STUDIES ON DIFFERENT SOURCES AND LEVELS OF SULPHUR ON PRODUCTIVITY AND QUALITY OF RAINFED SUNFLOWER (*Helianthus annus* L.)

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STUDIES ON DIFFERENT SOURCES AND LEVELS OF SULPHUR ON PRODUCTIVITY AND QUALITY OF RAINFED SUNFLOWER (*Helianthus annus* L.)

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By

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CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON DIFFERENT SOURCES AND LEVELS OF SULPHUR ON PRODUCTVITY AND QUALITY OF RAINFED SUNFLOWER (*Helianthus annus* L.)** submitted by **Mr. ABILASH** in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY,** College of Agriculture, Raichur, University of Agricultural Sciences, Raichur, is a record of research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

Raichur
July, 2017

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Affectionately dedicated
To

My Beloved Parents,
Sri. Nagaraj and Smt. Sarojamma
Lovely Brother, Sisters and Friends

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Gratitude is the fairest blossom which springs from the soul......…

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. . . . *Any omission doesn't mean lack of gratitude*

RAICHUR

JULY, 2017 ***(ABILASH B.N.)***

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LIST OF SYMBOLS AND ABBREVIATIONS

%	:	per cent
^{o}C	:	degree celsius
B: C	:	Benefit Cost Ratio
Ca	:	calcium
CD (P=0.05)	:	critical difference at 5 per cent level
cm	:	centimetre
dS m^{-1}	:	deciseimen per metre
EC	:	electrical conductivity
et al.	:	and others people
Fig.	:	figure
g	:	gram(s)
ha	:	hectare
HI	:	harvest Index
i.e.,	:	which is to say, in other words
K	:	potassium
kg	:	kilogram
LAI	:	leaf area index
m	:	metre
mg	:	milligram
N	:	nitrogen
NS	:	non significant
OC	:	organic carbon
P	:	phosphorus
ppm	:	parts per million
Rs	:	rupees
S	:	sulphur
S.Em+	:	standard error of mean
SSP	:	single super phosphate
viz.,	:	namely
Zn	:	zinc

Introduction

I. INTRODUCTION

Oil seed crops play a vital role in Indian agriculture as food for human and animals. Sunflower being one of the important edible oil crop in the world next to soybean, holds great promise because of its short duration (90-100 days), high seed multiplication ratio, wider adaptability, photo-insensitive, higher water use efficiency and drought tolerance. Presently in India, sunflower is cultivated in an area of 0.69 m. ha with a production of 0.55 m. t with an average productivity of 791 kg ha^{-1}. In Karnataka, it is grown in an area of 0.44 m. ha with a production of 0.30 m. t with productivity of 670 kg ha^{-1} (www.Indiastat.com, 2013-14). Major sunflower area is concentrated in the northern districts of Bijapur, Gulbarga, Raichur and Dharwad, which accounts for nearly 85 percent of total State acreage. In India, sunflower cultivation is progressively picking up especially in *rabi* and summer seasons. In recent times, the yield potential of the crop is reduced due to little amounts of organic manures used, poor recycling of crop residues, wide spread secondary and micronutrient deficiencies and insufficient use of sulphur containing fertilizers. The most commonly encountered problem is the occurrence of poor seed set and unfilled seed resulting in low oil recovery percentages. The essentiality of sulphur in the biosynthesis of oil in sunflower has been proved by Bhagat *et al.*, 2005. They indicated that the oil content in sunflower seed was increased by sulphur application. It also increased seed yield due to increase in the yield components. Crop uptake of sulphur by oil seeds is as much as that of phosphorus. Average sulphur uptake per tonne of economic yield of sunflower in India is in the range of 6.2 to 11.7 kg.

Sulphur is considered as quality nutrient as its application not only influences crop yield but also improves crop quality owing to its influence on protein metabolism, oil synthesis and formation of amino acids (Krishnamoorthy, 1989). It is a constituent of three amino acids *viz.* Methionin (21% S), Cysteine (26% S) and Cystine (27% S), which are the building blocks of protein. About 90% of plant sulphur is present in these amino acids. Sulphur is also involved in the formation of chlorophyll, glucosides and glucosinolates (mustard oils), activation of enzymes and sulphydryl (SH-) linkages that are the sources of pungency in onion, oils, *etc*. (Ghosh, 2002). Sulphur is a constituent of enzyme acetyl co A which is converted to melonyl co A by enzyme thiokinase whose activity inturn depends on sulphur supply (Karle *et al*., 1985). Sulphur nutrition occupies a unique position as it is involved in the synthesis of oil (Aulakh *et al.*, 1997). On an average, the improvement in oil content in major oilseeds due to sulphur application is 11.3 per cent in groundnut, 9.6 per cent in mustard, 9.2 per cent in soybean, 6.0 per cent in linseed and 3.8 per cent in sunflower (Sharma *et al*., 1991 and Tandon, 1991).

Sulphur is applied to soil through various sources like ammonium sulphate (24% S), single super phosphate (12% S), gypsum (13-18% S), elemental sulphur (100% S), pyrites (24% S), ammonium phosphate sulphate (15% S), zinc sulphate (11% S), copper sulphate (13% S), magnesium sulphate (14% S) *etc*. Sources of sulphur vary depending on the soil type. Among these sources, gypsum, SSP and ammonium sulphate are cheaper compared to ammonium phosphate sulphate, zinc sulphate, magnesium sulphate, copper sulphate and elemental sulphur.

Sulphur is a mobile element which is easily lost from the soil through leaching. The level of available sulphur reaches below the critical limit and sunflower is bound to suffer sulphur deficiency. Initial studies have indicated significant response of sunflower to sulphur fertilization (DOR, 1996). Soils, which are deficient in sulphur, cannot provide adequate sulphur to meet crop demand resulting in sulphur deficiency of crops and sub-optimal yields. Sulphur use was also reported to be very remunerative in many crop sequences involving oilseeds (Sudhakarababu and Hegde, 2003). Though sulphur is known to augment the oil content and grain yield of sunflower, the farmers are not using sulphur and sulphur bearing fertilizers. Knowledge regarding sulphur nutrition of sunflower is lacking which is particularly important when oilseed crops in general and sunflower is raised whose sulphur requirement is high.

Among the essential nutrients, significant research was done with major nutrients in improving sunflower grain yield and quality. However, secondary nutrients have received limited attention of the researchers. Higher yields and quality of sunflower oil can be realized only when all three major nutrients (N, P and K) and secondary nutrient (S) is supplied in sufficient quantity and in a balanced way. In sulphur nutrition, apart from determining the response, identification of the right source and dose is also very important to optimize production.

Most of the black soils in Northern Karnataka with arid climate are rich in free calcium and the sulphur nutrient element is render less available to the growing plant. As far as the information, gypsum as a source of sulphur used for sunflower crop to the extent of 100 kg ha^{-1} (Package of Practice, UAS Dharwad & Raichur, 2014) for rainfed sunflower. The quantity applied is very less and inadequate for improved varieties or hybrids. Hence, the field study was conducted to investigate the influence of different sources and levels of sulphur on growth attributes, yield attributes, yield, nutrient uptake and quality in sunflower under rainfed conditions with the following primary objectives.

1) To optimize quantity and sources of sulphur to enhance the productivity and quality of sunflower.

2) To study the effect of different sources and levels of sulphur on nutrient availability and uptake by sunflower.

3) To workout the economics of sunflower as influenced by different sources and levels of sulphur.

Review of Literature

II. REVIEW OF LITERATURE

The literature related to the present study on the "Studies on different sources of sulphur on growth and yield of sunflower (*Helianthus annuus* L.)" has been briefly reviewed in this chapter. Adequate supply of sulphur nutrient was found to result in higher production of photosynthates and their translocation from source to sink due to increased leaf area and dry matter production and ultimately resulted into higher seed and stalk yields (Aulakh *et al.* 1990 & Prabhuraj *et al.* 1993). Sulphur significantly improved the oil content and oil yield compared with other nutrients. This might be due to the fact that sulphur is an integral part of S-containing amino-acids such as cysteine, cystine and methionine (Gangadhara *et al.* 1990).

2.1 EFFECT OF SULPHUR ON GROWTH AND GROWTH PARAMETERS

2.1.1 Effect of sulphur sources

Reddy and Reddy (2001) conducted a field experiment during *rabi* season at college farm, Rajendranagar on clay soil having pH 8.02 and available S of 13.4 kg ha^{-1} revealed that ammonium sulphate proved to be superior in recording higher dry matter production at all the growth stages of soybean crop and the increase over gypsum was 11.7 and 7.5 per cent at 30 and 60 DAS, respectively.

Ventakesh *et al*. (2002) conducted a field study at Dharwad on vertisol during *rabi* season concluded that dry matter yield of safflower at flowering and maturity stages was significantly higher with application of sulphur in the form of ammonium sulphate over single super phosphate, elemental sulphur, gypsum and pyrites.

In a field study by Baviskar *et al.* (2005) on safflower on medium black clay soils reported that growth attributes like plant height, number of branches $plant^{-1}$ and dry matter accumulation $plant^{-1}$ were maximum with sulphur through single super phosphate compared to sulphur dust and gypsum.

Satish Kumar *et al*. (2011) conducted a field study on sunflower for two years at Allahabad (Uttar Pradesh) reported that the highest plant height, number of leaves $plant^{-1}$, stem girth, leaf area and dry weight of plant was obtained with the application of sulphur through gypsum compared to elemental sulphur.

2.1.2 Effect of sulphur levels

Bhagat and Soni (2000) conducted a field experiment for two consecutive years on mustard during *rabi* seasons at Rajouri (Jammu and Kashmir) revealed that application of sulphur significantly increased the plant height, primary and secondary branches upto 25 kg S ha^{-1}, whereas the response in terms of length of siliqua was significant up to 50 kg S ha^{-1}. Further increase in sulphur doses from 50 to 100 kg ha^{-1} improved the growth characters, but the effect was non significant.

Higher plant height and number of primary branches $plant^{-1}$ in groundnut was recorded with the application of 45 kg S ha^{-1} over control, 15 and 30 kg S ha^{-1} (Chaubey *et al*., 2000).

Nandanwar *et al.* (2000) conducted a field experiment in vertisol at Nagpur concluded that dry matter production of linseed increased with increase in sulphur dose from 0 to 60 kg ha^{-1}.

Sulphur fertilization significantly increased the dry matter yield of safflower at flowering and maturity stages and sulphur application at 45 kg ha^{-1} recorded the higher dry matter at both the stages of safflower compared to sulphur application at 0, 15 and 30 kg S ha^{-1} (Ventakesh *et al*., 2002).

Murthy and Muralidharudu (2003) found a significant increase in the dry weight of castor shoot at harvest with increasing the levels of sulphur from lower level (0 kg ha^{-1}) to higher level (110 kg ha^{-1}).

Safflower growth attributes like plant height, number of branches $plant^{-1}$ and dry matter accumulation $plant^{-1}$ were significantly higher by the treatment receiving 30 kg S ha^{-1} compared to 0, 15 and 45 kg S ha^{-1} (Baviskar *et al.,* 2005).

Dongarkar *et al*. (2005) conducted a field experiment during *rabi* season at Nagpur on clayey soil having pH 7.8 and available S of 8.26 kg ha^{-1} concluded that significant increase in plant height, number of branches, leaf area index and dry matter production of mustard were recorded with 40 kg S ha^{-1} over control and 20 kg S ha^{-1}.

Girish and Venkata Reddy (2005) revealed that the total dry matter yield of the soybean at flowering stage was significantly higher when sulphur was applied at 75 kg ha^{-1} but it was on par with the application of 60, 45 and 30 kg S ha^{-1}. At harvest, the total dry matter production of soybean was significantly higher at 75 kg S ha^{-1} and was on par with 60 and 45 kg S ha^{-1}.

Satish Kumar and Singh (2005) conducted a field experiment at Allahabad during *kharif* season observed that the growth attributing characters of sunflower *viz.*, plant height and stem girth increased with levels of increasing sulphur up to 30 kg S ha^{-1}.

Sarika *et al.* (2006) from their field study at Nagpur on medium black clay soil having pH 7.8 and available S of 5.3 mg kg^{-1} showed that the application of sulphur at 30 kg S ha^{-1} increased growth attributes like plant height, number of braches plant^{-1} and the dry matter plant^{-1} in linseed.

A field experiment was conducted on safflower at Raichur on black soil with clay loam texture by Vishwanath *et al*. (2006) reported that application of 40 kg S ha^{-1} recorded significantly higher growth attributes like plant height, number of leaves plant^{-1}, number of primary branches plant^{-1}, leaf area plant^{-1} and also significantly improved the dry matter production and its accumulation in different parts of safflower.

Harendra Kumar and Yadav (2007) from their field study on mustard for two consecutive *rabi* seasons at Faizabad found that the plant height increased significantly with each increment in the sulphur level upto 15 kg ha^{-1} and the difference in plant height due to further increase in the dose of sulphur were not significant during both the years.

Poomurgesan and Poonkodi (2008) concluded that application of 60 kg S ha^{-1} to sunflower recorded significantly higher plant height, leaf area index and dry matter production of 107.5 cm, 2.62 and 3278.2 kg ha^{-1}, respectively.

A field experiment conducted during *rabi* season in vetisols of Dharwad on safflower indicated that growth attributes *i.e.* plant height, number of leaves plant^{-1}, primary branches plant^{-1}, secondary branches plant^{-1} and dry matter production were higher with application of sulphur at 30 kg ha^{-1} as compared to control, 10 and 20 kg S ha^{-1} (Ravi *et al*., 2008).

Various growth attributes of Indian mustard *viz.*, plant height, leaves plant^{-1}, branches plant^{-1}, siliquae plant^{-1} and siliquae length increased significantly with application of sulphur at 45 kg ha^{-1} over 0, 15 and 30 kg ha^{-1} (Santosh Kumar *et al.*, 2011).

Satish Kumar *et al*. (2011) conducted a field study on sunflower for two years at Allahabad (Uttar Pradesh) reported that there was a linear and significant increase in plant in sulphur fertilizer from 0 to 45 kg S ha^{-1} during both the years.

Singh *et al*. (2013) from their field study on linseed during *rabi* season at Varanasi (UP) revealed that suphur fertilization at 40 kg S ha^{-1} recorded increased plant height, primary and secondary branches plant^{-1} and dry matter accumulation.

Patil *et al*. (2014) revealed that the highest values of plant height (56.80 cm), number of branches plant^{-1} (3.48) and dry matter accumulation plant^{-1} (11.86 g) by linseed were recorded with the application of 30 kg S ha^{-1} which was significantly superior over 20 and 10 kg S ha^{-1}.

Tulasi *et al.* (2014) conducted a field experiment at Nagpur during summer season on sesame concluded that application of 40 kg S ha^{-1} produced maximum number of branches and more plant height. Maximum dry matter accumulation was recorded with 40 kg S ha^{-1} which was significantly superior over 30, 20, 10 kg S ha^{-1} and control.

2.2 EFFECT OF SULPHUR ON YIELD ATTRIBUTES

2.2.1 Effect of sulphur sources

A field experiment was conducted for two years by Bandopadhyay and Samui (2000) on sandy loam soil having pH 7.8 observed that the yield attributes like number of pods plant^{-1}, shelling percentage and 100 kernel weight of groundnut were significantly superior with gypsum and SSP over pyrites. The performance of groundnut by application of gypsum and single superphosphate (SSP) was found on par with respect to yield components.

Application of sulphur through gypsum significantly increased the yield attributes like 100-kernal weight (1.99 and 2.53%), number of pods plant^{-1} (3.11 and 5.44%) and shelling percentage (1.55 and 2.21%) of groundnut over zinc-sulphate and elemental sulphur respectively which was statistically on par with single superphosphate (Chaubey *et al.,* 2000).

Prasad and Bharat Prasad (2002) from their field study for two years at Patna (Bihar) on Typic Haplaquent (sulphur deficient soils) indicated that yield attributes like number of branches plant^{-1}, number of capsules plant^{-1} and 1000 seed weight of linseed increased significantly with the application of sulphur as gypsum source than single super phosphate and ammonium sulphate.

Higher mean number of capitula (32.25) and number of seeds (320.94) plant^{-1} in safflower were significantly higher when sulphur was applied through single super phosphate over sulphur dust but was at par with sulphur through gypsum (Baviskar *et al.*, 2005).

Yield attributes like pods plant^{-1}, shelling percentage and 100 kernel weight of groundnut were significantly superior with gypsum and single superphosphate over pyrites and elemental sulphur. The performance of gypsum and SSP was significantly at par (Dutta and Patra, 2005).

Poomurgesan and Poonkodi (2008) concluded that yield attributes of sunflower *viz.*, head diameter, total number of seeds head^{-1} and 100 seed weight were highest with application of sulphur through gypsum than with lignite fly ash (LFA), pyrite and elemental sulphur.

Shubhangi *et al*. (2008) revealed that the significantly higher grain yield of 12.82 q ha^{-1} was obtained with the treatment receiving NPK + 60 kg ha^{-1} bentonite sulphur and it was at par with NPK + 40 kg bentonite sulphur. The yield parameters *i.e.* diameter of sunflower head and number of grains per head were recorded higher with the treatment NPK+60 kg ha^{-1} bentonite.

The maximum increase in head diameter, seed weight head^{-1} and test weight was obtained in sunflower when sulphur was applied through gypsum as compared to elemental sulphur (Satish Kumar *et al*., 2011).

Verma *et al*. (2012) found that number of capsules plant^{-1} and number of seeds capsule^{-1} of safflower were significantly higher with the application of sulphur through ammonium sulphate as compared to single superphosphate, elemental sulphur and gypsum.

2.2.2 Effect of sulphur levels

Results from a field study on groundnut revealed that application of sulphur up to 45 kg ha^{-1} significantly increased the shelling percentage and 100 kernal weight of groundnut which was statistically on par with 60 kg S ha^{-1} (Chaubey *et al*., 2000).

The treatment receiving 30 kg S ha^{-1} recorded higher number of capitula (35.66) and number of seeds plant^{-1} (330.38) in safflower over 0 and 15 kg S ha^{-1} in a field study at Nagpur by Baviskar *et al.* (2005).

Yield attributes like number of pods plant^{-1}, shelling percentage and 100 kernal weight of groundnut increased significantly by increasing doses of sulphur up to 30 kg ha^{-1} which was at par with that of 45 and 60 kg S ha^{-1} respectively (Dutta and Patra, 2005).

Kabade *et al*. (2006) concluded that application of 40 kg S ha^{-1} produced maximum number of filled seeds plant^{-1} (307.00) in sunflower which was found at par with 20 kg S ha^{-1}. Similarly the yield plant^{-1} was also increased with the application of 40 kg S ha^{-1} and found significant over 20 and 0 kg S ha^{-1}.

Fayyaz *et al*. (2007) revealed that yield and yield attributes were significantly affected by sulphur levels and seasons. Sulphur (20 kg ha^{-1}) affected yield and yield attributes positively as compared to control. Sulphur levels and hybrids exhibited significant differences for oil content during both the seasons. Interactive effects of sulphur and hybrids on yield were found to be significant.

The significantly higher number of siliquae plant^{-1} (334.24) and number of seeds siliquae^{-1} in mustard were recorded with application of sulphur at 45 kg S ha^{-1} which was on par with that of 30 kg S ha^{-1} during both the years (Harendra Kumar and Yadav, 2007)

Poomurgesan and Poonkodi (2008) concluded that application of 60 kg S ha^{-1} registered significantly higher head diameter (17.24), total number of seeds head^{-1} (102.1) and 100 seed weight (4.146) in sunflower over control.

Results indicated that the application of 30 kg S ha^{-1} recorded the significantly higher yield determining components such as number of capsules per plant (32.2), seed weight per head (0.84 g) and 1000 seed weight (61.6 g) in safflower as compared to control, 10 and 20 kg S ha^{-1} (Ravi *et al*., 2008).

Santosh Kumar *et al.* (2011) reported that sulphur application at 45 kg ha^{-1} increased significantly the yield attributing characters like seeds siliquae^{-1} and test weight of mustard over 0, 15 and 30 kg S ha^{-1}.

Bhainru Saini *et al. (*2012) studied the treatment combinations comprised of two sources of sulphur *viz.*, S_1=Elemental sulphur and S_2=Gypsum and four levels of sulphur *viz.*, L_1=15 kg S ha^{-1}, L_2=30 kg S ha^{-1}, L_3=45 kg S ha^{-1} and L_4=60 kg S ha^{-1} in sunflower. Application of 45 kg S ha^{-1} produced significantly higher seed (814 kg ha^{-1}) and stalk (1899 kg ha^{-1}) yields over other levels of sulphur, however, it was statistically on par with 60 kg S ha^{-1}.

In a field study on safflower at Raipur (Chhattisgarh) by Verma *et al*. (2012) revealed that application of sulphur at 45 kg ha^{-1} resulted significantly higher number of capsules plant^{-1} and number of seeds capsule^{-1} than control and it was at par with application of S at 15 or 30 kg ha^{-1}.

Singh and Singh (2013) from their field study at Varanasi (Uttar Pradesh) revealed that sulphur application at 60 kg S ha^{-1} significantly increased yield attributes like number of capsules plant^{-1}, seed weight head^{-1} and 1000 seed weight in safflower than 40 kg S ha^{-1}, though these two sulphur levels remained statistically comparable over control and 20 kg S ha^{-1}.

Patil *et al*. (2014) revealed that in linseed, application of 30 kg S ha^{-1} recorded significantly higher values of yield contributing parameters like number of capsules plant^{-1} (27.97), seed yield (7.50 q ha^{-1}) and straw yield (25.86 q ha^{-1}) as compared to 10 and 20 kg S ha^{-1}.

Tulasi *et al.* (2014) concluded that application of 40 kg S ha^{-1} recorded significantly higher number of capsules plant^{-1} (78.83), and grains capsules^{-1} (49.62) in sesame than control and 10 kg S ha^{-1} but was at par with 20 and 30 kg S ha^{-1}.

2.3 EFFECT OF SULPHUR ON YIELD

2.3.1 Effect of sulphur sources

A field experiment was conducted for two years on groundnut by Bandopadhyay and Samui (2000) on sandy loam soil with pH 7.8 observed that the pod yield and kernel yield of groundnut were significantly superior with gypsum and single super phosphate over pyrites.

