AFFECTIONATELY

DEDICATED TO,

MY BELOVED BROTHER ..... KESHAV

WHO IS IDEAL FOR ME ALWAYES

- - - - - - *RAHUL*

EFFECTS OF SULPHUR AND ZINC ON YIELD, OIL AND PROTEIN CONTENT OF SUNFLOWER IN VERTISOL

A thesis submitted to the
Mahatma Phule Krishi Vidyapeeth,
Rahuri.- 413 722. Dist. Ahmednagar.
Maharashtra State, India.

In partial fulfilment of the requirements for the degree
of
MASTER OF SCIENCE (AGRICULTURE)
in
SOIL SCIENCE

BY
RAHUL TUKARAM KAMBLE
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DEPARTMENT OF AGRICULTURAL CHEMISTRY
AND SOIL SCIENCE
MAHATMA PHULE KRISHI VIDYAPEETH
COLLEGE OF AGRICULTURE, PUNE 411005
MAHARASHTRA, INDIA.

2002

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B.Sc.(Agri.) Regn. No. 20183

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2002

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CANDIDATE'S DECLARTION

I hereby declare that the thesis entitled, "EFFECTS OF SULPHUR AND ZINC ON YIELD, OIL AND PROTEIN CONTENT OF SUNFLOWER IN VERTISOL" or part thereof has not been previously submitted by me or any other person to any other University or Institute for a Degree or Diploma.

(R. T. Kamble)

Place : Pune

Date : 28|06|02

Prof. B.P. Rote,
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College of Agriculture,
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Maharashtra State, (India) .

CERTIFICATE

This is to certify that the thesis entitled, "EFFECTS OF SULPHUR AND ZINC ON YIELD, OIL AND PROTEIN CONTENT OF SUNFLOWER IN VERTISOL" submitted to the Mahatama Phule Krishi Vidyapeeth , Rahuri, Dist. Ahmednagar, Maharashtra State, India, in partial fulfilment of the requirements of the degree of MASTER OF SCIENCE (*Agriculture*) in Soil Science, embodies the results of piece of bona fide research work carried out by Shri. Rahul Tukaram Kamble, under my guidance and supervision, and that no part of the thesis has been submitted for any other Degree or Publication.

The assistance and the help received during the course of this investigation have been acknowledged.

(B.P. Rote)
Research Guide and Chairman

Place : Pune
Date : 28|06|02

Dr. A.S. Jadhav
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CERTIFICATE

This is to certify that the thesis entitled, "EFFECTS OF SULPHUR AND ZINC ON YIELD, OIL AND PROTEIN CONTENT OF SUNFLOWER IN VERTISOL" submitted to the faculty of agriculture , Mahatma Phule Krishi Vidyapeeth, Rahuri in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE** (**AGRICULTURE**) in **SOIL SCIENCE**, embodies the results of a piece of bona fide research work carried out by Rahul Tukaram Kamble, under the guidance and supervision of Prof. B.P.Rote, Asso. Prof.of Agricultural Chemistry and Soil Science, College of Agriculture, Pune and that no part of the thesis has been submitted for any other Degree or Diploma.

(A.S.Jadhav)

Place : Pune

Date : 002

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Rahul Kamble

Place: Pune

Date: 28/06/02

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LIST OF ABBREVIATIONS

Sr. No.	Symbol	
1.	@	At the rate of
2.	av.	Available
3.	Ca	Calcium
4.	C.D.	Critical difference
5.	Cu	Copper
6.	dSm-1	decisimen per metee.
7.	*et al*	(et – alibi) meaning and others
8.	Fe	Iron
9.	Fig.	Figure
10.	g	Grams
11.	g plant $^{-1}$	Gram per plant
12.	kg	Kilogram
13.	kg ha^{-1}	Kilogram per hectare
14.	Mg	Magnesium
15.	Mn	Manganese
16.	mg	Milligram
17.	mg kg^{-1}	Milligram per kilogram
18.	Viz.	Namely
19.	N	Nitrogen
20.	ppm	parts per million
21.	P	Phosphorus
22	K	Potassium
23.	S	Sulphur
24.	S^0	Elemental Sulphur
25.	S.E.	Standard error
26.	t	Tonnes
27.	Zn	Zinc

ABSTRACT

EFFECTS OF SULPHUR AND ZINC ON YIELD, OIL AND PROTEIN CONTENT OF SUNFLOWER IN VERTISOL

BY

RAHUL TUKARAM KAMBLE

A candidate for the degree of

MASTER OF SCIENCE (AGRICULTURE)

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A pot culture experiment was conducted at Department of Agricultural Chemistry and Soil Science, College of Agriculture, Pune-5 during *kharif* 2001 with a view to study the effects of sulphur and zinc fertilization on yield, oil and protein content of sunflower cv. SS – 56. The pot culture trial was laid out in a Factorial Randomised Block Design with two replications. There were four levels of sulphur (0, 30, 60 and 90 kg S ha $^{-1}$) as elemental sulphur along with four levels of zinc (0, 20, 40 and 60 kg Zn ha $^{-1}$) as zinc oxide in various combinations.

Also, an incubation study was conducted in laboratory with three replications. There were three levels of sulphur (0, 30 and 60 kg S ha $^{-1}$) as elemental sulphur along with three levels of zinc (0, 20 and 40 kg Zn ha $^{-1}$) as zinc oxide in various combinations.

The seed yield, oil content and protein content were increased significantly due to application of sulphur at 90 kg ha $^{-1}$and zinc at 40 kg ha $^{-1}$.

Sulphur application significantly improved the uptake of N, P, K, S and Zn imposing synergistic effects of sulphur on uptake of these nutrients.

Synergistic effects of lower levels of zinc application (20 and 40 kg ha $^{-1}$)on the uptake of N, P, K, S and Zn were also noticed. However, Zinc application at higher level (60 kg ha $^{-1}$) exerts an antagonistic effect on uptake of P.

Non-significant effects of sulphur and zinc on the plant height and number of leaves were observed.

Also, in incubation study, it was observed that sulphur availability increased and zinc availability decreased as the incubation period increased.

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INTRODUCTION

1. INTRODUCTION

Oil seed crops give the secondary largest produce in India next to food grains. Oil seed mission is acting as catalyst for increasing seed and oil productivity of India. Oil seeds play a vital role in agricultural industry and foreign trade.

Sunflower (*Helianthus annuus L*) is one of the important oil seed crops in Indian farming and grown on variety of soils. Sunflower in now competing with other oil seed crops not only due to its low cost of cultivation, high yielding potential and as a best source of vegetable oil but also its several uses as raw materials in different industries like manufacture of alcohol, soaps, paints, varnishes, paper pulp etc.

Sunflower is not a season-bounded crop due to its photo-insensitiveness nature. In 1998-99, as compared to total oil seed production, sunflower contributed 7.5 % of the production.

As the production depends mainly on the vagaries of monsoon, which is main reason of declining yields of oil crops, which is resulted in the shortage of edible oil in the country. Other probable reasons for the declining yields are : unscheduled sowing date, inadequate and imbalanced nutrition and moisture stress at critical stages. Among these factors, mineral nutrition to sunflower plays an important role.

Among the nutrients, N, P and K are given the priority and very little attention is paid towards secondary nutrients and micronutrients, which are important for nutrition of sunflower. From the nutrition point of view, sulphur, one of the secondary nutrients, is very important to oil seed crops. Generally, crops require as much sulphur as they need phosphorus and 1/10 to 1/15 as much nitrogen, mainly in the form of sulphate ions (Kanwar, 1976). Therefore, sulphur is now recognised as the fourth major nutrient in addition to nitrogen, phosphorus and potassium.

Sulphur involves in metabolic processes and enzyme reactions responsible for growth and development of crop. Sulphur plays an important role in protein production because it is constituent of three essential amino acids viz. cysteine, cystine and methionine. It is involved in the formation of chlorophyll, glucosedes, activation of enzymes, formation of sulfhydryl linkage which provides the source of pungency in onions, oils etc. It is a part of co-enzyme-A, pyrophosphate, vitamins such as biotin and thiamine. Sulphur improves crop yield, oil percentage in oil seeds, plant proteins, cereal quality for milling and baking.

In recent years, sulphur deficiency in coarse textured soils has been frequently observed due to several reasons (Pasricha and Aulakh , 1986). Some of the reasons are high crop removal of sulphur, leaching losses, use of high analysis sulphur free fertilizers and wide spread of soil erosion etc, (Tandon 1986).

This declining sulphur availability to the crop should be taken into account because the application of sulphur to sunflower was reported to increase seed yield by 20 % (Ghosh , *et al.* 2000). Similarly, Jadhav (1998) observed that significant increase in yield and oil content of sunflower due to application 100 Kg S ha^{-1} .

Along with this secondary nutrient, micronutrients also play important role in sunflower nutrition. Zinc plays an important role in different plant metabolic processes like development of cell wall, respiration, photosynthesis, chlorophyll formation, enzyme activity and other bio-chemical functions. Among all micronutrients, Zn deficiency continues to be one of the key factors in determining crop production in India. This deficiency of Zn should be considered because it is observed that yield and quality of sunflower increases significantly due to application of Zn (Murthy, *et al.* 1999). Similarly, Prabhuraj *et a.l* (1995) observed that application of Zn increased seed yield and oil content of sunflower due to application of 5 ppm Zn..

Sulphur and zinc interaction is more striking. Antagonistic interaction was reported by Babhulkar *et al.* (2000) in safflower and Tripathi *et al.* (1997) in groundnut. However synergistic effect of S and Zn was reported by Bhal *et al* (1986) in groundnut .

Thus, there are quite meager studies on application of sulphur and zinc on sunflower under our condition. With this background, the present investigation was, therefore, undertaken to study the effects of Sulphur and Zinc on yield, oil and protein content of sunflower in Vertisol with following objectives:

1. To study the effects of different levels of sulphur and zinc on yield of sunflower,
2. To study the effects of different levels of sulphur and zinc on the uptake of nutrients by sunflower.
3. To study the effects of different levels of sulphur and zinc on protein and oil content of sunflower.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Sulphur, is one of the secondary nutrients and now a days, is being recognised as fourth major nutrient in addition to nitrogen, phosphorus and potassium. It plays multiple role in oilseed crops. Numerous studies were carried out to study the effect of sulphur on oilseed crops, which showed significant increase in yield, oil and protein content due to sulphur application on various soil types under varied climatic conditions.

Like sulphur, zinc, one of the micronutrients which is now gaining importance in oilseed production. Results on beneficial effect of zinc alone or in combination with other nutrients were reported by many workers in various crops. Some of the pertinent work is reviewed in this chapter under following subheads

2.1. Effects of Incubation

2.2. Effects of sulphur

2.3. Effects of zinc

2.4. Effects of sulphur and zinc interaction

2.1 Effect of incubation

2.1.1 Sulphur

Attoe and Olsen (1966) indicated that the rate of oxidation of sulphur was fast in the beginning which become constant after some time. It was also noted that whenever high amount of native S was available, there was slow and less oxidation of added elemental S.

In Vertisol of Parbhani,Badhe and Lande (1980) in a incubation condition of calcareous medium black soil, observed that all the sulphur bearing compound contributed towards its availability as compared to that in control.

As per Singh and Kumar (1982), atmospheric and soil temperature increased oxidation rate of S. Oxidation increased with time of incubation.

They also indicated that when elemental S was applied at 50 and 100 mg kg^{-1} in all soils the sulphur increased over control at all time of incubation.

Singh and Shrivastava (1993) studied oxidation and release pattern of S fertilizers i.e. gypsum, elemental sulphur and pyrite and revealed that elemental sulphur was linearly oxidized to extent of 66 percent at the end of incubation period.

In Andhra Pradesh, Sreemannarayana *et al.* (1995) studied release pattern of sulphur from red and black soil under field capacity. Result showed that continuous release of sulphur occurred up to 105 days in presence of S, particularly in Vertisol.

2.1.2 Zinc

Mishra and Tiwari (1966) reported that in presence of free $CaCO_3$ in the soil system, Zn is converted to Zn(OH, $Zn(OH)_2$, $Zn(OH)CO_3$ and $ZnCO_3$, with decreasing availability of zinc as incubation time goes on increasing.

With increasing incubation time, DTPA extractable Zn decreased due to fixation, more so soluble soils like $ZnSO_4$. Kalabasi *et al* (1978) .

Mahendra Singh and Mittal (1983) reported that in both Balsaland sand and Ladwa fine sandy loam soils, Zn content increased up to 21 days of incubation and decreased thereafter.

Chatterjee *et al.* (1983) observed that after 45 days of incubation amount of Zn under different treatments attained more or less similar values irrespective of Zn application.

Mahendra Singh *et al.* (1993) reported that with longer incubation time zinc availability goes on decreasing.

2.2 Effects of Sulphur

Number of experiments (Gangwar and Parameswaran,1976; Gangadhara *et al.*, 1990 and Das and Ghosh *et al*, 2000) were carried out to study the effects of sulphur on oilseeds at various locations and majority of them reported significant response on yield of oilseed crops due to sulphur application.

2.2.1`Yield

In field experiment of sunflower in rabi and spring season, Gangwar and Parameśwaran (1976) reported that the various yield contributing characters viz. diameter of head, dry matter yield and seed yield were significantly increased by sulphur application (20 Kg to 40 Kg S ha^{-1})

In Karnataka, Satyanarayana *et al.* (1977) reported that there was 30 percent increase in seed yield of sunflower by application of sulphur (20 Kg ha^{-1}) through elemental sulphur over control.

On calcareous soils of Marathwada, Raut and Ghonsikar (1981) found that application of sulphur @ 20 Kg ha^{-1} through potassium sulphate produced the highest yield of irrigated sunflower grown on black soils of Dharwad .

Badiger *et al.* (1985) in an experiment on sunflower in Karnataka soils reported that application sulphur at 10 ppm level gave maximum seed yield among graded doses of sulphur.

Tiwari (1985) reported response of sunflower to added sulphur. He obtained 18.36 q ha^{-1} seed yield of sunflower by application of S at the rate of 30 kg ha^{-1}.

Sulphur must be present in adequate amounts during early reproductive development stage of sunflower to obtain maximum yield (Hocking *et al.*, 1987).

The reduction in leaf surface area and dry matter in S deficiency in 8 days old sunflower plant was observed by Onkarsingh and Nandal (1987) as compared with plant supplied with sulphur.

On field experiments conducted in different states noticed that each unit of applied sulphur increased the yield of sunflower by 2–25 units, mustard by 2.4 –21 units and linseed by 12.9 – 17 units (Takkar, 1987).

On typic Chromusterts soils, Sagare *et al.* (1990) observed that application 40, 60, and 80 kg S ha^{-1} to sunflower increased grain yield in 40 kg S ha^{-1}. Further application of S also found significantly effective in increasing yield of sunflower.

