage (1.07 per cent), followed by S₃ (RMNa). Relatively, lower content of potassium in safflower was registered under S₂ (RAS) at flowering and harvest stage.

It is observed that the increasing levels of sulphur (0 to 30 kg S ha⁻¹) increased the potassium concentration in safflower. The concentration of potassium increased from 1.43 to 1.57 per cent at flowering stage, and at harvest stage, in seed 1.63 to 2.11 per cent and in straw yield it is ranged between 0.81 to 1.20 per cent significantly higher values of potassium concentration were recorded under L₃₀ (30 kg S ha⁻¹) level at all stages of safflower. Each incremental level of sulphur application was found significantly superior to its proceeding one.

Table-6a: Interaction effect of residual sulphur on the content of potassium (%) in the plant of safflower at flowering and harvest stage.

Treatments	Residual 'S' sources			
	S ₁	S ₂	S ₃	S ₄
	Residual 'S' levels.			
L ₀	1.64	1.62	1.63	1.64
L ₁₅	1.84	1.71	1.79	1.75
L ₃₀	2.28	1.92	2.18	2.07
SE±	0.01			
CD at 5%	0.03			
	At harvest (Straw yield)			
L ₀	0.85	0.74	0.83	0.83
L ₁₅	1.12	0.91	0.96	0.94
L ₃₀	1.24	1.15	1.22	1.18
SE±	0.006			
CD at 5%	0.018			

The interaction effect of residual sources and levels of sulphur on potassium concentration in safflower at flowering and harvest stage was found to be significant. It is revealed that at flowering stage, the treatment combination S₁L₃₀ showed maximum content of potassium in safflower followed by S₃L₃₀, S₄L₃₀ and S₂L₃₀. However, at flowering stage the higher values of potassium concentration was recorded under S₁L₃₀ (1.62 per cent) which was found statistically significant over all other combination other treatment combinations are ranged between 1.44 to 1.58 per cent.

Further, at harvest stage, in seeds and straw yield, the treatment combination S_1L_{30} registered maximum values of potassium 2.28 per cent and 1.24 per cent respectively which were statistically significant over all other treatment combinations. Followed by S_3L_{30} and S_4L_{30} . Which were statistically superior over control and L_{15} level of residual sulphur with all other residual sulphur sources.

4.3.4 Sulphur concentration :

The data revealed that the residual effect of different sources of sulphur significantly improved the concentration of sulphur at all the critical growth stages of safflower as showed in Table-6. The content of sulphur in safflower at flowering stage and at harvest stage in which seed and straw yield were ranged between 0.323 to 0.346 per cent, 0.42 to 0.45 per cent and 0.23 to 0.26 per cent respectively.

At flowering stage, significantly higher sulphur concentration was noticed under S_1 (RES) 0.346 per cent, followed by S_3 (0.343 per cent), S_4 (0.340 per cent) and S_2 (0.323 per cent).

At harvest stage, in which in seed and straw significantly higher concentrate was noticed in S_1 (RES) 0.45 per cent and 0.26 per cent respectively, followed by S_3 (RMCa) 0.44 and 0.25 per cent, respectively. Lowest value was noted in S_2 (RA) 0.42 and 0.23 per cent respectively.

The residual effect of graded levels of sulphur was also found to increase its concentration significantly at all growth stages of safflower. The increasing in sulphur concentration at flowering stage varied from 0.28 to 0.38 per cent. Similarly at harvest stage, in grains and straw it was found 0.40 to 0.47 per cent and 0.20 to 0.29 per cent, respectively.

Application of 45 kg S sulphur per hectare (L_{30}) recorded maximum content of sulphur in safflower at all growth stages. Statistically L_{30} (30 kg S ha⁻¹) was found to be superior to all other levels of sulphur.

Interaction effects of sources and levels of residual sulphur were found to be non-significant.

4.4 Residual effect of sources and levels of sulphur on uptake of nutrients by plant, grain and total uptake by safflower crop.

The results obtained on residual sulphur fertility in respect of uptake of N, P, K and S by safflower are presented.

4.4.1 Nitrogen uptake :

The residual effect of various sources of sulphur was found to be significant. Uptake of nitrogen in grain straw and total N uptake presented in Table-7. The N uptake by straw varied from 41.76 to 46.20 kg ha⁻¹. The variation in grain and total N uptake because of residual effect of various sulphur carriers was from 33.36 and 36.31 kg ha⁻¹ and 75.12 to 82.51 kg ha⁻¹ respectively. Among the various sulphur sources, significantly higher values of N uptake by straw, grain and total N uptake by safflower were registered in S₁ (RES) which was statistically superior to all other sources of sulphur. Where S₃ (RMNa) and S₄ (RMCa) were on par with each other relatively lower value of uptake of N was recorded under S₂ (RAS) and was found significantly lower as compared to all other sources.

The uptake of N by straw increased from 31.19 to 54.87 kg ha⁻¹, by grain 28.28 to 40.15 kg ha⁻¹ and total N uptake 59.48 to 95.02 kg ha⁻¹ respectively. Nitrogen uptake in straw, grain and total N uptake was recorded under L₃₀ (30 kg S ha⁻¹), the residual value L₃₀ (30 kg S ha⁻¹) was found to be highly significant over all levels.

Table-7: Effect of residual sulphur on uptake of nitrogen (kg ha⁻¹) by safflower.

Treatment	N uptake (kg ha ⁻¹)		
	<i>Straw</i>	<i>Grain</i>	<i>Total</i>
Residual 'S' source			
S ₁	46.20	36.31	82.51
S ₂	41.76	33.36	75.12
S ₃	44.65	35.42	80.08
S ₄	42.83	34.21	77.07
SE±	0.33	0.26	0.55
CD at 5%	0.98	0.77	1.61
Residual 'S' levels			
L ₀	31.19	28.28	59.48
L ₁₅	45.52	36.04	81.59
L ₃₀	54.87	40.15	95.02
SE±	0.28	0.22	0.47
CD at 5%	0.84	0.66	1.40
Interaction (S X L)			
SE±	0.57	0.45	0.95
CD at 5%	1.69	1.33	2.80

Table-7a: Interaction effect of residual sulphur on uptake of nitrogen (kg ha⁻¹) by safflower.

Treatments	Residual 'S' sources			
	S ₁	S ₂	S ₃	S ₄
Residual 'S' levels.				
			Straw	
L ₀	31.76	30.22	32.18	30.59
L ₁₅	47.50	43.67	46.13	44.79
L ₃₀	59.32	51.39	55.66	53.12
SE±	0.57			
CD at 5%	1.69			
			Grain	
L ₀	28.44	27.68	28.94	28.08
L ₁₅	37.34	34.67	36.40	35.76
L ₃₀	43.15	37.74	40.92	38.78
SE±	0.457			
CD at 5%	1.339			
			Total	
L ₀	60.20	57.90	61.12	58.68
L ₁₅	84.85	78.34	82.53	80.64
L ₃₀	102.48	89.14	96.58	91.90
SE±	0.95			
CD at 5%	2.80			

From the Table-7a, it is observed that the plant N uptake was observed maximum in S₁L₃₀ (59.32 kg ha⁻¹), followed by S₃L₃₀ (55.66 kg ha⁻¹) and S₄L₃₀ (53.12 kg ha⁻¹), but S₂L₃₀ (51.39 kg ha⁻¹) was found significantly lower as compared to other levels. Comparing the other combinations, treatment combination S₁L₃₀ achieved (59.32 kg ha⁻¹) N uptake in grain, which was statistically superior over other, but S₂L₃₀ (37.74 kg ha⁻¹) and S₁L₁₅ (37.34 kg ha⁻¹) which were on par with S₄L₃₀ (38.78 kg ha⁻¹) treatment combination. S₃L₃₀ (40.92 kg ha⁻¹) was also found to be on par with S₁L₃₀ in enhancing grain N uptake. From all the treatment combination S₁L₃₀ (102.48 kg ha⁻¹) noticed significantly higher values which was statistically significant and superior to all other combinations.

4.4.2 Phosphorus uptake :

It is observed from the Table-8 the P uptake by plant varied from 3.23 to 4.08 kg ha⁻¹. Similarly, grain uptake also increased due to residual effect of various sulphur carriers, indicating range from 2.91 to 3.36 kg ha⁻¹. The variation in total P uptake was from 6.06 to 7.44 kg ha⁻¹. Among the different sources, the residual effect of S₁ (RES) observed to be highly prominent indicating higher values for straw, grain and total P uptake were 4.08 kg ha⁻¹, 3.36 kg ha⁻¹ and 7.44 kg ha⁻¹ respectively which were statistically significant to all other sources, followed by S₁ (RMNa), S₄ (RMCa) and S₂ (RAS).

The residual effect of increasing levels of sulphur was also found to be favourable in improving straw, grain and total P uptake. The straw, grain and total P uptake ranged between, 2.35 to 4.86 kg ha⁻¹, 2.36 to 3.88 kg ha⁻¹ and 4.52 to 8.74 kg ha⁻¹ respectively due to residual effect of varied levels of sulphur significantly higher P uptake by straw, grain and total P uptake by safflower was registered under L₃₀ (30 kg ha⁻¹) which was superior to other levels of sulphur. While the lowest P uptake was noted under L₀ (Control) level.

Table-8: Effect of residual sulphur on uptake of phosphorus (kg ha⁻¹) by safflower.