The pod yield of groundnut was significantly influenced by gypsum treatment and the increase in pod yield over elemental sulphur and zinc sulphate was 4.90 and 3.93 per cent, respectively on pooled basis and statistically at par with single super phosphate (SSP) treatment (Chaubey *et al.,* 2000).

Reddy and Reddy (2001) revealed that ammonium sulphate recorded higher seed and stover yields in soybean at all the levels of applied sulphur than gypsum, the increase over gypsum being 7.3 and 6.7 per cent respectively.

A field trial was conducted for two years at Arnej (Gujarat) during winter on clay soil by Patel *et al*. (2002) concluded that sulphur application through ammonium sulphate recorded significantly higher safflower seed yield as compared to other sources *viz.*, single super phosphate, elemental sulphur and gypsum during both the years.

Results from a field experiment on linseed at Patna (Bihar) on Typic Haplaquent sulphur deficient soils revealed that significantly higher seed yield was obtained with application of gypsum as sulphur source followed by single super phosphate and ammonium sulphate (Prasad and Bharat Prasad, 2002).

Application of sulphur in the form of ammonium sulphate recorded the highest grain and straw yield of safflower compared to single super phosphate, elemental sulphur, gypsum and pyrites (Ventakesh *et al*., 2002).

Kubsad and Mallapur (2003) conducted an experiment at Annigeri (Karnataka) on vertisol during *rabi* under rainfed condition reported that application of sulphur in the form of single super phosphate resulted in significantly higher seed yield (1896 kg ha^{-1}) of safflower which was at par with elemental sulphur (1793 kg ha^{-1}) but significantly higher than yields with ammonium sulphate (1720 kg ha^{-1}) and gypsum (1742 kg ha^{-1}).

Baviskar *et al.* (2005) reported that seed and straw yield of safflower were significantly higher when sulphur was applied through single super phosphate over sulphur dust but was at par with sulphur through gypsum.

Dutta and Patra (2005) in their field experiment on groundnut at West Bengal on sandy loam alluvial soils observed that pod yield was significantly superior with gypsum and single super phosphate over pyrites and elemental sulphur.

A field experiment was conducted during *kharif* at Latur on deep black soil by Gokhale *et al.* (2005) concluded that significantly higher seed yield (2798 and 2707 kg ha^{-1}) of soybean recorded with application of gypsum and single super phosphate, respectively as compared to elemental sulphur (2509 kg ha^{-1}).

Sandeep Singh and Vinay Singh (2007) from their field experiment on alluvial soil at Agra (U.P) concluded that the seed and stover yield of linseed increased significantly when sulphur was applied through gypsum compared to elemental sulphur and pyrite.

Virender Sardana *et al.* (2007) conducted a field experiment at Ludhiana for two years in loamy sand soil reported that significantly higher seed yield in sunflower was registered with the application of ammonium sulphate during first year and with gypsum application during second year. In both the years, the seed yield was lowest with application of elemental sulphur as source of sulphur.

Seed and stalk yield of sunflower were significantly higher with application of sulphur through gypsum than with lignite fly ash (LFA), pyrite and elemental sulphur (Poomurgesan and Poonkodi, 2008).

In a field trail at Jabalpur (Madhya Pradesh) on clay loam soil having available sulphur of 6.8 kg ha^{-1} revealed that application of sulphur through different sources significantly increased the seed yield of sesame and among these sources elemental sulphur proved to be better than single super phosphate and gypsum (Deshmukh *et al.*, 2010).

Satish Kumar *et al*. (2011) concluded that significantly higher seed yield and stalk yield of sunflower was obtained with the application of sulphur through gypsum as compared to elemental sulphur.

Maximum seed yield (2125 kg ha^{-1}) and straw yield (5461kg ha^{-1}) of linseed was recorded under ammonium sulphate and it was higher by 25.6, 87.4 and 146.8 per cent over elemental sulphur, single super phosphate and gypsum, respectively (Tomar, 2012).

In a field experiment by Verma *et al*. (2012) found that seed and biological yield of safflower was significantly higher with the application of sulphur through ammonium sulphate as compared to single super phosphate, elemental sulphur and gypsum.

2.3.2 Effect of sulphur levels

Nandanwar *et al.* (2000) conducted a field experiment on vertisol at Nagpur concluded that grain yield of linseed increased with increase in sulphur level up to 45 kg ha^{-1}.

Surendra Singh *et al.* (2000) concluded that straw and grain yields of niger increased significantly with successive increase in the levels of sulphur up to 45 kg ha^{-1} and further increase in sulphur upto 60 kg S ha^{-1} reduced the yield.

Application of sulphur at 45 kg ha^{-1} significantly increased seed yield of safflower than that of control and 15 kg S ha^{-1} but remained at par with 30 kg S ha^{-1} in pooled results (Patel *et al*., 2002).

In a field trail on safflower at Dharwad during *rabi* season showed that grain and straw yield of safflower increased significantly up to 30 kg S ha^{-1} which was on par with 45 kg S ha^{-1} (Ventakesh *et al*., 2002).

Kubsad and Mallapur (2003) concluded that safflower seed yield increased significantly from 1373 kg ha^{-1} without sulphur application to 1837 kg ha^{-1} with application of sulphur at 30 kg ha^{-1}. However, there was no further significant increase in seed yield beyond 30 kg S ha^{-1} although an increasing trend was noticed up to 45 kg S ha^{-1}.

Duhoon *et al.* (2005) found that at Tikamgarh higher mean seed yield (854 kg ha^{-1}) of sesame was recorded with 45 kg S ha^{-1} and closely followed by 824 kg ha^{-1} with 30 kg S ha^{-1} and 777 kg ha^{-1} with 15 kg S ha^{-1} in a field experiment conducted at four locations during *kharif* season.

In a field study on groundnut at West Bengal on sandy loam alluvial soils having pH 6.5 and available sulphur of 8.03 ppm concluded that the pod yield of groundnut increased significant with the increasing doses of sulphur up to 45 kg ha^{-1} and further increase up to 60 kg S ha^{-1} did not prove beneficial (Dutta and Patra, 2005).

Seed yield of safflower increased significantly up to 60 kg S ha^{-1} over 30 kg S ha^{-1} and control in a field experiment conducted at Banswara (Rajasthan) by Dashora and Sharma (2006).

In a three years field experiment by Sarika *et al.* (2006) at Nagpur on medium black clay soil having pH of 7.8 and available sulphur of 5.3 mg kg^{-1} found that application of sulphur at 30 kg ha^{-1} increased the seed yield of linseed by 4.7 kg ha^{-1}.

Harendra Kumar and Yadav (2007) showed that significantly higher seed and stover yield of mustard were obtained with the application of sulphur at 45 kg ha^{-1} which was on par with sulphur application at 30 kg ha^{-1} and these were significantly superior over control.

Jat and Mehra (2007) showed that application of sulphur at 40 kg ha^{-1} significantly increased the seed yield of mustard by 24.9 and 9.5 per cent during first year and 24.8 and 9.9 per cent during second year over control and 20 kg S ha^{-1} respectively.

Sandeep Singh and Vinay Singh (2007) from their field experiment on alluvial soil at Agra (U.P) concluded that the seed and stover yield of linseed increased significantly with increasing levels of sulphur up to 60 kg ha^{-1}.

Kapila Shekhawat and Shivay (2008) from the field experiment on sunflower at IARI, New Delhi on sandy loam soils having available sulphur of 23.5 kg ha^{-1} and pH 7.3 observed that application of sulphur at 25 kg ha^{-1} increased the seed and stover yield over control, but further increment of sulphur application to 50 kg ha^{-1} remained statistically on par with that of 25 kg S ha^{-1} application.

Application of sulphur at 60 kg ha^{-1} recorded the maximum seed and stalk yield of 2162.1 and 4111.9 kg ha^{-1} of sunflower respectively as compared with control (Poomurgesan and Poonkodi, 2008).

In a field study on sesame at Jabalpur by Deshmukh *et al.* (2010) observed that with every incremental dose of sulphur application to sesame correspondingly increased the seed yield up to 45 kg S ha^{-1}.

Seed yield of safflower was significantly higher with application of sulphur at 30 kg ha^{-1} over 20, 10 kg S ha^{-1} and control in a field trial by Ravi *et al*. (2010) at Dharwad during *rabi* season.

Results from an experimental field conducted on mustard by Santosh Kumar *et al.* (2011) at Varanasi reported that sulphur application at 45 kg ha^{-1} increased significantly the seed and straw yield over 0, 15 and 30 kg S ha^{-1}.

Results from a field study on sunflower by Satish Kumar *et al*. (2011) at Allahabad found that seed yield and stalk yield was maximum with the application of sulphur at 45 kg ha^{-1} over 0, 15 and 30 kg S ha^{-1} during both the years.

Tomar (2012) concluded that the significantly higher seed yield (1581 kg ha^{-1}) and straw yield (4063 kg ha^{-1}) in linseed was recorded with 20 kg S ha^{-1} and these were significantly superior over 10 kg S ha^{-1} and further increase in sulphur level up to 30 kg ha^{-1} reduced the yield.

In a field study on safflower at Raipur (Chhattisgarh) by Verma *et al*. (2012) revealed that application of sulphur at 45 kg S ha^{-1} recorded higher seed and biological yield than control and it was at par with application of sulphur at 15 and 30 kg ha^{-1}.

A field experiment was conducted by Debnath and Basu (2013) on safflower at Nadia (West Bengal) concluded that application of sulphur at 20 kg S ha^{-1} was found more effective in increasing the seed yield of safflower as compared to 0, 40 and 60 kg S ha^{-1}.

Pavani *et al.* (2013) noticed that application of 30 kg S ha^{-1} recorded significantly higher seed yield (2048 kg ha^{-1}) over 0 and 15 kg S ha^{-1}. Application of 120 kg N ha^{-1} recorded maximum stalk yield (4072 kg ha^{-1}) over 60 and 90 kg N ha^{-1}. Application of 30 kg S ha^{-1} recorded more stalk yield (4028 kg ha^{-1}), whereas low stalk yield (3696 kg ha^{-1}) was observed in plots with no sulphur application.

Singh and Singh (2013) from their field study on safflower at Varanasi (U.P) on sandy clay loam having pH 7.6 revealed that sulphur application at 60 kg S ha^{-1} significantly increased the seed yield over 40 kg S ha^{-1}, though these two sulphur levels remained statistically comparable over control and 20 kg S ha^{-1}.

Amit *et al.* (2014) revealed that application of sulphur at 20 and 30 kg ha^{-1} with sulphur oxidizing biofertilizer registered higher seed yield (1932 and 2007 kg ha^{-1}, respectively) which was on par with sulphur at 30 kg ha^{-1} alone (1956 kg ha^{-1}) in sunflower crop. Application of sulphur 20 kg ha^{-1} with sulphur oxidizing biofertilizer was better in improving the yield and was found economically feasible.

Jadhao *et al*. (2014) conducted a field experiment at Akola during *kharif* season on soybean and reported that the significantly higher grain yield (19.64 q ha^{-1}) was recorded with the application of 30 kg S ha^{-1} which was at par with S @ 45 kg ha^{-1} (18.20 q ha^{-1}).

Tulasi *et al.* (2014) concluded that seed yield of sesame was maximum with 40 kg S ha^{-1} which was significantly superior over other treatments (30, 20, 10 kg S ha^{-1} and control) but found at par with 30 kg S ha^{-1} and 20 kg S ha^{-1}.

Muhammad Ajmal Rana *et al*. (2015) studied the interactive effect of sulphur and nitrogen on productivity of sunflower (*Helianthus annuus* L.). Maximum achene yield (2996 kg ha^{-1}) was obtained when sulphur and nitrogen were applied @ 75 and 120 kg ha^{-1}, respectively which was the outcome of better growth and yield contributing attributes *i.e.* more number of achenes per head (1330.7), dominant head diameter (25.3 cm) and higher 1000- achene weight.

2.4 EFFECT OF SULPHUR ON QUALITY

2.4.1 Effect of sulphur sources

A field experiment conducted by Bandopadhyay and Samui (2000) for two years on sandy loam soil having pH 7.8 resulted that oil content of groundnut was superior with gypsum and SSP over pyrites. The performance of gypsum and single super phosphate was statistically at par.

Reddy and Reddy (2001) revealed that ammonium sulphate resulted in higher oil content and protein content in soybean at any levels of sulphur compared with respective levels of sulphur from gypsum. The increase in oil and protein content due to ammonium sulphate over gypsum was 5.1 and 2.3 per cent, respectively.

Application of sulphur in the form of ammonium sulphate recorded the significantly higher oil yield of safflower over other sources *viz*., single super phosphate, elemental sulphur, gypsum and pyrites (Ventakesh *et al*., 2002).

Venkatesh *et al*. (2002) revealed that oil content in groundnut was significantly higher in gypsum treated plots than that when sulphur was applied as single super phosphate or elemental sulphur.

Giri *et al.* (2003) in their field study on mustard at Akola concluded that the oil and protein content were significantly higher with sulphur application through gypsum than through bensulf and single super phosphate.

An experiment conducted by Kubsad and Mallapur (2003) at Annigeri (Karnataka) on vertisol during *rabi* under rainfed condition reported that safflower oil yield was higher with application of sulphur in the form of single super phosphate which was at par with elemental sulphur but significantly higher than yields with ammonium sulphate and gypsum.

Dutta and Patra (2005) reported that the oil content of groundnut was significantly superior with gypsum and single super phosphate over pyrites and elemental sulphur. The performance of gypsum and single super phosphate was significantly at par.

A field experiment was conducted during *kharif* at Latur on deep black soil by Gokhale *et al.* (2005) concluded that the higher oil and protein content in soybean were obtained from gypsum (19.95% and 41.20%, respectively) and single super phosphate (19.74% and 40.97%, respectively) which were at par with each other and found significantly superior over elemental sulphur (19.34% and 39.40%, respectively).

Results of a field trial conducted for two years on groundnut showed maximum oil and protein content in groundnut when sulphur was supplied through gypsum compared to single super phosphate and iron pyrite (Kalaiyarasan *et al.*, 2007).

Virender Sardana *et al.* (2007) conducted a two years field experiment on sunflower at Ludhiana having loamy sand soil reported that application of ammonium sulphate resulted in the highest oil content in both the years (mean oil content 34.5%) compared to gypsum and elemental sulphur.

Application of sulphur through elemental sulphur significantly increased the oil yield of sesame and proved to be better than SSP and gypsum in a field experiment at Jabalpur (Madhya Pradesh) on clay loam soil with available sulphur of 6.8 kg ha^{-1} (Deshmukh *et al.*, 2010).

Tomar (2012) concluded that application of sulphur through ammonium sulphate gave maximum protein and oil content of linseed seed and it was significantly higher than elemental sulphur and single super phosphate.

2.4.2 Effect of sulphur levels

Singh *et al*. (2000) conducted a field experiment on linseed under dryland condition during winter season at Varanasi concluded that sulphur at 40 kg ha^{-1} recorded maximum oil content and proved significantly superior to control and 20 kg S ha^{-1}. Application of 20 kg S ha^{-1} recorded significantly higher oil yield than control. But both 20 and 40 kg S ha^{-1} were statistically at par for oil yield.

Oil content in niger seed increased linearly with successive increase in the levels from 0 to 60 kg S ha^{-1} of sulphur application and oil yield of niger increased steeply with sulphur application up to 45 kg ha^{-1} and decreased at 60 kg S ha^{-1} level (Surendra Singh *et al*., 2000).

Nagavani *et al*. (2001) conducted a two years field experiment at Tirupati (AP) during *rabi* seasons on sandy clay loam soil having neutral soil pH (7.4) revealed that application of sulphur up to 40 kg ha^{-1} significantly increased the oil content in sesame. However, further increase to 60 kg S ha^{-1} had no significant effect.

Kubsad and Mallapur (2003) concluded that safflower oil yield was significantly higher with application of sulphur at 30 kg ha^{-1} and there was no further significant increase in oil yield beyond 30 kg S ha^{-1} although an increasing trend was noticed up to 45 kg S ha^{-1}.

In a field study on sunflower at Vasaaputhur village, Chidambaram taluk (Tamil Nadu) in a sandy loam soil having pH of 6.70 and available S of 7.0 kg ha^{-1} reported that increasing levels of sulphur up to 60 kg ha^{-1} significantly increased the protein and oil content and the maximum protein content (19.13%) and oil content (37.69%) was recorded at 60 kg S ha^{-1} and it was on par with 50 kg S ha^{-1} (19.03 and 37.40%) and 40 kg S ha^{-1} (18.91 and 37.25%) respectively (Poonkodi and Poomurugesan, 2008).

Baviskar *et al.* (2005) conducted a field trail on safflower at Nagpur on medium black clay soils observed that highest oil percentage of safflower seed was recorded significantly with sulphur application at 30 kg ha^{-1} over 0 and15 kg S ha^{-1} except 45 kg S ha^{-1}.

Increasing the doses of sulphur up to 30 kg ha^{-1} increased significantly the oil content of groundnut which was at par with that of 45 and 60 kg S ha^{-1}, respectively (Dutta and Patra, 2005).

Saren *et al*. (2005) conducted a two years field experiment on sesame during summer season at Sriniketan (West Bengal) reported that the highest percentage of oil (48.10%) and oil yield (395.67 kg ha^{-1}) of sesame were recorded with application of the highest level of sulphur (45 kg ha^{-1}) though the effect was not significant with that of 30 kg S ha^{-1} and lower oil content and oil yield were found at control plots.

Dashora and Sharma (2006) reported that oil content of safflower seeds increased significantly with increasing the sulphur level up to 60 kg S ha^{-1} over 30 kg S ha^{-1} and control.

A field experiment on linseed was conducted by Sarika *et al.* (2006) at Nagpur on medium black clay soil having pH 7.8 and available S of 5.3 mg kg^{-1} revealed that significantly higher oil content and crude protein content were recorded with the application of 30 kg S ha^{-1} over 0, 10 and 20 kg S ha^{-1} to linseed.

The higher oil content in mustard was obtained with the application of sulphur at 45 kg S ha^{-1} which was on par with sulphur application at 30 kg ha^{-1} and the increase in oil content due to 45 kg S ha^{-1} over the control was 11.53 and 9.02 per cent during both the years (Harendra Kumar and Yadav, 2007).

Sandeep Singh and Vinay Singh (2007) conducted a field study on linseed for two years on alluvial soil at Agra (U.P) concluded that the oil yield increased significantly with increasing levels of sulphur up to 60 kg ha^{-1}. The application of 60 kg S ha^{-1} increased the oil yield by 36.7 and 36.2 per cent over the control in first and second year, respectively.

Ravi *et al.* (2008) concluded that oil and protein content of safflower seeds were highest with application of sulphur at 30 kg ha^{-1} and it was significantly superior over 20, 10 kg S ha^{-1} and control.

Application of 45 kg S ha^{-1} being at par with 30 kg S ha^{-1} recorded significantly higher oil content, oil yield, protein content and protein yield in mustard than 15 kg S ha^{-1} and control (Santosh Kumar *et al.*, 2009).

Patel *et al.* (2009) conducted a two years field experiment during summer season at Gujarat on groundnut in loamy sand soil concluded that significantly higher oil content and oil yield were found with 60 kg S ha^{-1} than lower levels of sulphur but it was at par with 40 kg S ha^{-1} in case of oil yield.

Results from a field study at Jabalpur (Madhya Pradesh) conducted for two years revealed that with every incremental dose of sulphur application up to 45 kg ha^{-1} to sesame correspondingly increased the oil yield over 15 and 30 kg S ha^{-1} (Deshmukh *et al.*, 2010).

Kadu Varun *et al.* (2011) revealed that sulphur application significantly influenced quality and yield of soybean in Inceptisol. Irrespective of sources, oil (22.7%) and protein (35.9%) content was significantly higher by the application of sulphur at 40 kg ha^{-1}.

Tomar (2012) concluded that significantly higher protein and oil content of linseed seed was recorded with 20 kg S ha^{-1} compared to other doses *viz*., 0, 10 and 30 kg S ha^{-1}.

A field experiment was conducted by Debnath and Basu (2013) on safflower at Nadia (West Bengal) concluded that application of sulphur at 40 kg ha^{-1} was found more effective in increasing the oil yield of safflower compared to 0, 20 and 60 kg S ha^{-1}.

Krishan Lal *et al* (2013) conducted field experiment on influence of different levels of sulphur (0, 20, 40 and 60 kg S ha^{-1}) and date of sowing (D1 early and D2 late sowing) on the yield and biochemical composition of sunflower varieties *viz.*, Teza-555 and NFSH-36. The protein content, oil content and amino acids (*viz.*, methionine and cystine) were recorded maximum in Teza-555 (V1) variety. The effect of sulphur (0, 20, 40, 60 kg S ha^{-1}) on protein content, oil content and amino acid (*viz*. methionine and cystine) were found in increasing trends. Maximum protein content (41.48%), oil content (41.18%), methionine (1.93%) and cystine (1.40%) were obtained at (60 kg S ha^{-1}) level of sulphur. oil content (40.24%) was recorded maximum in early (D1) date of sowing.

Oil and protein content of safflower seed increased significantly up to 40 kg S ha^{-1}, although there was improvement in the oil and protein content with subsequent increase in sulphur levels up to 60 kg ha^{-1} (Singh and Singh, 2013).

Tulasi *et al.* (2014) concluded that maximum oil yield in sesame was recorded due to 40 kg S ha^{-1} which was at par with 30 kg S ha^{-1} and 20 kg S ha^{-1} and significantly superior over treatment 10 kg S ha^{-1} and control.

2.5 EFFECT OF SULPHUR ON NUTRIENT AVAILABILITY OF SOIL

2.5.1 Effect of sulphur sources

Ventakesh *et al*. (2002) concluded that the availability of sulphur in soil after harvest of safflower was least with ammonium sulphate treated plot whereas it was highest with elemental sulphur followed by pyrite.

Higher N, P_2O_5 and S available status and balance sheet of nutrients in soil were recorded under ammonium sulphate in linseed. However, highest available and balance sheet of K_2O was recorded with gypsum followed by elemental sulphur (Tomar, 2012).

2.5.2 Effect of sulphur levels

Murthy and Muralidharudu (2003) found that available sulphur status of soil after castor crop harvest varied from 12.1 to 30.5 mg kg^{-1} and its content increased with increasing levels of sulphur.