In field experiment, at Dharwad, Gangadhara *et al.* (1990) reported that application of 5 –10 kg S ha^{-1} to sunflower significantly increased the seed yield of sunflower and antagonistic effect on plant height.

In another field experiment, Das and Mishra (1991) observed increased number of pods per plant and hundred seed weight of groundnut due to application of sulphur on clay loam type of soil.

Beneficial effect of sulphur on dry matter production and seed yield of mustard were reported by Rathore and Manohar (1990) on loamy sand soils of Jobner and on Vertisol of Madhya Pradesh by Dubey *et al.* (1992) .

Sreemannarayana *et al.* (1993), obtained the highest seed and stalk yield of sunflower grown on red sandy loam soil with increasing levels of sulphur up to 60 kg ha^{-1} through ammonium sulphate followed by gypsum and single super phosphate.

On medium black soils of Dharwad, Agasimani *et al.* (1993) reported that application of sulphur @ 10 kg ha^{-1} to groundnut resulted in increased pod yield over control to the extent of 11.3 % .

Sreemannarayana and Sreenevasa Raju (1994) observed that maximum dry matter yield of sunflower significantly increased with increasing levels of sulphur up to 60 kg ha^{-1} through ammonium sulphate followed by gypsum and single super phosphate.

Sreemannarayana *et al.* (1995) revealed that both seed and stalk yield of sunflower increased when 60 kg S ha $^{-1}$ was applied.

During summer and *kharif* season, Krishnamurthi and Mathan (1996) observed that application of sulphur @ 45 kg ha $^{-1}$ increased the seed yield by 6.2 and 14.9 percent.

Thunkle (1997) revealed that there was significant increase in seed yield of sunflower by addition of 50 kg S ha^{-1} through different sources.

Jadhav (1998) found significant increase in seed and stalk yield of rabi sunflower due to application of 100 kg S ha $^{-1}$.

Kedar (1999) reported that the yield of soybean increased significantly due to application of sulphur, the yield was increased because of the role played by sulphur in metabolic process and enzyme activation.

Deokar (1998) reported increased yield of groundnut due to the reduction in pH and application of higher levels of sulphur.

On sulphur deficient shallow soils in sunflower – groundnut cropping system, Malewar *et al.* (1998) observed that seed and straw yield of sunflower was influenced with graded levels of sulphur. Each increment of sulphur significantly increased grain yield of sunflower up to 30 kg S ha^{-1} application which was on par at application S @ 45 kg ha^{-1} .

Das and Ghosh (2000) experimented sulphur sources and levels on safflower and observed increase in yield and oil content.

Ghosh *et al.* (2000) reported that application of sulphur increased the yield by 20 % in sunflower.

In field experiment conducted at Rahuri Gada (2001) observed that among various levels of sulphur, 30 and 40 kg S ha^{-1} were needed to obtain higher economic yield of sunflower .

2.2.2 Oil and Protein content

Sulphur influences not only the yield of sunflower but also its quality. Sulphur is involved in oil synthesis and oil storage organs of proteinous nature which are rich in sulphur. Since, sulphur is an integral constituent of sulphur containing amino acids like methionine, cystine and cysteine, the increase in oil content due to application of sulphur improved quality of sunflower oil. Application of sulphur helps in conversion of amino acids into proteins (Chopra and Kanwar, 1966).

Tisdale and Nelson(1970). reported that 50 to 80 percent of total S in oil seed crops goes on making S – containing amino acids and rest is required for other S containing compounds.

Dube and Mishra (1970) explained that the addition of sulphur has been shown to be beneficial in enhancing amounts of methionine, cystine and cysteine of groundnut protein.

In sulphur-phosphorus interaction, Gangwar and Parmeswaran (1976) observed significant increase in oil and protein content of sunflower.

In field experiment at Karanataka with sunflower, Badiger *et al.* (1985) reported that application of sulphur increased oil content by 2 percent as compared to non sulphur applied plants.

Tandon (1986) reviewed the effect of sulphur on oil seed crops and reported that sulphur can increase the oil content of seeds. On an average, sulphur improved the oil content of mustard by 8.5 percent, rai by 7.3 percent, groundnut by 8.5 percent and sunflower by 3.6 percent as sulphur is directly involved in fatty acid and protein synthesis.

Remarkable increase in oil content was observed by Singh (1986) with application foliar spray of 0.1 percent H_2SO_4 as the sulphur source.

Hocking *et al.*(1987) noticed significant increase in sulphur containing amino acid like cystine, cysteine and methionine by application of sulphur to sunflower.

Gangadhara *et al.* (1990) obtained increase in oil content, oil yield, crude protein and test weight of sunflower with increasing levels of S application up to 10 kg S ha^{-1} on Dharwad soil.

Channal and Rao (1991) reported that application of sulphur helps in filling up sunflower seed.

In field trial with groundnut on clayey soil, Choudhary *et al.* (1991) reported that application of sulphur @ 60 kg ha^{-1} increased oil content by 4.36 percent and protein content by 6.5 percent over control.

Singh *et al.* (1991) recorded 6.2 – 6.7 percent increase in oil content of groundnut kernel with 500 kg S ha^{-1} through pyrite. Similar results were obtained by Singh *et al.* (1993) and Singh and Singh(1996).

In soybean, Khilari and Narkhede (1995) reported that application of sulphur @ 30, 60 and 90 kg ha^{-1} increased the protein content by 4.7, 6.2 and 8.1 percent respectively over control. The corresponding increase in oil content of soybean seed was 4.4, 8.5 and 12.2, percent respectively over control.

On red loam soil, Sreemannrayna *et al.* (1995) revealed that sulphur application @ 0, 20, 40 and 60 kg ha^{-1}, the oil content and protein content of sunflower seed increased significantly with increasing levels.

Thunkle (1997) revealed that there was significant increase in oil content due to addition of 50 kg S ha^{-1}.

Jadhav (1998) found significant increase in oil content of sunflower due to application of 100 kg S ha^{-1}.

In field experiment conducted at Rahuri, Gada (2001) observed that sulphur application @ 30 kg ha^{-1} and 40 kg ha^{-1} were beneficial for oil and protein content in sunflower.

2.2.3 Uptake of nutrients

The application of sulphur not only increased the dry matter production as well as yield of crop in question, but also increased the concentration and thereby, the uptake of nutrients applied. This has been proved by the results of numerous experiments carried out elsewhere. This aspect is reviewed in a summarized form given below.

Gangwar and Parmaswaran (1976) reported that application of S alone and in combination with P to Sunflower increased the content and uptake of N, P and S of sunflower plant was less as compared to 75 percent bloom stage in both rabi and spring crop .

Marok and Dev (1979) observed that sulphur uptake by sunflower increased with sulphur application, the critical concentration of sulphur was 0.24 percent at pre bloom stage in sunflower.

In greenhouse experiment, Sharma and Dev (1980) observed that application sulphur alone and in combination with nitrogen increased total uptake of nitrogen and sulphur.

Janzen (1982) reported that application of higher levels of sulphur might have increased the surface area exposed to sulphur-oxidising organisms which might have resulted in linear increase in plant available sulphur.

Singh and Sahu (1986) reported that average uptake of sulphur by sunflower was around 14 kg ha^{-1}.

On Dharwad soil, Gangadhara *et al.* (1990) recorded that application of 5 and 10 kg S ha^{-1} increased the concentration of sulphur, boron, iron, manganese and copper in fourth leaf of sunflower at 60 DAS.

In greenhouse experiment, at Pantnagar, Sharma *et al.* (1990) reported synergistic effect of sulphur application @ 80 ppm on zinc uptake by mustard .

Sagare *et al.* (1990) noticed that the application of 40, 60 and 80 Kg S ha^{-1} to sunflower increased the uptake of N, P and K .

Higher uptake of 27.6, 29.6, 21.4 and 74.5 percent of N, P, K ,and S respectively were observed by Sharma and Gupta (1991) by application of 60 Kg S ha^{-1} to soybean on Vertisol .

Serrmannarayana *et al.* (1993) found significant increase in uptake of N, P, S, Ca, Zn and B with sulphur application .All the nutrients uptake were relatively high at maturity than flowering stage.

Sreemannarayana and Sreenivasa Raju (1994) obtained significant increase in total uptake of sulphur by sunflower at all stages of crop growth with application of sulphur .

Sreemannarayana *et al.* (1995) revealed that the uptake of micronutrients was more at flowering stage than maturity stage and uptake was more in stalk as compared to head and S levels increased up to 60 Kg ha^{-1}

Under field condition, sulphur application @ 20 Kg ha^{-1} increased the concentration and uptake of N, P, K ,and S by linseed crop at flowering, and harvesting stage of the crop (Joggi *et al.*, 1995) .

Khilari and Narkhede(1995) reported that application of sulphur @ 90 Kg ha^{-1} resulted in the increase in uptake of Zn and the concentration of micronutrients(Fe, Zn and Mn) in soybean plant decreased with decrease in level of sulphur.

Increased uptake of N,P and S by soybean crop due to application of Sulphur @ 50 kg ha^{-1} through gypsum was noticed by Yengade *et al.* (1995).

Gada (2001) observed that higher levels of sulphur application were beneficial for enhancing the concentration of nitrogen, phosphorus and sulphur in sunflower.

2. 3 Effects of Zinc

2. 3.1 Yield

Among the micronutrients, zinc plays an important role in increasing the yield as well as oil and protein content in oil seed plants, in general and sunflower in particular .

In a field experiment, Deshpande (1974) observed that the foliar application of zinc increased the pod yield by 15.5 percent over control. In a separate trial, Kapur *et al.* (1975) observed that the application of zinc @ 15 ppm in the form of $ZnSO_4$ to zinc deficient silty loam soil increased the yield, number of pods, number of seeds in soybean crop significantly.

In a field experiment, on sandy loam soil, the response of groundnut to applied lime and trace elements was studied by De and Chatterjee (1976). They noticed that the zinc application @ 25 kg ha^{-1} increased pod yield of groundnut by 4.2 percent over control.

Satyanarayana *et al.* (1977) reported that there was progressive and significant increase in the yield of sunflower as the level of zinc increased.

Channal (1978) obtained significant effect of Zn on yield of sunflower in Vertisol.

Soil analysis below 0.7 ppm DTPA extractable zinc, response to applied Zinc is expected (Katyal and Sharama ,1979) .

On zinc deficient soil, Hilton and Zubriski (1985) reported that application of 5 kg zinc ha^{-1} significantly enhanced the seed yield of sunflower.

Mishra *et al.* (1985) showed that application of Zn along with NPK increased seed yield as 16.92 q ha^{-1} compared to NPK alone.

Gowda *et al.* (1994) observed that increased level of zinc increased the pod yield of groundnut significantly.

In pot culture experiment, Tomar *et al.* (1987) reported increased dry matter yield due to application of Zn to sunflower .

Tisdale *et al.* (1995) reported that higher levels of zinc cannot give higher yields in calcareous as it converted into insoluble forms.

At Coimbatore, in a field experiment on clay loam soil , Balusamy *et al.* (1996) reported that the application of Zinc @ 10 Kg ha^{-1} along with FYM @10 *t* ha^{-1} resulted in significant increase in 100 seed weight of Soybean .

Wankhade *et al.* (1998) reported antagonistic effect of zinc on growth of soybean.

Murthy *et al.* (1999) revealed that sunflower gives response to Zn significantly increasing yield and quality.

Among micronutrients, zinc increased the yield followed by manganese. (Shukla and Warsi, 2000).

2.3.2 Oil and Protein content

The application of zinc to sunflower has been reported to increase yield. It is obvious that the increased yield would also influence the oil and protein content of sunflower.

On Chromustert soil, Timohenko (1972) showed that application of zinc at seed maturity increased the seed oil content of sunflower.

In field trial, Channal (1978) revealed that seed yield and oil content of sunflower were increased significantly due to application of zinc.

Takkar *et al.* (1987) reported that spraying of zinc increasedthe oil content of oil seed crops significantly.

Kene *et al.* (1990) revealed that application zn increased oil content of sunflower in a field trial.

Muralidharudu and Singh (1990) reported that increase in oil content of sesamum might be due to activation of NADPH dependent hydrogenase in fatty acid synthesis by zinc.

Effect of zinc on mustard was studied by Shrikrishana and Singh (1992) at Kanpur during rabi season for two consecutive years of 1983 and 1984. The highest oil and glucoside content in seeds and protein content in cake recorded in both years.

In field experiment Prabhuraj *et al.* (1995) reported increased oil content of sunflower on sandy loam soil due to application of zinc.

Sinsinwar (1995) reported that the application 0.5 percent $ZnSO_4$ spray to groundnut increased protein content by 6.02 percent over control.

In pot culture experiment, Deokar (1998) reported increase in oil and protein content of groundnut significantly due to application of 20 kg Zn ha^{-1} up to 3.51 & 4.66 percent respectively. Similarly, in a pot experiment carried out at Akola, Wankhede *et al* (1998) revealed the increase in oil content of sunflower due to application of zinc.

Babhulkar *et al.* (2000) reported significant increase in oil and protein content of safflower due to application Zn @ 40 kg ha^{-1} on Vertisol.

2.3.3 Uptake of Nutrients

Several workers reported antagonistic as well as synergistic relationships between zinc and other macro and micronutrients. Reduction in phosphorus content of groundnut kernel due to application of zinc on sandy loam soil was reported by De and Chatterjee(1976).

Reddy *et al.* (1985) noticed higher accumulation of N, P and Zn in kernels of groundnut due to application of zinc.

Bhal *et al.* (1986) reported synergistic effects between sulphur and zinc in groundnut.

In pot culture experiment with sunflower, Tomer et al. (1987) observed that the application of zinc increased uptake of zn and availability.

On sandy loam soil, Devarajan *et al.* (1988) observed that application of 0.5 % Zn increased yield and nutrient uptake by sunflower.

Kocher *et al.* (1990) recorded an increase in sulphur uptake by groundnut up to 20 kg Zn ha^{-1} application and decrease beyond this rate might have resulted from imbalance nutrition or interference of zinc in utilization of sulphur at metabolic sites.

In a field trial Shrikrishna and Singh (1992) reported that application of zinc @ 45 kg $ZnSO_4$ ha^{-1} increased significantly its content and uptake and decreased the content and uptake of phosphorus and sulphur in seed and stover of mustard .

On black calcareous as well as red non calcareous soils of Tamil nadu, Devarajan and Palaniappan (1995) reported significant increase in uptake of Zn, Cu, Fe and Mn due to application of 5 kg Zn ha^{-1} as $ZnSO_4$ by soybean.

Revathi *et al.* (1996) reported significant increase of uptake of P, K, Ca, and Mg by groundnut due to application Zn @ 25 kg $ZnSO_4$ ha^{-1}.