Treatment	P uptake (kg ha ⁻¹)		
	Straw	Grain	Total
Residual 'S' sources			
S ₁	4.08	3.36	7.44
S ₂	3.23	2.91	6.06
S ₃	3.78	3.19	6.94
S ₄	3.56	3.11	6.45
SE±	0.09	0.05	0.12
CD at 5%	0.26	0.16	0.36
Residual 'S' levels			
L ₀	2.35	2.36	4.52
L ₁₅	3.78	3.19	6.19
L ₃₀	4.86	3.88	8.74
SE±	0.08	0.05	0.01
CD at 5%	0.23	0.14	0.31
Interaction (S × L)			
SE±	0.15	0.09	0.21
CD at 5%	NS	0.27	0.62

Table-8 a: Interaction effect of residual sulphur on uptake of phosphorus (kg ha⁻¹) by safflower.

Treatments	Residual 'S' sources			
	S ₁	S ₂	S ₃	S ₄
Residual 'S' levels.	Grain uptake			
L ₀	2.35	2.32	2.44	2.34
L ₁₅	3.37	2.98	3.22	3.19
L ₃₀	4.36	3.44	3.91	3.81
SE±	0.093			
CD at 5%	0.273			
	Total uptake			
L ₀	4.97	4.36	4.75	4.02
L ₁₅	7.49	6.03	7.29	6.84
L ₃₀	9.85	7.81	8.80	8.50
SE±	0.213			
CD at 5%	0.624			

Interaction effects of residual sulphur sources and levels is presented in Table 8a that, the higher P uptake by grains was noted in S₁L₃₀ showing 4.36 kg ha⁻¹, followed by S₃L₃₀ (3.91 kg ha⁻¹). Statistically S₁L₃₀ was significantly superior to all other combinations in enhancing P uptake by grains. Comparing the significance of other combinations S₂L₃₀ treatment combination having 3.44 kg ha⁻¹ grain P uptake which was found statistically on par with S₄L₃₀ (3.81 kg ha⁻¹) S₁L₁₅ (3.37 kg ha⁻¹) and S₃L₁₅ (3.22 kg ha⁻¹) combinations. Further, the treatment combination S₁L₃₀ (8.5 kg ha⁻¹) total P uptake, which was on par with S₂L₃₀ (7.81 kg ha⁻¹) and S₁L₁₅ (7.49 kg ha⁻¹) but the treatment combination S₁L₃₀ (9.85 kg ha⁻¹)

showed maximum value and also which was statistically significant to all other treatment combinations.

4.4.3 Potassium uptake :

The data presented in Table-9 indicated that the residual effect of different sources of sulphur. The variations in straw and grain K uptake ranged from 29.93 to 36.61 kg ha⁻¹ and 23.96 to 28.20 kg ha⁻¹ respectively. Similarly, the total K uptake varied from 53.92 to 64.40 kg ha⁻¹. Among the sources of sulphur, S₁ (RES) showed higher straw, grain and total K uptake by safflower, but S₁ and S₃ were found to be on par with each other in influencing K uptake by plant relatively higher values of straw, grain and total K uptake were recorded under S₁ (RES) showing 36.61 kg ha⁻¹, 28.28 kg ha⁻¹ and 64.40 kg ha⁻¹, respectively.

The residual effect of varied levels of sulphur significantly improved the K uptake by safflower. From the data, presented in Table-9, it is confirmed that each level of sulphur (0 to 30 kg ha⁻¹) increased the K uptake by straw, grain and total K uptake by safflower. The residual effect of increasing levels of sulphur increased the straw K uptake, grain K uptake and total K uptake were ranged between 21.31 to 44.59 kg ha⁻¹, 19.27 to 33.21 kg ha⁻¹ and 40.68 to 77.82 kg ha⁻¹, respectively significantly higher values or straw, grain and total K uptake were found under L₃₀ (30 kg S ha⁻¹) level and statistically L₃₀ was found to be significantly superior over other levels of sulphur.

The interaction effects residual sulphur on uptake of K (kg ha⁻¹) presented in Table-9a, the higher K uptake by straw was noted in S₁L₃₀ showing 48.97kg ha⁻¹ followed by S₃L₃₀ (46.00 kg ha⁻¹) and S₄L₃₀ (42.64 kg ha⁻¹) so statistically, S₃L₃₀ was significantly superior to all other combinations. However, in grain K uptake was found that the S₁L₃₀ combination showed maximum value of 37.84 kg ha⁻¹ which was significantly higher than other treatment combinations. Further S₃L₃₀ showed 34.63 kg ha⁻¹ followed by S₄L₃₀ (31.60 kg ha⁻¹) and S₂L₃₀ (28.76 kg ha⁻¹).

Table-9: Effect of residual sulphur on uptake of potassium (kg ha^{-1}) by safflower.

Treatment	K uptake (kg ha^{-1})		
	Straw	Grain	Total
Residual 'S' sources			
S ₁	36.61	28.20	64.40
S ₂	29.93	23.96	53.92
S ₃	33.61	26.74	60.33
S ₄	31.88	25.42	57.31
SE \pm	0.17	0.23	0.36
CD at 5%	0.51	0.68	1.04
Residual 'S' levels			
L ₀	21.31	19.27	40.68
L ₁₅	33.12	25.76	58.62
L ₃₀	44.59	33.21	77.82
SE \pm	0.15	0.20	0.31
CD at 5%	0.44	0.58	0.90
Interaction (S X L)			
SE \pm	0.30	0.40	0.62
CD at 5%	0.89	1.17	1.81

Table-9 a: Interaction effect of residual sulphur on uptake of potassium (kg ha⁻¹) by safflower.

Treatments	Residual 'S' sources			
	S ₁	S ₂	S ₃	S ₄
Residual 'S' levels.	<i>Straw uptake</i>			
L ₀	22.31	18.95	22.27	21.70
L ₁₅	38.55	30.09	32.56	31.30
L ₃₀	48.97	40.76	46.00	42.64
SE±	0.303			
CD at 5%	0.887			
	<i>Grain uptake</i>			
L ₀	19.35	18.83	19.65	19.27
L ₁₅	27.41	24.29	25.94	25.40
L ₃₀	37.84	28.76	34.63	31.60
SE±	0.40			
CD at 5%	1.172			
	<i>Total uptake</i>			
L ₀	41.66	37.90	41.93	40.91
L ₁₅	64.97	54.39	58.50	56.70
L ₃₀	86.82	69.52	80.64	74.25
SE±	0.617			
CD at 5%	1.809			

Similarly the total K uptake was noted maximum in S₁L₃₀ (86.82 kg ha⁻¹) followed by S₃L₃₀ (80.64 kg ha⁻¹) and S₄L₃₀ (74.25 kg ha⁻¹). So the statistically significant treatment combination was S₁L₃₀ to all other combinations.

4.4.4 Sulphur uptake :

The results (Table 10) revealed that the residual effect of various sources of sulphur significantly enhanced the plant, grain and total S Uptake at harvest stage in safflower. The sulphur uptake by safflower plant and grain at harvest ranged from 7.41 to 9.01 kg ha⁻¹ and 5.84 to 6.51 kg ha⁻¹ respectively also the total S uptake was ranged between 13.26 to 15.52 kg ha⁻¹. As the data showed that, different sources of sulphur caused significant variation in sulphur uptake in plant and S uptake also the total S uptake by safflower, the different among them were of very narrow range. The range values of S uptake by safflower plant (9.01 kg ha⁻¹), grain (6.51 kg ha⁻¹) at harvest stage and total (15.52 kg ha⁻¹) S uptake were noted under S₁ (RES) source, followed by S₃ (RMNa) Source and S₄ (RMCa) source. Statistically, S₁ (RES) was significantly superior to all other sources. Relatively, lower magnitude of plant and grain at harvest and also in total S uptake was noted under S₂ (RAS) which were 7.41 kg ha⁻¹, 5.84 kg ha⁻¹ and 13.26 kg ha⁻¹ respectively.

The residual effect of various levels of sulphur also differed significantly in affection the S uptake by plant, grain and total S uptake in safflower. The plant and grain S uptake ranged between 5.37 to 11.13 kg ha⁻¹ and 4.76 to 7.37 kg ha⁻¹ respectively. Also the total S uptake ranged between 10.13 to 18.51 kg ha⁻¹.

Table 10 : Effect of residual sulphur on uptake of sulphur (kg ha⁻¹) by safflower :

Treatments	P uptake (Kg ha ⁻¹)		
	Plant	Grain	Total
Residual 'S' sources			
S ₁	9.01	6.51	15.52
S ₂	7.41	5.84	13.26
S ₃	8.59	6.28	14.88
S ₄	7.85	6.08	13.94
SE±	0.141	0.08	0.211
CD at 5%	0.415	0.23	0.618
Residual 'S' levels			
L ₀	5.37	4.76	10.13
L ₁₅	8.14	6.41	14.55
L ₃₀	11.13	7.37	18.51
SE±	0.122	0.070	0.182
CD at 5%	0.359	0.20	0.535
Interaction (S X L)			
SE±	0.245	0.14	0.365
CD at 5%	0.718	0.41	1.070

Table-10a : Interaction effect of residual sulphur on uptake of sulphur (kg ha⁻¹) by safflower.

Treatments	Residual 'S' sources			
	S ₁	S ₂	S ₃	S ₄
Residual 'S' levels.	<i>Plant uptake</i>			
L ₀	5.50	5.12	5.63	5.23
L ₁₅	8.57	7.54	8.48	7.96
L ₃₀	12.94	9.57	11.65	10.35
SE±	0.245			
CD at 5%	0.718			
	<i>Grain uptake</i>			
L ₀	4.75	4.64	4.94	4.70
L ₁₅	6.70	6.10	6.46	6.39
L ₃₀	8.07	6.79	7.46	7.17
SE±	0.140			
CD at 5%	0.410			
	<i>Total uptake</i>			
L ₀	10.26	9.76	10.57	9.93
L ₁₅	15.27	13.65	14.94	14.35
L ₃₀	21.02	16.36	19.12	17.53
SE±	0.365			
CD at 5%	1.070			

The levels L_{30} (30 kg S ha^{-1}) recorded maximum S uptake by plant, grain and the total S uptake which was statistically superior to all other levels of sulphur. The maximum values were noted in L_{30} level in plant, grain and total S uptake were 11.13 kg ha^{-1} , 7.37 kg ha^{-1} and 18.51 kg ha^{-1} respectively. Followed by L_{15} and L_0 levels.