Nutrient availability of N, P, K, S, Zn and Fe content in soil were lowest with application of 30 kg S ha^{-1} in safflower which was significantly lower over control, 10 and 20 kg S ha^{-1} (Ravi *et al*., 2010).

Tomar (2012) concluded that application of 20 kg S ha^{-1} in linseed recorded higher available and balance sheet of N ha^{-1}, while 30 kg S ha^{-1} recorded higher available and balance of P_2O_5, K_2O and S.

Jadhao *et al.* (2014) conducted a field experiment at Akola during *kharif* season on soybean reported that significantly higher available N (226.74 kg ha^{-1}), K (335.88 kg ha^{-1}) and S (12.18 kg ha^{-1}) were recorded with the application of 45 kg S ha^{-1} over 30, 15 kg S ha^{-1} and control. The available phosphorus and zinc due to different levels of sulphur was found to be non significant.

2.6 EFFECT OF SULPHUR ON NUTRIENTS UPTAKE

2.6.1 Effect of sulphur sources

Sakal *et al.* (1993) concluded that total sulphur uptake of groundnut was significantly higher when sulphur was supplied through ammonium sulphate followed by single super phosphate and gypsum.

Results of the field study on mustard by Giri *et al.* (2003) reported that total uptake of sulphur, nitrogen and phosphorus were significantly highest with sulphur supplied through gypsum than sulphur through bensulf and SSP.

Total uptake of sulphur by safflower was observed significantly more with sulphur application through single superphosphate over sulphur dust and gypsum. The less uptake of sulphur was observed by sulphur application through sulphur dust (Baviskar *et al.*, 2005).

Gokhale *et al.* (2005) concluded that significantly higher sulphur uptake by seed and straw in soybean were observed due to gypsum (5.87 and 5.29 kg ha^{-1}, respectively) and SSP (5.80 and 5.21 kg ha^{-1}, respectively) which was at par with each other and found significantly superior over elemental sulphur (5.27 and 4.68 kg ha^{-1}, respectively).

Sandeep Singh and Vinay Singh (2007) in their field experiment conducted for two years on alluvial soil at Agra (U.P) concluded that in linseed the uptake of N, P and S significantly higher with gypsum than with pyrites and elemental sulphur, which may be attributed to higher seed and stover production with gypsum.

Total sulphur uptake by the safflower crop at maturity was significantly higher when gypsum was used as a source of sulphur compared to elemental sulphur as sulphur source (Satish Kumar *et al*., 2011).

Application of sulphur sources significantly influenced the nutrients uptake (N, P, K and S) in seed, straw and total in linseed and the maximum values were recorded under ammonium sulphate followed by elemental sulphur (Tomar, 2012).

2.6.2 Effect of sulphur levels

Babhulkar *et al*. (2000) concluded that the total uptake of N, P, K, S and Zn by safflower significantly increased due to application of sulphur up to 45 kg ha^{-1} over 0, 30 and 60 kg ha^{-1} and further increase in sulphur level up to 60 kg ha^{-1} had a decline effect on uptake of these nutrients due to increase in yield at higher levels.

Panda *et al*. (2000) conducted a field experiment on mustard at Kalyani (West Bengal) concluded that increase in sulphur levels up to 60 kg ha^{-1} increased N, P, K and S uptake both in seed and stover compared to lower levels (0, 20 and 40 kg S ha^{-1}).

Significant increase in S uptake by seed and straw of niger was obtained with increasing levels of sulphur upto 45 kg ha^{-1} and total mean S uptake was two to three fold higher at 45 kg ha^{-1} of sulphur application over control (Surendra Singh *et al.*, 2000).

Results from a field experiment on sandy loam soil having pH 6.70 and available soil sulphur of 7.0 kg ha^{-1} reported that application of 60 kg S ha^{-1} to sunflower recorded the maximum nutrient content (N, P and S) of seed and stalk. But the performance of 60, 50 and 40 kg S ha^{-1} doses were comparable to each other (Poonkodi and Poomurgesan, 2008).

Higher S uptake by safflower was recorded with the application of 30 kg S ha^{-1} which was significantly superior over 15 and 45 kg S ha^{-1} whereas lower S uptake was recorded with control (Baviskar *et al.*, 2005).

Total uptake of phosphorus (8.68 kg ha^{-1}1) and sulphur (5.60 kg ha^{-1}) was significantly higher with the application of 30 kg S ha^{-1} in linseed as compared to remaining sulphur levels *viz*., 0, 10 and 20 kg ha^{-1} (Sarika *et al.*, 2006).

Harendra Kumar and Yadav (2007) from their field study on mustard for two consecutive *rabi* seasons at Faizabad found that sulphur application at 45 kg ha^{-1} showed significant increase in the sulphur uptake over that of 15 kg ha^{-1}.

Jat and Mehra (2007) showed that N, P, K and S uptake by mustard increased significantly up to 60 kg S ha^{-1} application except nitrogen and potassium uptake in seed where significant increase was recorded only up to 40 kg S ha^{-1}.

Sandeep Singh and Vinay Singh (2007) from their field trial on alluvial soil at Agra (U.P) concluded that the total uptake of N, P and S significantly increased linearly with increasing sulphur levels from 0 to 60 kg S ha^{-1} in linseed.

Results of the field experiment on sunflower by Kapila Shekhawat and Shivay (2008) at IARI, New Delhi on sandy loam soils having available sulphur of 23.5 kg ha^{-1} and pH 7.3 concluded that different levels of sulphur improved the uptake of N, S and B significantly in the seed stover and as well as total, however P uptake remained unaffected at both the doses of sulphur *i.e.* 25 kg ha^{-1} and 50 kg ha^{-1} in linseed. The rate of increase in uptake was higher at 25 kg S ha^{-1} application than at 50 kg S ha^{-1}.

Nutrient uptake of N, P, K, S, Zn and Fe in safflower were higher with application of sulphur at 30 kg ha^{-1} and it was significantly superior over control, 10 and 20 kg S ha^{-1} among the sulphur levels (Ravi *et al*., 2008).

Application of sulphur at 45 kg ha^{-1} to mustard resulted in significant increase in the sulphur uptake over that of 15 kg ha^{-1} and control and it was at par with 30 kg S ha^{-1} (Santosh Kumar *et al.*, 2009).

Najar *et al*. (2011) conducted a field experiment for two consecutive years during *kharif* season revealed that total uptake of N, P, K S, Ca and Mg by soybean was recorded maximum with the application of 40 kg S ha^{-1} over other rest of the treatments (10, 20, 30 kg ha^{-1}and control) but at par with 30 kg S ha^{-1}, although the increasing levels of sulphur increased the uptake of these elements significantly when compared to control.

The total sulphur uptake by the sunflower crop at flowering and maturity stages increased significantly with each increment in sulphur application and reached to the higher when 45 kg S ha^{-1} was applied (Satish Kumar *et al*., 2011).

Harshal *et al.* (2012) in a field experiment at Nagpur on linseed concluded that total N (48.37 kg ha^{-1}), P (11.28 kg ha^{-1}), K (17.25 kg ha^{-1}) and S (7.8 kg ha^{-1}) uptake were significantly higher at sulphur level at 20 kg ha^{-1} which was found to be at par with sulphur level at 15 kg ha^{-1} (48.31 N, 11.03 P, 16.89 K and 7.68 kg S ha^{-1}, respectively).

Nutrient uptake of N, P, K and S were increased by linseed seed, straw and total uptake with the rise in sulphur level from 0 to 20 kg ha^{-1}. Application of 30 kg S ha^{-1} was slightly lower than 20 kg S ha^{-1} (Tomar, 2012).

Singh and Singh (2013) from their field study on safflower concluded that sulphur application with 60 kg ha^{-1} increased uptake of N by 5.8, 14.4 and 21.8 per cent, uptake of P by 7.0, 19.1 and 48.3 per cent, uptake of S by 10.8, 18.9 and 38.6 per cent and uptake of total N, P and S by 6.9, 15.9 and 30.6 per cent over 40, 20 kg S ha^{-1} and control, respectively.

Amit *et al.* (2014) revealed that application of 30 kg S ha^{-1} and 20 S kg ha^{-1} with sulphur oxidizing biofertilizer was recorded higher nutrient uptake in sunflower crop.

2.7 EFFECT OF SULPHUR ON ECONOMICS

2.7.1 Effect of sulphur sources

Results of the field experiment on safflower at Gwalior (Madhya Pradesh) revealed that significantly higher net return was realized with the application of ammonium sulphate followed by single super phosphate, gypsum and agriculture grade pyrites (Sharma *et al*., 1998).

Application of sulphur through single super phosphate in safflower recorded significantly higher net returns (₹ 15,527 ha^{-1}) and B: C (3.29) ratio over ammonium sulphate, elemental sulphur and gypsum (Kubsad and Mallapur, 2003).

Verma *et al*. (2012) from field experiment on Alfisols of Chhattisgarh found that significantly higher net returns on safflower were obtained with the application of sulphur through ammonium sulphate obviously due to higher seed yield followed by application of sulphur through SSP.

2.7.2 Effect of sulphur levels

Vishwakarma *et al*. (1999) concluded that application of 10 kg S ha^{-1} proved more remunerative than other levels in soybean because it fetched the higher net profit (₹ 3188 ha^{-1}) and B: C ratio (1.26) closely followed by 20 kg S ha^{-1} which had to the maximum gross profit (₹ 14,548 ha^{-1}).

Net returns on safflower crop significantly increased from ₹ 9493 ha^{-1} in control to ₹ 14,806 ha^{-1} in 30 kg S ha^{-1} and there was no further significant increase with increase in the level of sulphur up to 45 kg ha^{-1} was observed by Kubsad and Mallapur (2003).

Higher net returns were obtained with the treatment receiving 60 kg S ha^{-1} which was closely followed by 30 kg S ha^{-1} and both were found significantly superior over no sulphur application to safflower (Dashora and Sharma, 2006).

The higher net return of ₹13,734 ha^{-1} was recorded with the application of sulphur at 45 kg ha^{-1} compared to 0, 15 and 30 kg S ha^{-1} in a field study on mustard for two consecutive *rabi* seasons at Faizabad by Harendra Kumar and Yadav (2007).

Sandeep Singh and Vinay Singh (2007) from the field experiment on linseed at Agra (U.P) on alluvial soil concluded that net returns increased with the increase in sulphur rate up to 60 kg S ha^{-1} and the B: C ratio in sulphur fertilizer was 1.75, 1.84 and 1.96 due to application of 20, 40 and 60 kg S ha^{-1} respectively.

Ravi *et al.* (2008) from the field study on safflower at Dharwad during *rabi* season concluded that the treatment receiving 30 kg S ha^{-1} recorded the higher cost of cultivation (₹ 6,094 ha^{-1}), gross returns (₹ 25,625 ha^{-1}), net returns (₹ 19,513 ha^{-1}) and benefit : cost ratio (4.20) as compared to other treatments.

Application of 45 kg S ha^{-1} gave the maximum net returns (₹ 13568 ha^{-1}) and B: C ratio (2.45) in mustard followed by 30, 15 kg S ha^{-1} and control respectively (Santosh Kumar *et al.*, 2009).

Patil *et al*. (2014) revealed that the higher gross monetary returns of ₹ 33557 ha^{-1} and net monetary returns of ₹ 17489 ha^{-1} were recorded in linseed with the application of 30 kg S ha^{-1} which was significantly more than application of 20 and 10 kg S ha^{-1}. The highest B: C ratio of 2.09 was observed with the application of 30 kg S ha^{-1} followed by application of 20 kg S ha^{-1} (2.00) and 10 kg S ha^{-1} (1.89).

2.8 INTERACTION EFFECT OF SOURCES AND LEVELS OF SULPHUR

2.8.1 Growth parameters

Mishra and Agrawal (1994) from their field study on soybean at Varanasi reported that higher plant height and number of primary branches plant^{-1} were obtained with application of sulphur at 40 kg S ha^{-1} through ammonium sulphate compared to single super phosphate and elemental sulphur.

Intodia and Tomer (1997) revealed that application of different sources of sulphur *i.e.*, elemental sulphur @ 60 kg S ha^{-1} and gypsum @ 40 and 60 kg S ha^{-1} increased the leaf area index (LAI) of sunflower at 60 DAS (2.43, 2.64 & 2.66, respectively) compared to control (2.08) on clay loam soil during *kharif* season. On the other hand, the above treatments had no significant effect on plant height.

Reddy and Reddy (2001) conducted a field experiment during *rabi* season at Agriculture College farm, Rajendranagar on clay soil revealed that application of ammonium sulphate @ 40 and 60 kg S ha^{-1} were on par and recorded significantly higher dry matter production in soybean over other combinations.

Poomurugesan and Poonkodi (2008) revealed that in sunflower irrespective of the sources of sulphur tried, application of 60 kg S ha^{-1} through gypsum, lignite fly ash (LFA), pyrite and elemental sulphur recorded the maximum growth attributes *viz*., plant height, leaf area index and dry matter production over control. But in case of gypsum and LFA the effect of 60 and 45 kg S ha^{-1} were comparable with each other.

Jadav *et al*. (2010) conducted a three years field experiment at Junagadh (Gujarat) on medium black soils revealed that application of 20 kg S ha^{-1} in the form of gypsum recoded significantly higher length of main spike and number of spikes plant^{-1} of castor crop than the rest of the treatments. However, it remained at par with 30 kg S ha^{-1} in the form of gypsum.

2.8.2 Yield and yield attributes

During *kharif* season, application of sulphur through various sources influenced significantly on yield and yield attributing parameters of sunflower (Intodia and Tomar, 1997). Application of elemental sulphur @ 60 kg S ha^{-1} and gypsum @ 40 and 60 kg S ha^{-1} registered higher head diameter (16.17, 16.82 and 17.05 cm), higher seed weight per capitulum (22.99, 25.70 and 25.87 g), higher seed yield (1226, 1310 & 1344 kg ha^{-1}) when compared with control respectively on clay loam soils of Chittorgarh.

Tamak *et al*. (1997) reported that sulphur application through gypsum @ 25 and 50 kg ha^{-1} as basal dose to sunflower increased head diameter (18.3 and 19.5 cm, respectively) during *spring* season at Hissar.

Interaction effects between sources and levels of sulphur for pod yield of groundnut indicated that the increased level of sulphur up to 30 kg ha^{-1} applied through gypsum and single super phosphate produced significantly higher pod yield than the use of pyrites or elemental sulphur (Dutta and Patra, 2005).

Madhurendra *et al.* (2006) conducted a field experiment at Dholi (Bihar) during *rabi* season concluded that significantly higher seed yield (1256 kg ha^{-1}) of sunflower was obtained with application of sulphur at 40 kg S ha^{-1} through ammonium sulphate over other treatments.

Usha Rani *et al.* (2008) reported that graded levels of sulphur at rates of 20, 40 and 60 kg ha^{-1} applied through elemental S significantly increased the seed yield of the sunflower crop over the control by 5.4, 10.7, and 18.1 per cent, respectively, whereas the corresponding increases in case of gypsum ($CaSO_4.2H_2O$) were 25.1, 28.8, and 33.9 per cent, respectively. The greatest seed yield of sunflower (1175 kg ha^{-1}) was obtained with 60 kg S ha^{-1} through gypsum under rainfed conditions.

Jadav *et al*. (2010) revealed that application of 20 kg S ha^{-1} in the form of gypsum recorded significantly higher castor seed yield (3079 kg ha^{-1}) but it remained statistically at par with 20 kg S ha^{-1} and 30 kg S ha^{-1} in the form of SSP and 30 kg S ha^{-1} in the form of gypsum.

Yatheesh *et al.* (2013) conducted a field experiment to study the effect of different levels (10, 20, 30, and 40 kg S ha^{-1}) and sources of sulphur (SSP and gypsum) on growth and yield of soybean. The studies revealed that application of sulphur at 40 kg ha^{-1} as SSP significantly increased the yield followed by sulphur at 40 kg ha^{-1} as gypsum.

Srivastava and Jagadish Kumar (2015) reported that application of 20 kg sulphur ha^{-1} through single super phosphate recorded significantly higher seed yield (2685 kg ha^{-1}) of castor as compared to 20 kg sulphur ha^{-1} through gypsum (2577 kg ha^{-1}) and control (2093 kg ha^{-1}).

2.8.3 Quality

Sharma and Bansal (1998) reported on safflower, ammonium sulphate application equivalent to 30 kg S ha^{-1} resulted in significantly higher oil content and estimated oil yield of 31.24 per cent and 415 kg ha^{-1} respectively.

Venkatesh *et al*. (2002) conducted field experiment during *kharif* season on groundnut at Meghalaya revealed that protein content increased significantly by application of sulphur up to 15 kg ha^{-1} when applied as single superphosphate or gypsum as compared to elemental sulphur.

Addition of 45 kg S ha^{-1} through gypsum to groundnut registered signficantly higher oil content (49.4%, 49.3%) and protein content (25.6%, 25.7%) in both the years respectively as compared to other treatments (Kalaiyarasan *et al*., 2007).

Patel *et al*. (2009) conducted a field experiment during *rabi* season at Sardarkrushinagar having sandy loams revealed that application of sulphur at 40 kg ha^{-1} in the form of gypsum to variety GM-1 recorded significantly higher oil content in mustard seed.

2.8.4 Nutrient uptake

Kalaiyarasan *et al.* (2007) from their field experimental at Tamil Nadu on red lateritic soil having available sulphur of 18.2 kg ha^{-1} found that gypsum application at 45 kg S ha^{-1} recorded maximum uptake of N (142, 144 kg ha^{-1}), P (16.0, 16.5 kg ha^{-1}), K (112.6, 116.9 kg ha^{-1}) and S (14.6, 15 kg ha^{-1}) by groundnut during both the years respectively as compared to single super phosphate and iron pyrite.

2.8.5 Economics

Deshmukh *et al.* (2010) found that application of 15 kg S ha^{-1} through elemental sulphur fetched the maximum net monetary returns (₹ 11427 ha^{-1}) closely followed by 45 kg S ha^{-1} through SSP (₹ 11336 ha^{-1}), 30 kg S ha^{-1} through elemental sulphur (₹ 11263 ha^{-1}) and 30 kg S ha^{-1} through gypsum (₹ 11191 ha^{-1}). The highest B: C ratio of 2.56 was recorded with 30 kg S ha^{-1} through gypsum in sesame.

Geetha *et al.* (2010) conducted a field experiment on sunflower at Bangalore during *kharif* season revealed that application of 20 kg S ha^{-1} through gypsum recorded maximum net returns (₹ 19,951 ha^{-1}), harvest index (0.34) and B:C ratio (1.95) compared to other treatments however, elemental sulphur recorded very low net returns.

Jadav *et al*. (2010) conducted a three years field experiment at Junagadh (Gujarat) on medium black soils revealed that the maximum net income of ₹ 45,067 ha^{-1} and B: C ratios of 3.3 were obtained when castor crop was fertilized with 20 kg S ha^{-1}. It was closely followed by 20 kg S ha^{-1} as single super phosphate (₹ 38,262 ha^{-1}) and 30 kg S ha^{-1} as gypsum (₹ 41,268 ha^{-1}).

Srivastava and Jagadish Kumar (2015) reported that application of 20 kg S ha^{-1} through SSP accrued the higher gross returns (₹ 88,605 ha^{-1}), net returns (₹ 66,233 ha^{-1}) and B:C ratio (3.96) compared to control (₹ 69,096, 47,003 and 3.13, respectively) in castor.

Material and Methods

III. MATERIAL AND METHODS

A field experiment entitled "Studies on different sources and levels of sulphur on productivity and quality of rainfed sunflower (*Helianthus annuus* L.) was carried out during *kharif* season of 2016 at Main Agriculture Research Station, Raichur. The details of experimental materials used, procedures followed and techniques adopted during the course of present investigation are described in this chapter.

3.1 LOCATION OF THE EXPERIMENTAL SITE

The experiment was conducted at Main Agriculture Research Station, Raichur in Plot No. 162 during *kharif* 2016-17. Raichur is situated in the North Eastern Dry Zone (Zone-2) of Karnataka between 16º15' N latitude and 77º 20' E longitude with an altitude of 389 m above the mean sea level.

3.2 CLIMATE AND WEATHER CONDITION

The mean monthly meteorological data of rainfall, temperature and relative humidity during the period of experimentation (2016-17) recorded at the meteorological observatory of the MARS, Raichur are presented in Table 1 and depicted in Fig. 1.

3.3 SOIL CHARACTERISTICS OF THE EXPERIMENTAL SITE

Representative composite soil sample was drawn from the experimental site at 0 to 30 cm soil depth before establishment of the experiment. The collected soil sample was air dried, grind to pass through 2 mm sieve and used for the analysis of various soil parameters by following standard procedures. The physical and chemical properties of soil at the experimental site are given in the Table 2.

Based on soil analysis, the soil of the experimental site was classified as clay loam in texture, slightly alkaline in soil reaction, low in organic carbon and available nitrogen, medium in available phosphorus and sulphur and high in available potassium.

3.4 PREVIOUS CROP GROWN

During the previous year (2015-16), pigeon pea crop was cultivated in the experimental site.