Similarly, in pot culture experiment, Deokar (1998) reported synergistic effect of lower level of zinc application (20 kg ha^{-1}) and higher level exerts antagonistic effects on uptake of P, Ca, Mg, S, Zn, Fe, Mn and Cu. by groundnut

2. 4 Effects of Sulphur and Zinc Interaction

In a field experiment, Channal (1978) observed that application of 20 kg S ha^{-1} and Foliar spray of 0.5 % Zn gave the highest yields (2.35 *t*) and oil content (40.3 %) of sunflower.

On zinc deficient soil of Haryana, Shulka and Prasad (1979) in green house experiment reported significant increase in pod yield of groundnut (60.64 % over control) due to application of 15 ppm sulphur through K_2SO_4 along with 10 ppm zinc as zinc Oxide.

An experiment at Panjab, on groundnut to study interaction effect of sulphur and Zinc was carried by Bhal *et al.* (1986) denoted that the interaction effect of Zinc and Sulphur on the pod yield was significant and positive. Increased pod yield was obtained with combined application of 20 kg Zn and 15 kg S ha^{-1} to the tune of 9.44 percent in year 1980 and 12.29 percent in the year 1981.

In other oil seed like mustard, the maximum increased (77.8 percent) seed yield was recorded due to application of 10 ppm zinc and 80 ppm sulphur in combination (Sharma *et al.* 1990).

In field experiment on sandy loam soil with sunflower, Prabhuraj *et al.* (1995) observed application 10 ppm sulphate and 5 ppm Zn give the highest seed yield to 3.05 *t* ha^{-1}.

Singh and Singh (1996) revealed that application of 20 kg ZnO and 30 kg ha^{-1} sulphur has significantly increased the grain yield of soybean.

In an experiment at Karnataka Vasudevan *et al.* (1997) observed the highest yield with all combination of sulphur and micronutrients with sunflower.

Tripathi *et al.* (1997) observed antagonistic interaction between S and Zn in Checkpea.

In pot culture experiment, Deokar (1998) observed the non-significant interaction between sulphur and zinc for uptake of nutrients, oil and protein content of groundnut.

A positive interaction between sulphur and zinc was observed by Ghosh *et al.* (2000) in groundnut with application of 15kg S ha^{-1} and 10 kg Zn ha^{-1} .

Babhulkar *et al.* (2000) observed interaction of sulphur and zinc was significant and the highest seed yield (29.34q ha^{-1}) and straw yield (93.23 q ha^{-1}) were obtained with the combined application of 45 kg S and 15 kg Zn ha^{-1} and antagonistic interaction was found for the uptake of potassium and oil content in a field experiment during rabi 1996 – 97 with safflower.

MATERIALS AND METHODS

3 MATERIALS AND METHODS

The pot culture experiment was conducted at the Department of Agricultural Chemistry and Soil Science, College of Agriculture, Pune during *kharif* 2001.

The details of materials used, experimental techniques and analytical methods adopted during this investigation are summarised in this chapter .

3.1 Materials :

3.1.1 Soil

The representative soil samples (0-15 cm) deficient in sulphur and zinc were collected from the E-1 block of the farm of Agriculture College , Pune. The soil samples were dried under shade, pounded in wooden mortar and pestle and sieved through 2 mm sieve and analysed for physical and chemical properties. The physical and chemical properties are presented in Table 1.

3.1.2 Seeds

The seeds of sunflower (Cv. SS – 56) were obtained from office of the Associate Director of Research National Agricultural Research Project, Scarcity Zone, Solapur and are used for experiment. The pre sowing treatment of Bavistin (5 grams per Kg of seed) was given to control seed borne diseases.

3.1.3 Fertilizers

The recommended dose of N, P and K (60 Kg N , 30 Kg P_2O_5 and 30 Kg K_2O ha^{-1}) through Urea, Diammonium Phosphate and Muriate of Potash, respectively was given before sowing for all treatments.

3.1.3.1 Sulphur and Zinc Fertilizers

Calculated quantities of Sulphur and Zinc (Table –2) as per the treatments were given through elemental Sulphur and Zinc Oxide, respectively before sowing by thoroughly mixing with soil.

3.1.4 Pots

Cement pots of the capacity 22 kg soil per pot were used (height - 29cms and diameter – 33.5 cms). Pots with a hole at bottom were prepared by adding pebbles (10 cm layer) and 20 kg soil per pot with polyethylene lining.

3.1.5 Bowls

The twenty seven plastic bowls of 2 kg capacity were used for the incubation study.

Table 1. Physical and Chemical properties of Soil

Sr No.	Soil properties	Values
A	PHYSICAL	
1.	Partical size analysis	
	Coarse sand (%)	10.30
	Fine sand (%)	22.46
	Silt (%)	25.84
	Clay (%)	41.40
2.	Textural class	Clay loam
3.	Moisture (%)	7.00
4.	Field capacity (%)	38.00
B	CHEMICAL	
1.	pH (1:2.5)	7.5
2.	EC (dS m^{-1})	0.54
3.	Organic carbon (%)	0.61
4.	Calcium carbonate equivalent (%)	7.00
5.	Available nitrogen (Kg ha^{-1})	230.00
6.	Available phosphorus (Kg ha^{-1})	27.00
7.	Available potassium (Kg ha^{-1})	355.00
8.	Available sulphur (ppm)	4.00
C	DTPA extractable micronutrients	
1.	Iron (ppm)	2.5
2.	Manganese (ppm)	6.5
3.	Zinc (ppm)	0.5
4.	Copper (ppm)	2.20

Table 2. Details of treatments

Levels of sulphur (Kg ha^{-1})	
0	S_0
30	S_1
60	S_2
90	S_3
Levels of zinc (Kg ha^{-1})	
0	Zn_0
20	Zn_1
40	Zn_2
60	Zn_3
Design – FRBD	
No of replications - 2	

3.2 Experimental Details

The experiment was conducted in a Factorial Randomized Block Design with sixteen treatments replicated two times. Six seeds of sunflower (Cv. SS-56) were dibbled in each pot. Thinning was carried out at 9^{th} day after sowing and finely three healthy seedlings were kept in each pot. Weeding, watering and regular plant protection measures are adopted.

3.2.1 Sampling

One plant from each of pot was uprooted at flowering. At maturity stage, remaining two plants was uprooted. Plant sample was washed thoroughly with distilled water and then air dried in shade and subsequently in hot air oven. The yield was recorded. The dried plant samples were ground in Willey mill to pass through twenty mash and used for chemical analysis .

Plant samples were analysed for the uptake of N, P, K, S and Zn. Sunflower seeds were analysed for oil and protein content. Post harvest soil samples were collected from each pot and analysed for macro and micronutrients.

3.2.2 Plant analysis

The plant samples were digested in diacid (H_2SO_4 : H_2O_2 (1:1)) mixture as per the method prescribed by Parkinson and Allen (1975). This extract was used for determination of N. Plant samples digested in HNO_3 : $HClO_4$ (9:4) mixture separately (Johnson and Ulrich 1959) were used for determination of P,K,S and Zn. The methods adopted for plant analysis are given in Table 3.

3.2.3 Yield and Quality Parameters

3.2.3.1 Yield of seeds per pot and per hectare

Yield of seed was obtained by removing heads from the plants. The heads were dried in sun. After wards seeds were separated from them and seed weight per pot was recorded and then reported on hectare basis by multiplying with hectare factor.

3.2.3.2 Protein content

Nitrogen percentage was estimated by Microkjeldahl (modified kjeldahl) method (Piper 1966), Protein percentage of grain was estimated by multiplying the nitrogen percentage by 6.25 factor.

3.2.3.3 Oil content

Oil percentage of grain was determined by Soxhlet extractor using ether as a solvent (Ranganna, 1994) .

3.2.3.4 Computation of Nutrient uptake

The nutrient concentration in plant samples was multiplied by the corresponding dry matter yield to obtain nutrient uptake (g $plant^{-1}$) at flowering and also at harvest stage .

3.2.4 Statistical analysis

The data recorded were statistically analysed by adopting the technique of variance (Fisher, 1970) and test of significance was carried out as described by Panse and Sukhatme.(1967)

3.2.5 Incubation Studies

An incubation study was conducted in order to observe the availability of sulphur and zinc in soil. The air dried, sieved one Kg soil was taken in plastic bowl and replicated thrice. The requisite amount of sulphur at 0, 30 and 60 Kg ha^{-1} and zinc at 0,20 and 40 Kg ha^{-1} along with basal dose of N, P and K (60 Kg N , 30 Kg P_2O_5 and 30 Kg K_2O ha^{-1}) mixed with soil. Distilled water was added as when required to maintain soil moisture content at field capacity. The soil samples from each pot were drawn at 0, 15, 30, 45, 60 and 75 days of incubation and were analysed for available sulphur and zinc .

Table 3. Treatment for incubation

Levels of sulphur (Kg ha^{-1})	
0	S_0
30	S_1
60	S_2
Levels of zinc (Kg ha^{-1})	
0	Zn_0
20	Zn_1
40	Zn_2

Design – FRBD

No of replications - 3

Table 4. Methods used for soil and plant analysis

Sr No.	Parameter	Method used	Reference
I	**Soil analysis**		
1.	Partical size distribution	International Pipette method	Black (1965)
2.	pH	Glass electrode (1:2.5 soil:water ratio)	Piper (1966)
3.	EC	Conductometric	Jackson (1967)
4.	Organic carbon	Walkley and Black	Nelson and Sommer (1982)
5.	Available N	Alkaline permangnate method	Subbiah and Asiija (1956)
6.	Available P	Olsen P (0.5 M $NaHCO_3$ pH 8.5)	Olsen *et al.* (1954)
7.	Available K	Flame Photometer (Neutral, 1 N NH_4OAc)	Kudsen *et al* (1982)
8.	Available S	Turbidimetric	Williams and Steinberg(1964)
9.	DTPA-extractable micronutrients	Atomic Absorption Spectrometry	Lindsay and Norvell(1978)
II	**Plant analysis**		
1.	Nitrogen	Micro-kjeldahl	Bremner(1965)
2.	Phosphorus	Vandomolybdate phosphoric acid yellow colour	Jackson(1967)
3.	Potassium	Flame photometric	Chapman and Pratt(1961)
4.	Sulphur	Turbidimetric	Tabatabi and Bremner(1982)
5.	Micronutrient	Atomic Absorption spectrometry	Lindsay and Norvell(1978)
III	**Quality Parameters**		
1.	Protein content	Microkjeldahl's	Piper(1966)
2.	Oil content	Soxhlet method	Ranganna(1994)

RESULTS AND DISCUSSION

4 RESULT AND DISCUSSION

4.1 Yield :

It is revealed from the data presented in table 5 and fig.1 that seed yield of sunflower increased significantly due to application of increased levels of sulphur and zinc.

Effect of sulphur :

The increasing levels of sulphur from 30 to 90 kg ha $^{-1}$ increased the seed yield significantly over control. The highest yield (6.50 q ha^{-1}) was recorded due to the application of the higher level (90 kg S^0 ha $^{-1}$) of sulphur and it was significantly superior over all the treatments (40%percent increase over control). The next effective treatment was 60 kg S^0 ha $^{-1}$ which was significantly superior over control (27%percent increase over control) . The lowest yield was recorded in control.

The response to the application of sulphur at 90 kg ha^{-1} obtained in the present investigation might be due to the decrease in soil pH from 7.5 (initial) to 7.3 (harvest).This reduction in pH might have resulted in increase the availability of the nutrients in general and sulphur in particular. The increased sulphur level and availability of nutrients in turn might have resulted in higher seed yield of sunflower (Deokar, 1998).

The increased levels of sulphur, increased the yield of sunflower, the results obtained were in accordance with Malewar *et al.* (1998) and Kedar, (1999) who reported that seed and straw yield of sunflower were increased due to application of graded levels of sulphur. The yield was increased because of the role played by the sulphur in metabolic processes and enzyme activation.

Increased seed yield of sunflower by addition of 50 kg ha $^{-1}$ sulphur through different sources was reported by Thunkle (1997). Similarly, in field experiment, Gangadhara *et al.* (1990) reported that application of 5-10 kg S ha $^{-1}$ to sunflower significantly increased the seed yield of sunflower. Similar results were reported by Rathore and Manohar (1990) in mustard and Ghosh *et al.* (2000) in sunflower .

Table : 5 Effect of sulphur and zinc on the seed yield (q ha $^{-1}$) of sunflower.

	Seed yield (q ha $^{-1}$)
Levels of sulphur (kg ha $^{-1}$)	
0	4.64
30	5.17 (11%)
60	5.90 (27%)
90	6.50 (40%)
S.E($\pm$)	0.029
C.D at 5%	0.09
Levels of zinc (kg ha $^{-1}$)	
0	4.68
20	5.73 (22%)
40	6.56 (40%)
60	5.24 (11%)
S.E($\pm$)	0.029
C.D at 5%	0.09
Interaction	
S.E($\pm$)	0.058
C.D at 5%	NS

[Figures in paranthesis indicate percent increase over control]