The residual interaction effect of sources and levels of sulphur on S uptake by plant, grain and total S uptake were found significant in affecting total S uptake by safflower. The persual of the data (Table 10a) indicated that plant, S grain and total S uptake was higher under S_1L_{30} treatment combination showing 12.94 kg ha^{-1} , 8.07 kg ha^{-1} and 21.02 kg ha^{-1} respectively. Followed by S_3L_{30} (11.65 kg ha^{-1}) in plant S uptake, S_3L_{30} (7.46 kg ha^{-1}) in grain and S_3L_{30} (19.12 kg ha^{-1}) in the total S uptake. The S_1L_{30} combination was found statistically significant to all other treatment combinations. Comparing the significance of other combinations, it was noted that combination S_1L_{15} which was statistically on par with S_2L_{30} , and S_3L_{15} treatment combinations.

4.5 Residual effect of sulphur sources and their levels on sulphur fraction in soil at flowering and harvest stage of safflower.

4.5.1 Fractions of residual sulphur in soil at flowering stage of safflower :

It is revealed from data (Table 11) that, the residual effect of various sources of sulphur significantly improved the different fractions of sulphur in soil. The residual effect of sources of sulphur improved the $\text{SO}_4\text{-S}$ (Available sulphur), org-S, Non- $\text{SO}_4\text{-S}$ and **Total -S** content in soil. The content of $\text{SO}_4\text{-S}$ in soil increased from 28.16 to 31.65 mg kg^{-1} $\text{SO}_4\text{-S}$. Org-S in soil ranged between 158.81 to $178.88 \text{ mg kg}^{-1}$ in soil. Also Non- $\text{SO}_4\text{-S}$ ranged between 116.00 to $130.25 \text{ mg kg}^{-1}$ and Total-S varied from 302.97 to $340.79 \text{ mg kg}^{-1}$. Among the sources, S_1 (RES) recorded maximum content of $\text{SO}_4\text{-S}$ (31.65 mg kg^{-1}), org-S ($178.88 \text{ mg kg}^{-1}$), Non- $\text{SO}_4\text{-S}$ ($130.25 \text{ mg kg}^{-1}$) and the total-S ($340.79 \text{ mg kg}^{-1}$). Similarly, the values of the all sulphur fractions of sulphur were recorded in S_3 (RMNa) indicating 29.76, 167.53, 122.10 and $319.41 \text{ mg kg}^{-1}$, $\text{SO}_4\text{-S}$, org-S, Non- $\text{SO}_4\text{-S}$ and total-S respectively. However, S_1 (RES) was found significantly

Table 1f :Residual effect of different sources and levels of sulphur on fractions of sulphur in soil (mg kg⁻¹) at flowering stage of safflower :

Treatment	SO₄-S	Org-S	Non SO₄-S	Total-S
Residual 'S' sources				
S ₁	31.65	178.88	130.25	340.79
S ₂	28.16	158.81	116.00	302.97
S ₃	30.34	169.47	123.73	323.58
S ₄	29.76	167.53	122.10	319.41
SE±	0.41	0.76	0.93	0.88
CD at 5%	1.22	2.23	2.74	2.60
Residual 'S' levels				
L ₀	22.85	125.19	91.49	239.53
L ₁₅	30.96	174.47	127.24	332.80
L ₃₀	36.13	206.26	150.33	392.75
SE±	0.36	0.66	0.81	0.76
CD at 5%	1.06	1.93	2.37	2.25
Interaction (S × L)				
SE±	0.72	1.32	1.62	1.53
CD at 5%	NS	3.87	4.75	4.50

superior to all other sources in influencing org-S, Non-SO₄-S and total-S except SO₄-S, whereas, source S₃ (RMNa) and S₄ (RMCa) were on par with each other. However, lower content of all the fractions of sulphur were recorded in S₂ (RAS) indicating SO₄-S (28.16 mg kg⁻¹), org-S (158.81 mg kg⁻¹) Non-SO₄-S (116.00 mg kg⁻¹) and total-S (302.97 mg kg⁻¹) content in soil.

The level of sulphur improved the SO₄-S, org-S, Non SO₄-S and total-S content in soil. The SO₄-S content in soil varied from 22.85 to 36.13 mg kg⁻¹, while org-S ranged between 125.19 to 206.26 mg kg⁻¹, also, Non SO₄-S varied from 91.49 to 150.33 mg kg⁻¹ and total-S varied from 239.53 to 392.74 mg kg⁻¹. Among the levels of sulphur, L₃₀ (30 kg S ha⁻¹) recorded maximum content of all the fractions of sulphur, indicating 36.13 mg kg⁻¹ SO₄-S, 206.26 mg kg⁻¹ Org-S, 150.33 mg kg⁻¹ Non SO₄-S and 392.74 mg kg⁻¹ total-S. Similarly, L₃₀ (30 kg S ha⁻¹) was found superior to all other levels of sulphur, it was noted that each increment level of sulphur application increased all the fractions of sulphur in soil significantly as that of preceding levels.

Table-11a : Interaction effect of sources and levels of sulphur on fractions of sulphur in soil (mg kg⁻¹) at flowering stage of safflower.

Treatments	Residual 'S' sources			
	<i>S</i> ₁	<i>S</i> ₂	<i>S</i> ₃	<i>S</i> ₄
Residual 'S' levels.	<i>Organic sulphur</i>			
L ₀	132.79	119.40	121.68	126.89
L ₁₅	184.52	161.65	178.93	173.18
L ₃₀	219.34	195.37	207.81	202.52
SE±	1.32			
CD at 5%	3.87			
	<i>Non SO₄-S</i>			
L ₀	96.73	87.50	89.25	92.48
L ₁₅	134.41	117.63	130.14	126.77
L ₃₀	159.62	142.87	151.79	147.04
SE±	1.62			
CD at 5%	4.75			
	<i>Total -S</i>			
L ₀	253.14	228.80	233.71	242.48
L ₁₅	351.77	307.71	340.85	330.87
L ₃₀	417.47	372.41	396.19	384.88
SE±	1.53			
CD at 5%	4.50			

The residual interaction effect of different sources and levels of sulphur were found significant in influencing org-S, Non SO₄-S and total-S, except SO₄. From the compiled data in Table 11 a, it is revealed that, the higher value of org-S (219.34 mg kg⁻¹), Non SO₄-S, (159.62 mg kg⁻¹) and Total-S (417.47 mg kg⁻¹) recorded in treatment combination S₁L₃₀. However, statistically S₁L₃₀ found superior to all other treatment combinations. Comparing other treatment combinations S₃L₃₀ recorded org-S (207.81 mg kg⁻¹), Non SO₄-S (151.79 mg kg⁻¹) and total-S (396.19 mg kg⁻¹) which was par with treatment combination S₄L₃₀ and S₁L₁₅. (Table. 11 a)

4.5.2 Fractions of residual sulphur in soil at harvest stage of safflower :

The data presented in Table 12, from which it is observed that, the residual effect of various sources of sulphur significantly improved the different fractions of sulphur in soil. The residual effect of sources of sulphur improved the SO₄-S, org-S, Non SO₄-S in soil increased from 17.08 to 20.39 mg Kg⁻¹ SO₄-S also, org-S varied from 108.94 to 129.16 mg kg⁻¹. Similarly Non-SO₄-S ranged between 77.71 to 91.57 mg kg⁻¹ and total-S increased from 203.37 to 241.12 mg kg⁻¹ among all sources S₁ (RES) recorded the higher content of SO₄-S (20.39 mg kg⁻¹), org-S (129.16 mg kg⁻¹), Non SO₄-S (91.57 mg kg⁻¹) and total-S (241.12 mg kg⁻¹). Similarly, the values of the all sulphur fractions of sulphur were recorded in S₃ (RMNa) indicating 18.29, 116.61, 83.24 and 218.05 mg kg⁻¹ with SO₄-S, Org.-S, Non-SO₄-S and total-S, respectively. Also the values of the all sulphur fractions were recorded in S₄ (RMCa) indicating 19.19, 121.68, 86.88 and 227.75 mg kg⁻¹ with SO₄-S, Org.-S, Non-SO₄-S and total-S, respectively. However, S₁ (RES) was found significantly superior to all other sources in influencing Org-S and total-S. except SO₄-S, and Non-SO₄-S also, the lower content of all other fractions of sulphur were recorded in S₂ (RAS) indicating SO₄-S (17.08 mg kg⁻¹), Org.-S (108.94 mg kg⁻¹), Non-SO₄-S (91.57 mg kg⁻¹) and total-S (241.12 mg kg⁻¹) content in soil.

Table 12 : Residual effect of different sources and levels of sulphur on fractions of sulphur in soil (mg kg⁻¹) at harvest stage of safflower:

Treatment	Sulphur fractions			
	SO ₄ -S	Org-S	Non SO ₄ -S	Total-S
Residual 'S' sources				
S ₁	20.39	129.16	91.57	241.12
S ₂	17.08	108.94	77.71	203.70
S ₃	18.29	116.61	83.24	218.05
S ₄	19.19	121.68	86.88	227.75
SE±	0.39	0.91	0.83	1.23
CD at 5%	1.14	2.69	2.44	3.63
Residual 'S' levels				
L ₀	13.93	89.92	62.37	166.14
L ₁₅	18.94	120.40	86.70	226.05
L ₃₀	23.34	146.96	105.48	275.78
SE±	0.39	0.79	0.72	1.07
CD at 5%	0.99	2.32	2.11	3.14
Interaction (S × L)				
SE±	0.67	1.59	1.44	2.14
CD at 5%	NS	4.65	NS	6.28

Table-12a : Interaction effect of sources and levels of sulphur on fractions of sulphur in soil (mg kg⁻¹) at harvest stage of safflower.