Table 1. Mean monthly meteorological data for the year 2016-17 and mean of the last 84 years (1932-2016) recorded at Main Agricultural Research Station, Raichur

Month	Rainfall (mm)		Temperature (°C)				Relative humidity (%)	
			Mean maximum		Mean minimum			
	1932-2016	2016-17	1932-2016	2016-17	1932-2016	2016-17	1932-2016	2016-17
April	70.70	0.00	39.90	41.80	22.60	28.30	77.00	48.00
May	71.50	87.20	39.70	39.60	22.50	26.60	80.00	66.00
June	182.70	194.10	35.30	33.80	22.30	24.20	82.00	84.00
July	62.50	143.20	33.40	31.80	20.50	23.50	79.00	86.00
August	21.20	78.00	32.90	32.40	19.10	23.10	79.00	86.00
September	4.00	292.50	32.20	29.20	16.20	22.60	76.00	92.00
October	1.20	39.20	31.50	31.20	16.80	19.70	77.00	84.00
November	1.10	0.00	31.30	34.20	18.50	22.30	62.00	82.00
December	44.30	8.20	30.50	30.20	22.60	15.60	56.00	81.00
January	13.00	0.00	31.30	30.60	24.40	16.20	53.00	76.30
February	42.90	0.00	32.50	33.90	25.30	19.20	60.00	61.00
March	113.80	26.40	36.50	38.50	23.30	23.40	79.00	72.00
Total	**628.90**	**868.70**	-	-	-	-	-	-

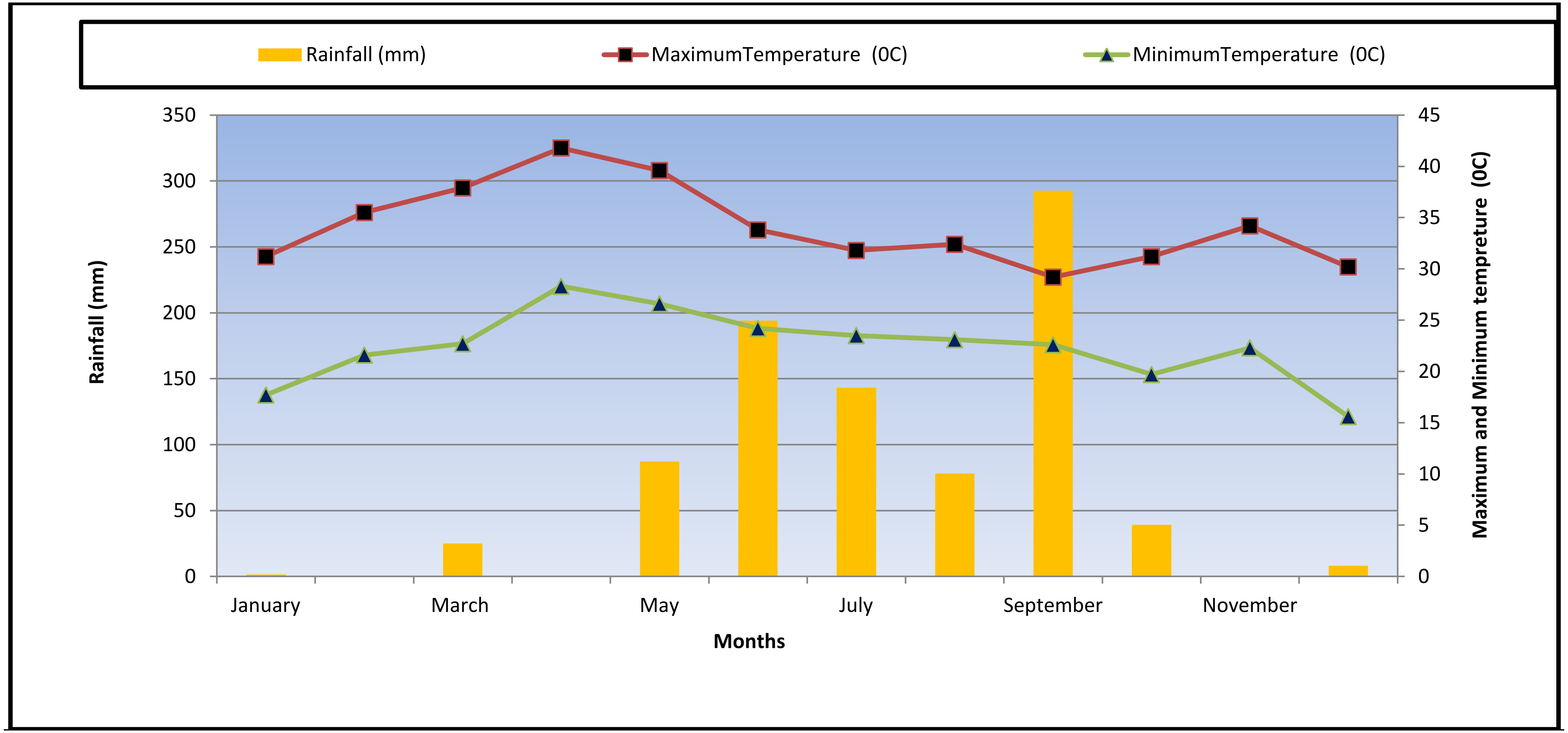

Fig. 1. Mean monthly meteorological data for the year 2016-17 at the Main Agricultural Research Station, Raichur

Table 2. Physico-chemical properties of soil at the experimental site

Sl. No.	Particulars	Value
I.	**Physical analysis**	
	Particle size distribution	
	Sand (%)	22.81
	Silt (%)	24.34
	Clay (%)	52.40
	Textural class	Clay loam
II.	**Chemical properties**	
	Soil pH (1:2.5)	8.18
	Electrical conductivity (dS m^{-1})	0.28
	Organic carbon (g kg^{-1})	4.15
	CEC (c mol (p^{+}) kg^{-1})	47.65
	Available major and secondary nutrients	
	Available nitrogen (kg ha^{-1})	238.8
	Available P_2O_5 (kg ha^{-1})	23.5
	Available K_2O (kg ha^{-1})	387.4
	Available sulphur (kg ha^{-1})	18.6
	Available calcium (c mol (p^{+}) kg^{-1})	25.1
	Available magnesium (c mol (p^{+}) kg^{-1})	10.3
	DTPA extractable micronutrients (mg kg^{-1})	
	Zinc	0.43
	Iron	7.45
	Manganese	7.81
	Boron	0.49

3.5 EXPERIMENTAL DETAILS

3.5.1 Season

The experiment was conducted during *kharif* 2016 with sunflower crop

3.5.2 Design, layout and replication

The field experiment was laid out in Factorial RBD design and replicated thrice with twelve treatments (Plate 1, 2, 3 and 4 respectively) and the layout of which is illustrated in Fig. 2.

3.5.3 Details of Experiment

The details of the experiment is given below.

Design	:	Factorial RBD
No. of treatments	:	12
No. of replications	:	3
Crop	:	Sunflower (KBSH-44)
Spacing	:	60 cm x 30 cm
Location	:	Agriculture College Farm, Raichur

3.5.4 Plot size:

Gross plot	:	6.6 m x 3.3 m
Net plot	:	5.4 m x 2.7 m

3.5.5 Spacing

Inter row	:	60 cm
Intra row	:	30 cm

3.5.6 Treatments details of field experiment

Factor 1: Sources of sulphur

S_1: Elemental sulphur

S_2: Gypsum

S_3: Ammonium sulphate

S_4: Single super phosphate

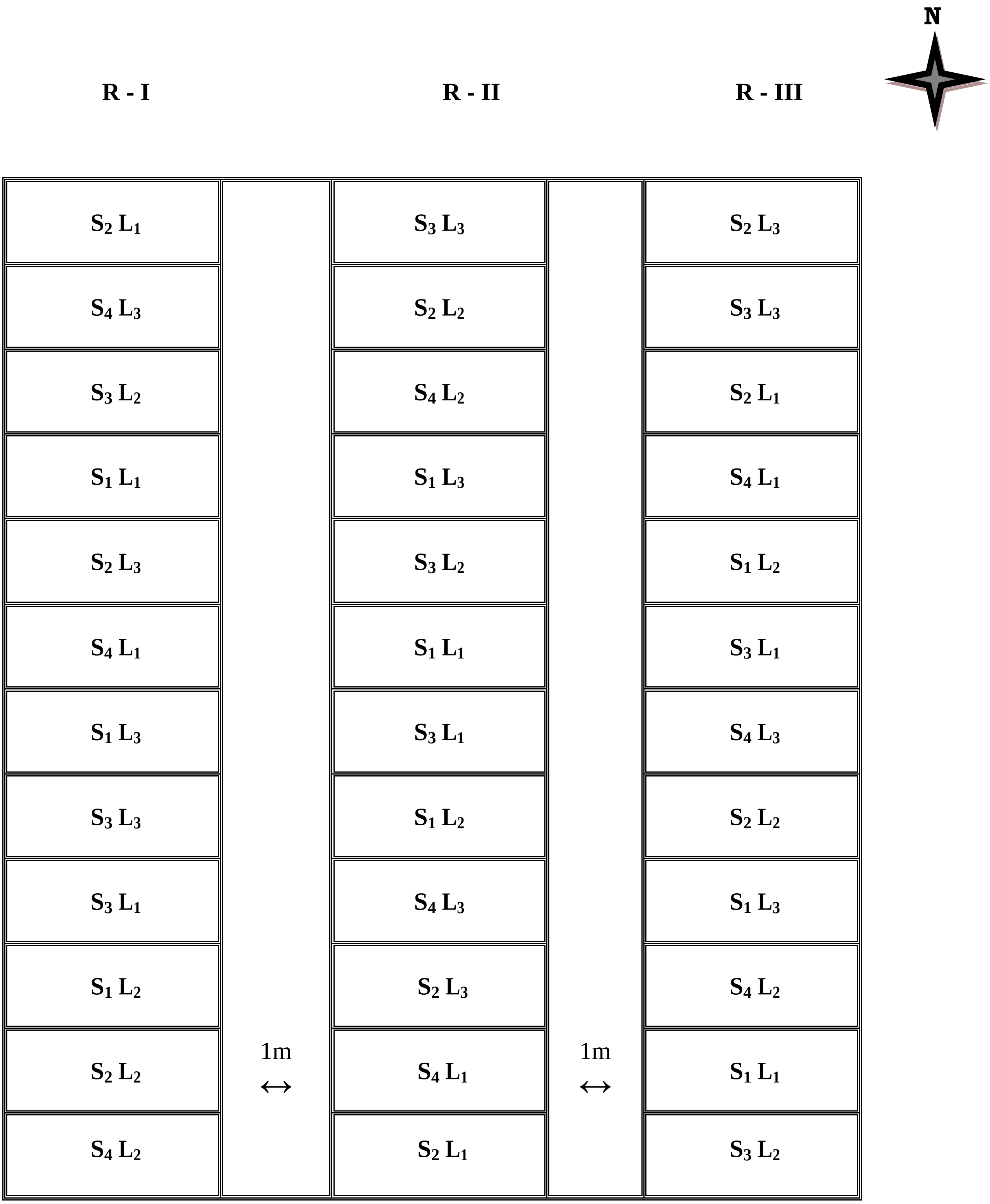

Fig.2. Layout plan of the experimental site

Plate 1. General view of experimental plot at 30 DAS of sunflower crop

Plate 2. General view of experimental plot at 30 DAS of sunflower crop

Plate 3. General view of experimental plot at 75 DAS of sunflower crop

Plate 4. General view of experimental plot at harvest of sunflower crop

Factor 2: Levels of Sulphur

L_1: 15 kg ha^{-1}

L_2: 30 kg ha^{-1}

L_3: 45 kg ha^{-1}

Treatment combinations

T_1 (S_1L_1): Elemental sulphur @ 15 kg S ha^{-1}

T_2 (S_1L_2): Elemental Sulphur @ 30 kg S ha^{-1}

T_3 (S_1L_3): Elemental Sulphur @ 45 kg S ha^{-1}

T_4 (S_2L_1): Gypsum @ 15 kg S ha^{-1}

T_5 (S_2L_2): Gypsum @ 30 kg S ha^{-1}

T_6 (S_2L_3): Gypsum @ 45 kg S ha^{-1}

T_7 (S_3L_1): Ammonium sulphate @ 15 kg S ha^{-1}

T_8 (S_3L_2): Ammonium sulphate @ 30 kg S ha^{-1}

T_9 (S_3L_3): Ammonium sulphate @ 45 kg S ha^{-1}

T_{10} (S_4L_1): Single super phosphate @ 15 kg S ha^{-1}

T_{11} (S_4L_2): Single super phosphate @ 30 kg S ha^{-1}

T_{12} (S_4L_3): Single super phosphate @ 45 kg S ha^{-1}

Note: RDF (N: P_2O_5: K_2O =90 kg ha^{-1}: 90 kg ha^{-1}: 60 kg ha^{-1} + 6 t FYM ha^{-1})

for each treatments RDF is applied as per recommendation.

3.5.7 Description of sources of sulphur

1. Elemental sulphur

It contains 90 per cent sulphur is known to improve the metabolism of nitrogen, phosphorus and potassium. Elemental sulphur can be used where sulphur deficiency in soils is known to exist.

2. Ammonium sulphate

It is a white crystalline salt, completely soluble in water, containing 20-21per cent N and 24 per cent S. The entire nitrogen is in ammonical form and sulphur in sulphate form both of which are readily available to plants.

3. Gypsum

It is a dehydrated form of calcium sulphate with 20 per cent water. It is a white yellowish or occasionally brown opaque solid material ground to a fine powder. It contains 16-19 per cent Ca and 17 per cent sulphur in sulphate form.

4. Single superphosphate

It is a ash gray to brownish coloured phosphate fertilizers with 16 per cent water soluble P_2O_5. In addition to Phosphorus it contains 12 per cent S and 21 per cent Ca.

3.5.8 Other details

Date of sowing : 16/8/2016

Date of harvest : 25/11/2016

3.6 CULTIVATION DETAILS

3.6.1 Land preparation

The land was ploughed with tractor after the harvest of pigeon pea crop and harrowed twice to crush the clods. Stubbles and weeds were removed from the experimental plot and the soil was brought to fine tilth. The experimental site was applied with FYM @ 6.0 t ha^{-1} in the first week of July 2016. The experimental layout was prepared as per the plan.

3.6.2 Treatments imposition

A uniform dose of 90 kg P_2O_5 and 60 kg K_2O ha^{-1} was applied through diammonium phosphate (DAP) and muriate of potash (MOP) as basal dose to all the plots at the time of sowing. Nitrogen (90 kg ha^{-1}) was applied through urea, half at sowing and the remaining half as topdressing at 30 DAS to all the treatments. Sulphur was applied as per the treatments in the form of elemental sulphur, gypsum, ammonium sulphate and single super phosphate at the time of sowing. The doses of nitrogen and phosphorus were adjusted when sulphur was applied through ammonium sulphate and SSP.

3.6.3 Sowing

Healthy and well matured certified seeds of sunflower (KBSH-44) were procured from the Seed Unit of UAS, Raichur. The seeds were soaked overnight and shade dried for an hour before sowing. A pre-sowing irrigation was given and sowing was taken up at optimum soil moisture content. The seeds were sown on 16-08-2016 by hand dibbling at each hill with a spacing of 60 cm x 30 cm.

3.6.4 Gap filling and thinning

Gap filling was done one week after the sowing and thinning was done two weeks after sowing to maintain optimum plant population. One healthy seedling per hill was maintained.

3.6.5 Weeding

Hand weeding was done at 15, 40 and 65 days after sowing to avoid the crop weed competition.

3.6.6 Plant protection

Sunflower was sprayed with Karate @ 0.7 ml per litre of water to control the *Spodoptera litura* and *Helicoverpa armigera* (head borer) at 20, 40 and 60 DAS. No pest and disease was noticed throughout the crop period.

3.6.7 Protective irrigation

The crop was given one protective irrigation on 20-08-2016 to avoid moisture stress to the standing crop.

3.6.8 Harvesting and threshing

The crop was considered maturity, when the back of heads turned to lemon yellow. The heads of border rows were harvested first and treated as bulk. Later the heads of the crop from net plot was harvested. The heads were sun dried, shelled with hand and the seeds were separated. Later seeds were sun dried to a moisture content of 14 per cent, cleaned and weighed separately for each plot. The stalk yield was recorded after sun drying.

3.7 DETAILS OF COLLECTION OF EXPERIMENTAL DATA

Five plants were selected randomly from net plot and tagged for recording growth and yield attributes throughout crop growth period.

3.7.1 Pre-harvest observations

3.7.1.1 Plant height (cm)

Plant height was measured from the ground level up to the base of node which the first fully opened leaf from the top was borne at flowering and at harvest and expressed in centimetres.

3.7.1.2 Number of green leaves

Total number of fully opened trifoliate leaves was counted in the five plants and average was taken as number of leaves per plant.

3.7.1.3 Leaf area per plant

The leaf area per plant was worked out by disc method on dry weight basis as per the procedure suggested by vivekanandan *et al*. (1972).

$$LA = (Wa \times A) / Wd$$

Where,

LA= Leaf area (dm^2)

Wa= Oven dry weight of all leaves (inclusive of 5 disc weight)

Wd= Oven dry weight of 5 discs

A= Area of 5 discs (dm^2)

3.7.1.4 Leaf area index (LAI)

Leaf area index was estimated at 30 and 60 DAS and at harvest of crop. From the measured values of leaf area, LAI was computed taking into account the area occupied by each plant according to the following formula as suggested by Watson (1952).

$$\text{Leaf area index (LAI)} = \frac{\text{Total leaf area}}{\text{Unit area}}$$

3.7.1.5 Total dry matter production

Plant samples for dry matter studies were collected at 30 DAS, 60 DAS and at harvest of crop. At each sampling, five plants were uprooted at random in each treatment and partitioned into leaf, stem and reproductive parts. These samples were oven dried at 70^o C in a hot air oven for 72 hours till a constant weight. The dry weight of different plant parts was recorded; the dry matter production per plant was obtained with the summation of dry weight of all plant parts and was expressed in g plant^{-1}.

3.7.2 Post-harvest observations

Five tagged plants from the net plot area which were chosen for recording growth parameters. The plants were harvested separately and various yield components were recorded.

3.7.2.1 Head (capitulum) diameter

Diameter of the heads from the labelled plants were measured, average diameter was worked out and expressed in centimetres.

3.7.2.2 Head weight

Weight of the heads from the labelled plants were measured, average weight was worked out and expressed in grams.

3.7.2.3 Number of filled and unfilled seeds per head

From the total number of seeds produced per head, filled and unfilled seeds were separated, counted and expressed as number of filled and unfilled grains per head separately.

3.7.2.4 100-seed weight

Five composite samples of 100 seeds each were drawn from the net plot produce of each treatment and weights were recorded. The averages of weight were calculated and expressed in grams.

3.7.2.5 Grain yield (kg ha^{-1})

Grains obtained from the net plot were thoroughly sun dried, weighed and yield was expressed in kg ha^{-1}.

3.7.2.6 Stalk yield (kg ha^{-1})

Stalk obtained from net plot was thoroughly sun dried, weighed and expressed as stalk yield in kg ha^{-1}.

3.7.2.7 Harvest index (HI)

The relationship of economic yield (grain) to the total biological yield was estimated by using the following formula and was expressed in percentage.

$$\text{Harvest Index (HI)} = \frac{\text{Economic yield}}{\text{Total biological yield}} \times 100$$

3.7.2.8 Oil content (%)

Oil content in the grains of each treatment was estimated by Nuclear Magnetic Resonance (NMR) method as suggested by Tiwari *et al.*, (1974) and expressed as percentage.

3.7.2.9 Oil yield (kg ha^{-1})

Oil yield in the grains of each treatment was calculated by multiplying oil content with grain yield.

$$\text{Oil yield (kg ha}^{-1}\text{)} = \frac{\text{Grain yield x oil content}}{100}$$

3.7.3.0 Protein content (%)

The crude protein content in sunflower grain was computed by multiplying percent nitrogen content of grain by the factor 6.25

3.8 CHEMICAL ANALYSIS OF SOIL

Composite soil sample was collected before layout of the experiment to determine the initial soil proportion of N, P, K and S. The soil samples were also collected from each treatment after harvest of sesame crop to assess the change in nutrient status. The soil samples collected from 0-30 cm depth were dried under shade, grinded with wooden pestle and mortar, passed through 2 mm sieve and were used for analysis.

3.8.1 Soil reaction

Soil pH was determined in 1:2.5 soil : water suspension using pH meter with glass electrode (Jackson, 1973).

3.8.2 Electrical conductivity (dS m^{-1})

Electrical conductivity was determined in 1:2.5 soil : water extract using digital conductivity bridge and expressed as dS m^{-1} (Jackson, 1973).

3.8.3 Organic carbon (g kg^{-1})

Soil organic carbon was determined by using Walkley and Black's method (1934). A known weight of soil was treated with excess volume of potassium dichromate solution ($K_2Cr_2O_7$) in the presence of concentrated H_2SO_4. Organic carbon in the soil was oxidized to CO_2. The excess of potassium dichromate unused was titrated back against ferrous ammonium sulphate (FAS) in the presence of concentrated phosphoric acid and diphenyl amine indicator. The organic carbon content in the soil was calculated by using following formula:

$$\text{Organic carbon (g kg}^{-1}\text{)} = \frac{\text{(Sample TV-Blank TV) x } N\text{. of FAS x 0.003 x 100 x 1}N\text{ } K_2Cr_2O_7 \text{ x 1.33}}{\text{Weight of soil sample (g)}} \text{ x10}$$

3.8.4 Available nitrogen (kg ha^{-1})

The available nitrogen was determined by alkaline potassium permanganate method (Hesse, 1971). A known weight of soil was treated with excess amount of potassium permanganate with 25 per cent NaOH solution. The liberated ammonia was trapped in boric acid mixed indicator solution and determined by titration against standard H_2SO_4. The available nitrogen content of the soil was calculated by following formula.

$$\text{Available N (kg ha}^{-1}\text{)} = \frac{\text{(Sample TV-Blank TV) x } N\text{. of } H_2SO_4 \text{ x 0.014 x 100 x 10000 x 2.24}}{\text{Weight of soil sample (g)}}$$

3.8.5 Available phosphorus (kg ha^{-1})

Available phosphorus in soil was extracted by Olsen's extractant and phosphorus was determined by stannous chloride molybdophosphoric blue color method (Hesse, 1971). Available phosphorus in soil was extracted by using 0.5 M $NaHCO_3$. The blue color was developed by chloromolybdic acid and intensity of blue color was determined at 660 nm. The available phosphorus content of the soil was calculated by following formula.