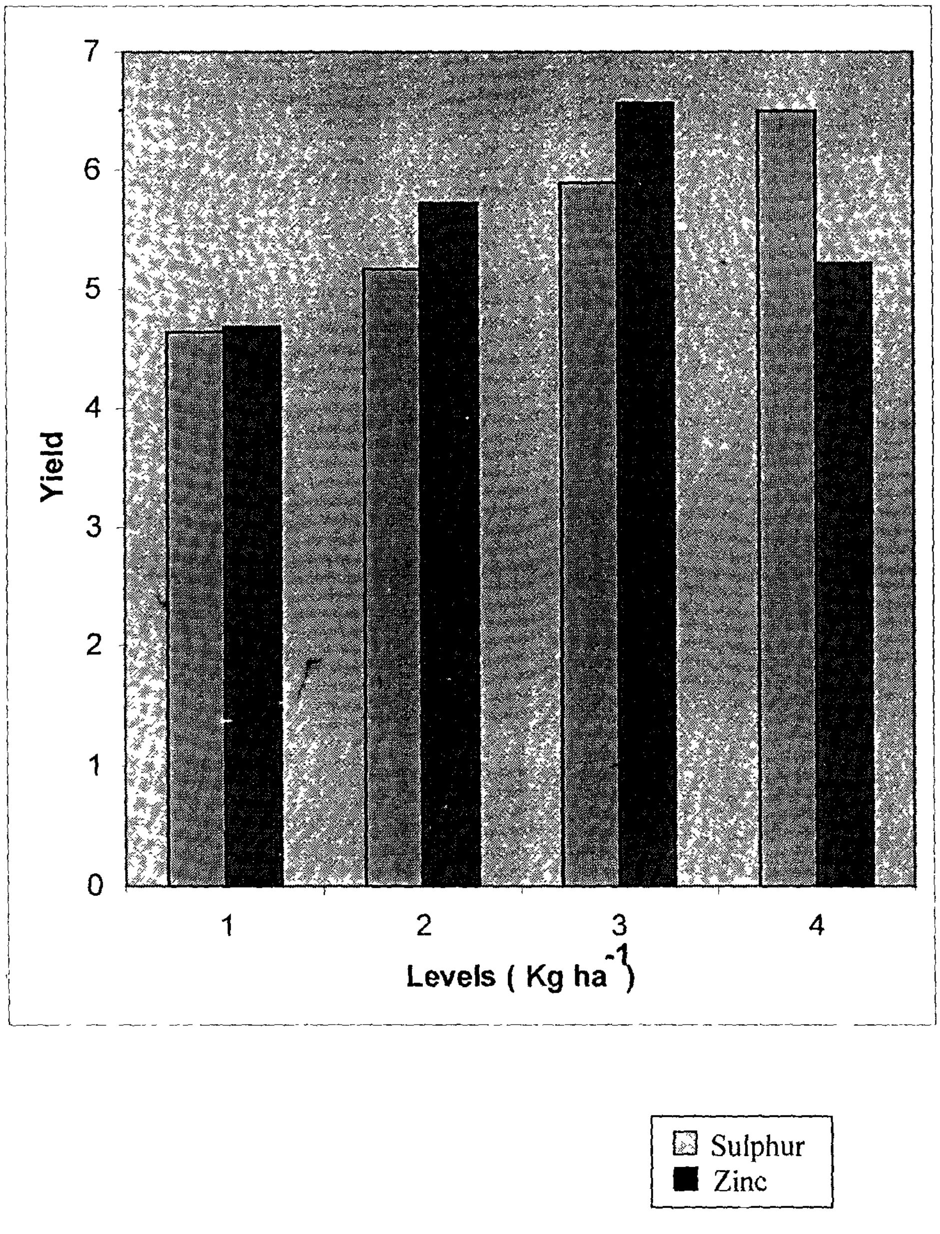


Fig 1 : Effect of sulphur and zinc on the seed yield (q ha $^{-1}$) of sunflower

Effect of zinc

Application of zinc was also increased the yield significantly. The most superior treatment recorded was 40 kg Zn ha $^{-1}$ which increased the yield by 40 percent over control. It was significantly superior over all the zinc treatments .The application of 20 kg Zn ha $^{-1}$ increased the yield (5.73 q ha $^{-1}$) which was significantly superior over 60 kg Zn ha $^{-1}$. The yield recorded in control was inferior to all zinc treatments.

From data presented in Table 5 it was observed that the application of Zn at 40 kg ha^{-1} resulted in the highest yield of sunflower and lower yield due to the highest level of zinc (60 kg ha $^{-1}$). The reduction in yield at higher level of zinc might be because of the two reasons. Firstly , at high pH zinc precipitates as zinc insoluble amorphous soil Zn, $ZnFe_2SO_4$ and $ZnSiO_4$, which reduces Zn $^{++}$ in soil. Secondly, zinc adsorption by carbonates is partly responsible for reduced Zn $^{++}$ availability in calcareous soils. Evaluation of the reasons of Zn $^{++}$ adsorption reveals that $CaCO_3$ content was the principle factor contributing to the zinc concentration, therefore in calcareous soil the higher rates of zinc application did not give response (Tisdale, *et al* 1995) .

The soil used in present investigation having 0.5 ppm zinc concentration and the results obtained were in accordance with the results obtained by Katyal and Sharma (1979) who were observed that soil analysis below 0.7 ppm DTPA extractable zinc, expected to give response to the applied zinc. Such type of results were also reported by Murthy *et al* (1999) in sunflower.

Effect of sulphur and zinc interaction

The interaction effects were non-significant

4.2 Number of leaves

The data about the number of leaves was presented in Table 6 at flowering and harvesting stages of the sunflower.

Effect of sulphur

At flowering the application of sulphur at the highest level (90 kg S^0 ha^{-1}) gave more number of leaves as compared to other treatments. The differences were not significant. The low number of leaves were recorded in the control.

At harvesting similar trend was observed. The application of higher level of sulphur gave more number of leaves. But the differences were non-significant. The application of zinc at higher level (60 kg $ha^{-1)}$ gave more number of leaves. The differences were non-significant. The lowest number of leaves were recorded in control .

The results obtained were in accordance with the observations reported by Gangadhara *et al.* (1990) in sunflower.

Effect of zinc

Due to zinc application, the non-significant effect was observed though more number of leaves were recorded due to application of 60 kg Zn ha^{-1} at flowering and harvesting stages.

The results obtained were in accordance with the observations reported by Wankhade *et al.* (1998) in soybean .

Effect of sulphur and zinc interaction

Interaction effects were non-significant .

Table : 6 Effect of sulphur and zinc on the number of leaves

	Number of leaves	
	At flowering	At harvesing
Levels of sulphur (kg ha $^{-1}$)		
0	23.84	16.00
30	24.37	16.50
60	25.13	17.12
90	25.60	17.35
S.E($\pm$)	0.286	0.260
C.D at 5%	NS	NS
Levels of zinc (kg ha $^{-1}$)		
0	24.22	15.00
20	24.90	16.40
40	24.27	17.07
60	24.60	18.60
S.E($\pm$)	0.286	0.260
C.D at 5%	NS	NS
Interaction		
S.E($\pm$)	0.572	0.52
C.D at 5%	NS	NS

4.3 Height of plant

The data in respect of height of plant is presented in Table 7 at flowering and harvest stages of sunflower.

Effect of sulphur

At flowering, the maximum height was recorded due to application of sulphur at highest level @ 90 kg S^0 ha^{-1}. The remaining treatments were recorded the lower height than it but more than control. The differences were non-significant. The lowest height was recorded in control.

The similar trend was observed at harvesting also. Due to application of higher level of sulphur (90 kg S^0 ha^{-1}) there was more height than the remaining treatments, however the differences were non-significant. The lowest height was recorded in control.

The similar type of results were reported by Gangadhara *et al.* (1990) in sunflower.

Effect of zinc

Zinc application was recorded non-significant though there was more height due to application of Zn at 40 kg ha^{-1}. The lowest height was recorded in control.

The application Zn at 40 kg S^0 ha^{-1} have the maximum height as compared to the other treatments. The differences were non-significant though the height increased as compared to control.

The similar type of results were reported by Wankhade *et al.* (1998) in soybean.

Effect of sulphur and zinc interaction

The interaction effects were non-significant.

Table : 7 Effect of sulphur and zinc on the plant height (cms)

	Plant height	
	At flowering	At harvesting
Levels of sulphur (kg ha^{-1})		
0	41.92	83.83
30	42.70	86.00
60	43.90	87.53
90	44.20	90.40
S.E($\pm$)	0.79	0.057
C.D at 5%	NS	NS
Levels of zinc (kg ha^{-1})		
0	42.12	84.00
20	43.10	86.57
40	44.40	91.86
60	43.80	85.43
S.E($\pm$)	0.79	0.057
C.D at 5%	NS	NS
Interaction		
S.E($\pm$)	0.79	0.144
C.D at 5%	NS	NS

4.4 Uptake of nitrogen

Effect of sulphur

The uptake of nitrogen by sunflower at flowering was influenced significantly due to application of various levels of sulphur and zinc. The highest uptake (0.66 g plant $^{-1}$) of nitrogen was recorded due to the application of 90 kg S^0 ha $^{-1}$ (Table 8 , fig 2). The application of 60 kg S^0 ha $^{-1}$ resulted into 0.53 g of nitrogen uptake plant $^{-1}$ which is the next effective treatment in this respect (fig 2) .The application of 90 kg S^0 ha $^{-1}$ was significantly superior over the 60 kg S^0 ha $^{-1}$. The application of 30 kg S^0 ha $^{-1}$ recorded still significantly lower value of nitrogen uptake (0.43 g plant $^{-1}$) as compared to the remaining two treatments (60 and 90 kg ha^{-1}). The lowest nitrogen uptake was recorded in control (0.34 g plant^{-1}).

At harvest, similar type of trend was observed in respect of the sulphur. The highest uptake of nitrogen was recorded (0.078 g plant $^{-1}$) due to application of sulphur at 90 kg S^0 ha $^{-1}$. The next effective treatment followed was 60 kg S^0 ha $^{-1}$. The nitrogen uptake was 0.065 g plant $^{-1}$ which was significantly superior over the 30 kg S^0 ha $^{-1}$. The lowest uptake of nitrogen was recorded in control. The uptake due to application of 90 kg S^0 ha $^{-1}$ significantly superior over all three treatments.

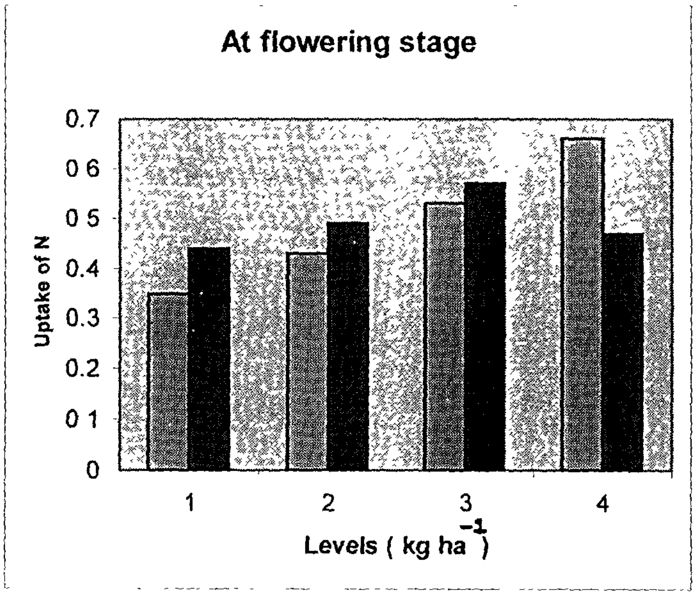
The results presented in Table 8 and fig 2 indicated that application of sulphur at 90 kg ha $^{-1}$ level increased the uptake of the nitrogen at flowering and harvesting stage.

The fairly well status of mineralized sulphur in the experimental soil was indicative of adequate nitrogen status in soil. The highest doses of sulphur must have resulted in increased level of nitrogen (Tisdale *et al.* , 1995). In present investigation, increased uptake of nitrogen at higher levels of sulphur application might be due to increased nitrogenase activity due to sulphur.

The results observed in present study were in accordance with the results obtained by the Sagare *et al.* (1990) and Yengade *et al.* (1995) .

Table : 8 Effect of sulphur and zinc on the uptake of nitrogen

Treatments	Uptake of nitrogen	
	At flowering (g $plant^{-1}$)	At harvesting (g $seed^{-1}$)
Levels of sulphur (kg ha^{-1})		
0	0.34	0.048
30	0.43	0.056
60	0.53	0.065
90	0.66	0.078
S.E(±)	0.013	0.001
C.D at 5%	0.04	0.003
Levels of zinc (kg ha^{-1})		
0	0.41	0.054
20	0.51	0.060
40	0.57	0.068
60	0.47	0.063
S.E(±)	0.013	0.001
C.D at 5%	0.04	0.003
Interaction		
S.E(±)	0.026	0.001
C.D at 5%	NS	NS



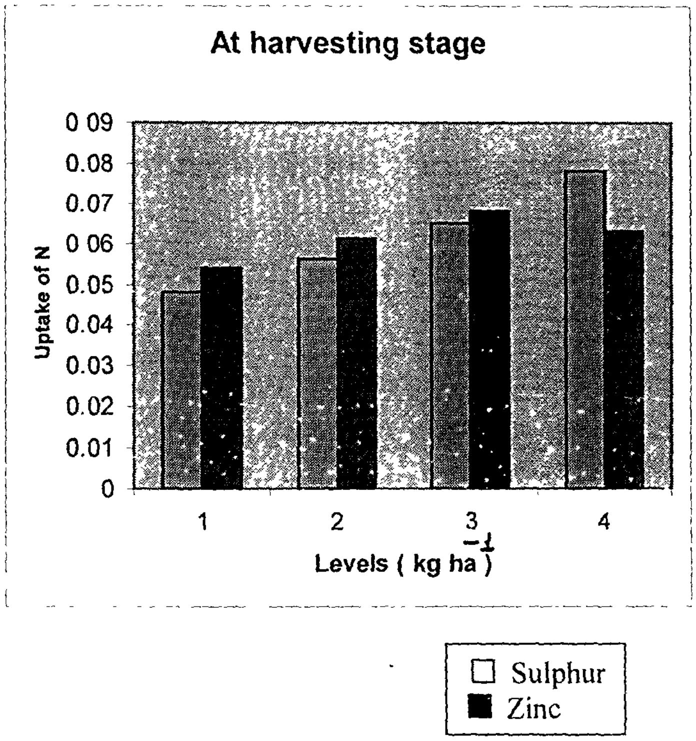


Fig.2 Effect of sulphur and zinc on the uptake of nitrogen (g plant $^{-1}$)

Effect of zinc

As regards the effect of zinc on nitrogen uptake at flowering the application of 40 kg Zn ha $^{-1}$ resulted into the highest (0.57 g plant $^{-1}$) nitrogen uptake by the plant at flowering. It was followed by the 20 kg Zn ha $^{-1}$ (0.51 g plant $^{-1}$) closely followed by the 60 kg Zn ha $^{-1}$. These two treatments were at par. The 40 kg Zn ha $^{-1}$ treatment was statistically significant over all the treatments. The lowest nitrogen uptake was recorded in control (0.41 g plant $^{-1}$) as compared to other treatments.

At harvesting, the highest nitrogen uptake (0.068 g plant $^{-1}$) was observed due to the application of 40 kg Zn ha $^{-1}$. The nitrogen uptake of remaining two treatments (20 and 60 kg ha $^{-1}$) are similar and at par. These two treatments were significantly inferior to the application of 40 kg Zn ha $^{-1}$ but these two treatments were significantly superior to control. The lowest nitrogen uptake was recorded in control.

Application of Zn has been reported both synergistic as well as antagonistic effect on the uptake of nitrogen. It is known fact that Zn plays role in protein synthesis and hence a better utilization of adsorbed nitrogen through synergism between them becomes understandable.

Zinc application has been reported to increase the nitrogen content in seeds of groundnut (Reddy *et al.* , 1985) similar results were observed by Devarajan *et al.* (1988). Deokar (1998) reported synergistic effect at higher levels of zinc on the nitrogen uptake by groundnut.

Effect of sulphur and zinc interaction

The interaction effects were non-significant.