Treatments	Residual 'S' sources			
	<i>S</i> ₁	<i>S</i> ₂	<i>S</i> ₃	<i>S</i> ₄
Residual 'S' levels.	<i>Organic sulphur</i>			
L ₀	94.51	85.26	88.67	91.27
L ₁₅	130.13	109.73	117.19	124.55
L ₃₀	162.84	131.82	143.96	149.22
SE±	1.59			
CD at 5%	4.65			
	<i>Total - S</i>			
L ₀	176.58	155.02	163.92	169.04
L ₁₅	243.37	206.37	221.23	233.21
L ₃₀	303.42	249.72	268.99	281.01
SE±	2.14			
CD at 5%	6.28			

Fig 3 : Residual effect of sulphur sources and levels on sulphur fractions in soil at flowering stage

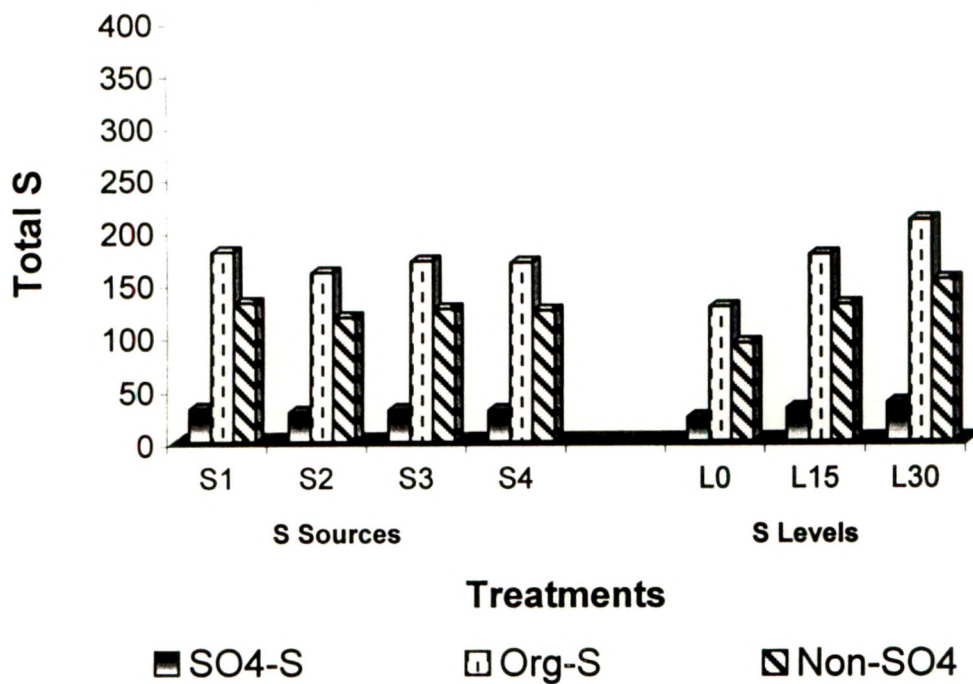
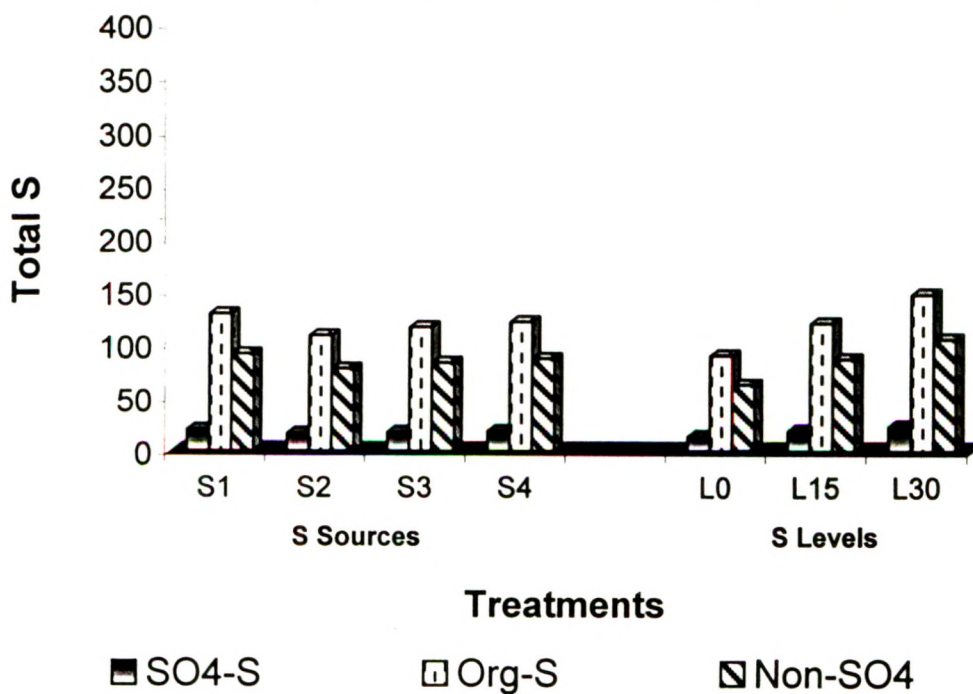


Fig 4 : Residual effect of sulphur sources and levels on sulphur fractions in soil at harvest stage



The levels of sulphur improved the SO₄-S, Org.-S, Non SO₄-S and total-S content in soil. The SO₄ content in soil varied from 13.93 to 23.34 mg kg⁻¹, while Org.-S ranged between 89.92 to 146.96 mg kg⁻¹, Non SO₄-S varied from 62.37 to 105.48 mg kg⁻¹ and total-S ranged between 166.14 to 275.78 mg kg⁻¹. Among the levels of sulphur, L₃₀ (30 kg S ha⁻¹) recorded maximum content of all the fractions of sulphur, indicating SO₄-S (23.34 mg kg⁻¹), Org.-S (146.96 mg kg⁻¹), Non SO₄-S (105.48 mg kg⁻¹) and total-S (275.78 mg kg⁻¹). It was noted that each incremental level of sulphur application increased all the fractions of sulphur in soil significantly as that of preceding levels. Statistically, L₃₀ (30 kg S ha⁻¹) was found superior to all other levels of sulphur.

The residual interaction effect of different sources and levels of sulphur were found significant in influencing Org-S and total-S, except SO₄-S and Non-SO₄-S. From data presented in Table-12a, it is revealed that the higher value of Org.-S was recorded in S₁L₃₀ having 162.84 mg kg⁻¹ followed by S₄L₃₀ (149.22 mg kg⁻¹) and S₃L₃₀ (143.96 mg kg⁻¹) also the lowest value of Org-S recorded in S₂L₃₀ (131.82 mg kg⁻¹). Also S₁L₃₀ showed higher value of total-S in soil (303.42 mg kg⁻¹), followed by S₄L₃₀ (281.01 mg kg⁻¹) and S₃L₃₀ (268.99 mg kg⁻¹). The lowest value noted in S₂L₃₀ (249.72 mg kg⁻¹) which was on par with S₁L₁₅. Statistically S₁L₃₀ was noted superior to all other treatment combinations.

4.6 Simple correlation coefficient between fractions of residual sulphur in soil and yield parameters of safflower.

Simple correlation coefficient between sulphur fractions in soil and yield parameters of safflower are noted in Table-13. From the data, significant and positive correlation of different fractions of sulphur with yield parameter is observed when SO₄-S was correlated with total dry matter yield, oil percentage, seed yield and oil yield of safflower. The relationship was found highly positive and significant showing 'r' values as 0.934**, 0.857**, 0.937** and 0.944** respectively. Similarly, Org.-S, Non SO₄-S and total-S also showed significant and strongly positive correlation with all the yield parameters of safflower. Org.-S was correlated with total dry matter, oil percentage, seed yield and oil yield of

Table-13: Residual effect of different sulphur fractions and their relationship with yield parameters of safflower.

Treatment.	Yield parameters			
	Seed yield	Total dry matter	Oil percentage	Oil yield
Sulphur fraction				
1. Available sulphur	0.937**	0.934**	0.857**	0.944**
2. Organic-S	0.958**	0.961**	0.828**	0.955**
3. Non-sulphate sulphur	0.966**	0.996**	0.831**	0.959**
4. Total-S	0.965**	0.966**	0.821**	0.955**

safflower, the relationship was found highly positive and significant showing 'r' values as 0.961**, 0.828**, 0.958** and 0.955** respectively. Also the significant 'r' values in Non-SO₄ and total-S were noted as, in total dry matter, 0.996** and 0.966**, in oil percentage 0.831** and 0.821**, in seed yield 0.966** and 0.965** and in oil yield 0.959** and 0.955** respectively.

Relatively, highest values of correlation coefficient were recorded 'r' values between Non-SO₄-S and total dry matter yield (0.996**), while lowest values were observed between total-S and oil percentage (0.821**) by safflower.



Discussion

DISCUSSION

The results obtained from the field experiment conducted in investigation on residual sulphur sources and graded level of sulphur in safflower are discussed under following heads :

5.1 Characterisation of experimental soil.

The experimental soil was identical to that of deep black soils of Marathwada region derived from basaltic parent material (Gajbe *et al*, 1976). As per Malewar (1976) these soils can be grouped under vertisols, according to the USDA system of soil classification.

The mechanical analysis of experimental soil revealed that, soil was clay in texture, calcareous in nature and moderately supplied with available N, P₂O₅, K₂O and S.