3.8.6 Available potassium (kg ha^{-1})

Available potassium was extracted with neutral normal ammonium acetate solution and was determined using flame photometer as described by Jackson (1973). The available potassium content of the soil was calculated by following formula.

$$\text{Available } K_2O \text{ (kg ha}^{-1}\text{)} = \frac{\text{ppm x Volume of extract x Volume made x 1.20 x 2.24 x } 10^6}{10^6 \text{ x Weight of soil sample x Aliquot taken}}$$

3.8.7 Available sulphur (kg ha^{-1})

Available sulphur in the soil was extracted from soil using 0.15 per cent calcium chloride as outlined by Black (1965). The sulphur in the extract was estimated by turbidometric method using $BaCl_2$ as stabilizing agent. The turbidity was measured using UV spectrophotometer (Spectornic 20-D) at 420 nm. Sulphur was calculated by using following formula.

$$\text{Available S (kg ha}^{-1}\text{)} = \frac{\text{Graph ppm x Volume of extract x Volume made x 2.24 x } 10^6}{10^6 \text{ x Weight of soil sample x Aliquot taken}}$$

3.9 COLLECTION AND PREPARATION OF PLANT SAMPLES

3.9.1 Collection and preparation of plant samples

Treatment wise plant samples were collected at 30, 60 DAS and at harvest by uprooting the entire plant carefully. Collected plant samples washed thoroughly with razzing tap water first dried under shade and then, oven dried in hot air oven at 65^0C till a constant weight was obtained. Dried plant samples were powdered with the help of mixer and stored in polythene bags for further chemical analysis of nitrogen, phosphorous, potassium and sulphur.

3.9.2 Digestion of plant samples

Powdered plant samples were pre-digested separately in HNO_3. The pre-digested samples were digested with di acid (HNO_3: $HClO_4$) mixture at 10:4 ratio till clear solution was observed, cooled and dilute in HCl. The content was made up to known volume by using double distilled water. A known quantity of liquid was used for further analysis of N, P, K and S.

3.9.3 Nitrogen content

Nitrogen content in plant sample was determined by Kjeldhal's method. Dried plant sample (0.5 g) was digested using 10 ml of concentrated sulphuric acid in presence of 0.3 g of catalytic mixture containing of K_2SO_4, $CuSO_4$ and selenium powder in the ratio of 40: 20: 1 in the micro kjeldhal digestion unit. After complete digestion the samples were distilled using micro-kjeldhal unit and the liberated ammonia was trapped in boric acid containing mixed indicator and titrated against 0.01 N H_2SO_4 (Jackson 1973). From the volume of acid consumed by ammonia per cent of nitrogen content was calculated

$$\text{Nitrogen (\%)} = \frac{\text{Titre value x N. } H_2SO_4 \text{ x Dilution factor}}{\text{Weight of plant sample (g) x 100}}$$

3.9.4 Wet ashing of plant samples for nutrient analysis

One gram plant sample was first pre-digested with 5 ml nitric acid and then digested with diacid mixture consisting of nitric acid and perchloric acid (10:4). The clear digested materials were made up to 50 ml volume using 6 N HCl and were subsequently used for the analysis of P, K and S.

3.9.5 Phosphorus

The phosphorus in the plant sample was determined by Vanadomolybdo phosphate yellow colour method in nitric acid medium. The intensity of colour was read at 420 nm wave length using spectrophotometer (Jackson 1973).

3.9.6 Potassium

Potassium in the plant sample was estimated by atomizing the diluted plant extract in the flame photometer as described by Jackson (1973).

3.9.7 Sulphur

The sulphur in di-acid plant extract was estimated by turbidimetric method and the turbidity developed was read on spectrophotometer at 420 nm (Jackson 1973).

3.10 CORRELATION STUDIES

Correlation studies were made between yield of sunflower and growth components, yield attributes, quality parameters, N, P, K, and S in soil and plant and uptake of these nutrients by the crop.

3.10.1 Economics

The prices of the inputs that were prevailing at the time of their use were considered for work out the cost of cultivation of sunflower.

1. Labour charges
2. Seeds
3. Fertilizers
4. Plant protection chemicals
5. Miscellaneous (marketing charges, etc.)

3.10.2 Net returns

The net return per hectare was calculated by deducting the cost of cultivation from gross returns per hectare.

3.10.3 Benefit cost ratio

The benefit cost ratio was calculated as follows.

$$\text{Benefit cost ratio} = \frac{\text{Gross returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

3.11 STATISTICAL ANALYSIS

The data recorded on various parameters during the course of investigation were statistically analyzed duly following the analysis of variance technique for factorial randomized block design. The statistical significance was tested with F test at 0.05 level of probability and wherever the F value was found significant, critical difference (CD) was worked out to test the significance.

Experimental Results

IV. EXPERIMENTAL RESULTS

An investigation was undertaken to elicit information on growth parameters, yield attributes, quality, concentration and uptake of nutrients, soil nutrient status and economics of the experiment entitled "Studies on different sources and levels of sulphur on productivity and quality of rainfed sunflower (*Helianthus annuus* L.)" conducted during *kharif* 2016. The results of the investigation are presented in this chapter.

4.1 Effect of different sources and levels of sulphur on growth of sunflower

4.1.1 Plant height (cm)

Experimental data on effect of different sources and levels of sulphur on plant height of sunflower was analysed statistically and presented in the Table 3.

4.1.1.1 Effect of sulphur sources

Among different sources of sulphur, significantly higher plant height (184.10 and 185.66 cm) was observed with ammonium sulphate (S_1) as a source of sulphur at 60 DAS and at harvest over other sources of sulphur *viz*., SSP (S_4), gypsum (S_2) and elemental sulphur (S_1). However, sulphur sources did not show significant influence on plant height at 30 DAS.

4.1.1.2 Effect of sulphur levels

Different levels of sulphur showed significant influence on plant height of sunflower at all the growth stages. Among different levels of sulphur significantly higher plant height (68.09, 188.07 and 187.04 cm) was recorded with 45 kg S ha^{-1} (L_3) at 30, 60 DAS and at harvest and significantly superior to 30 kg S ha^{-1} (L_2) and 15 kg S ha^{-1} (L_1). The plant height increased with increasing sulphur level from 15 kg S ha^{-1} (L_1) to 45 kg S ha^{-1} (L_3).

4.1.1.3 Interaction effect of sulphur sources and levels

The interaction effect of different sources and levels of sulphur was found to be non significant with respect to plant height of sunflower at all the growth stages.

4.1.2 Number of leaves

Experimental data on number of leaves per plant influenced by sulphur sources and levels was analysed statistically and presented in the Table 4.

Table 3. Effect of different sources and levels of sulphur on plant height (cm) of sunflower at different growth stages.

Treatments	30 DAS	60 DAS	Harvest
Sulphur sources			
S_1 – Elemental sulphur	63.49	175.75	177.20
S_2 – Gypsum	64.66	176.99	178.48
S_3 – Ammonium sulphate	66.13	184.10	185.66
S_4 – Single super phosphate	64.82	181.57	182.96
S.Em±	0.83	2.20	2.23
CD (P=0.05)	NS	6.46	6.54
Sulphur levels (kg S ha^{-1})			
L_1 – 15 kg ha^{-1}	61.20	172.75	175.86
L_2 – 30 kg ha^{-1}	65.03	177.99	180.32
L_3 – 45 kg ha^{-1}	68.09	188.07	187.04
S.Em ±	0.72	1.90	1.93
CD (P=0.05)	2.11	5.60	5.66
Interaction (S x L)			
S.Em ±	1.44	3.81	3.86
CD (P=0.05)	NS	NS	NS

DAS – Days after sowing NS – Non significant

Table 4. Effect of different sources and levels of sulphur on number of leaves of sunflower at different growth stages.

Treatments	30 DAS	60 DAS	Harvest
Sulphur sources			
S_1 – Elemental sulphur	17.49	20.28	16.49
S_2 – Gypsum	17.94	21.14	17.14
S_3 – Ammonium sulphate	18.37	22.37	17.68
S_4 – Single super phosphate	18.14	21.74	17.36
S.Em±	0.37	0.50	0.28
CD (P=0.05)	NS	1.47	0.83
Sulphur levels (kg S ha^{-1})			
L_1 – 15 kg ha^{-1}	15.73	19.16	15.34
L_2 – 30 kg ha^{-1}	18.64	21.10	17.50
L_3 – 45 kg ha^{-1}	19.59	23.89	18.66
S.Em ±	0.32	0.43	0.24
CD (P=0.05)	0.94	1.27	0.72
Interaction (S x L)			
S.Em ±	1.44	0.86	0.49
CD (P=0.05)	NS	NS	NS

DAS – Days after sowing NS – Non significant

4.1.2.1 Effect of sulphur sources

Experimental data on sulphur sources showed significant influence on number of leaves per plant at all the growth stages except at 30 DAS. Significantly higher number of leaves were recorded at 60 DAS and thereafter declined at harvest stage. Among the different sources of sulphur significantly higher number of leaves plant^{-1} (22.37 and 17.68) was recorded with application of sulphur through ammonium sulphate (S_3) at 60 DAS and at harvest compared to SSP (S_4), gypsum (S_2) and elemental sulphur (S_1) and however, it was statistically on par with SSP and gypsum.

4.1.2.2 Effect of sulphur levels

Differences in number of leaves per plant at all the stages of growth were significant due to different levels of sulphur. Number of leaves plant^{-1} increased with increasing levels of sulphur up to 45 kg S ha^{-1} at all the stages of growth. However significantly higher number of leaves plant^{-1} (19.59, 23.89 and 18.66) was recorded with 45 kg S ha^{-1} (L_3) at all the growth stages of crop.

4.1.2.3 Interaction effect of sulphur sources and levels

There was no significant difference noticed with the interaction effect between different sources and levels of sulphur on number of leaves plant^{-1} at all the growth stages

4.1.3 Leaf area plant^{-1} (cm^2)

The perusal data on leaf area plant^{-1} of sunflower at different stages of growth as influenced by different sources and levels of sulphur was analysed statistically and presented in Table 5.

4.1.3.1 Effect of sulphur sources

Sources of sulphur failed to exert significant influence on leaf area plant^{-1} at 30 DAS and had significant effect at 60 DAS and at harvest. At 60 DAS, ammonium sulphate (S_3) recorded significantly higher leaf area plant^{-1} (2919.11 cm^2) as compared to SSP (S_4) (2825.78 cm^2), gypsum (S_2) (2817 cm^2) and elemental sulphur (S_1) (2752 cm^2). At harvest ammonium sulphate (1585.44 cm^2) recorded significantly higher leaf area plant^{-1} compared to gypsum (1541.56 cm^2) and elemental sulphur (1526.22 cm^2) and however it was statistically on par with SSP (1568.0 cm^2).

Table 5. Effect of different sources and levels of sulphur on leaf area plant^{-1} (cm^2) of sunflower at different growth stages

Treatments	30 DAS	60 DAS	Harvest
Sulphur sources			
S_1 – Elemental sulphur	1217.44	2752.00	1526.22
S_2 – Gypsum	1232.89	2817.00	1541.56
S_3 – Ammonium sulphate	1297.11	2919.11	1585.44
S_4 – Single super phosphate	1264.33	2825.78	1568.0
S.Em±	21.13	20.80	14.09
CD (P=0.05)	NS	60.99	41.33
Sulphur levels (kg S ha^{-1})			
L_1 – 15 kg ha^{-1}	1139.00	2576.50	1465.42
L_2 – 30 kg ha^{-1}	1237.50	2842.83	1557.67
L_3 – 45 kg ha^{-1}	1382.33	3066.08	1642.83
S.Em ±	18.3	18.01	12.20
CD (P=0.05)	53.68	52.82	35.79
Interaction (S x L)			
S.Em ±	36.61	36.02	24.4
CD (P=0.05)	NS	NS	NS

DAS – Days after sowing NS – Non significant

4.1.3.2 Effect of sulphur levels

Different levels of sulphur had a significant effect on leaf area plant^{-1} (cm^2) at all the growth stages of sunflower. Application of 45 kg S ha^{-1} (L_3) recorded significantly higher leaf area plant^{-1} at 30, 60 DAS and at harvest (1382.33, 3066.08 and 1642.83 cm^2, respectively).

4.1.3.3 Interaction effect of sulphur sources and levels

None of the interaction effects of sources and levels of sulphur found non significant with respect to leaf area plant^{-1} at all the growth stages of sunflower.

4.1.4 Leaf area index

Experimental data on LAI at different growth stages as influenced by different sources and levels of sulphur in sunflower was analysed statistically and presented in the Table 6.

4.1.4.1 Effect of sulphur sources

Sources of sulphur had significantly influenced LAI at all the growth stages except 30 DAS. Maximum being at 60 DAS and thereafter declined at harvest. At 60 DAS, ammonium sulphate recorded significantly higher LAI (1.62) compared to SSP (1.57), gypsum (1.57) and elemental sulphur (1.53). At harvest ammonium sulphate (0.88) recorded significantly higher LAI which was significantly superior over elemental sulphur (0.85) and however it was on par with SSP (S_4) (0.87) and gypsum (S_2) (0.86).

4.1.4.2 Effect of sulphur levels

Differences in LAI plant^{-1} at all the stages of growth were significant owing to different levels of sulphur. Significantly higher LAI was noticed at 60 DAS and declined thereafter as the crop progressed towards physiological maturity. Among the different levels of sulphur, significantly higher LAI (0.77, 1.70 and 0.91) was recorded with 45 kg S ha^{-1} (L_3) at 30, 60 DAS and at harvest stage and significantly superior to 30 kg S ha^{-1} (L_2) and 15 kg S ha^{-1} (L_1).

4.1.4.3 Interaction effect of sulphur sources and levels

The interaction effect between different sources and levels of sulphur on LAI was not significant at all the growth stages of crop.

Table 6. Effect of different sources and levels of sulphur on leaf area index (LAI) of sunflower at different growth stages

Treatments	30 DAS	60 DAS	Harvest
Sulphur sources			
S_1 – Elemental sulphur	0.68	1.53	0.85
S_2 – Gypsum	0.68	1.57	0.86
S_3 – Ammonium sulphate	0.72	1.62	0.88
S_4 – Single super phosphate	0.70	1.57	0.87
S.Em±	0.011	0.01	0.007
CD (P=0.05)	NS	0.03	0.02
Sulphur levels (kg S ha^{-1})			
L_1 – 15 kg ha^{-1}	0.63	1.43	0.81
L_2 – 30 kg ha^{-1}	0.69	1.58	0.87
L_3 – 45 kg ha^{-1}	0.77	1.70	0.91
S.Em ±	0.01	0.01	0.006
CD (P=0.05)	0.03	0.02	0.02
Interaction (S x L)			
S.Em ±	0.02	0.02	0.013
CD (P=0.05)	NS	NS	NS

DAS – Days after sowing NS – Non significant

4.1.5 Dry matter production (g plant^{-1})

Data pertaining to sulphur sources and levels on dry matter production in different parts of plant at different growth stages was analysed statistically and presented in Table 7, 8 and 9.

4.1.5.1 Effect of sulphur sources on dry matter production in different parts of plant

The data on dry matter production in different parts of the plant of sunflower indicated significant variations due to sources of sulphur at all the growth stages except at 30 DAS. At 60 DAS, among various sources of sulphur, application of ammonium sulphate (102.97 g) recorded significantly higher dry matter compared to gypsum (95.17 g) and elemental sulphur (89.73 g) but statistically on par with SSP (99.78 g). At harvest, similar trend was observed as followed at 60 DAS. Ammonium sulphate recorded significantly higher dry matter plant^{-1} (138.93 g) compared to other sources of sulphur (130.85 and 123.38 g for gypsum and elemental sulphur) and however it was on par with SSP (135.15 g). At 30 DAS higher dry matter was accumulated in stem compared to leaves. Whereas at 60 DAS and at harvest, more dry matter was accumulated in stem followed by head as compared to leaves.

4.1.5.2 Effect of sulphur levels on dry matter production in different parts of plant

The data on dry matter production plant^{-1} of sunflower indicated significant variations due to different levels of sulphur at all the growth stages. At 30 DAS, significantly higher total dry matter production was recorded with 45 kg S ha^{-1} (30.84 g) compared to 30 kg S ha^{-1} (27.38 g) and 15 kg S ha^{-1} (24.81 g). At 60 DAS irrespective of sources, application of 45 kg S ha^{-1} produced significantly higher dry matter plant^{-1} (110.68 g) and however, there was no significant differences with the application of 15 and 30 kg S ha^{-1} (81.43 and 98.63 g plant^{-1}, respectively). At harvest among the levels of sulphur, significantly higher dry matter production plant^{-1} was observed in the treatment receiving 45 kg S ha^{-1}(146.61 g) followed by 30 kg S ha^{-1} (134.87 g) and 15 kg S ha^{-1} (114.74 g).

4.1.5.3 Interaction effect of sulphur sources and levels

Interaction effect between different sources and levels of sulphur failed to reach the level of significance with respect to dry matter production plant^{-1} of sunflower at all the growth stages.

Table 7. Effect of different sources and levels of sulphur on dry matter production ($g\ plant^{-1}$) in different parts of sunflower at 30 DAS

Treatments	Leaf weight	Stem weight	Total weight
Sulphur sources			
S_1 – Elemental sulphur	10.81	16.07	26.88
S_2 – Gypsum	11.02	16.39	27.41
S_3 – Ammonium sulphate	11.63	16.76	28.39
S_4 – Single super phosphate	11.38	16.64	28.02
S.Em±	0.23	0.35	0.4
CD (P=0.05)	NS	NS	NS
Sulphur levels (kg S ha^{-1})			
L_1 – 15 kg ha^{-1}	9.68	15.13	24.81
L_2 – 30 kg ha^{-1}	11.16	16.22	27.38
L_3 – 45 kg ha^{-1}	12.80	18.04	30.84
S.Em ±	0.2	0.30	0.34
CD (P=0.05)	0.58	0.9	1.01
Interaction (S x L)			
S.Em ±	0.4	0.60	0.7
CD (P=0.05)	NS	NS	NS

DAS – Days after sowing NS – Non significant

Table 8. Effect of different sources and levels of sulphur on dry matter production (g plant^{-1}) in different parts of sunflower at 60 DAS

Treatments	Leaf weight	Stem weight	Head weight	Total weight
Sulphur sources				
S_1 – Elemental sulphur	15.50	44.67	29.57	89.73
S_2 – Gypsum	15.77	48.07	31.34	95.17
S_3 – Ammonium sulphate	16.56	51.21	35.21	102.97
S_4 – Single super phosphate	16.24	50.00	33.54	99.78
S.Em±	0.15	0.95	0.86	1.7
CD (P=0.05)	0.43	2.80	2.52	4.96
Sulphur levels (kg S ha^{-1})				
L_1 – 15 kg ha^{-1}	14.86	41.76	24.82	81.43
L_2 – 30 kg ha^{-1}	15.90	49.17	33.55	98.63
L_3 – 45 kg ha^{-1}	17.29	54.53	38.86	110.68
S.Em ±	0.13	0.82	0.74	1.46
CD (P=0.05)	0.38	2.42	2.18	4.30
Interaction (S x L)				
S.Em ±	0.25	1.65	1.5	2.93
CD (P=0.05)	NS	NS	NS	NS

DAS – Days after sowing NS – Non significant

Table 9. Effect of different sources and levels of sulphur on dry matter production (g plant^{-1}) in different parts of sunflower after harvest

Treatments	Leaf weight	Stem weight	Head weight	Total weight
Sulphur sources				
S_1 – Elemental sulphur	15.33	55.03	53.01	123.38
S_2 – Gypsum	15.52	58.99	56.34	130.85
S_3 – Ammonium sulphate	16.31	62.41	60.21	138.93
S_4 – Single super phosphate	15.97	60.65	58.54	135.15
S.Em±	0.14	1.13	1.20	2.31
CD (P=0.05)	0.42	3.31	3.53	6.80
Sulphur levels (kg S ha^{-1})				
L_1 – 15 kg ha^{-1}	14.61	51.48	48.65	114.74
L_2 – 30 kg ha^{-1}	15.68	60.64	58.55	134.87
L_3 – 45 kg ha^{-1}	17.07	65.69	63.86	146.61
S.Em ±	0.12	0.98	1.04	2.0
CD (P=0.05)	0.36	2.87	3.06	5.9
Interaction (S x L)				
S.Em ±	0.25	1.95	2.08	4.01
CD (P=0.05)	NS	NS	NS	NS

DAS – Days after sowing NS – Non significant

4.2 Effect of different sources and levels of sulphur on yield and yield attributes of sunflower

4.2.1 Head weight

Experimental data on head weight of sunflower was analysed statistically and found significantly influenced by sulphur sources and levels and is presented in Table 10.

4.2.1.1 Effect of sulphur sources on head weight of sunflower

Different sulphur sources showed significant influence on head weight of sunflower. Significantly higher weight of head plant^{-1} (60.21 g) was obtained with the treatment receiving ammonium sulphate (S_3) as a source of sulphur compared to gypsum (S_2) and elemental sulphur (S_1) and however it was statistically on par with SSP (S_4).

4.2.1.2 Effect of sulphur levels on head weight of sunflower

Different levels of sulphur showed significant influence on head weight of sunflower. Among the different levels of sulphur significantly higher head weight plant^{-1} (63.86 g) was recorded with the treatment receiving 45 kg S ha^{-1} (L_3) and it was superior over 30 kg S ha^{-1} (L_2) (58.55g) and 15 kg S ha^{-1} (L_1) (48.65 g).

4.2.1.3 Interaction effect of sulphur sources and levels on head weight of sunflower

The interaction effect of sources and levels of sulphur on weight of head plant^{-1} of sunflower was found to be non significant.

4.2.2 Head diameter

Application of different sources and levels of sulphur exerted significant effect on head diameter. The data was presented in the Table 10.

4.2.2.1 Effect of sulphur sources on head diameter of sunflower

An examination of data presented in Table 10 revealed that sources of sulphur caused significant variations in the head diameter at harvest stage of the crop. Among the sources of sulphur significantly higher diameter of head (16.81cm) was recorded with the treatment receiving ammonium sulphate (S_3) as a source of sulphur and however it was statistically on par with SSP (S_4). Significantly lower diameter of head (15.42 cm) was observed with the treatment receiving elemental sulphur (S_1) as a source of sulphur which showed statistical inferiority over rest of the sulphur sources.

4.2.2.2 Effect of sulphur levels on head diameter of sunflower

A perusal data presented in Table 10 revealed that the effect of levels of sulphur on head diameter was found to be significant at harvest stage of the crop. As the sulphur levels increased, the diameter of head was also increased significantly up to 45 kg S ha^{-1}. Significantly higher head diameter (18.13 cm) was observed with 45 kg S ha^{-1} which was statistically superior over 15 and 30 kg S ha^{-1}.

4.2.2.3 Interaction effect of sulphur sources and levels on head diameter of sunflower

The interaction effect of sources and levels of sulphur on head diameter $plant^{-1}$ was non significant.

4.2.3 100 seed weight (g)

Data obtained on 100 seed weight (g) during the period of study was analysed statistically and presented in Table 10.