4.5 Uptake of phosphorus

Effect of sulphur

At flowering, phosphorus uptake by plant was influenced significantly due to application of sulphur at various levels (Table 9 and fig 3) Significantly the highest uptake (0.086 g plant $^{-1}$) of phosphorus was noticed due to application of the 90 kg S^0 ha $^{-1}$. The application of 60 kg S^0 ha $^{-1}$ was observed to be next effective treatment. The application of 30 kg S^0 ha $^{-1}$ followed this both treatments the lowest uptake was recorded in control. The application of 90 kg S^0 ha $^{-1}$ was significantly higher than other treatments.

At harvest (Table 9) , the highest uptake (0.033 g plant $^{-1}$) was observed at the level of 60 kg S^0 ha $^{-1}$. The next effective treatment 90 kg S^0 ha $^{-1}$ followed by it. The uptake of phosphorus in the 60 kg S^0 ha^{-1} and 90 kg S^0 ha^{-1} were at par . The level 30 kg S^0 ha $^{-1}$ closely followed to the 90 kg S^0 ha $^{-1}$. These two treatments were at par. The lowest uptake of phosphorus was recorded in the control.

The data presented in Table 9 , indicated that higher uptake of phosphorus was noticed due to application of 90 kg S^0 ha $^{-1}$ at flowering and at harvesting higher uptake was observed due to 60 kg S^0 ha $^{-1}$ application. Similar results were reported by Gangwar and Parameswara (1976) in sunflower and Sharma and Gupta (1991) in soybean.

Effect of zinc

Though, the application of various levels of zinc did not result into significant difference in the uptake of phosphorus by sunflower, at flowering, the increased uptake of phosphorus was noticed due to application 40 kg Zn ha $^{-1}$ followed by the 20 kg Zn ha $^{-1}$.

Non-significant differences in respect of uptake of phosphorus due to application of zinc were observed in sunflower. The highest uptake was recorded due to the application of 20 kg Zn ha $^{-1}$. The lowest uptake was recorded in the control .

Table:9 Effect of sulphur and zinc on the uptake of phosphorus

Treatments	Uptake of phosphorus	
	At flowering (g plant $^{-1}$)	At harvesting(g seed^{-1})
Levels of sulphur (kg ha $^{-1}$)		
0	0.043	0.014
30	0.060	0.027
60	0.076	0.033
90	0.086	0.030
S.E(±)	0.002	0.001
C.D at 5%	0.006	0.003
Levels of zinc (kg ha $^{-1}$)		
0	0.062	0.020
20	0.071	0.029
40	0.080	0.025
60	0.064	0.021
S.E(±)	0.002	0.021
C.D at 5%	NS	NS
Interaction		
S.E(±)	0.002	0.006
C.D at 5%	NS	NS

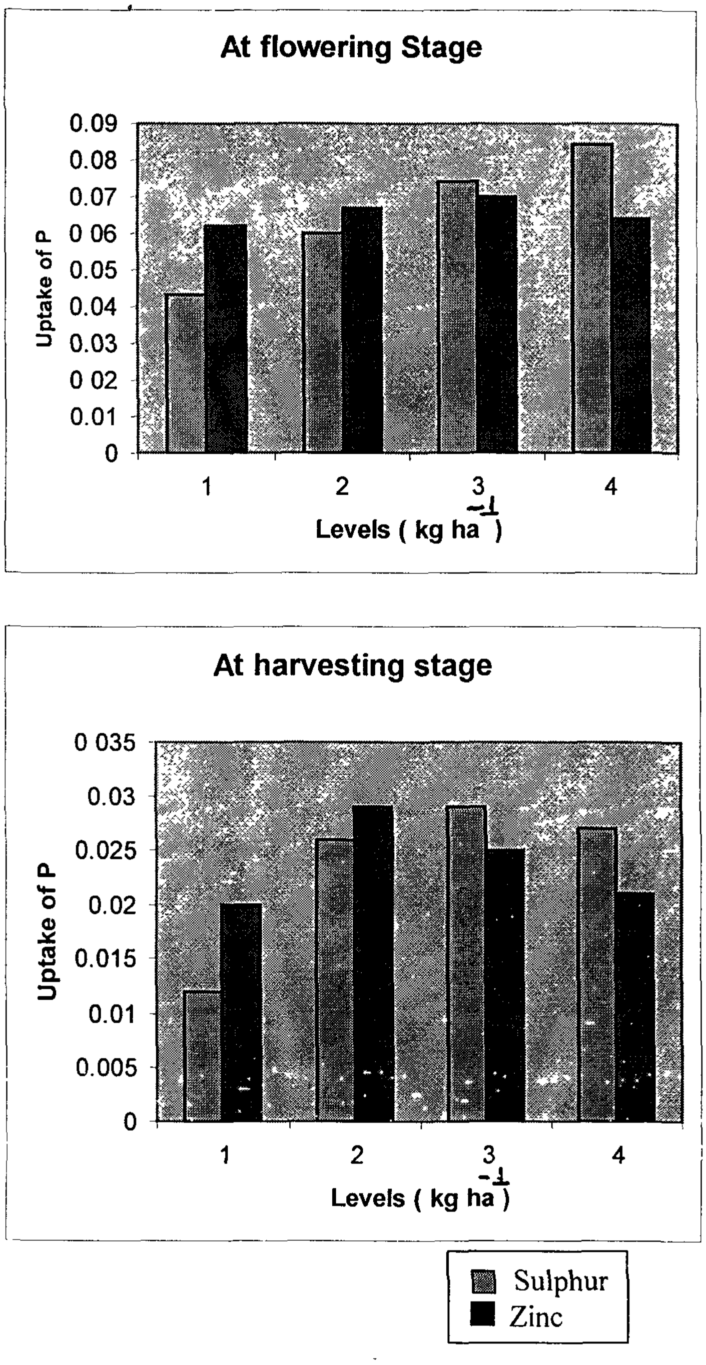


Fig. 3 Effect of sulphur and zinc on the uptake of phosphorus (g plant $^{-1}$)

From the data, it was observed that the application of Zn at various levels did not affect the uptake of phosphorus by sunflower at flowering and harvesting. Though the increased uptake of phosphorus due to application of 20 kg zinc ha^{-1} was noticed at flowering and harvesting. The decreased uptake of phosphorus by sunflower due to increased doses of zinc was noticed in present study indicating antagonistic effect between these two nutrients.

Similar results were reported by De and Chattrajee (1976) in groundnut and Shrikrishna and Singh (1992) in mustard.

Effect of sulphur and zinc interaction

The interaction effects were non-significant.

4.6 Uptake of Potassium

Effect of sulphur

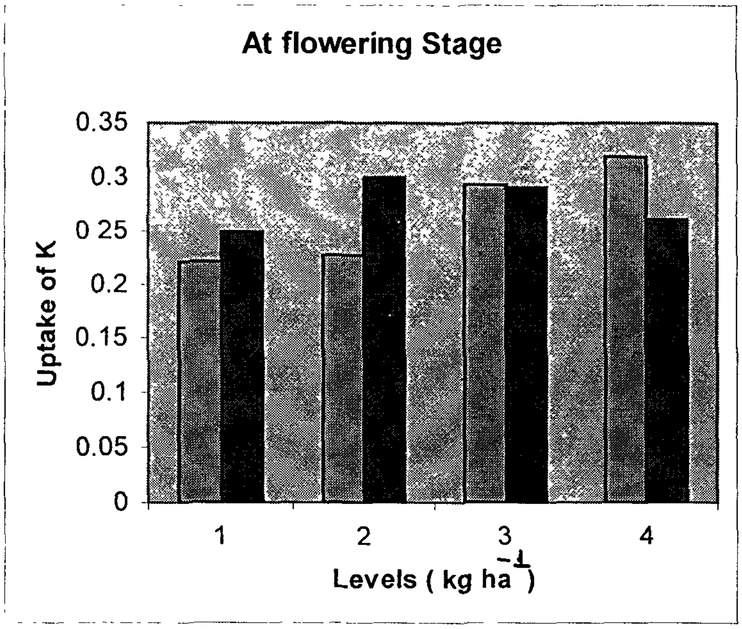
Potassium uptake by sunflower at flowering was significantly affected due to application of sulphur. The highest uptake of potassium was observed in treatment receiving 90 kg S^0 ha^{-1} which was significantly superior over the remaining treatments (Table 10 , fig 4). The next effective treatment was 60 kg S^0 ha^{-1} following by it which was significantly superior over remaining two treatments (30 and 0 kg ha^{-1}). The lowest uptake of potassium (0.221 g plant ^{1}) was recorded in control.

At harvesting, the highest uptake of potassium was noticed due to application of the 60 kg S^0 ha^{-1} which was significantly superior over all the treatments. The application of 90 kg S^0 ha^{-1} was observed next effective treatment to it. The lowest uptake of potassium was recorded in the control.

From the data presented in Table 10 and fig 4 , it was observed that there was increased uptake of potassium due application of sulphur @ 90 kg S^0 ha^{-1} at flowering and 60 kg S^{-0} ha^{-1} at harvest This might be due to the synergistic mechanism between sulphur and potassium . Similar type of results were obtained by Sreemannarayana and Sreenevasa Raju (1995), Sharma and Gupta (1991) and Joggi *et al.* (1995) in groundnut.

Table:10 Effect of sulphur and zinc on the uptake of potassium (g plant $^{-1}$)

Treatments	Uptake of potassium	
	At flowering (g plant^{-1})	At harvesting (g seed^{-1})
Levels of sulphur (kg ha $^{-1}$)		
0	0.221	0.062
30	0.266	0.095
60	0.293	0.120
90	0.318	0.115
S.E($\pm$)	0.002	0.002
C.D at 5%	0.006	0.006
Levels of zinc (kg ha $^{-1}$)		
0	0.248	0.085
20	0.300	0.125
40	0.290	0.119
60	0.260	0.101
S.E($\pm$)	0.002	0.002
C.D at 5%	0.006	0.006
Interaction		
S.E($\pm$)	0.005	0.005
C.D at 5%	NS	NS



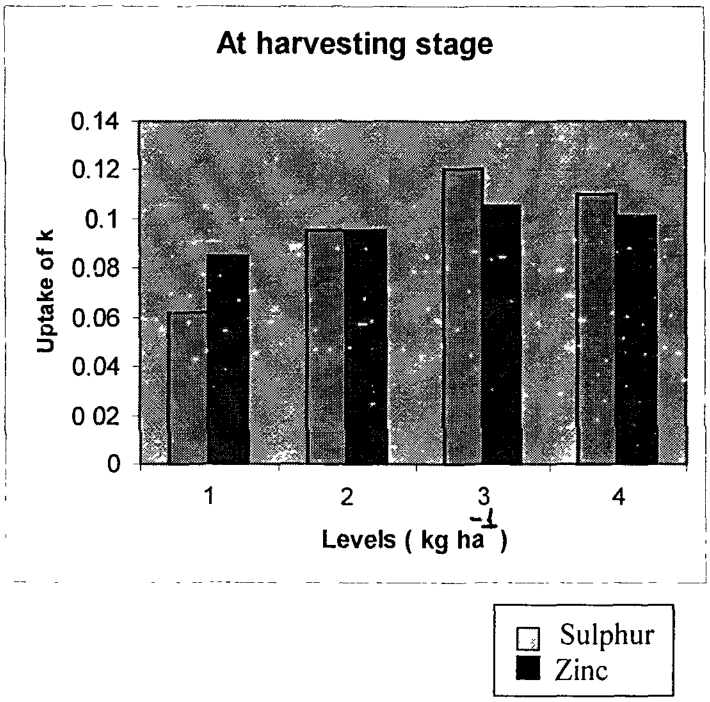


Fig.4 Effect of sulphur and zinc on the uptake of potassium (g plant $^{-1}$)

Effect of zinc

The application of zinc increased the uptake of potassium. The highest uptake was observed in the treatment receiving the 20 kg Zn ha $^{-1}$ which was significantly superior over the 40 kg Zn ha $^{-1}$ and 60 kg Zn ha $^{-1}$. The lowest uptake of potassium was recorded in control which significantly inferior to all treatments.

The highest uptake of potassium observed due to application of 20 kg Zn ha $^{-1}$ which was significantly superior over the application at 60 kg Zn ha $^{-1}$. The potassium uptake due to application of 20 kg Zn ha $^{-1}$ and 40 kg Zn ha $^{-1}$ were at par. The lowest uptake of potassium by sunflower at harvest was observed in control.

From the data it was observed that there was significant increase of potassium uptake due to application zinc. This might be due to the synergistic interaction between these two nutrients. Similar results were reported by Reddy *et al.*.(1985) and Revathi *et al.* (1996).

Effect of sulphur and zinc interaction

The interaction effects were non-significant.

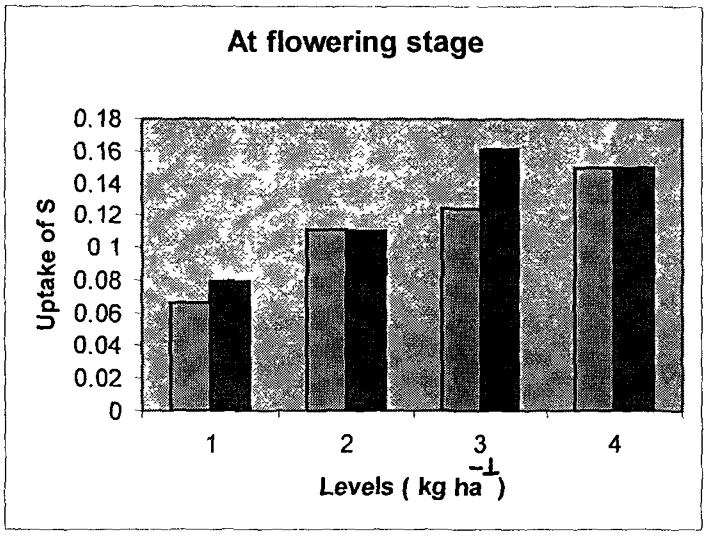
4.7 Uptake of Sulphur

Effect of sulphur

As regards the effect of different levels of sulphur application on the uptake of sulphur at flowering, the highest uptake of sulphur was recorded due to the highest sulphur application @ 90 kg S^0 ha $^{-1}$ (0.150g plant $^{-1}$) followed by the 60 kg S^0 ha $^{-1}$ (Table 11). The highest level of sulphur was significantly superior over the other treatments. The lowest level of sulphur was significantly inferior. The lowest uptake was recorded in the control (0.060 g plant $^{-1}$) .