5.2 Grain and dry matter yield of safflower.

Data presented in Table 4 revealed that, grain yield and dry matter yield at flowering and harvest stage of safflower varied with different residual sulphur sources. Treatment S₁ (RES) found to be best source. Elemental sulphur (S₁) when applied to the soil begin to fracture into smaller particles giving unique release characteristics, which had strong implication for residual effect also S₃ (RMNa) and S₄ (RMCa) were noted as second and third among the S-sources, respectively. Lowest values of grain and dry matter yield were recorded in S₂ (RAS) this might because of faster oxidation proceeds to convert sulphur into SO₄ ions and, thus, relatively less residual sulphur effect may exists. Similar results were recorded by Takkar (1988).

Application of graded levels of sulphur significantly improved the yield of safflower, possibly by enhancing symbiotic activity as reported by Bharadwaj and Pathak (1968). The increase in grain and dry matter yield might be result of more availability of sulphur to the crops indicating essentiality of sulphur in lipid synthesis and growth of oilseed crops (Purvimath *et al*, 1983; Karle *et al*, 1989).

The interaction effect of residual sources and levels of sulphur also improved the grain as well as dry matter yield of safflower showing positive and significant relationship between sources and levels of sulphur. The positive interaction may be attributed to intrinsic properties of both the parameters.

5.3 Quality attributes of safflower.

The residual effect of different sources and levels of sulphur (Table-5) also influenced the protein, oil percentage and oil yield of safflower. Among the sources, Residual elemental sulphur was found better performance, this may happens due to plant take up S-mainly as $\text{SO}_4\text{-S}$ and microorganisms (*Thiobacillus* spp.) helps in the transformation of residual elemental sulphur. Similar result was obtained by Arora *et al* (1991) in groundnut.

Similarly, levels of sulphur increased protein as well as oil percentage in oil seed crops due to direct involvement in the synthesis of lipids (Kumar and Singh, 1980; Sagare *et al.*, 1990; Malewar and Ismail, 1997) and protein (Kanwar and Mudahar, 1986), this results were found in L_{30} (30 kg S ha^{-1}) level, however, though oil yield (kg ha^{-1}) increased due to more available sulphate sulphur to the crop as sulphate reduced by plants appears ultimately in these amino acids, which constitute about 80 - 90 per cent of total-S in oil seed crops (Rennenberg and Lamoureux, 1990). Increase in the oil yield (kg ha^{-1}) is definitely result of increase in grain yield and partly with increase in oil content in safflower grains.

5.4 Concentrations and uptake of nutrients.

Concentrations and uptake of nutrients such as N, P, K and S were found to be significant in residual sulphur sources and their levels in safflower. (Table 6, 7, 8, 9 and 10). Among the sulphur sources, application of residual elemental sulphur source increases the concentration and uptake of nutrients over other sources. The better efficiency of residual elemental sulphur in influencing the absorption of N, P, K and S may be attributed to long term residual effect of elemental sulphur which provides higher amount of available sulphur (SO_4) ions to crop, which are essential for better yield and quality of crop (Sagare and Bhalkar, 1980).

The content of plant nutrients N, P, K and S were found to be increased with the advancement of plant growth and thereafter declined gradually at harvest of safflower. Higher values of these nutrients at early stage could be due to greater root proliferation, more adsorption and accumulation in relatively less biomass and partly due to application of 'S' well in advance, resulting in more soil nutrient concentration and its availability which increased the absorption by the roots. The lower absorption of nutrients in the latter growth stage might be due to dilution effect because of sufficient biomass production (Dube and Khan, 1993, and Aulakh *et al*, 1977). However, levels of sulphur significantly increased the concentration and uptake of nitrogen, which may be mediated through the influence of this element on mineralization of soil nitrogen. Residual effects on sulphur increases the nitrate production resulting into better utilization by the crop as reported by [Sachdev and Deb, (1990) ; Rennenberg and Langoureaux, (1990) and Oke, (1970)]. The increase of uptake may be attributed to increase the concentration of N in plant and seed. Significant increase in dry matter production is one of the reasons for better nutrient uptake reported by Jain *et al*. (1995).

Residual sulphur fertilization also improved the P-concentration and uptake in safflower, which may be because of increase P-absorption due to ability of sulphur to mobilize phosphorus into available form. Karle (1982) and Survase *et al*. (1986).

Residual effect of sources and levels of sulphur also enhanced concentration and uptake of K - by plant, which might be a result of better absorption of potassium by the plant proliferated roots and its further translocation to the grain and dry matter produce. The positive and synergistic effect of sulphur sources and levels alone and combinely on the content and uptake of potassium in plant. Jain (1995) and Tripathi *et al* (1992) also reported effective utilization on potassium through the extensive root system developed by crop plant under S-application.

Increase in the concentration and uptake of sulphur due to residual effect of sulphur sources and their levels, might be attributed to improved nutrient

availability in appropriate proportion leading to greater intake and better growth which in turn caused higher S uptake from the soil (Meena and Singh, 1998). Similarly more observations in these regards were noted by Singh *et al* (1986) in groundnut and Sharma and Gupta (1992).

5.5 Residual effect of applied S on fractions of sulphur in soil.

In soil, sulphur occurs in different forms, SO_4 - S, organic- S, Non- SO_4 -S. These forms constitute the bulk of the total-S. The interrelation between them with one another can be help in finding the response of crop to its application (Badigar *et al.*, 1985).

Various applied residual sulphur sources and their levels influenced the fraction of sulphur (SO_4 -S, Org-S, Non SO_4 -S and Total-S) at flowering and harvest stage of the crop as shown in Table 11 and 12, respectively.

The applied residual sources and levels of S indicated an average of percent contribution to total S of SO_4 -S found at flowering stage (9.31 per cent) and at harvest stage it was (8.50 per cent). Similarly, an average per cent contribution to Total-S of Org-S found at flowering stage (53.48 per cent) and at harvest stage it was (52.49 per cent) also Non SO_4 -S found values at flowering stage (38.24 per cent) and at harvest (38.10 per cent). It is observed that influence of graded levels of S-appeared to be higher than the sources in respect to Org-S. The relatively higher contribution of Org-S to total-S may be associated to high clay content, low organic matter and sufficient $CaCO_3$ content in soil (Evans and Rost, 1945). Among the sulphur sources, applied residual element sulphur source has influenced these fractions to maximum extent followed by applied RMNa and RMCa source. But sulphur fractions were least affected by applied RAS source. This might have resulted in better release of sulphur fractions with the applied RES also, synergistic effect of Sulphur, Nitrogen, Phosphorus and Calcium on the availability of sulphur was identified by several workers (Bapat *et al*, 1986 and Survase *et al.*, 1986).

Similarly, levels of applied sulphur also found to increase all the fractions, which is due to rhizospheric effect as reported by Badigar *et al* (1985) and Patil

and Reddy (1987). Such type of finding also reported by Dikshit *et al* (1995) in a long term experiment on the build up of S-fractions by the residual value of added S.

Interaction effect of different sources and levels of applied residual sulphur on fraction of sulphur found statistically significant except $\text{SO}_4\text{-S}$ at flowering stage and $\text{SO}_4\text{-S}$ and Non $\text{SO}_4\text{-S}$ at harvest stage.

5.6 Relationship between sulphur fractions and yield parameters.

From the Table-13 it is observed that, from the correlation studies that, all the fractions of sulphur showed highly significant and positive correlation with total dry matter, grain yield oil yield and oil percentage of safflower, which suggesting that, these S-fractions are contributing to the way of available S-in soil and ultimately resulting into better growth attributes yield attributing characters in the crop. Similar type of observation with regards to S-fractions in relation to yield attributing characters in safflower were recorded by Patil and Reddy (1987) also Praveen Kumar *et al* (1985) recorded positive interrelations between grain yield of black gram with sulphur fractions.



**Summary and
Conclusions**

SUMMARY AND CONCLUSIONS

The experiment was conducted at the departmental farm of Agricultural Chemistry and Soil Science, Marathwada Agricultural University, Parbhani during 1998-99 in order to study the residual effect of different sources and their levels of sulphur in safflower (Sharada). The experiment includes four applied residual sulphur sources (RES, RAS, RMNa, RMCa) thus twelve treatment combinations were replicated thrice in Factorial Randomized Block Design. The summary of the results and conclusions drawn from them are presented in the following orders.

Safflower showed the positive response to applied residual sulphur fertilization by increasing seed and straw yields with respect to all residual sulphur sources. Among these residual element sulphur source has showed its superiority to all other sources, followed by residual sources of RMNa, RMCa and RAS. Increase in yield of safflower was noted with each incremental dose of residual applied sulphur upto 30 kg S ha^{-1} . Also, interaction effect of residual sources and their levels of sulphur were significant in improving the seed and straw yield of safflower.

Residual effect of applied 'S' found to improve to the quality attributes of safflower significantly viz. Protein, oil content and oil yield, with residual elemental sulphur source, similarly, these quality attributes significantly improved with graded levels of applied residual sulphur upto 30 kg S ha^{-1} . Interaction effect of applied residual sources and levels of sulphur also found to improve oil yield. Concentration and uptake of N, P, K and S were also influenced by the applied residual sulphur through various sources and their graded doses. Residual elemental sulphur source was significantly better to all other sources in increasing concentrations and uptake of these nutrients in safflower at flowering and harvest stages. N, P, K and S concentration and uptake in safflower was higher upto flowering stage and then it was declined upto harvest stage of crop. The nitrogen content of grains was higher as compared to straw with all the sources of applied residual sulphur. Levels of applied residual sulphur significantly increased

concentration and uptake of N, P, K, and S and every incremental dose upto 30 kg S ha⁻¹.