4.2.3.1 Effect of sulphur sources on seed weight of sunflower

The data presented in Table 10 revealed that different sources of sulphur cause significant variation in 100 seed weight at harvest stage of the crop. Among the sulphur sources, ammonium sulphate (S_3) application resulted in significantly higher 100 seed weight (5.16 g) and however it was statistically on par with SSP (S_4). Whereas sulphur application through elemental sulphur (S_1) recorded the lower 100 seed weight (4.76 g).

4.2.3.2 Effect of sulphur levels on seed weight of sunflower

An examination of data presented in Table 10 revealed that the variations in 100 seed weight owing to different levels of sulphur were found significant at harvest stage of the crop. Among the different levels of sulphur, 100 seed weight was significantly higher (5.45 g) with increased sulphur levels of S up to 45 kg S ha^{-1} (L_3) compared to 30 kg S ha^{-1} (5.11 g). Whereas the lower 100 seed weight was recorded with 15 kg S ha^{-1} (4.31 g).

4.2.3.3 Interaction effect of sulphur sources and levels on seed weight of sunflower

The interaction effect between the sources and levels of sulphur on 100 seed weight was found non significant.

4.2.4 Number of filled grains $head^{-1}$

Data obtained on number of filled grains $head^{-1}$ during the period of study was analysed statistically and presented in Table 11.

Table 10. Effect of different sources and levels of sulphur on head weight (g plant^{-1}), head diameter (cm) and 100 seed weight (g) of sunflower.

Treatments	Head weight	Head diameter	100 seed weight
Sulphur sources			
S_1 – Elemental sulphur	53.01	15.42	4.76
S_2 – Gypsum	56.34	15.84	4.89
S_3 – Ammonium sulphate	60.21	16.81	5.16
S_4 – Single super phosphate	58.54	16.52	5.01
S.Em±	1.20	0.27	0.09
CD (P=0.05)	3.53	0.81	0.27
Sulphur levels (kg S ha^{-1})			
L_1 – 15 kg ha^{-1}	48.65	13.97	4.31
L_2 – 30 kg ha^{-1}	58.55	16.35	5.11
L_3 – 45 kg ha^{-1}	63.86	18.13	5.45
S.Em ±	1.04	0.24	0.08
CD (P=0.05)	3.06	0.70	0.23
Interaction (S x L)			
S.Em ±	2.08	0.48	0.16
CD (P=0.05)	NS	NS	NS

DAS – Days after sowing NS – Non significant

4.2.4.1 Effect of sulphur sources on number of filled grains of sunflower

Number of filled grains head^{-1} after harvesting differed significantly due to application of different sources of sulphur. Among the sources, significantly higher filled grains head^{-1} (660.53) was recorded with the application of ammonium sulphate (S_3) compared to gypsum (619.70) and elemental sulphur (601.41) and however it was on par with SSP (642.81).

4.2.4.2 Effect of sulphur levels on filled grains of sunflower

With respect to levels, application of 45 kg S ha^{-1} recorded significantly higher filled grains head^{-1} (723.96) and it decreased with decrease in the sulphur levels and it was significantly superior over 30 kg S ha^{-1} (626.67).Whereas the lower filled grains head^{-1} was recorded with 15 kg S ha^{-1} (542.7).

4.2.4.3 Interaction effect of sulphur sources and levels

There was no significant difference with respect to interaction effect between different sources and levels of sulphur on filled grains head^{-1} of sunflower.

4.2.5 Number of unfilled grains head^{-1} of sunflower

The data on number of unfilled grains head^{-1} as influenced by different sources and levels of sulphur was analysed statistically and presented in Table 11.

4.2.5.1 Effect of sulphur sources on unfilled grains head^{-1} of sunflower

Number of unfilled grains head^{-1} of sunflower at harvest stage was not significantly influenced by different sources of sulphur.

4.2.5.2 Effect of sulphur levels on unfilled grains head^{-1} of sunflower

Number of unfilled grains head^{-1} of sunflower decreased gradually with increase in the sulphur levels. Significantly higher number of unfilled grains head^{-1} (125.03) was obtained with sulphur application at 15 kg S ha^{-1} (L_1) and it was statistically on par with sulphur application at 30 kg S ha^{-1} (L_2). Whereas lower number of unfilled grains head^{-1} (99.93) was obtained with sulphur application at 45 kg S ha^{-1} (L_3).

4.2.5.3 Interaction effect of sulphur sources and levels on number of unfilled grains head^{-1} of sunflower

There was no significant difference with respect to interaction effect of sources and levels of sulphur on number of unfilled grains head^{-1} of sunflower.

4.2.6 Total number of grains head^{-1}

The data on total number of grains head^{-1} as influenced by different sources and levels of sulphur was analysed statistically and presented in Table 11.

4.2.6.1 Effect of sulphur sources on grains head^{-1} of sunflower

Total number of grains head^{-1} at harvest stage of sunflower was not significantly influenced by different sources of sulphur.

4.2.6.2 Effect of sulphur levels on grains head^{-1} of sunflower

Total number of grains head^{-1} of sunflower increased gradually with increase in the sulphur levels. Significantly higher number of grains head^{-1} (823.90) was obtained with sulphur application at 45 kg S ha^{-1} (L_3) compared to 30 kg S ha^{-1} and 15 kg S ha^{-1}

4.2.6.3 Interaction effect of sulphur sources and levels

There was no significant difference with respect to interaction effect of sources and levels of sulphur on total number of grains head^{-1} of sunflower.

4.2.7 Grain yield (kg ha^{-1})

The data obtained on effect of various sources and levels of sulphur on grain yield of sunflower was analysed statistically and presented in Table 12.

4.2.7.1 Effect of sulphur sources on grain yield of sunflower

An examination of data presented in Table 12 and Fig. 3 revealed that sources of sulphur caused significant variation in grain yield of sunflower at harvest stage of the crop. Among the sulphur sources, application of ammonium sulphate (S_3) recorded significantly higher grain yield (1648.0 kg ha^{-1}) compared to elemental sulphur (1536.33 kg ha^{-1}) and it was on par with SSP (1632.33 kg) and gypsum (1592.22 kg ha^{-1}).

4.2.7.2 Effect of sulphur levels on grain yield of sunflower

A perusal of data presented in Table 12 and Fig. 4 revealed that variations in grain yield due to levels of sulphur were found significant at harvest stage of the crop. The increase in levels of sulphur exhibited the increment in grain yield of sunflower up to 45 kg S ha^{-1}. Application of 45 kg S ha^{-1} registered significantly higher grain yield (1719.83

Table 11. Effect of different sources and levels of sulphur on number of filled and unfilled grains head^{-1} of sunflower

Treatments	Number of filled grains head^{-1}	Number of unfilled grains head^{-1}	Total number of grains head^{-1}
Sulphur sources			
S_1 – Elemental sulphur	601.41	125.52	726.93
S_2 – Gypsum	619.70	116.91	736.61
S_3 – Ammonium sulphate	660.53	100.10	760.63
S_4 – Single super phosphate	642.81	109.93	752.74
S.Em±	10.97	6.22	12.82
CD (P=0.05)	32.19	NS	NS
Sulphur levels (kg S ha^{-1})			
L_1 – 15 kg ha^{-1}	542.70	125.03	667.73
L_2 – 30 kg ha^{-1}	626.67	114.38	741.05
L_3 – 45 kg ha^{-1}	723.96	99.93	823.90
S.Em ±	9.50	5.40	11.10
CD (P=0.05)	27.88	15.81	32.57
Interaction (S x L)			
S.Em ±	19.01	10.78	22.21
CD (P=0.05)	NS	NS	NS

DAS – Days after sowing NS – Non significant

kg ha^{-1}) and showed statistical superior over of 15 and 30 kg S ha^{-1} which exhibited significant differences in grain yield among themselves. The significantly lower grain yield (1478.17 kg ha^{-1}) was recorded with 15 kg S ha^{-1} which showed statistical inferiority over rest of the sulphur levels.

4.2.7.3 Interaction effect of sulphur sources and levels

The interaction effect between the sources and levels of sulphur in sunflower regarding grain yield was found to be non significant.

4.2.8 Stalk yield (kg ha^{-1})

Data obtained on stalk yield plant^{-1} during the period of study was analysed statistically and presented in Table 12.

4.2.8.1 Effect of sulphur sources on stalk yield

Different sources of sulphur had significant influence on stalk yield (Fig. 3) of sunflower at harvest stage. Among the sources, application of ammonium sulphate (S_3) resulted in significantly higher stalk yield (2504.29 kg ha^{-1}) compared to gypsum (S_2) and elemental sulphur (S_1) and however it was on par with SSP (S_4) with stalk yield of 2467.49 kg ha^{-1}.

4.2.8.2 Effect of sulphur levels on stalk yield

The increasing levels of sulphur showed positive effect on stalk yield (Fig. 4). Significantly higher stalk yield (2558.75 kg ha^{-1}) was recorded with 45 kg S ha^{-1} (L_3) and superior to 30 kg S ha^{-1} (L_2) and 15 kg S ha^{-1} (L_1). The stalk yield was increased significantly with increased levels of sulphur up to 45 kg ha^{-1} (L_3) and with decrease in the sulphur levels the stalk yield was decreased.

4.2.8.3 Interaction effect of sulphur sources and levels

Interaction effect of sulphur sources and levels were found to be non significant in case of stalk yield of sunflower.

4.2.9 Harvest index (%)

Experimental data on harvest index (Table 12) was analysed statistically and found non significant with various sources and levels of sulphur.

Table 12. Effect of different sources and levels of sulphur on grain yield (kg ha^{-1}), stalk yield (kg ha^{-1}) and harvest index (%) of sunflower

Treatments	Grain yield	Stalk yield	Harvest index
Sulphur sources			
S_1 – Elemental sulphur	1536.33	2352.60	39.00
S_2 – Gypsum	1592.22	2375.93	39.58
S_3 – Ammonium sulphate	1648.00	2504.29	39.71
S_4 – Single super phosphate	1632.33	2467.49	40
S.Em±	28.35	41.03	---
CD (P=0.05)	83.16	120.33	---
Sulphur levels (kg S ha^{-1})			
L_1 – 15 kg ha^{-1}	1478.17	2313.25	38.96
L_2 – 30 kg ha^{-1}	1608.67	2403.23	39.70
L_3 – 45 kg ha^{-1}	1719.83	2558.75	40
S.Em ±	24.55	35.53	---
CD (P=0.05)	72.02	104.21	---
Interaction (S x L)			
S.Em ±	49.11	71.06	---
CD (P=0.05)	NS	NS	---

DAS – Days after sowing NS – Non significant

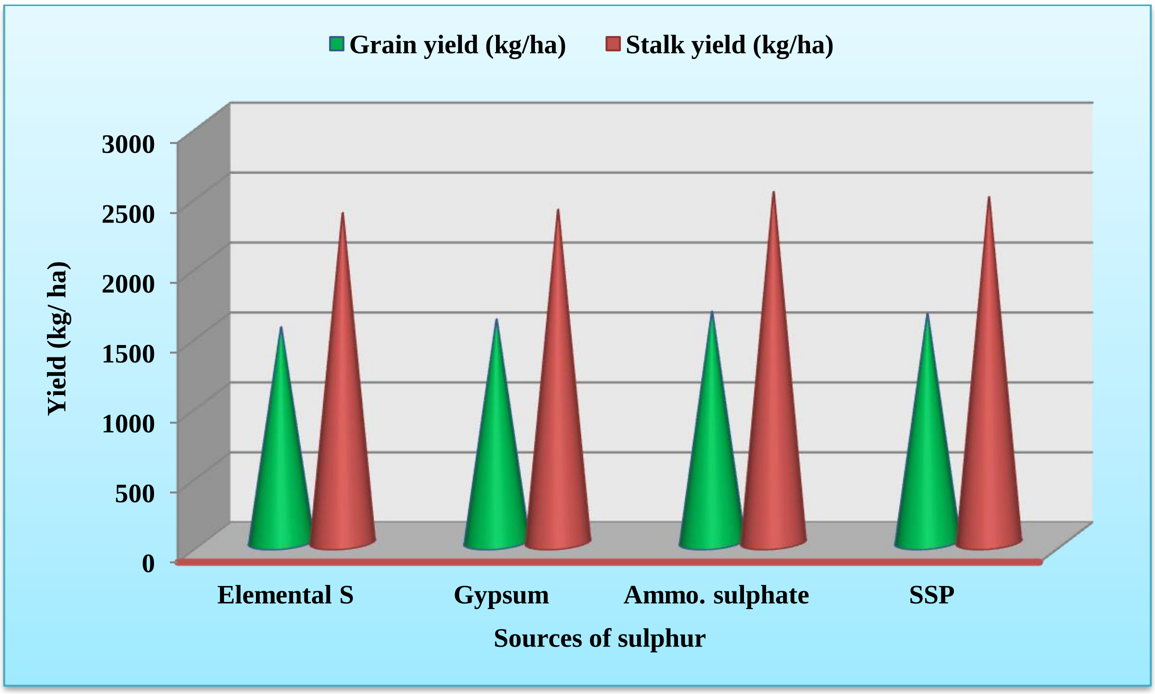

Fig. 3. Effect of different sources of sulphur on grain and stalk yield of sunflower

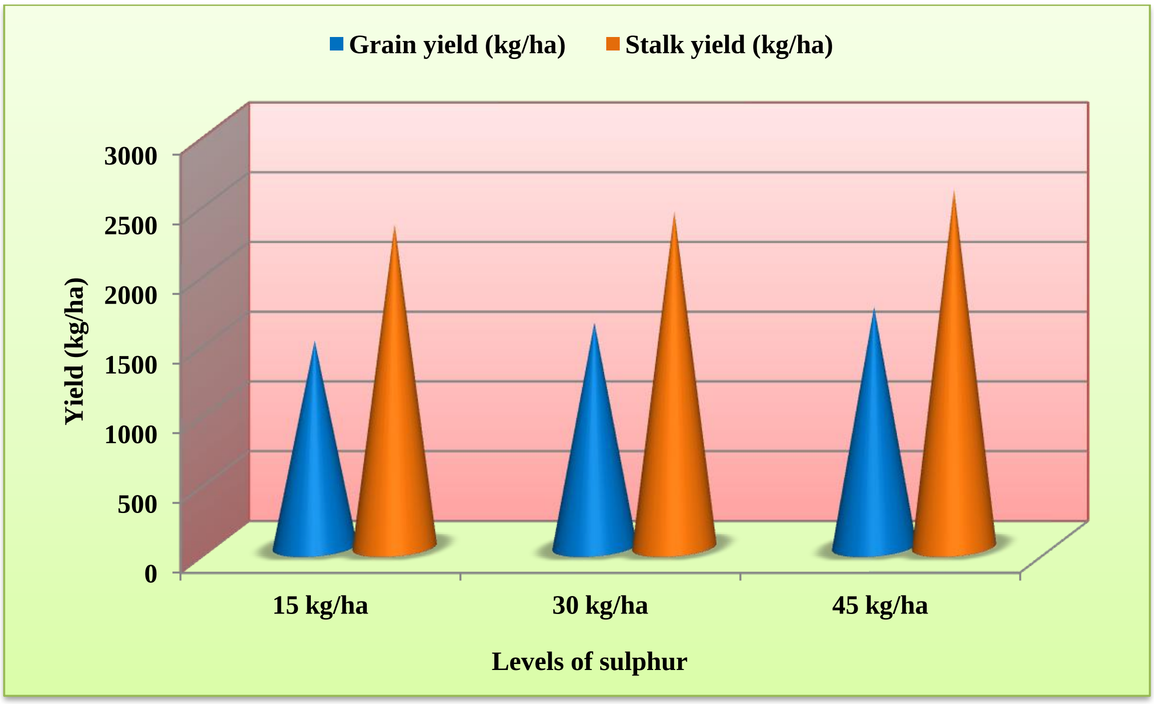

Fig. 4. Effect of different levels of sulphur on grain and stalk yield of sunflower

4.3 Effect of different sources and levels of sulphur on quality parameters of sunflower

4.3.1 Oil content (%)

The data on oil content (%) as affected by different sources and levels of sulphur during the period of study was analysed statistically and presented in Table 13.

4.3.1.1 Effect of sulphur sources on oil content of sunflower grains

Different sources of sulphur varied significantly in their effectiveness on oil content (Fig. 5). Among the sources, significantly higher oil content (37.84%) was recorded with the application of ammonium sulphate (S_3) compared to gypsum (35.19%) and elemental sulphur (34.83%) and however it was on par with SSP (36.23%).

4.3.1.2 Effect of sulphur levels on oil content of sunflower grains

The data on oil content (Table 13 and Fig. 6) showed that significant differences were manifested in the oil content of grains due to higher levels of sulphur application. The treatment receiving 45 kg S ha^{-1} (L_3) resulted in significantly higher oil content (38.23%) over 15 kg S ha^{-1} (33.01%) and however it was on par with 30 kg S ha^{-1} (36.84%). The increasing levels of sulphur showed positive effect on oil content of sunflower grains.

4.3.1.3 Interaction effect of sulphur sources and levels on oil content of sunflower grains

The interaction effect of sulphur sources and levels on oil content of sunflower was found to be non significant.

4.3.2 Oil yield (kg ha^{-1})

Data obtained on oil yield (kg ha^{-1}) during the period of study was analyzed statistically and presented in Table 13.

4.3.2.1 Effect of sulphur sources on oil yield of sunflower

Application of different sources of sulphur significantly increased the oil yield of sunflower. Among the sulphur sources, significantly higher oil yield (624.84 kg ha^{-1}) was obtained with the application of sulphur through ammonium sulphate (S_3) and was found statistically superior over elemental sulphur (S_1) and gypsum (S_2) and however it was on par with SSP (593.35 kg ha^{-1}).

4.3.2.2 Effect of sulphur levels on oil yield of sunflower

Oil yield of sunflower increased steeply with increase in the application rates of sulphur and attained maximum at higher levels of sulphur. Significantly higher oil yield was obtained with sulphur application at 45 kg S ha^{-1} (L_3) and decreases with lower levels. Oil yield of sunflower was ranged from 489.52 kg ha^{-1} at 15 kg S ha^{-1} (L_1) to 657.75 kg ha^{-1} at 45 kg S ha^{-1} (L_3).

4.3.2.3 Interaction effect of sulphur sources and levels on oil yield of sunflower

The interaction effect of sulphur sources and levels on oil yield of sunflower was found to be non significant.

4.3.3 Protein content (%)

Data on protein content (%) was analysed statistically and was significantly differed due to sulphur sources and levels, shown in Table 13.

4.3.3.1 Effect of sulphur sources on protein content of sunflower grains

Application of different sources of sulphur significantly increased the protein content in grains of sunflower (Fig. 5). Among the different sources of sulphur used, application of ammonium sulphate recorded significantly higher protein content (16.22%) compared to elemental sulphur (14.57%) and however it was statistically on par with gypsum (15.60%) and SSP (15.76%).

4.3.3.2 Effect of sulphur levels on protein content of sunflower grains

Application of higher levels of sulphur significantly increased the protein content of sunflower grains (Fig. 6). There was differential increase in protein content with the application of higher levels of sulphur than lower levels. The treatment receiving 45 kg S ha^{-1} (L_3) resulted in significantly higher protein content (17.08%) and it was significantly superior over 30 kg S ha^{-1} (15.32%) and 15 kg S ha^{-1} (14.22%).

4.3.3.3 Interaction effect of sulphur sources and levels

The interaction effect of sources and levels of sulphur was found to be non significant with respect to protein content of sunflower grains.

Table 13. Effect of different sources and levels of sulphur on oil content (%), oil yield (kg ha^{-1}), protein content (%) and protein yield (kg ha^{-1}) of sunflower grains

Treatments	Oil content (%)	Oil yield (kg ha^{-1})	Protein content (%)	Protein yield (kg ha^{-1})
Sulphur sources				
S_1 – Elemental sulphur	34.83	538.79	14.57	225.82
S_2 – Gypsum	35.19	562.27	15.60	249.56
S_3 – Ammonium sulphate	37.84	624.84	16.22	268.68
S_4 – Single super phosphate	36.23	593.35	15.76	258.33
S.Em±	0.76	15.25	0.40	8.80
CD (P=0.05)	2.23	44.72	1.16	25.81
Sulphur levels (kg S ha^{-1})				
L_1 – 15 kg ha^{-1}	33.01	489.52	14.22	210.69
L_2 – 30 kg ha^{-1}	36.84	592.16	15.32	246.87
L_3 – 45 kg ha^{-1}	38.23	657.75	17.08	294.23
S.Em ±	0.65	13.20	0.34	7.62
CD (P=0.05)	1.93	38.73	1.0	22.35
Interaction (S x L)				
S.Em ±	1.31	26.41	0.68	15.24
CD (P=0.05)	NS	NS	NS	NS

DAS – Days after sowing NS – Non significant

4.3.4 Protein yield (kg ha^{-1})

Experimental data obtained on effect of different sources and levels of sulphur on protein yield **(**kg ha^{-1}) of sunflower grains after harvest was analyzed statistically and presented in Table 13.

4.3.4.1 Effect of sulphur sources on protein yield of sunflower

Different sources of sulphur had significant influence on protein yield (kg ha^{-1}) of sunflower. Among the sources, significantly higher protein yield (268.68 kg ha^{-1}) was recorded with the application of ammonium sulphate (S_3) compared to elemental sulphur (225.82 kg ha^{-1}) and however it was on par with SSP (258.33 kg ha^{-1}) and gypsum (249.56 kg ha^{-1}).

4.3.4.2 Effect of sulphur levels protein yield of sunflower

The increased levels of sulphur showed positive effect on protein yield of sunflower seeds. Among the different levels of sulphur significantly higher protein yield (294.23 kg ha^{-1}) was recorded with the application of 45 kg S ha^{-1} (L_3) and it was superior to 30 kg S ha^{-1} (246.87 kg ha^{-1}) and 15 kg S ha^{-1} (210.69 kg ha^{-1}).

4.3.4.3 Interaction effect of sulphur sources and levels

There was no significant effect on interaction effect of sulphur sources and levels on protein yield of sunflower.