Table:11 Effect of sulphur and zinc on the uptake of sulphur

Treatments	Uptake of sulphur	
	At flowering (g $plant^{-1}$)	At harvesting (g $seed^{-1}$)
Levels of sulphur (kg ha^{-1})		
0	0.060	0.022
30	0.111	0.027
60	0.124	0.046
90	0.150	0.050
S.E($\pm$)	0.003	0.001
C.D at 5%	0.009	0.004
Levels of zinc (kg ha^{-1})		
0	0.079	0.028
20	0.110	0.045
40	0.161	0.040
60	0.095	0.036
S.E($\pm$)	0.003	0.001
C.D at 5%	0.009	0.004
Interaction		
S.E($\pm$)	0.006	0.005
C.D at 5%	NS	NS



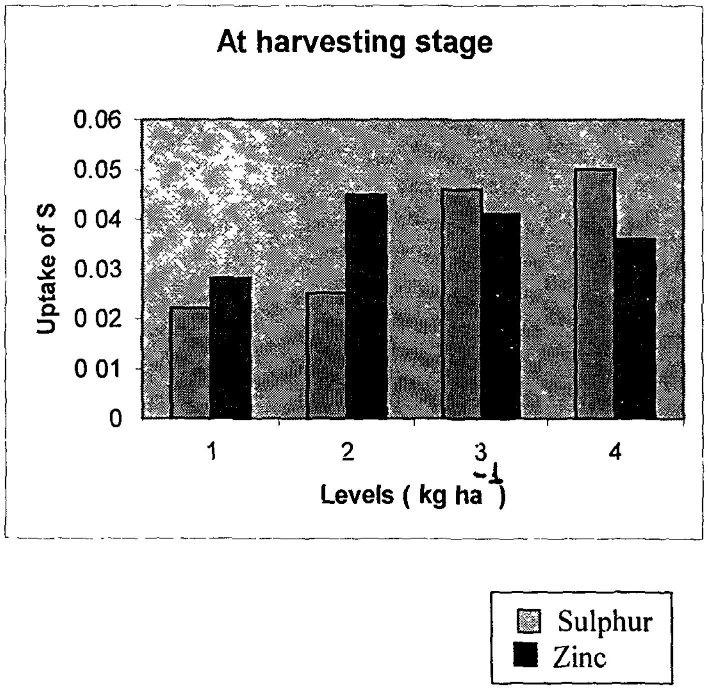


Fig.5 Effect of sulphur and zinc on the uptake of sulphur (g plant $^{-1}$)

At harvesting the uptake of sulphur due to application of S was followed the similar trend as observed at flowering (Table 11). The highest uptake was recorded due to the application of sulphur @ 90 kg S^0 ha $^{-1}$ which was significantly superior over the sulphur uptake due to 30 kg S ^{0}ha $^{-1}$ (0.027 g plant $^{-1}$) The uptake of S due to application of sulphur @ 90 kg S ^{0} ha $^{-1}$ and 60 kg S ^{0} ha $^{-1}$ were at par. The lowest uptake was recorded in the control.

The higher levels of sulphur increased the uptake due to increased concentration of sulphur. Applications of heavier rates of sulphur might have increased the surface area exposed to sulphur–oxidising organisms which might have resulted a linear increase in the release of plant available sulphur (Janzen, *et al.*1982) which might have taken up by the plant and might have resulted in the increased uptake of sulphur. Similar results were reported by Marok and Dev (1979) and Gada (2001).

Effect of zinc

At flowering, the highest uptake of sulphur was recorded due to application of 40 kg Zn ha $^{-1}$ followed by the 20 kg Zn ha $^{-1}$. The highest level of zinc is significantly superior over control.

As regards to the zinc application, at harvesting the highest uptake of sulphur was recorded due to application to zinc @ 20 kg ha $^{-1}$(0.045 g plant $^{-1}$) , the remaining two treatments were at par but significantly superior over the control.

The uptake of sulphur by plant was significantly increased due to application zinc. The highest uptake was recorded at 20 kg Zn and 40 kg ha $^{-1}$ there after, increase in the zinc level decreased the uptake of sulphur. An increase in sulphur uptake up to 20 kg Zn ha $^{-1}$ application and decreased beyond this rate might have resulted from imbalanced nutrition or interference of zinc in the sulphur utilizations at metabolic sites (Kochar *et al.*, 1990) . Similar results were reported by Deokar in groundnut (1998) and Sharma *et al.* (1990) in mustard .

Effect of sulphur and zinc interaction

The interaction effects were non-significant.

4.8 Uptake of zinc

Effect of sulphur

The application of sulphur at various levels resulted into significant difference in the uptake of zinc by sunflower at flowering. The highest uptake was recorded due to application 60 kg S^0 ha $^{-1}$. The next effective treatment was 90 kg S^0 ha $^{-1}$, these two treatments were at par (Table 12) . These two treatments were significantly superior over control.

From data presented in Table 12, it was observed that there was significant increase in uptake of zinc (1.69 mg plant $^{-1}$) at harvesting due to application of highest level of sulphur (90 kg ha $^{-1}$) which significantly superior over all treatments. The next effective treatment was application of sulphur @ 60 kg ha $^{-1}$ which was superior over rest of two treatments. The lowest uptake was recorded in control.

The result showed that there was a synergistic effects between sulphur and zinc. Similar interaction was also reported by Bhal *et al.* (1986) in groundnut crop. The higher uptake of zinc by the plant might be due to increased solubility of zinc in soil as a result of lowering of pH caused by the application of sulphur in soil. The similar type of result were reported by Sharma *et al.* (1990) in mustard, Khilari and Narkhede (1995) in soybean and Sreemannarayana and Sreenivasa Raju (1994) in sunflower.

Effect of zinc

Regarding zinc at flowering, significantly the highest uptake was recorded due to the application of Zn at 40 kg Zn ha $^{-1}$. The next effective treatment was 60 kg Zn ha $^{-1}$ but these two treatments were at par. The application of 20 kg Zn ha $^{-1}$ was significantly inferior to rest two levels but superior over control.

At harvesting, application of zinc was increased uptake of zinc significantly at harvesting. The highest uptake (1.60 mg plant $^{-1}$) was recorded due to application of zinc

Table:12 Effect of sulphur and zinc on the uptake of zinc

Treatments	Uptake of zinc	
	At flowering (mg plant^{-1})	At harvesting (mg seed^{-1})
Levels of sulphur (kg ha $^{-1}$)		
0	1.68	0.972
30	2.25	1.243
60	3.75	1.606
90	3.67	1.690
S.E($\pm$)	0.06	0.003
C.D at 5%	0.18	0.009
Levels of zinc (kg ha $^{-1}$)		
0	1.92	1.021
20	2.67	1.311
40	3.43	1.600
60	3.25	1.575
S.E($\pm$)	0.06	0.003
C.D at 5%	0.18	0.009
Interaction		
S.E($\pm$)	0.13	0.006
C.D at 5%	NS	NS

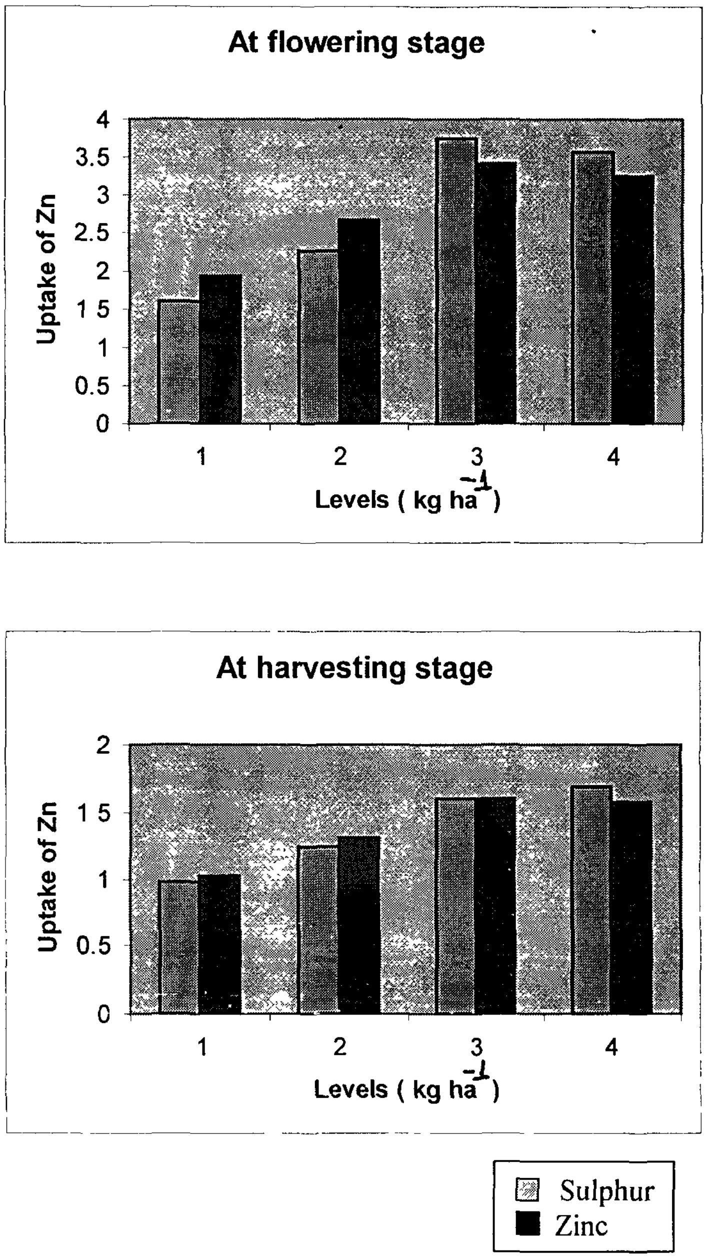


Fig.6 Effect of sulphur and zinc on the uptake of zinc (mg plant $^{-1}$)

40 kg Zn ha $^{-1}$ which was superior over.all treatments. The next treatment which is significantly superior over control was 60 kg Zn ha $^{-1}$.

Significantly increased uptake of zinc by plant at flowering and harvesting was recorded due to application of 40 kg Zn ha $^{-1}$. This might be due to the fact that the application of Zn to soil might have resulted in increased uptake of zinc by plant due to increase availability in soil. Similar results were recorded by Tomar and Gangwar (1987) in sunflower and Devranjan and Palaniappan (1995) in soybean.

Effect of sulphur and zinc interaction

The interaction effects were non-significant.

4.9 Oil content

The data presented in Table 13 indicated that application of sulphur and zinc resulted in significant increase in oil content of seeds of sunflower.

Effect of sulphur

With increasing levels of sulphur application from 30 to 90 kg ha $^{-1}$ there was significant progressive increase in oil content. The highest oil content was recorded due to application of 90 kg S^0 ha $^{-1}$ (10.8% increase over control). The next effective treatment in this respect was 60 kg S^0 ha $^{-1}$ resulting into 8.8 percent increase over control in oil content. The lowest oil content was recorded in the control which was significantly inferior to other treatments.

The application of sulphur enhanced the oil content significantly at each increasing level of sulphur application (Table 13). This was because sulphur helped in maximum utilization and conversion of carbohydrates into oils .In fatty acids synthesis, acetyl CoA is converted into malonyl CoA . In this conversion, an enzyme acetic thiokinase is involved, the activity of which depends up on sulphur supply. More over, acetyl CoA itself contains sulphur and sulfhydryl group. With increasing sulphur application the supply of sulphur to the plant was increased causing increased uptake. Thus, increased sulphur supply to the enzymes causes an increase in oil content of seeds.

The results obtained were in accordance with the Tandon (1986) who reviewed the effect of sulphur on oil seed crops and reported that sulphur

Table : 13 Effect of sulphur and zinc on the oil content (%) of seeds of sunflower.

	Oil content (%)
Levels of sulphur (kg ha $^{-1}$)	
0	36.94
30	38.30 (3.6)
60	40.21 (8.8)
90	40.93 (10.8)
S.E($\pm$)	0.04
C.D at 5%	0.12
Levels of zinc (kg ha $^{-1}$)	
0	38.02
20	40.08 (5.4)
40	39.73 (4.4)
60	38.29 (0.7)
S.E($\pm$)	0.04
C.D at 5%	0.12
Interaction	
S.E($\pm$)	0.07
C.D at 5%	NS

[Figures in paranthesis indicate percent increase over control]

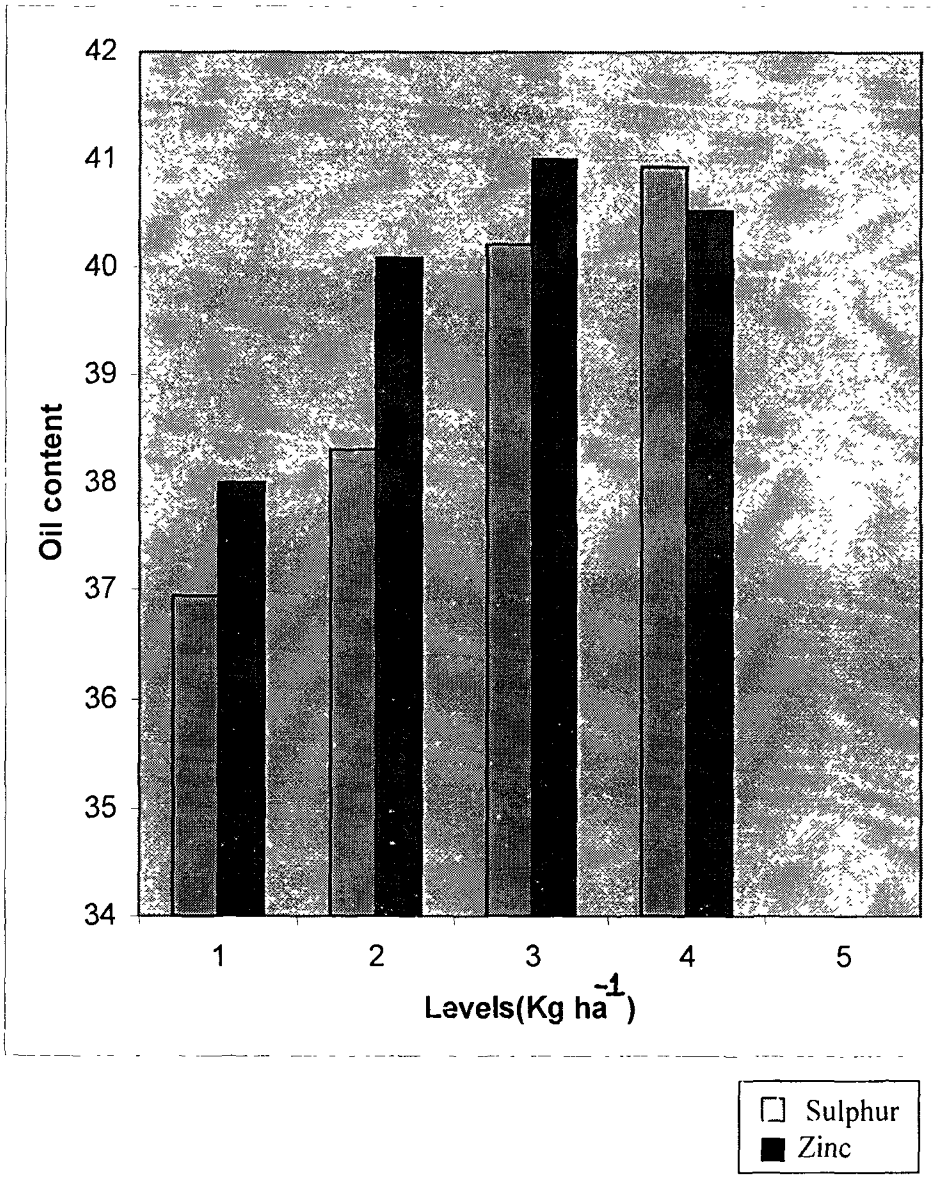


Fig 7 : Effect of sulphur and zinc on the oil content(%)) of sunflower.

improved oil content of mustard by 8.5 percent, rai by 7.3 percent, groundnut by 8.5 percent and sunflower by 3.6 percent. Similarly, Badiger *et al.* (1985) also reported that application of sulphur increased oil content by 2 percent as compared to non sulphur applied plants of sunflower. Similar results were also reported by Jadhav (1998) and Gada (2001) in sunflower.