Fractions of soil sulphur were estimated during the flowering and harvest stage of safflower applied residual sulphur sources and their graded levels were significantly improved sulphate sulphur (SO₄-S), organic sulphur, Non sulphate sulphur and Total sulphur. There was decline in contribution of SO₄-S to total sulphur upto harvest stage of crop, however, organic sulphur and Non sulphate sulphur contribution to total sulphur was slightly increased or remains constant due to various sources of sulphur. Among the sources, applied residual elemental sulphur improved these fractions significantly over other sources followed by Mahadhan-Na, Mahadhan-Ca and Acidam-90. Similarly, all the fractions of sulphur were increased significantly with applied graded residual levels of sulphur upto 30 kg S ha⁻¹.

Interaction effect of sources and levels of sulphur was found to improve the various sulphur fractions at flowering and harvest stage of safflower. From this it is concluded that, Total-S, Org-S, and Non SO₄-S and SO₄-S are inter related with each to increase the sulphur availability in soil, so their proper equilibrium need to be maintained in soil.

In the simple correlation studies, fractions of sulphur such as SO₄-S, Org-S, Non SO₄-S and total-S were significantly and positively correlated with each other. Among the yield attributing characters like, grain yield, oil content, protein and oil yield in safflower recorded their positive and significant relationship with SO₄-S, org-S, Non SO₄-S and total-S.

The present study though has given favourable effect of applied residual sulphur sources and their levels to safflower in heavy textured vertisol type of soil, it still needs further confirmation by conducting multilocational studies with different rates of application and choice of sulphur. It is necessary to study the sulphur availability through the applied residual sulphur sources and responses to various oilseed crops when applied in combinations with N, P and K fertilizers or under integrated nutrient management systems.



Literature Cited

LITERATURE CITED

- A.O.A.C. (1975). Official method of Analysis, Ed. 12, Association of Official Analytical Chemists, Washington, D.C.
- Abbas Mohd. ; Surendra, S. ; Tomar, S.S. and Nigam, K.B. (1995). Effect of P and S fertilization in safflower. *Indian J. Agron.* **40** (2) : 243-248.
- Anonymous (1998). Balanced fertilization cropping sulphur deficiency. Annual Progress Report, Indian Grassland and Fodder Research Institute, Jhansi.
- Arora, R. ; Hundal, H.S. and Sekhon, G.S. (1991). Efficiency of different sulphur carriers to peanut, maize and wheat on an alkaline soil. *J. Indian Soc. Soil Sci.* **39** (3) : 591-592.
- Aulakh, M.S. ; Dev, G. and Arora, B.R. (1976). Effect of S fertilization on the N-S relationship in alfalfa Pl. *Soil* **45** (1) : 75-80.
- Aulakh, M.S. ; Pasricha, N.S. and Azad, A.S. (1990). P-S interrelationship for soybeans on P and S deficient soil. *Soil Sci.* **150** (4) : 705-708.
- Aulakh, M.S. ; Pasricha, N.S. and Dev. G. (1977). Response of different crops to sulphur fertilization in Punjab Fert. News. **22** (9) : 32-36.
- Aulakh, M.S. and Pasricha, N.S. (1979). Response of gram and lentil to P as influenced by applied S and its residual effects on moog. *Bull. Indian Soc. Soil Sci.*, **12** : 433-438.
- Aulakh, M.S. and Pasricha, N.S. (1997). Role of balanced fertilization in oilseed based cropping system. *Fert. News* **42** (4) : 101-111.
- Badigar, M.K. ; Rosalind Michael ; Jayaram, N. and Shivaraj, B. (1985). Studies on same aspects of soil sulphur and response of sunflower to sulphur application *J. Indian Soc. Soil Sci.* **33** (1) : 73-77.
- Bahl, G.G. ; Dhillon, K.S. and Pasricha, N.S. (1990). Effect of sources, dose and time of sulphur application to groundnut-wheat cropping sequency. *Int. J. Tropical Agric.* **8** : 229-239.

- Balanagoudar, S.R. and Satyanarayana, T. (1990). Depth distribution of different forms of sulphur in Vertisols and Alfisols. *J. Indian Soc. Soil Sci.* **38** : 634-640.
- Bapat, P.N. ; Sharma, B.L. ; Rathore, G.S. and Khamparia, R.S. (1997). Forms of sulphur and suitability of sulphur extractants for linseed crop grown on vertisols of M.P. *J. Indian Soc. Soil Sci.* **45** (3) : 523-525.
- Bapat, P.N. ; Sinha, S.B. and Shinde, D.A. (1986). Effect of sulphur and phosphorus on yield and nutrient content of black gram. *J. Indian Soc. Soil* **34** : 82-86.
- Beaten, J.D. and Wagar, R.E. (1985). Sulphur a vital component of maximum economic yield system. *Sulphur in India. Agril. Res.*, **9** : 2-7.
- Bhardwaj, S.P. and Pathak, A.N. (1968). Effect of sulphur on bacterial nodulation of groundnut *Curr. Sci.* **37** : 351-362.
- Bhilegaonkar, M.W. (1989). Effect of phosphorus, sulphur and boron on yield, uptake of nutrients and quality of safflower. M.Sc. (Agri.) Thesis, M.A.U., Parbhani.
- Biswas, B.C. and Tewatia, R.K. (1991). Results of FAO sulphur trials network in India. *Fert. News.* **36** (4) : 11-35.
- Black, C.A. (1965). *Methods of soil Analysis, Part 2.* American Society of Agron. Inc. Madison Wisconsin, USA.
- Bopat, P.N. (1989). Response of wheat to the sources and levels of sulphur in vertisols. I. Soil and plant test for diagnosing sulphur deficiency in soybean plant and soil **70** : 133-140.
- Chapman, H.D. and Pratt, P.F. (1961). *Methods of Analysis for soils, plants and waters,* Univ. of California, Div. Agric. Sci. California.

- Chaudhary, H.P. and Das, S.K. (1996). Effect of P, S and Mo application on yield of rainfed black gram and their residual effect on safflower and soil and water conservation in an eroded soil J. Indian Soc. Soil Sci. **44** (4) : 741-745.
- Chesnin, L. and Yein, C.H. (1951). Turbidimetric determination of available sulphur. Soil Sci. Soc. Am. Proc. **15** : 149-151.
- Dev, G. and Kumar, V. (1982). Secondary Nutrients In Review of Soil Research in India. Bull. Indian Soc. Soil Sci. **12** : 342-360.
- Dharkanath, K. Mohite, A.V. and Patil, M.D. (1995). Sulphur status of some important soil series of vertisols of Maharashtra State. J. Indian Soc. Soil Sci., **43** (3) : 364-367.
- Dhillan, N.S. and Dev, G. (1978). Effect of elemental sulphur application on the soybean J. Indian Soc. Soil Sci., **26** (1) : 55-57.
- Dikshit, P.B. ; Gautam, S.K. ; Turker, O.R. and Khatik S.K. (1995). Effect of long term fertilizer application under multiple cropping system on the forms and content of potassium and sulphur in Jabalpur Chromusterts. Indian J. Agric. Res. **29** (1) : 29-35.
- Dolui, A.K. and Nayek, A.K. (1981). Distribution of different forms of sulphur in same red and lateritic soil profiles of West Bengal. Indian Agric. **25** (3) : 185-189.
- Dube, O.P. and Khan, R.A. (1993). Effect of nitrogen and sulphur content in Indian mustard and their residual balance in soil. Indian J. Agron. **38**(4) : 582-587.
- Dwivedi, A.K. and Bapat, P.N. (1998). Sulphur phosphorous interaction on the synthesis of nitrogenous fractions and oil in soybean. J. Indian Soc. Soil Sci. **46** (2) : 254-257.
- Evans, C.A. and Rost, C.O. (1995). Total organic sulphur of minnessotto soils. Soil Sci. **59** : 125-137.

- *FAO-FIAC (1992). The important of sulphur for crop production food and agriculture organisation of the United Nations and the fertilizer Industry Co-ordination Committee, Rome, pp 62.
- Gabhane, V.V. ; Vaidya, P.H. and Ravankar, H.N. (1998). Nutrient dynamics in vertisol as influenced by long term application of IPNS to sorghum-wheat sequence. *Bull. Indian Institute Soil Sci.* **2** : 208-211.
- Gajbe, M.V. ; Lande, M.G. and Varade, S.B. (1976). Soils of Marathwada J. *Maharashtra Agril. Univ.* **1** : 59-62.
- Ganesh Murthy, A.N. ; Mongia, A.D. and Singh, N.T. (1989). Sulphur status and response of rice to sulphur on same soils of Andaman and Nicobar Islands. *J. Indian Soc. Soil Sci.* **43** (4) : 637-641.
- Ganesh Murthy, A.N.J. (1996). Critical limit of sulphur content and effect of S application on grain and oil yield of rainfed soybean in vertic Ustochrepts. *J. Indian Soc. Soil Sci.* **44** (2) : 290-294.
- Gangadhar, G.A. ; Manjunathaiah, H.M. and Satyanarayana, T. (1990). Effect of sulphur on yield, oil content of sunflower and uptake of micronutrient by Plant. *J. Indian Soc. Soil Sci.* **38** (2) : 692-695.
- Gupta, S.P. ; Gupta, V.K. and Ramkala (1995). Extractant and critical limit for available S in Aridisols. *J. Indian Soc. Soil Sci.* **43** (3) : 478-479.
- Hariram and Dwivedi, K.N. (1994). Delineation of sulphur deficient soil groups in the central alluvial tract of U.P. *J. Indian Sof. Soil. Sci.* **42** (2) : 284-285.
- Islam, M.R. ; Riasat, T.M. and Jahiruddin, M. (1997). Direct and residual effect of S, Zn and B on yield and nutrient uptake in Rice-wheat cropping system. *J. Indian Soc. Soil. Sci.* **45** (1) : 126-129.
- Jackson, M.L. (1973). Soil chemical analysis Prentice Hall of India Private Ltd., New Delhi.