4.4 Effect of different sources and levels of sulphur on nutrient uptake (kg ha^{-1}) of sunflower

4.4.1 Nitrogen uptake (kg ha^{-1})

Data on nitrogen uptake by leaf, stalk, seed and total nitrogen (kg ha^{-1}) at different growth stages of sunflower was analysed statistically and presented in Table 14.

4.4.1.1 Effect of sulphur sources on nitrogen uptake by sunflower crop

The data on uptake of N in different parts of the plant of sunflower indicated significant variations due to sources of sulphur at 30, 60 DAS and at harvest except in leaf and stalk at 30 DAS. At 30 DAS, ammonium sulphate recorded significantly higher total N uptake (16.52 kg ha^{-1}). At 60 DAS, ammonium sulphate recorded significantly

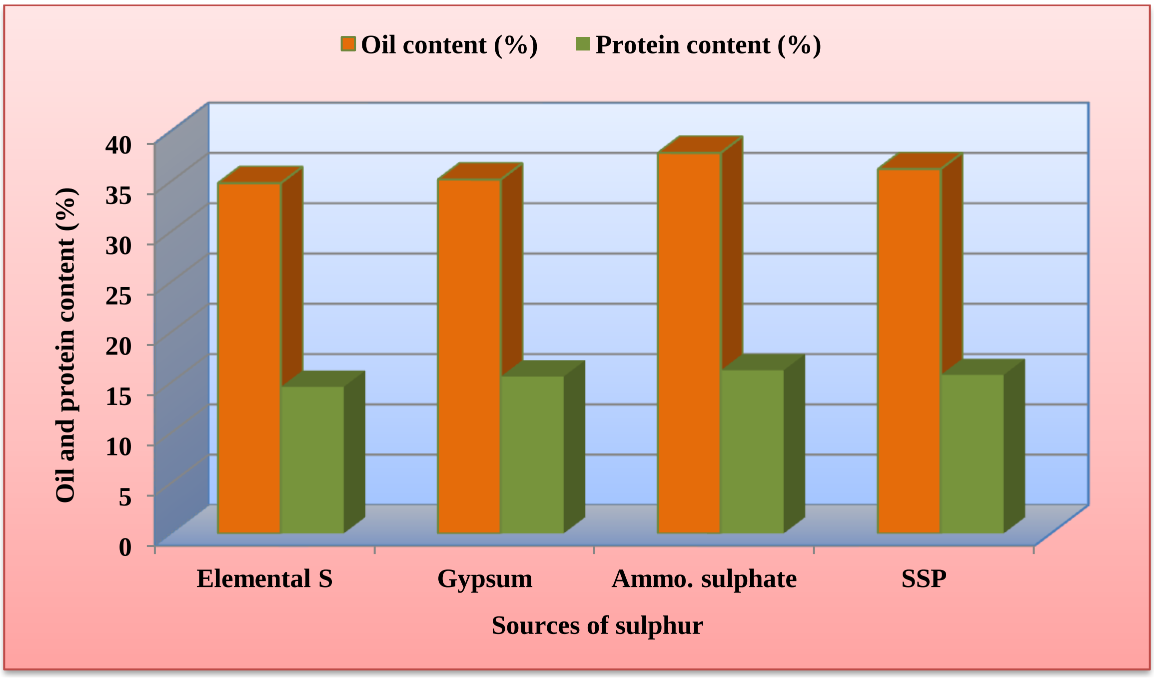

Fig. 5. Effect of different sources of sulphur on oil and protein content of sunflower

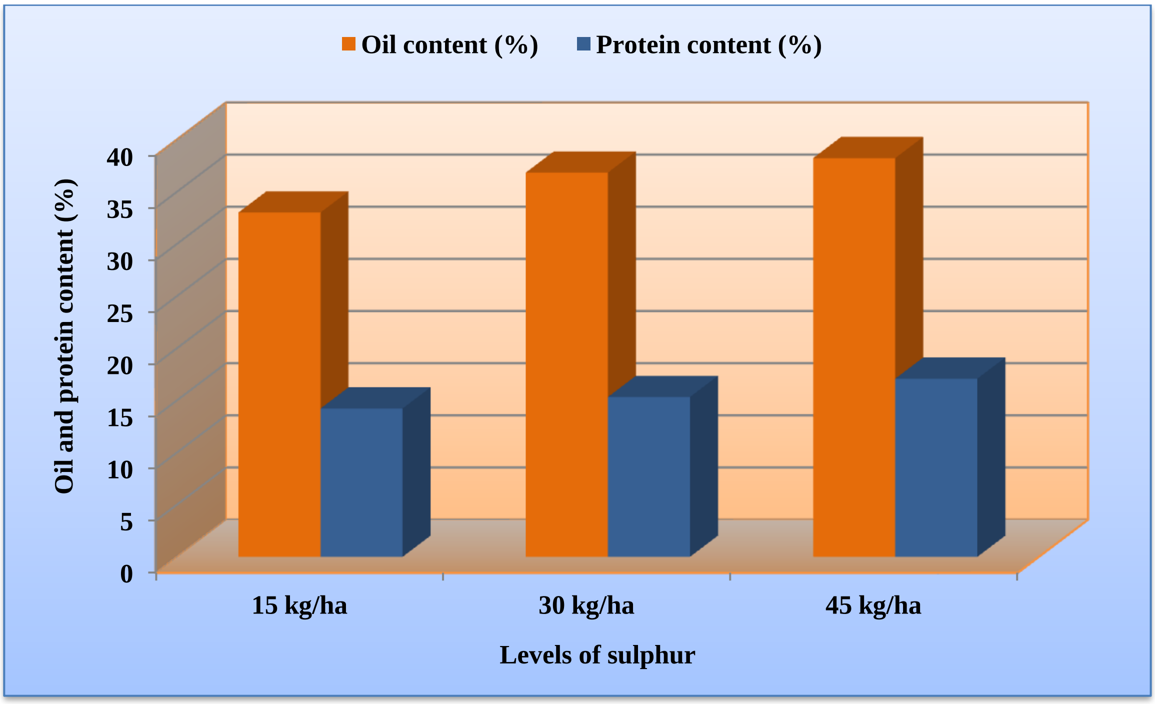

Fig. 6. Effect of different levels of sulphur on oil and protein content of sunflower

Table 14. Effect of different sources and levels of sulphur on uptake of nitrogen (kg ha^{-1}) at different growth stages of sunflower

Treatments	30 DAS			60 DAS			At harvest			
	Leaf	Stalk	Total	Leaf	Stalk	Total	Leaf	Stalk	Seed	Total
Sulphur sources										
S_1 – Elemental sulphur	5.09	8.53	13.62	13.48	14.84	28.32	19.71	22.49	36.13	78.33
S_2 – Gypsum	5.17	8.89	14.07	14.24	16.17	30.41	20.83	23.42	39.93	84.18
S_3 – Ammonium sulphate	6.00	10.52	16.52	15.74	18.17	33.91	23.20	27.36	42.99	93.55
S_4 – Single super phosphate	5.49	9.65	15.15	15.46	17.28	32.74	21.81	25.07	41.33	88.20
S.Em±	0.26	0.51	0.55	0.44	0.52	0.70	0.80	0.88	1.40	1.61
CD (P=0.05)	NS	NS	1.62	1.30	1.54	2.07	2.34	2.57	4.13	4.73
Sulphur levels (kg S ha^{-1})										
L_1 – 15 kg ha^{-1}	4.38	7.50	11.88	13.89	14.01	27.90	18.97	20.84	33.71	73.52
L_2 – 30 kg ha^{-1}	5.24	9.56	14.80	14.62	16.42	31.04	21.06	24.79	39.50	85.34
L_3 – 45 kg ha^{-1}	6.70	11.13	17.83	15.68	19.41	35.09	24.13	28.13	47.08	99.34
S.Em ±	0.23	0.44	0.48	0.38	0.45	0.61	0.70	0.76	1.21	1.40
CD (P=0.05)	0.67	1.30	1.40	1.12	1.33	1.80	2.03	2.23	3.57	4.10
Interaction (S x L)										
S.Em. ±	0.45	0.88	0.95	0.76	0.86	1.22	1.38	1.52	2.44	2.80
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 15. Effect of different sources and levels of sulphur on uptake of phosphorus (kg ha^{-1}) at different growth stages of sunflower

Treatments	30 DAS			60 DAS			At harvest			
	Leaf	Stalk	Total	Leaf	Stalk	Total	Leaf	Stalk	Seed	Total
Sulphur sources										
S_1 – Elemental sulphur	0.95	1.87	2.93	1.03	3.34	4.37	2.97	6.67	8.44	18.08
S_2 – Gypsum	1.11	2.17	3.25	1.07	3.44	4.52	3.01	7.20	9.02	19.24
S_3 – Ammonium sulphate	1.30	4.32	5.60	1.34	4.02	5.36	3.21	8.03	9.43	20.66
S_4 – Single super phosphate	1.24	2.97	4.14	1.17	3.61	4.78	3.10	7.73	9.19	20.03
S.Em±	0.06	0.56	0.57	0.05	0.11	0.12	0.06	0.11	0.09	0.17
CD (P=0.05)	0.18	1.65	1.67	0.17	0.33	0.36	0.17	0.32	0.27	0.51
Sulphur levels (kg S ha^{-1})										
L_1 – 15 kg ha^{-1}	1.04	1.59	2.52	0.97	2.80	3.76	2.86	6.04	8.55	17.45
L_2 – 30 kg ha^{-1}	1.15	2.69	3.83	1.15	3.48	4.63	3.07	7.37	9.03	19.48
L_3 – 45 kg ha^{-1}	1.25	4.22	5.59	1.35	4.54	5.88	3.29	8.82	9.47	21.58
S.Em ±	0.05	0.49	0.50	0.05	0.09	0.11	0.05	0.09	0.08	0.15
CD (P=0.05)	0.16	1.43	1.45	0.14	0.28	0.32	0.14	0.28	0.23	0.44
Interaction (S x L)										
S.Em. ±	0.11	0.97	0.98	0.10	0.20	0.22	0.10	0.19	0.16	0.30
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 16. Effect of different sources and levels of sulphur on uptake of potassium (kg ha^{-1}) at different growth stages of sunflower

Treatments	30 DAS			60 DAS			At harvest			
	Leaf	Stalk	Total	Leaf	Stalk	Total	Leaf	Stalk	Seed	Total
Sulphur sources										
S_1 – Elemental sulphur	13.34	42.63	55.97	21.11	72.96	94.06	26.82	114.67	11.09	152.58
S_2 – Gypsum	13.84	46.54	60.38	21.80	75.80	97.60	27.32	119.35	11.62	158.29
S_3 – Ammonium sulphate	15.84	51.31	67.15	24.36	89.73	114.09	31.16	136.58	14.28	182.03
S_4 – Single super phosphate	14.38	50.01	64.39	23.36	83.64	107.00	30.41	126.01	12.66	169.95
S.Em±	0.63	2.19	2.17	0.74	3.71	3.50	0.83	4.58	0.60	4.50
CD (P=0.05)	NS	6.42	6.36	2.18	10.9	10.26	2.45	13.41	1.75	13.21
Sulphur levels (kg S ha^{-1})										
L_1 – 15 kg ha^{-1}	12.27	38.30	50.57	20.63	66.14	86.77	25.92	116.45	9.81	152.18
L_2 – 30 kg ha^{-1}	14.40	48.12	62.51	22.35	82.67	105.02	29.11	124.36	12.38	166.50
L_3 – 45 kg ha^{-1}	16.38	56.46	72.83	24.99	92.78	117.78	31.76	131.65	15.05	178.46
S.Em ±	0.55	1.89	1.88	0.64	3.21	3.03	0.72	3.96	0.51	3.89
CD (P=0.05)	1.62	5.56	5.51	1.89	9.44	8.88	2.11	11.63	1.52	11.42
Interaction (S x L)										
S.Em. ±	1.10	3.7	3.76	1.29	6.43	6.06	1.33	7.93	1.03	7.8
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

higher N uptake in leaf (15.74 kg ha^{-1}), stalk (18.17 kg ha^{-1}) and total (33.91 kg ha^{-1}) compared to elemental sulphur (13.48, 14.84 and 28.32 kg ha^{-1}) and gypsum (14.24, 16.17 and 30.41 kg ha^{-1}) in leaf, stalk and total respectively and however it was on par with SSP (S_4). At harvest stage ammonium sulphate recorded significantly higher N uptake in leaf (23.20 kg ha^{-1}), stalk (27.36 kg ha^{-1}), seed (42.99 kg ha^{-1}) and total (93.55 kg ha^{-1}) compared to gypsum and elemental sulphur and however it was on par with SSP (S_4). Among the different parts of the plant higher N uptake was recorded in seed than leaf and stalk samples.

4.4.1.2 Effect of sulphur levels on nitrogen uptake by sunflower crop

The data on nitrogen uptake by leaf, stalk, seed and total (kg ha^{-1}) indicated significant variations due to different levels of sulphur at all the growth stages. At 30 DAS, significantly higher nitrogen uptake (6.7, 11.13 and 17.83 kg ha^{-1}) was recorded with 45 kg S ha^{-1} compared to 30 kg S ha^{-1} (4.38, 7.50 and 11.88 kg ha^{-1}) and 15 kg S ha^{-1} (4.38, 7.50 and 11.88 kg ha^{-1}) in leaf, stalk and total respectively. At 60 DAS irrespective of sources, application of 45 kg S ha^{-1} produced significantly higher N uptake (15.68, 19.41 and 35.09 kg ha^{-1}) in leaf, stalk and seed compared to 15 and 30 kg S ha^{-1} and however N uptake in leaf was on par with 30 kg ha^{-1}. At harvest among the levels of sulphur, highest N uptake was observed in the treatment receiving 45 kg S ha^{-1} (24.13, 28.13, 47.08 and 99.34 kg ha^{-1}) followed by 30 kg S ha^{-1} (21.06, 24.79, 39.50 and 85.34 kg ha^{-1}) and 15 kg S ha^{-1} (18.97, 20.84, 33.71 and 73.52 kg ha^{-1}) in leaf, stalk, seed and total nitrogen uptake of sunflower.

4.4.1.3 Interaction effect of sulphur sources and levels

Interaction effect of different sulphur sources and levels were found to be non significant in case of N uptake by leaf, seed, stalk and total.

4.4.2 Phosphorus uptake (kg ha^{-1})

The data obtained on uptake of phosphorus (kg ha^{-1}) at different growth stages of sunflower during the period of study was analysed statistically and presented in Table 15.

4.4.2.1 Effect of sulphur sources on phosphorus uptake by sunflower crop

Phosphorus uptake in leaf, seed, stalk and total was significantly influenced due to different sulphur sources at all the growth stages of sunflower. At 30 DAS application of ammonium sulphate (S_3) recorded significantly higher P uptake (1.30, 4.32 and 5.60 kg ha^{-1}) in leaf, stem and total respectively, compared to elemental sulphur (0.95, 1.87 and 2.93 kg ha^{-1}) and gypsum (1.11, 2.17 and 3.25 kg ha^{-1}) and however it was on par with SSP (1.24, 2.97 and 4.14 kg ha^{-1}). At 60 DAS, ammonium sulphate (1.34, 4.02 and 5.36 kg ha^{-1}) recorded significantly higher P uptake in leaf, stem and total respectively, compared to SSP (S_4), gypsum (S_2) and elemental sulphur (S_1) and however P uptake in leaf was on par with SSP (1.17 kg ha^{-1}). At harvest similar trend was observed as followed at 60 DAS, ammonium sulphate recorded significantly higher P uptake (3.21, 8.03, 9.43 and 20.66 kg ha^{-1}) in leaf, stalk, seed and total fallowed by SSP (S_4), gypsum (S_2) and elemental sulphur (S_1) and however total P uptake was on par with SSP.

4.4.2.2 Effect of sulphur levels on phosphorus uptake by sunflower crop

The increase in the levels of sulphur increased the uptake of P in leaf, seed, stalk and total at all the growth stages. At 30 DAS, significantly higher P uptake (1.25, 4.22 and 5.59 kg ha^{-1}) was recorded with 45 kg S ha^{-1} compared to 30 kg S ha^{-1} (1.15, 2.69 and 3.83 kg ha^{-1}) and 15 kg S ha^{-1} (1.04, 1.59 and 2.52 kg ha^{-1}) in leaf, stalk and total, respectively. Similar trend was fallowed at 60 DAS, where 45 kg S ha^{-1} (1.35, 4.54 and 5.88 kg ha^{-1}) recorded higher P uptake fallowed by 30 (1.15, 3.48 and 4.63 kg ha^{-1}) and 15 kg S ha^{-1} (0.97, 2.80 and 3.76 kg ha^{-1}) in leaf, stalk and total, respectively. At harvest stage higher uptake of P was recorded with 45 kg S ha^{-1} (3.29, 8.82 9.47 and 21.58 kg ha^{-1}) in leaf, stalk, grain and total respectively, compared to 30 kg S ha^{-1} (3.07, 7.37 9.03 and 19.48 kg ha^{-1}) and 15 kg S ha^{-1} (2.86, 6.04, 8.55 and 17.45 kg ha^{-1}).

4.4.2.3 Interaction effect of sulphur sources and levels

Interaction effect of sulphur sources and levels were found to be non significant in case of P uptake by leaf, seed, stalk and total.

4.4.3 Potassium uptake (kg ha^{-1})

Data on potassium uptake by leaf, seed, stalk and total (kg ha^{-1}) at different growth stages was analysed statistically and significantly differed due to sulphur sources and levels and shown in Table 16.

4.4.3.1 Effect of sulphur sources on uptake of K by crop at different growth stages

There was a significant increase in the uptake of K in leaf, seed, stalk and total with the application of different sources of sulphur at all the growth stages of sunflower except at 30 DAS in leaf. At 30 DAS, there was no significant effect on K uptake in leaf and however significantly higher K uptake was noticed with stalk and total. Among different sources, ammonium sulphate (51.31 and 67.15 kg ha^{-1}) recorded significantly higher uptake of K in stalk and total over other sources and however potassium uptake in stalk was on par with SSP (50.01 kg ha^{-1}) and gypsum (46.54 kg ha^{-1}) whereas with respect to total uptake it was on par with SSP (64.39). At 60 DAS significantly higher uptake of K was recorded with application of ammonium sulphate (24.36, 89.73 and 114.09 kg ha^{-1}) in leaf, stalk and total fallowed by gypsum (21.80, 75.8 and 97.06 kg ha^{-1}) and elemental sulphur (21.11, 72.96 and 94.06 kg ha^{-1}) and however it was on par with SSP (23.36, 83.64 and 107 kg ha^{-1}). At harvest stage significantly higher K uptake was noticed with the application of ammonium sulphate (31.16, 136.58, 14.28 and 182.03 kg ha^{-1}) in leaf, stalk, seed and total uptake respectively, compared to gypsum and elemental sulphur and however it was on par with SSP (30.41, 126.01, 12.66 and 169.52 kg ha^{-1})

4.4.3.2 Effect of sulphur levels on uptake of K by crop at different growth stages

Different levels of sulphur improved the uptake of K in the leaf, seed, stalk and total at all the growth stages. The rate of increase in uptake was higher at higher levels of sulphur than at the lower application rates. At 30 DAS, significantly higher K uptake (16.38, 56.46 and 72.83 kg ha^{-1}) was recorded with 45 kg S ha^{-1} compared to 30 kg S ha^{-1} (14.40, 48.12 and 62.51 kg ha^{-1}) and 15 kg S ha^{-1} (12.27, 38.30 and 50.57 kg ha^{-1}) in leaf, stalk and total respectively.

Similar trend was fallowed at 60 DAS, where 45 kg S ha^{-1} (24.99, 92.78 and 117.78 kg ha^{-1}) in leaf, stalk and total recorded significantly higher K uptake fallowed by 30 and 15 kg S ha^{-1}. At harvest among the levels of sulphur, significantly higher K uptake was observed in the treatment receiving 45 kg S ha^{-1} (31.76, 131.65, 15.05 and 178.46 kg ha^{-1}) in leaf, stalk, seed and total respectively, compared to 30 and 15 kg S ha^{-1} and however K uptake in stalk (124.36) was on par with 30 kg S ha^{-1}.

4.4.3.3 Interaction effect of sulphur sources and levels

Interaction effect of sulphur sources and levels were found to be non significant in case of K uptake by leaf, seed, stalk and total of sunflower.

4.4.4 Sulphur uptake (kg ha^{-1})

Data on sulphur uptake by leaf, seed, stalk and total (kg ha^{-1}) at different growth stages was analysed statistically and significantly differed due to sulphur sources and levels and shown in Table 17.

4.4.4.1 Effect of sulphur sources on sulphur uptake (kg ha^{-1}) by sunflower

There was a significant increase in the uptake of S in leaf, seed, stalk and total with the application of different sources of sulphur at all the growth stages of sunflower (Fig. 7). At 30 DAS among the sources of sulphur significantly higher uptake of S was recorded with ammonium sulphate (2.33, 3.28 and 5.6 kg ha^{-1}) in leaf, stalk and total compared to gypsum (1.89, 2.73 and 4.62 kg ha^{-1}) and elemental sulphur (1.48, 2.22 and 3.70 kg ha^{-1}) and however it was on par with SSP (2.16, 2.93 and 5.09 kg ha^{-1}). At 60 DAS similar trend was observed as followed at 30 DAS, ammonium sulphate (3.08, 5.08, and 8.16 kg ha^{-1}) recorded significantly higher S uptake in leaf, stalk and total fallowed by gypsum (S_2) and elemental sulphur (S_1) and however it was on par with SSP (S_4). At harvest stage significantly higher S uptake was recorded with ammonium sulphate (3.66, 7.37 and 4.53 kg ha^{-1}) in leaf, stalk, seed and total compared to gypsum (S_2) and elemental sulphur (S_1) and however it was on par with SSP (3.28, 6.94, 4.41 and 14.63 kg ha^{-1})

4.4.4.2 Effect of sulphur levels on sulphur uptake (kg ha^{-1}) by sunflower

The sulphur uptake by the crop at 30, 60 DAS and at harvest increased significantly with increase in sulphur application and reached to higher when 45 kg S ha^{-1} (L_3) was applied (Fig. 8). The uptake of S was significantly increased with increasing sulphur level (15 to 45 kg S ha^{-1}). At 30 DAS higher uptake of sulphur (2.81, 4.06 and 6.88 kg ha^{-1}) was recorded in leaf, stem and total with 45 kg S ha^{-1} significantly superior to 30 (L_2) and 15 kg S ha^{-1} (L_1).