Effect of zinc

The application of Zn also resulted in significant increase in oil content of sunflower. Though, zinc application at all levels resulted into increase in the oil content as compared to control, significantly the highest oil content was recorded at zinc level of 20 kg ha $^{-1}$ (5.4 percent increase over control). The next effective treatment was 40 kg Zn ha $^{-1}$ (4.4 percent increase over control). The further increased in level of zinc was found to decrease oil content in seeds. The lowest oil content was recorded in control.

Application of zinc (20 kg ha $^{-1}$) was also reported the increase in oil content of sunflower seeds (Table 13) . This increase in oil content might be due to the activation of NADPH dependent hydrogenase in fat synthesis by zinc (Muralidharudu and Singh, 1990). The results obtained in present investigation were in conformity with results obtained by Shrikrishna and Singh (1992) who reported the highest oil and gulcoside content in seed of mustard and Deokar (1998) also reported increase in oil content of groundnut significantly due to application of 20 kg Zn ha $^{-1}$. Similar type of results also reported by Wankhede *et al.* (1998) in sunflower and Babhulkar *et al.* (2001) in safflower.

Effect of sulphur and zinc interaction

Interaction effects were non-significant.

4.10 Protein content

Effect of sulphur

Protein content of sunflower seed was also influenced significantly due to application of sulphur as well as zinc at various levels (Table 14). The highest sulphur level (90 kg ha $^{-1}$) resulted in significantly highest protein content of sunflower seed (16.40percent increased over control). Application of

Table : 14 Effect of sulphur and zinc on the protein content (%) of seeds of sunflower.

	protein content (%)
Levels of sulphur (kg ha $^{-1}$)	
0	12.86
30	14.41 (12.05)
60	14.73 (14.5)
90	14.97 (16.40)
S.E($\pm$)	0.03
C.D at 5%	0.1
Levels of zinc (kg ha $^{-1}$)	
0	13.74
20	14.03 (2.1)
40	15.03 (9.3)
60	14.17 (3.1)
S.E($\pm$)	0.03
C.D at 5%	0.1
Interaction	
S.E($\pm$)	0.06
C.D at 5%	NS

[Figures in paranthesis indicate percent increase over control]

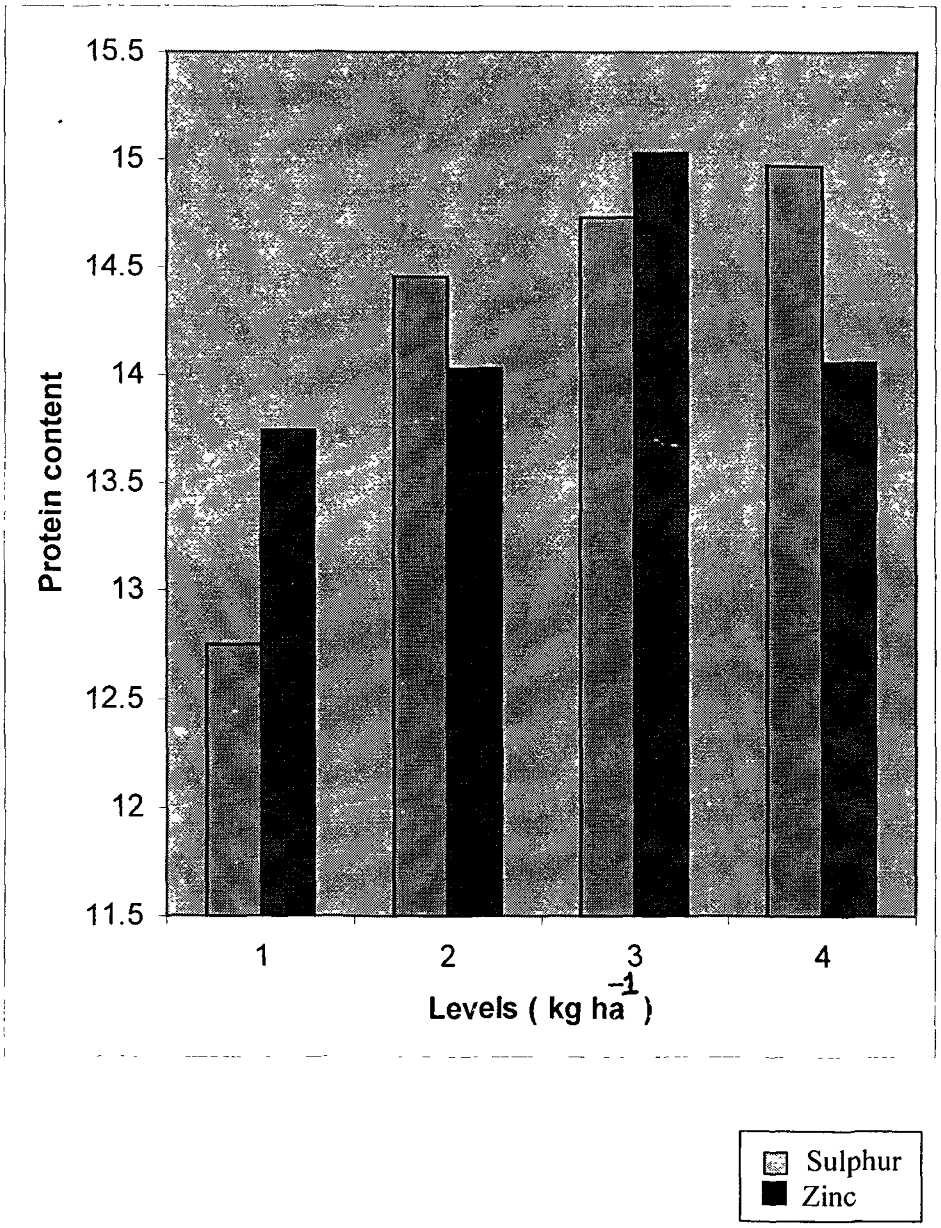


Fig 8 : Effect of sulphur and zinc on the protein content (%) of sunflower.

sulphur @ 30 and 60 kg ha $^{-1}$ was significantly superior over control. They increased protein content by 12.05 and 14.5 percent over control respectively.

The data presented in Table 14 indicated that there was significant increase in protein content of sunflower seeds due to application graded levels of sulphur i.e. from 30 to 90 kg ha $^{-1}$. This was because of the fact that sulphur is a constituent of amino acids like methionine, cystine and cysteine. Thus sulphur is directly involved in fatty acid and protein systhesis (Tandon, 1986) . Also, sulphur application accelerated the metabolic pathway of protein synthesis and thus, plants made normal growth and synthesized more proteins. Tisdale *et al.* (1970) reported that 50 to 80 percent of total S in oil seed crops goes on making S containing amino acid and rest is required for other S containing compounds.

Thus, results obtained in present investigation are in accordance with results reported by Khilari and Narkhede (1995) who have reported that application of sulphur @ 30, 60 and 90 kg ha $^{-1}$increased the protein content by 4.7, 6.2 and 8.1 percent, respectively, over control in soybean. Similar results also reported by sremannanarayana *et al.* (1995) and Gangadhara *et al.* (1990) in sunflower.

Effect of zinc

Regarding zinc, the protein content was increased significantly due to application of 40 kg zn ha $^{-1}$ (9.3 percent increase over control) which was significantly superior over other treatments. Though , 60 kg Zn ha $^{-1}$ was observed to decreased protein content, it was observed to be superior over control. The lowest protein content was recorded in control.

The application of zinc had significantly increased the protein content of sunflower seeds (Table 14). This is because zinc function in plant largely as metal activator of enzyme like cysteine, desulphydrase, dihydropeptidase and glycel-glycine dipeptidase. Thus addition of zinc might have activated the enzyme responsible for production of oil and proteins and might have resulted I in higher protein content.

The results obtained were conformity with Deokar (1998) who reported that there is increase in protein content up to 4.66 percent due to application of zinc. The beneficial effects of zinc on protein content of sunflower was also reported by Sinsinwar (1995) in groundnut and Babhulkar *et al.* (2000) in safflower.

Effect of sulphur and zinc interaction

The interaction effect was non-significant.

4.11 Incubation study

4.11.1 Available sulphur

The data pertaining effect of incubation on sulphur was presented in Table 15 .

As the application of sulphur goes on increasing from 0 to 60 kg ha level, the availability of sulphur goes on increasing. Significantly the highest sulphur was recorded due to application of sulphur @ 60 kg ha $^{-1}$, after 15 days of incubation periods. After 30 days of incubation of lowest sulphur recorded in the control but it was higher than 15 days of incubation days. After 45 days of incubation similar type of trend was observed, sulphur availability increased from lower level (control) to higher level (60 kg S ha $^{-1}$) of sulphur application after 60 and 75 days of incubation it was observed that sulphur availability increased as compared to 15, 30 and 45 days of incubation and highest sulphur recorded after 75 days of incubation.

As the days of incubation goes on increasing the availability of S also goes on increasing. Numerically the highest available sulphur was observed at the 75 days of incubation. The lowest available sulphur was recorded at zero days of incubation. The treatments having more sulphur application gave the highest available sulphur at 75 days of incubation.

The increased availability of sulphur was due to the oxidation of sulphur. The Thiobacillus bacteria responsible for it, converts the sulphur to sulphate form (SO_4^{-2}) .

The release of sulphur occurred up to 105 days of incubation in presence of sulphur, particularly in Vertisol (Sreenannarayana and Sreenevasa Raju ,

Table : 15 Effect of incubation on the sulphur and zinc content of soil (ppm)

	Incubation period (days)					
	0	15	30	45	60	75
Levels of sulphur (kg ha $^{-1}$)	←		S (ppm)			→
0	3.5	5.2	8.4	10.75	13.25	16.10
30	4.5	6.3	9.5	11.90	14.80	17.65
60	5.1	6.9	8.9	12.10	15.60	19.20
S.E($\pm$)	0.03	0.07	0.10	0.17	0.24	0.13
C.D at 5%	NS	0.2	0.3	0.51	0.73	0.40
Levels of zinc (kg ha $^{-1}$)	←		Zn (ppm)			→
0	0.42	0.65	0.58	0.42	0.29	0.20
20	0.49	0.72	0.66	0.47	0.37	0.28
40	0.53	0.74	0.71	0.55	0.44	0.35
S.E($\pm$)	0.004	0.006	0.013	0.003	0.003	0.006
C.D at 5%	NS	0.02	0.04	0.01	0.01	0.02
Interaction	←		S x Zn (ppm)			→
S.E($\pm$)	0.08	0.12	0.04	0.1	0.1	0.18
C.D at 5%	NS	NS	NS	NS	NS	NS

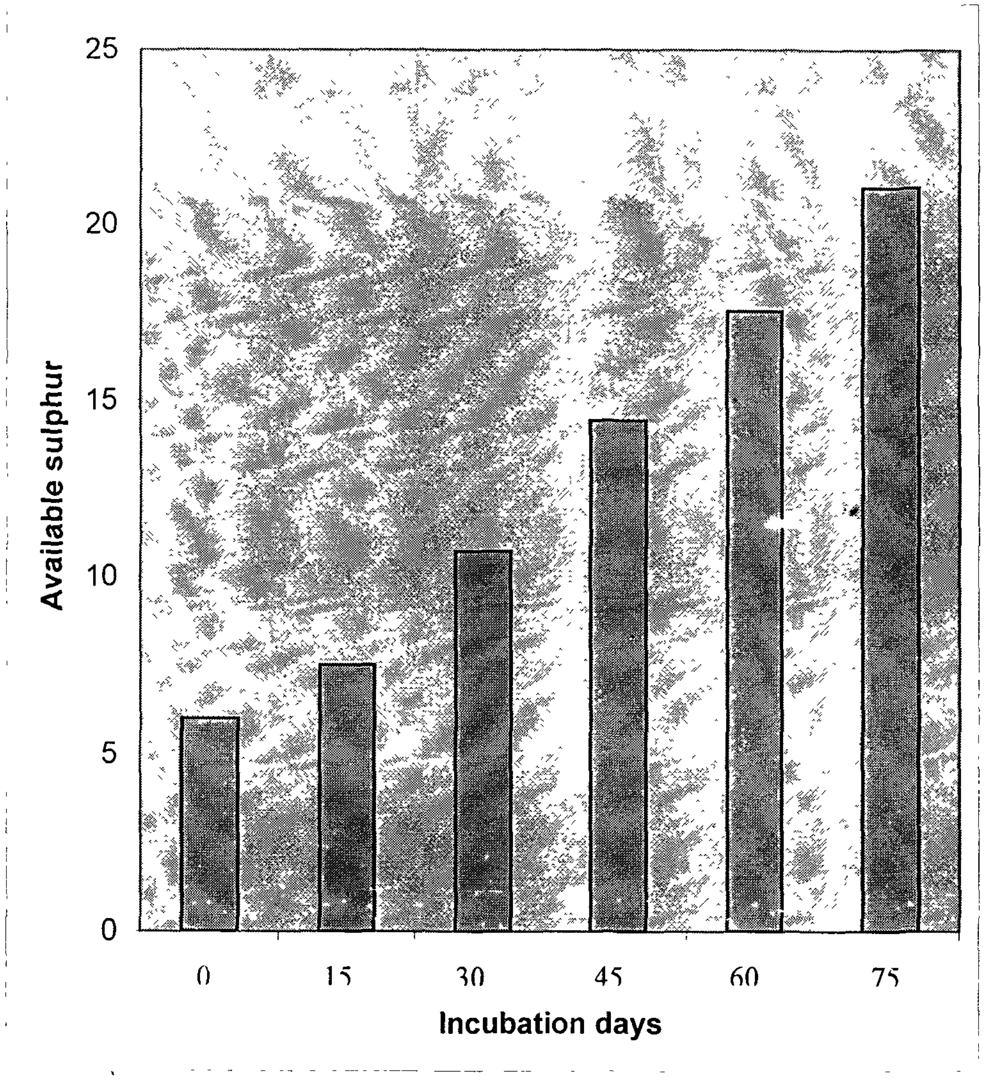


Fig 9 : Effect of incubation on available sulphur(ppm)

1995). Hence in present investigation sulphur availability goes on increasing as the number of days of incubation goes on increasing.