- Jadhav, P.M. (1998). Sulphur status of soils and its effect on yield and quality of sunflower. M.Sc. (Agri.) Thesis, Dept. of Agril. Chem. and Soil Sci., Marathwada.
- Jain, G.L. ; Sahu, M.P. and Somani, L.L. (1984). In balanced fertilization programme with special reference to secondary and micronutrients nutrition of crops under intensive cropping. Proc. FAI/NR. Seminar, Jaipur, pp 147-174.
- Jain, N.K., Vyas, A.K. and Singh, A.K. (1995). Effect of phosphorus and sulphur fertilization on growth and nutrient uptake by mustard. Ann. Agric. Res. **16** (3) : 389-390.
- Kachhave, K.G.; Gawande, O.D.; Kohire and Mane, S.S. (1997). Influenced of various sources and levels of sulphur on nodulation yield and uptake of nutrients by chickpea J. Indian Soc. Soil Sci. **45** (3) : 590-591.
- Kailash Kumar (1995). Effect of phosphorus and sulphur nutrition on yield, quality and nutrient uptake of Indian rape (*Brassica napus*) in acid Haplaquet : Ann. Agric. Res. **16** (1) : 36-39.
- Kanwar, J.S. and Mudahar, M.S. (1986). Fertilizer food production Martinus Nijhoff/Dr. W. Junk Publishers, Dordrecht, Netherlands.
- Karle, B.G. (1982). Influence of P-S fertilization and rhizobium inoculation on yield, nutrient uptake, protein and oil content of groundnut. Ph. D. Thesis submitted to M.A.U., Parbhani.
- Karle, B.G. and Malewar, G.V. (1989). Ann. Res. Rev. Report Dept. of Agril. Chem. And Soil Sci., M.A.U., Parbhani (M.S.).
- Kher, D. and Singh, N. (1993). Different forms of sulphur in mustard growing soils of North Kashmir. J. Indian Soc. Soil Sci., **41** (1) : 164-165.
- Kilmer, V.G. and Nearing, D.C. (1960). Determination of available sulphur in soils. Soil Sci. Soc. Amer. Proc. **24** (5) : 337-340.

- Kolape, S.S. ; Dhane, S.S. ; Dongale, J.H. and Chaudhan, A.S. (1991). Sulphur status in rice soils in Konkan J. Maharashtra Agric. Univ. **16** (1) : 97-98.
- Kumar, V. and Singh, M. (1980). Sulphur, phosphorous and molybdenum interaction in relation to growth, uptake and utilization of sulphur in soybean Soil Sci. **129** : 297-304.
- Lande, M.G. ; Varade, S.B. and Badhe, N.N. (1977). Sulphur status and its relationship with physico-chemical properties of Marathwada soils. J. Maharashtra Agril. Univ. **2** (3) :195-201.
- Malewar, G.▼. (1976). Placement of black soils of Marathwada in comprehensive system of soil classification. J. Maharashtra Agril. Univ., **1** :155-159.
- Malewar, G.▼. and Randhawa, N.S. (1977). Zinc and manganese status of cakareous ad non-cakareous soils of Marathwada Res. Bull. M.A.U., Parbhani, **1**(11) : 158-159.
- Malewar, G.▼. and Ismail (1997 a). Sulphur research in soils and crops in Maharashtra : An appraisal, Proc. Seminar on “ Role of sulphur in Agriculture Production”. The commissionerate of Agriculture, Maharashtra State, Pune and the Dharamsi Morarji Chemical Co. Ltd., Mumbai, Monday 5th May, 1997.
- Malewar, G.▼. and Ismail (1997 b). Sulphur in balanced fertilization in Western India. Proc. Symp. “ Sulphur in Balanced Fertilization ” organised by TSI/FAI/IFA, held at New Delhi. Feb. 13-19 pp.
- Malewar, G.▼. and Ismail (1998 a). Micronutrient Scenario in soils of Maharashtra and their extent of deficiencies in various regions of the state. Annual report, Dept. of Agric. Chem. & Soil Sci. M.A.U., Parbhani.

- Malewar, G.V. ; Patil, V.D. and Hanwate, G.R. (1998 **b**). Delineation of sulphur deficiency of oilseed growing area of Gangakhed Tahsil and response for sulphur application in safflower-groundnut cropping system. Ann. Report (1997-98), Dept. of Agril. Chem. & Soil Sci., M. A. U., Parbhani. pp-23.
- Malewar, G. V. Mali, C.V. (1998 **c**). Delineation of sulphur deficiency of oilseed dominated area of Latur Tahsil and response for sulphur application in soybean-safflower cropping system. Ann. Report, Dept. of Agril. Chem. & Soil Sci., M. A. U., Parbhani. pp-27.
- Mandal, D. and Singh, R. (1997). Forms of sulphur in Tarai and Bhabar soils and their relationship with soil properties. Proc. National Seminar on "Development in soil Science : 1997". 60nd Annual Convention of Indian Soc. Soil Sci. pp. 98.
- Maniyar, V.G. (1979). Physico-chemical properties of normal and salt affected soils of Parbhani district. M.Sc. (Agril.) Thesis. Marathwada Agricultural University, Parbhani.
- Mc Lachlan, K.D. and De Marco, D.G. (1975). Changes in soil sulphur fractions with fertilizer additions and cropping treatments. Aust. J. Soil Sci. **13** : 169-176.
- Meena, O.S. and Singh, D. (1998). Effect of sulphur and zinc application on onion yield and sulphur and zinc uptake in three soil orders. J. Indian Soc. Soil Sci. **46** (4) : 636.
- Naphade, P.S. ; Patil, D.B. and Naphade, K.T. (1997). Direct and residual effect of sulphur application on soybean S-wheat sequence. Proc. Seminar on "Role of sulphur in Agriculture Production". The commissionerate of agriculture, Maharashtra State, Pune and the Dharamsi Morarji Chemical Co. Ltd. Mumbai, 5th May, 1997 pp 14.
- Oke, O.L. (1970). Mineralization of soil nitrogen. Ibid **18** : 297-302.

- Olsen, S.R. ; Cole, C.V. ; Watanabe, F.S. and Dean, L.A. (1954). Estimation of available phosphorous by extraction with sodium bicarbonate circ, 939, USDA, p 19.
- Padmaja, G. and Sreenivasa Raju, A. (1992). Effect of moisture regimes and incubation periods on release of sulphur in some vertisols and Alfisols of Nalgonda, Mahaboobnagar and Kurnool district. J. Res. APAU. 20 (4) : 204-210.
- Pal, Y. and Singh, R. (1994). Status of soil sulphur and wheat yield in a long term rice-wheat sequence managed with different doses of N and P. Indian J. Agric. Res. 28 (4): 270-274.
- Paliyal, S.S. and Verma, T.S. (1999). Effect of phosphorous on crop yields in wheat-soybean cropping sequence in acid Alfisols amended with lime and gypsum. J. Indian Soc. Soil Sci. 47 (2) : 377-379.
- Pandey, D.K. ; Tiwari, K.N. and Tiwari, R.C. (1989). Different forms of sulphur in alluvial soils. J. Indian Soc. Soil Sci. 37 (1) : 161-163.
- Panse, V.G. and Sukhatme, P.V. (1985). Statistical methods for Agricultural workers ICAR, New Delhi.
- Pasricha, N.S. and Aulakh, M.S. (1986). Role of S in the nutrition of groundnut Ferti. News. 31 (9) : 17-21.
- Patel, K.P. and Marsonia P.J. (1985). Sulphur supplying power of some calcareous medium black soils of Junagadh district. Indian J. Agric. Res. 19 (4) : 197-203.
- Patgiri, D.K. and Baruah, T.C. (1993). Effect of sulphur on soil properties, yield and oil content of Toria. J. Indian Soc. Soil. Sci. 41(2) : 391-392.
- Pathak, A.N. and Pathak, R.K. (1972). Effect of sulphur component of some fertilizers on groundnut. Indian J. Agric. Res. 6 : 23-26.
- Patil, C. and Reddy, V.R. (1987). Soil sulphur forms and their availability to sunflower Curr. Res. 16 (10) : 133-135.

- Patil, J.D. ; Tanawade, S.K. and Zende, G.K. (1981). Relationship between different forms of S and the soil attributes like organic carbon, pH, clay and percent free lime contents of Maharashtra soils. *J. Maharashtra Agric. Univ.*, 6 (1) : 1-3.
- Patil, N.D. and Ghonsikar, C.P. (1985). Soils of India and their management fertilizer Association of India, New Delhi pp 250-265.
- Piper, C.S. (1966). Soil and plant analysis. Hans Publishers, Bombay.
- Plummer, D. (1988). An Introduction to practical Biochemistry. 3rd Ed. Tata McGraw Hall Publication, Delhi.
- Prasad, F.M. ; Sisodia, D.S. ; Varshney, M.L. and Verma, M.M. (1991). Effect of different levels of S and P on growth, Dry matter ; oil content and uptake of nutrients by soybean *News Agricst.* 2 (1) : 15-18.
- Praveen Kumar, B.V. ; Narsimharao, P.V. ; Subbarao, A. and Subbarao, I.V. (1985). Sulphur fraction in Krishna Western Delta Alluvium in relation to black gram production. *Andhra Agric. J.* 32 : 157-159.
- Puri, A.H. (1949). Soils their physics and chemistry. Reinhold Publishing Corporation, New York, USA.
- Purvimath, S.S. (1983). Yield and quality improvement of safflower as influenced by fertilizer, nitrogen, phosphorous, sulphur and Boron. M.Sc. (agril.) Thesis, Univ., Agril. Sci. Bangalor.
- Rathore, P.C. and Manohar, S.S. (1990). Effect of S and N on seed yield and N-uptake by mustard. *Agro. J.* 35 (4) : 361-363.
- Rawat, V.S. and Srinivas (1979). Studies on sulphur in soils of Udaipur. *Fert. News.* 24 (10) : 37-40.
- Reddy, V.M.K., Reddy, S.M. and Seshagirirao, M. (1993). Studies on availability , response and critical limits of sulphur to groundnut in Alfisols. *J. Indian Soc. Soil Sci.* 41(4) : 699-703.