Similar results were reported by Badhe and Lande (1980) and Singh and Shrivastva (1993).

4.11.2 Available zinc

The data pertaining to effect of incubation on zinc was presented in Table 15 .

The application of zinc @ 40 kg ha^{-1} gave the highest available zinc as compared to remaining two treatments (0 and 20 kg ha^{-1}) after 15 days of incubation days which was the significantly superior treatment, the application of 20 kg Zn ha^{-1} and 40 kg Zn ha^{-1} were recorded at par. After 30 days of incubation significantly the higher zinc was recorded due to application of zinc @ 40 kg Zn ha which was decreased as compared to 15 days of incubation. After 45 days of incubation the lowest zinc was recoded in the control and the highest was recorded due to the highest level of zinc application. The similar type of trend was recorded after 60 days and 75 days incubation. The availability goes on increasing as the level of application of zinc increased on from 0 to 40 kg Zn ha but with the incubation time the availability goes on decreasing from the 15 days to 75 days of incubation period. The interaction effect of sulphur and zinc was non-significant.

From data, it was observed that as the days of incubation goes on increasing the availability of zinc goes on decreasing. After 15 days of incubation, availability of zinc increased as compared zero days of incubation. But, further increase in the incubation time decreased availability of zinc. After 30 days of incubation, availability decreased numerically as compared to the 15 days of incubation. The lowest available zinc was recorded after 75 days incubation.

The decreased availability of zinc was because of free $CaC0_3$ in soil system, as Zn is converted to Zn OH , $Zn(OH)_2$, $Zn(OH)CO_3$ and $ZnCO_3$ and get into unavailable form (Mishra and Tiwari , 1996).

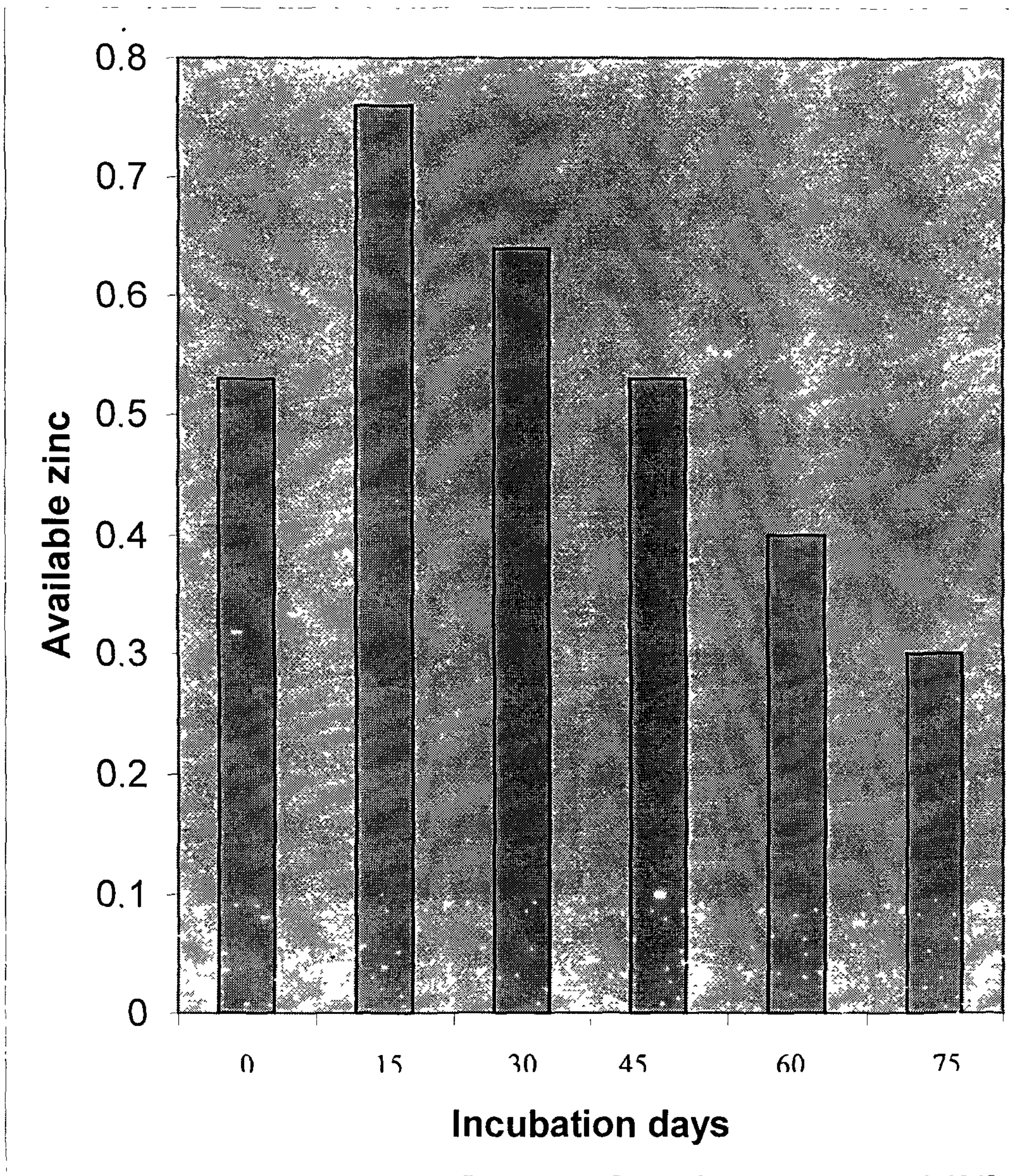


Fig 10 : Effect of incubation on available zinc (ppm)

The similar results were also recorded by Kalabasi *et al* (1978) who reported that with increasing incubation time, DTPA extractable Zn decreased due to fixation.

The results obtained were also in accordance with Chatterjee *et al.* (1983).

4.12 Chemical properties of the soil after harvest of crop

The data presented in Table 16 indicated that the pH of soil after harvest of crop observed to be decreased from 7.5 (initial) to 7.3 (harvest) due to application of sulphur. The EC of soil after harvest of crop was reported to increase due to application of sulphur at various levels. The application of zinc at various levels along with sulphur resulted in increasing available N after harvest of crop. While, available P was noticed to be increased due to application of sulphur with increasing levels and decreased with successive zinc levels. The available S and K were observed to be increased due to application of sulphur.

The available zinc after harvest of crop was reported to increased due to the application of zinc. Available Fe, Mn and Cu after harvest of crop were reported to be increased due to application of sulphur at various levels as compared to initial soil.

Table 24 : Chemical properties of soil after harvest of crop .

Sr No	Treatments	pH	EC dSm	av.N kg ha^{-1}	av.P kg ha^{-1}	av.K kg ha^{-1}	av.S mg kg^{-1}	av.Zn mg kg^{-1}	av.Fe mg kg^{-1}	av.Mn mg kg^{-1}	av.Cu mg kg^{-1}
1	S_0Zn_0	7.5	0.27	228.0	27.00	242.3	4.4	4.9	4.2	7.1	3.10
2	S_0Zn_1	7.7	0.31	232.5	30.00	249.2	4.6	3.9	5.3	8.2	3.20
3	S_0Zn_2	7.8	0.33	242.7	29.00	270.7	5.1	4.1	3.9	8.1	3.31
4	S_0Zn_3	7.9	0.34	240.9	29.00	235.4	5.3	4.5	3.8	7.5	3.07
5	S_1Zn_0	7.7	0.64	237.4	31.00	231.4	7.2	4.8	7.5	9.8	3.13
6	S_1Zn_1	7.4	0.62	231.3	34.00	301.8	9.4	3.5	8.9	11.20	3.24
7	S_1Zn_2	7.3	0.58	253.5	30.00	295.5	12.8	4.2	8.0	13.72	3.31
8	S_1Zn_3	7.3	0.86	242.4	29.00	270.8	13.5	4.3	7.7	11.00	3.22
9	S_2Zn_0	7.2	0.89	244.7	31.00	255.9	14.7	4.4	10.1	13.25	3.28
10	S_2Zn_1	7.3	0.91	238.4	35.00	267.3	15.8	3.4	6.25	16.75	3.35
11	S_2Zn_2	7.3	0.90	234.2	33.00	310.4	16.3	4.1	5.87	14.92	3.42
12	S_2Zn_3	7.2	1.01	238.9	31.00	307.2	16.9	4.3	4.48	12.72	3.44
13	S_3Zn_0	7.3	1.04	231.3	29.00	295.4	18.0	3.1	7.45	15.42	3.21
14	S_3Zn_1	7.3	1.05	242.8	32.00	283.8	20.3	3.2	6.33	15.62	3.39
15	S_3Zn_2	7.3	1.06	231.7	31.00	276.3	22.5	3.9	5.60	17.50	3.34
16	S_3Zn_3	7.3	1.07	244.5	30.00	269.9	23.2	4.3	4.9	18.80	3.30

SUMMARY AND CONCLUSIONS

5 SUMMARY AND CONCLUSION

5.1 Summary

The present investigation to study the effects of sulphur and zinc on the yield, oil and protein content of sunflower Cv SS – 56 was carried out at the Department of Agricultural Chemistry and Soil Science, College of Agriculture, Pune 5. The experiment was conducted in pots during *kharif*, 2001. It was laid out in Factorial Randomized Block Design with two replications. There were four levels of sulphur (0, 30, 60 and 90 kg ha $^{-1}$) as elemental sulphur and zinc (0, 20, 40, and 60 kg ha $^{-1}$) as zinc oxide each, and their combinations. The incubation study was also conducted in laboratory with three replications. There were three levels of sulphur (0, 30, and 60 kg ha $^{-1}$) as elemental sulphur and three levels of zinc(0, 20, and 40 ha^{-1}) as zinc oxide and there combinations.

The soil used for the experimental purpose was of Vertisol order (deficient both in S and Zn). The yield, oil and protein content were recorded to evaluate treatment effects. The height of plant and number of leaves were recorded at flowering and harvesting. The uptake of N, P, K, S, and Zn was recorded at flowering and harvesting stages. The availability of S and Zn was recorded in incubation at fifteen days interval for 75 days. The important finding emerged from this investigation are summarized below :

The yield was increased significantly due to application sulphur as well as zinc at various levels. The yield increased significantly due to application of sulphur at 90 kg ha $^{-1}$ and Zn at 40 kg ha^{-1}.

Regarding the quality of sunflower, oil and protein content of grain were significantly enhanced due to application of different levels of sulphur and zinc. The increased oil and protein content were 10.8 percent and 16.40 percent, respectively over control due to application of sulphur at 90 kg ha $^{-1}$ level. While, the application of zinc resulted in significant increase in oil and protein content as 5.4 percent and 9.3 percent over control due to application zinc at 40 kg Zn ha $^{-1}$.

The uptake of nitrogen by the plant at flowering and harvesting were increased significantly due to application of 90 kg S ha $^{-1}$ and 40 kg Zn ha $^{-1}$. However, the uptake of phosphorus was influenced due to application of 90 kg sulphur ha $^{-1}$ and 60 kg sulphur ha $^{-1}$ at flowering and harvesting.

Regarding uptake of potassium it was increased significantly due to application of sulphur (90 kg ha $^{-1}$) and zinc application @ 40 kg ha^{-1} increased the uptake of potassium significantly at harvesting and @ 20 kg ha^{-1} at flowering. The application of sulphur and zinc resulted in significant increase in the uptake of sulphur. The sulphur uptake increased at 90 kg S ha^{-1} at flowering and harvesting stages. The zinc application (40 kg Zn ha $^{-1}$) and (20 kg Zn ha $^{-1}$) increased uptake of sulphur at flowering and harvesting respectively.

Uptake of zinc was significantly increased due to application of sulphur @ 60 kg ha^{-1} at flowering and 90 kg ha^{-1} at harvesting. Application of zinc (40 kg ha^{-1}) significantly increased uptake of zinc at flowering and harvesting.

The non–significant effects of sulphur and zinc on the number of leaves and height of plant were recorded.

Availability of sulphur goes on increasing and zinc availability goes on decreasing as incubation period increased.

5.2 Conclusions

1. The seed yield of sunflower C.v. SS-56 was increased significantly with increasing levels of sulphur (from 0 to 90 kg ha $^{-1}$) and zinc (from 0 to 40 kg ha^{-1}). Sulphur application at 90 kg ha $^{-1}$ and zinc at 40 kg ha^{-1} were found significant treatments for increasing seed yield.
2. The oil content of seeds of sunflower was significantly enhanced due to application of sulphur and zinc. The highest level of sulphur (90 kg ha $^{-1}$) and lower level of zinc (40 kg ha $^{-1}$) were reported to increase the oil content of seeds .
3. The protein content of grains of sunflower significantly increased due to application of sulphur and zinc . The 90 kg S ha $^{-1}$ and 40 kg Zn ha $^{-1}$

reported to be significant enhancement of protein content of seed of sunflower.

4. Synergistic effects of sulphur and nitrogen, zinc and nitrogen were noticed which resulted in significant increase in uptake of nitrogen at flowering and harvesting of plant.
5. Synergistic effects of sulphur (90 kg ha^{-1} and 60 kg ha^{-1}) on phosphorus uptake and antagonistic effect of zinc on phosphorus uptake by plant was noticed in the present study.
6. The uptake of potassium increased significantly due to application of sulphur (90 kg ha^{-1}) at flowering and (60 kg ha^{-1}) at harvesting. However application of zinc 40 kg ha^{-1} at flowering and 20 kg ha^{-1} at harvesting increased the uptake of potassium significantly.
7. The application of sulphur (90 kg ha^{-1}) and zinc (40 kg ha^{-1}) reported significant increase in the uptake of sulphur at flowering and harvesting stage of sunflower.
8. The uptake of zinc increased due to application of sulphur (60 kg ha^{-1}) at flowering and (90 kg ha^{-1}) at harvesting. However, application of zinc increased uptake due to application of 40 kg ha^{-1} at flowering and harvesting.
9. In incubation study, sulphur availability increased and zinc availability decreased as period of incubation goes on increasing from o-75 days.
10. In general, the application of higher levels of sulphur and lower levels of zinc was proved best combination resulting in significant increase in yield, oil and protein content of sunflower as well as uptake of nutrients.

In conclusion, it may be stated that these inferences are based on pot trial results. For confirmation of these results, the investigation needs to be repeated particularly under field conditions.

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6 LITERATURE CITED

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* **Originals not seen.**

VITA

7 VITA

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