- Rennenberg, H. and Lamoureux, G.L. (1990). Sulphur Nutrition and Sulphur Assimilation in higher plants. Academic Publishing, Hague Netherland.
- Ruhal, D.S. and Paliwal, K.V. (1978). Status and Distribution of sulphur in soils of Rajasthan. *J. Indian Soc. Soil Sci.*, pp 98.
- Sachdev, M.S. and Deb, D.L. (1990). Nitrogen and sulphur uptake and efficiency in mustard-moog-maize cropping system. *Fert. News* **35**(7) : 49-55.
- Sagare, B.N. ; Guhe, Y.S. and Atre, A.H. (1990). Yield and nutrient harvest by sunflower in response to sulphur and magnesium application in Typic Chromusterts Ann, *Plant Physiol.* **4** (1) : 15-21.
- Sagare, B.N. and Bhalkar, D.V. (1986). Effect of applied sulphur and phosphorus in groundnut nutrition and their residual effect on wheat. *J. Maharashtra Agric. Univ.*, **11** : 261-263.
- Sahoo, A.K. ; Saha, K.D. and Gupta, S.K. (1998). Sulphur distribution in same mangrove soils of sundarbans *J. Indian Soc. Soil Sci.* **46**(1):138-140.
- Santhy, P. ; Multhuvel, P. ; Murugappan, V. and Salvi, D. (1998). Long term effect of continuous cropping and fertilization on crop yields and soil fertility status *J. Indian Soc. Soil Sci.* **46** (2) : 391-394.
- Satpute, B.R. (1990). Studies on a few aspects on sulphur availability in soils of Jayakwadi Command Area. M.Sc. (Agri.) Thesis, M.A.U., Parbhani.
- Satpute, B.R. and Malewar, G.V. (1991). Annual Report Dept. Agril. Chem. and Soil Sci., M.A.U., Parbhani.
- Sharma, P.A. and Gupta, R.K. (1992). Response of rainfed soybean-safflower sequence to nitrogen and sulphur fertilization in vertisols. *Indian J. Agrc. Sci.* **62** : 529-534.
- Shinde, D.A. ; Sawankar, N.S. ; Sachidanand, B. and Soni, B.K. (1982). Major nutrient status of soybean at different growth stages affected by P and S application *JNKVV Res. J.* **16** (1) : 38-45.

- Singh, D. and Singh, V. (1994). Response of soybean to, K, S and Zn application on yield and uptake fert. News. **39** (2) : 53-55.
- Singh, F. ; Singh, V. ; Singh, R.M. and Singh, M. (1995). Forms of sulphur in some alluvial soils of U.P. Ann. Agric. Res. **16** (3) : 167-168.
- Singh, H.G. ad Sahu, M.P. (1986). Response of oilseed to sulphur. Fert. News **31** (9) : 23-30.
- Singh, K.K. Kumar, R. and Pingolia, A.L. (1998). Effect of sources and levels of sulphur on oil and protein content mustard. J. Indian Soc. Soil. Sci. **46** (1) : 150-151.
- Singh, K.P. ; Surendra Singh ; Sarkar, A.K. ; Singh, R.P. and Arvind Kumar (1996). Status and response of sulphur and micronutrients in soil on Bihar Plateau for higher crop productivity. Fert. News. **41** (8) : 41-47.
- Singh, M. (1988). Sulphur management in coarse textured alluvial soils. Proc. TSI-FAI Symp. sulphur in Indian Agriculture, New Delhi S III/1 (1-19).
- Singh, M. ; Karwasra, S.P.S. and Khere, A.P. (1990). Evaluation of some soil test methods for diagnosing sulphur deficiency in mustard J. Indian Soc. Soil Sci. **38** (2) : 336-338.
- Singh, M.V. (1995). Sulphur research in Bihar Fert. News. **40** (8) : 37-40.
- Singh, S. ; Singh, A.P. ; Singh, B. and Singh, S. (1991). Direct and residual effect of Pyrites on yield, sulphur content and quality characteristics of groundnut and mustard J. Indian Soc. Soil Sci. **39** : 228-331.
- Singh, S.K. and Tiwari, R.C. (1989). Effect of applied and residual S on sesamum-mustard. Proc. USA-FACT Seminar on sulphur, Bangar. pp 208.
- Singh, Surendra, Sinha, S.K., Singh, R. N., Shaha, P.B. and Gupta, B.P. (2000). Yield, S-uptake and oil content of niger as influenced by applied sulphur on acidic soils of Bihar. J. Indian Soc. Soil Sci. (121-124).

- Sreemannarayana and Sreenivasa Raju (1993). Direct and residual effect of applied sulphur in sunflower based cropping system. *fert. News.* **30** (9) : 39-42.
- Subba Rao, A. and Ganesh Murthy, A.N. (1994). Soybean responses to applied P and S on vertic Ustochrepts in relation to available phosphorous and sulphur. *J. Indian Soc. Soil. Sci.* **42** (4) : 606-610.
- Subbiah, B.V. and Asija, G.C. (1956). A rapid procedure for the estimation of available nitrogen in soils *Curr. Sci.* **25** : 259-266.
- Survase, D.N. ; Dongale, J.H. and Kadrekar, S.B. (1986). Growth, yield, quality and composition of groundnut as influenced by FYM, calcium sulphur and boron in lateritic soil. *J. Maharashtra Agric. Univ.* **11** (1) : 49-51.
- *TSI (1982). Sulphur – the fourth major nutrient. The sulphur Institute, Washington, DC pp : 52.
- Tabatabai, M.A. and Bremner, J.M. (1970). A simple turbidimetric method of determination of total sulphur in plant *Agron. J.* **62** : 805-808.
- Takkar, P.N. (1988). Sulphur status of Indian Soils. *Proc. TSI-FAI symp. Sulphur in Indian agricultural soils, Dhaka, Bangladesh.* pp. 299.
- Takkar, P.N. and Nayyar, V.K. (1984). Crop response to micronutrient application. *Proc. FAI-NRC Seminar, Jaipur,* 19-123.
- Tanawada, S.K. ; Patil, J.D. and Zende, G.K. (1976). The forms and content of S in soil of Maharashtra State *J. Maharashtra Agril. Univ.* **1** :1-6.
- Tandon, H.L.S. (1995). *Sulphur Research and Agricultural Production in India.* 3rd Ed. FDCO, New Delhi.
- Tiwari, K.N. (1989). *Sulphur Research and Agricultural Production in U.P. Bulletin, CSAUAT, Kanpur,* pp 46.
- Tiwari, K.N. (1990). *Sulphur Research and Agricultural production in U.P. Sulphur in Agriculture* **14** : 29-34

- Tiwari, K.N. ; Nigam, V. and Pathak, A.N. (1983). Evaluation of some soil test methods for diagnosing sulphur deficiency in alluvial soils of U.P. J. Indian Soc. Soil Sci. **31** (2) : 245-249.
- Tiwari, R.C. ; Singh, S.K. and Pandey, D.K. (1992). Influence of sulphur application on yield and chemical composition of some crops. fert. News. **37** (6) : 23-26.
- Tiwari, S. and Sakal, R. (1997). Evaluation of soil test crop response of rice to sulphur application on old alluvial soils. J. Indian Soc. Soil Sci. **45** (4) : 842-844.
- Tripathi, P.N. and Sharma, N.L. 1995. Effect of gypsum and pyrites on yield and quality of mustard in salt affected soils of Western Uttar Pradesh. J. Indian Soc. Soil Sci. **43** : 290-291.
- Tripathi, S.B. ; Singh, R.S. and Tripathi, R.K. (1995). Effect of S-fertilization on forage yields, S-uptake and soil fertility under different crop sequences. J. Indian Soc. Soil Sci. **43** (4) : 641-645.
- Williams, C.H. and Steinberg, A. (1959). Soil sulphur fractions as chemical indices of available sulphur in some Australian soils. Aust. J. agric. Res. **10** : 340-352.
- Yengade, P.W. and Ghonsikar, C.P. (1997). Effect of P and S fertilization on quality of sunflower grown in typic Haplusterts. National Seminar on developments in Soil. Sci. Calcutta. Oct. 18-21, 1997. pp 223

APPENDIX

List of Abbreviations

Agric	Agriculture
CEC	Cation Exchange Capacity
cm	Centimeter
dsm^{-1}	Desisimens per meter
et al	Others
FAI	Fertilizer Association of India
FAO	Food and Agricultural Organisation.
FIAC	Fertilizer Industrial Association Committee.
IFA	International Fertilizer Association.
J	Journal
K	Potassium
kg^{-1}	Per kilogram
kg ha^{-1}	Kilogram per hectare.
mg kg^{-1}	Miligram per kilogram
N	Nitrogen
Non-SO ₄ -S	Non Sulphate Sulphur.
Org-S	Organic Sulphur.
RAS	Residual Acidum Sulphur.
RES	Residual Elemental Sulphur.
RM _{Ca}	Residual Mahadhan (Ca)
RM _{Na}	Residual Mahadhan (Na)
r	Correlation coefficient.
S	Sulphur
Sci	Science.
SO ₄ -S	Sulphate Sulphur.
Soc.	Society.
Total-S	Total Sulphur.
TSI	The Sulphur Institute.