At 60 DAS significantly higher uptake of sulphur (3.6, 5.82 and 9.42 kg ha^{-1}) in different parts of the plant was recorded with 45 kg S ha^{-1} compared to 30 and 15 kg S ha^{-1}. At harvest significantly higher S uptake (4.63, 8.25, 5.33 and 18.07 kg ha^{-1}) was recorded with 45 kg S ha^{-1} in leaf, stalk, seed and total respectively compared to 30 kg S ha^{-1} and 15 kg S ha^{-1}.

Table 17. Effect of different sources and levels of sulphur on uptake of sulphur (kg ha^{-1}) at different growth stages of sunflower

Treatments	30 DAS			60 DAS			At harvest			
	Leaf	**Stalk**	**Total**	**Leaf**	**Stalk**	**Total**	**Leaf**	**Stalk**	**Seed**	**Total**
Sulphur sources										
S_1 – Elemental sulphur	1.48	2.22	3.70	2.07	3.56	5.62	2.74	6.20	3.72	12.49
S_2 – Gypsum	1.89	2.73	4.62	2.21	4.11	6.32	3.07	6.53	3.87	13.47
S_3 – Ammonium sulphate	2.33	3.28	5.60	3.08	5.08	8.16	3.66	7.37	4.53	15.56
S_4 – Single super phosphate	2.16	2.93	5.09	2.78	4.75	7.53	3.28	6.94	4.41	14.63
S.Em±	0.16	0.15	0.17	0.13	0.14	0.23	0.14	0.17	0.20	0.32
CD (P=0.05)	0.49	0.44	0.51	0.40	0.43	0.70	0.41	0.50	0.61	0.94
Sulphur levels (kg S ha^{-1})										
L_1 – 15 kg ha^{-1}	1.22	1.41	2.63	1.38	2.80	4.18	1.81	5.36	2.96	9.96
L_2 – 30 kg ha^{-1}	1.87	2.90	4.76	2.62	4.51	7.12	3.13	6.68	4.11	13.91
L_3 – 45 kg ha^{-1}	2.81	4.06	6.88	3.60	5.82	9.42	4.63	8.25	5.33	18.07
S.Em ±	0.14	0.13	0.15	0.11	0.14	0.20	0.12	0.15	0.17	0.27
CD (P=0.05)	0.40	0.38	0.44	0.35	0.40	0.60	0.35	0.44	0.50	0.55
Interaction (S x L)										
S.Em. ±	0.28	0.26	0.30	0.23	0.25	0.41	0.24	0.30	0.34	0.53
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

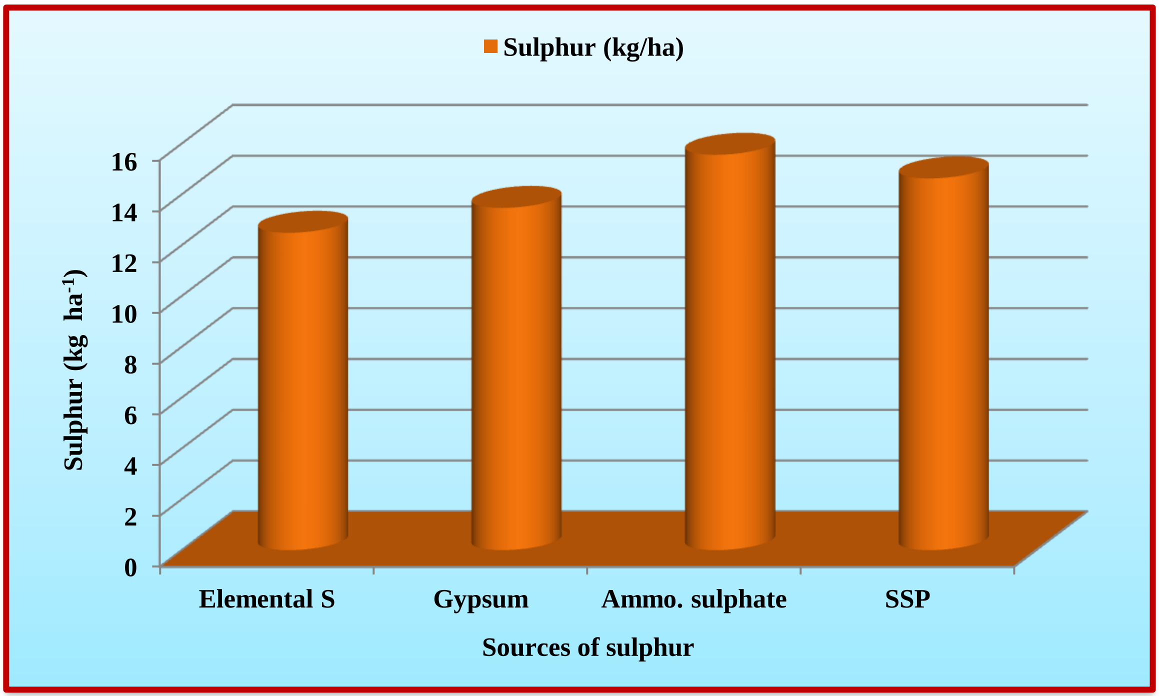

Fig. 7. Effect of different sources of sulphur on total uptake of sulphur by sunflower

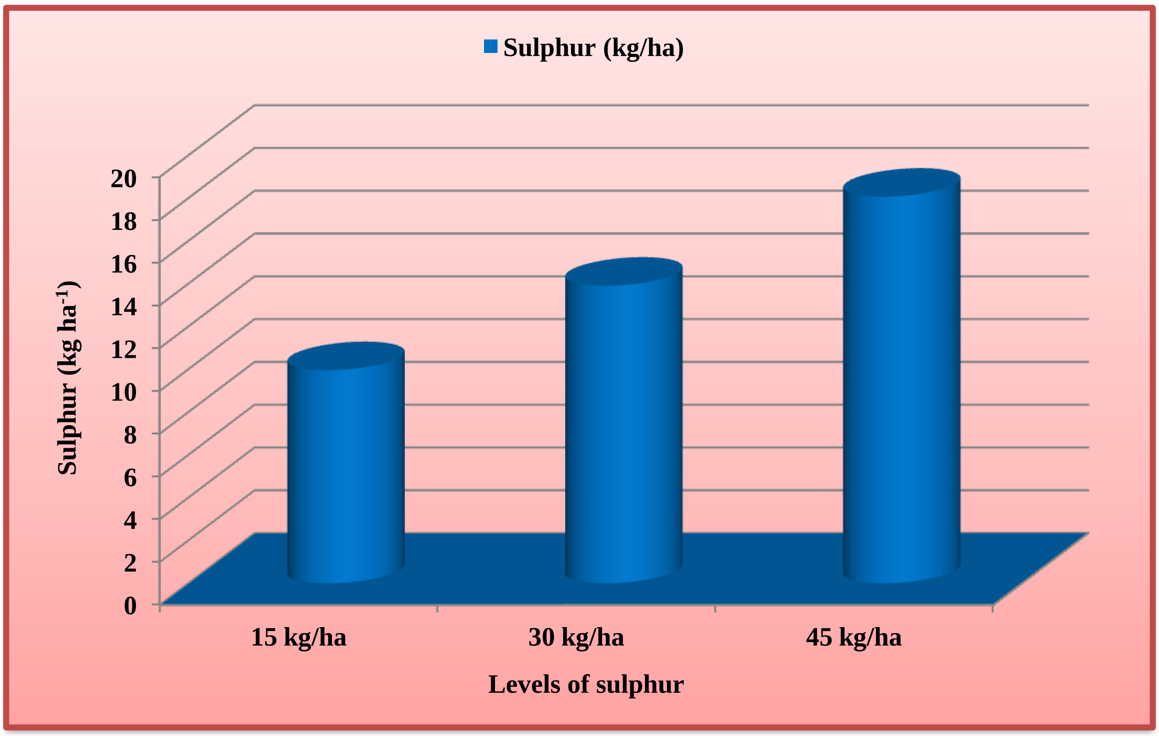

Fig. 8. Effect of different levels of sulphur on uptake of sulphur by sunflower

4.4.4.3 Interaction effect of sulphur sources and levels

Interaction effect of sulphur sources and levels were found to be non significant in case of S uptake by leaf, seed, stalk and total of sunflower.

4.5 Effect of different sources and levels of sulphur on chemical properties of soil after harvest of sunflower

4.5.1 Soil reaction

Experimental data obtained on soil reaction during the period of study was analyzed statistically and presented in Table 18. The pH 1:2.5 (soil water ratio) of soil did not vary significantly due to various sources and levels of sulphur. In general pH of the soil ranged from 7.51 to 7.82 with respect to sources and 7.56 to 7.73 with respect to levels of sulphur.

4.5.2 Electrical conductivity (dSm^{-1})

Effect of different sources and levels of sulphur on electrical conductivity of soil during the period of study was analyzed statistically and presented in Table 18. No significant difference in electrical conductivity of soil was observed among different sources and levels of sulphur. Electrical conductivity of soil ranged from 0.14 to 0.16 dSm^{-1} with respect to sources and levels of sulphur.

4.5.3 Organic carbon ($g\ kg^{-1}$)

Data obtained on the organic carbon content of soil as influenced by various sources and levels of sulphur was statistically analyzed and presented in Table 18. Different sources and levels of sulphur had not influenced significant effect on organic carbon content of soil. In general, organic carbon content of the soil ranged from 4.16 to 4.57 $g\ kg^{-1}$ with respect to sources and 4.09 to 4.49 $g\ kg^{-1}$ with respect to levels of sulphur.

4.6 Effect of different sources and levels of sulphur on available nutrient status of soil after harvest of sunflower

4.6.1 Available N ($kg\ ha^{-1}$) in the soil

Data pertaining to available N ($kg\ ha^{-1}$) in the soil after harvest of sunflower was analyzed statistically and significantly differed due to sulphur sources and levels of sulphur and shown in Table 19.

Table 18. Effect of different sources and levels of sulphur on chemical properties of soil after harvest of sunflower

Treatments	pH	EC (dSm^{-1})	OC ($g\ kg^{-1}$)
Sulphur sources			
S_1 – Elemental sulphur	7.51	0.14	4.16
S_2 – Gypsum	7.63	0.15	4.19
S_3 – Ammonium sulphate	7.82	0.16	4.57
S_4 – Single super phosphate	7.70	0.14	4.46
S.Em±	0.08	0.005	0.13
CD (P=0.05)	NS	NS	NS
Sulphur levels (kg S ha^{-1})			
L_1 – 15 kg ha^{-1}	7.56	0.14	4.09
L_2 – 30 kg ha^{-1}	7.70	0.14	4.46
L_3 – 45 kg ha^{-1}	7.73	0.16	4.49
S.Em ±	0.071	0.004	0.12
CD (P=0.05)	NS	NS	NS
Interaction (S x L)			
S.Em ±	0.14	0.008	0.24
CD (P=0.05)	NS	NS	NS

DAS – Days after sowing NS – Non significant

Table 19. Effect of different sources and levels of sulphur on available nutrients status (kg ha^{-1}) of soil after harvest of sunflower

Treatments	N	P_2O_5	K_2O	S
Sulphur sources				
S_1 – Elemental sulphur	71.95	30.13	245.44	13.62
S_2 – Gypsum	74.69	31.09	252.44	14.15
S_3 – Ammonium sulphate	79.11	34.21	265.89	16.35
S_4 – Single super phosphate	76.80	33.09	257.89	14.54
S.Em±	1.08	1.12	5.09	0.58
CD (P=0.05)	3.18	NS	NS	1.70
Sulphur levels (kg S ha^{-1})				
L_1 – 15 kg ha^{-1}	68.07	30.44	249.50	12.28
L_2 – 30 kg ha^{-1}	76.00	31.98	252.08	14.16
L_3 – 45 kg ha^{-1}	82.85	33.96	264.67	17.55
S.Em ±	0.94	0.97	4.41	0.50
CD (P=0.05)	2.57	NS	NS	1.47
Interaction (S x L)				
S.Em ±	1.88	1.94	8.82	1.00
CD (P=0.05)	NS	NS	NS	NS

DAS – Days after sowing NS – Non significant

4.6.1.1 Effect of sulphur sources

Various sources of sulphur influenced significantly on available nitrogen content present in the soil after harvest of the crop. Among the different sources of sulphur used, higher available N content (79.11 kg ha^{-1}) in the soil was recorded under ammonium sulphate (S_3) treated plot compared to gypsum (74.69 kg ha^{-1}) and elemental sulphur (71.95 kg ha^{-1}) and however it was on par with SSP (76.80 kg ha^{-1}).

4.6.1.2 Effect of sulphur levels

Application of 45 kg S ha^{-1} (L_3) significantly increased available nitrogen (82.85 kg ha^{-1}) content in the soil after harvest of sunflower compared to 30 kg S ha^{-1} (L_2) and 15 kg S ha^{-1} (L_1). The available N content in the soil decreased with decrease in the sulphur levels.

4.6.1.3 Interaction effect of sulphur sources and levels

Interaction effect between different sources and levels of sulphur did not showed any significant effect with respect to available nitrogen content in the soil after harvest of sunflower.

4.6.2 Available P_2O_5 (kg ha^{-1}) in the soil

Data pertaining to available P_2O_5 in soil after harvest of the sunflower was analyzed statistically and presented in the Table 19. There was no significant effect was noticed with respect to various sources and levels of sulphur and interaction of sulphur sources.

4.6.3 Available K_2O (kg ha^{-1}) in the soil

Data pertaining to available K_2O in soil after harvest of the crop was analyzed statistically and presented in Table 19. Different sources and levels of sulphur had not influenced significant effect on available K_20 (kg ha^{-1}) in the soil.

4.6.4 Available S (kg ha^{-1}) in the soil

Experimental data pertaining to available S (kg ha^{-1}) in the soil due to different sources and levels of sulphur after harvest of sunflower was analysed statistically and shown in Table 19.

4.6.4.1 Effect of sulphur sources

Application of different sources of sulphur significantly influenced the available S in the soil after harvest of the sunflower (Fig. 9). Among the different sulphur sources, application of ammonium sulphate (S_3) increased the S content in the soil after harvest of crop compared to SSP (S_4), gypsum (S_2) and elemental sulphur (S_1).Significantly higher available S content of 16.35 kg ha^{-1} was recorded with ammonium sulphate (S_1) compared with that of 14.54 kg ha^{-1}, 14.15 kg ha^{-1} and 13.62 kg ha^{-1} of SSP (S_4), gypsum (S_2) and elemental sulphur (S_1), respectively.

4.6.4.2 Effect of sulphur levels

At harvest stage, the available sulphur content in soil increased from its initial status in all the treatments with increase in sulphur levels (Fig 10). However, significantly higher available sulphur content in soil was recorded with 45 kg S ha^{-1} and the lower with 15 kg S ha^{-1}. The higher S content of 17.55 kg ha^{-1} was recorded with L_3 (45 kg S ha^{-1}) which was significantly superior over rest of the sulphur levels.

4.7 Economics

Data pertaining to economics of sunflower was analysed statistically and significantly differed due to sulphur sources and levels and shown in Table 20.

4.7.1 Effect of sulphur sources

Sulphur application through ammonium sulphate (S_3) recorded higher gross returns (₹ 65,920.0 ha^{-1}), net returns (₹45,962 ha^{-1}) and B: C ratio (3.25) as compared to other sources *viz*., single super phosphate (S_2), gypsum (S_3) and elemental sulphur (S_1). Elemental sulphur (S_1) recorded the lowest gross returns, net returns and B: C ratio. (₹ 61,453.33, 39,229.33 and 2.76)

4.7.2 Effect of sulphur levels

The significantly higher gross returns (₹ 68793.33 ha^{-1}) and net returns (₹ 47,617.58 ha^{-1}) were recorded with the application of 45 kg S ha^{-1} (L_3) which was significantly more than application of 30 kg S ha^{-1} (L_2) and 15 kg S ha^{-1} (L_1). Each increasing level of sulphur increased the economic yield significantly which ultimately resulted in increased gross and net returns ha^{-1}. The significantly higher B:C ratio (3.19) was observed with the application of 45 kg S ha^{-1} (L_3) followed by 30 kg S ha^{-1} (3.06) and 15 kg S ha^{-1} (2.96).

Table 20. Economics of sunflower as influenced by different sources and levels of sulphur

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B:C
Sulphur sources				
S_1 – Elemental sulphur	22224.00	61453.33	39229.33	2.76
S_2 – Gypsum	19959.00	63688.89	43729.89	3.19
S_3 – Ammonium sulphate	20282.67	65920.00	45962.00	3.25
S_4 – Single super phosphate	20328.50	65293.33	45515.00	3.21
Sulphur levels (kg S ha^{-1})				
L_1 – 15 kg ha^{-1}	19945.00	59126.67	39290.92	2.96
L_2 – 30 kg ha^{-1}	20646.63	64346.67	43918.67	3.06
L_3 – 45 kg ha^{-1}	21504.00	68793.33	47617.58	3.19

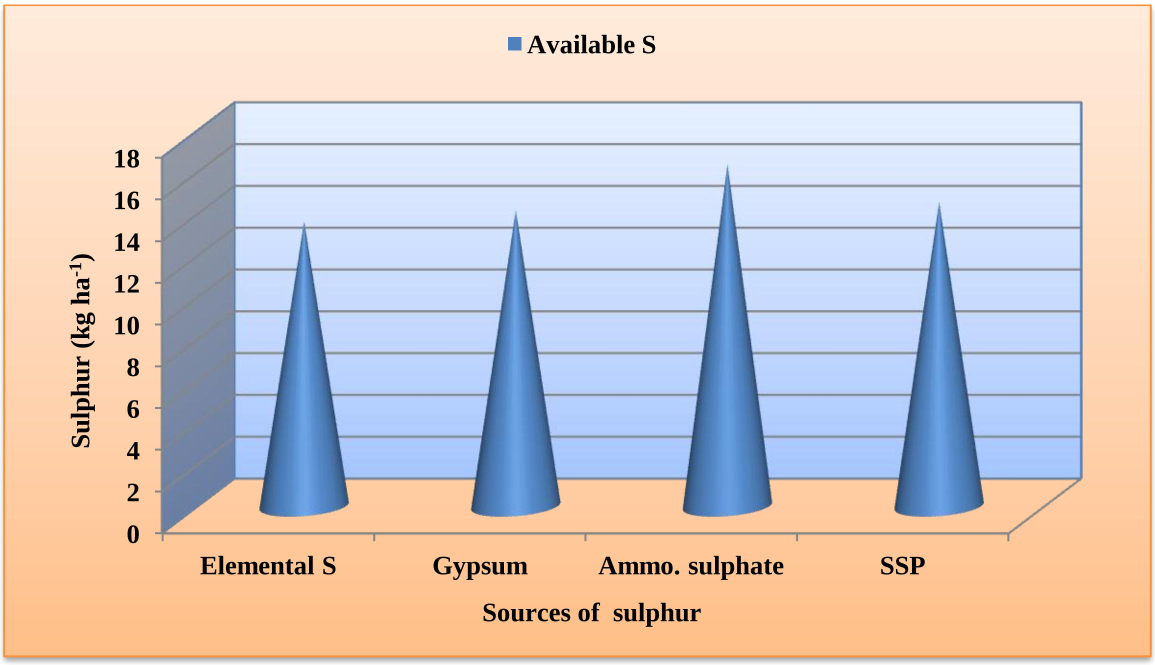

Fig. 9. Effect of different sources of sulphur on available S in soil after harvest

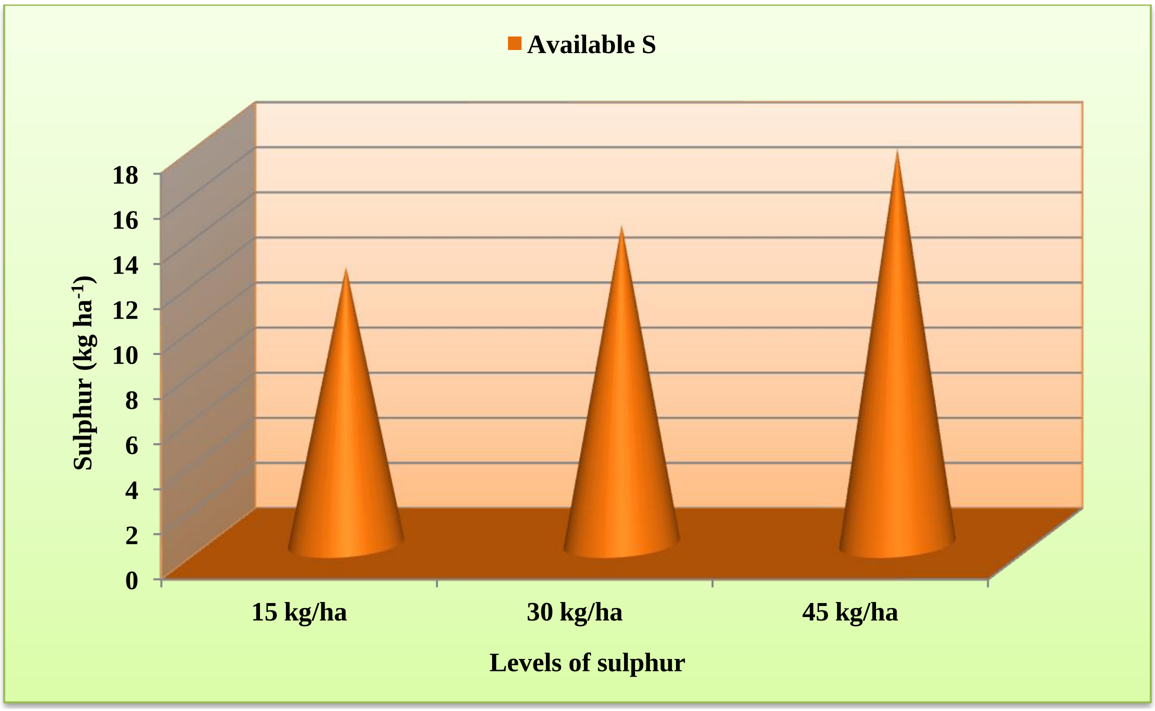

Fig. 10. Effect of different levels of sulphur on available S in soil after harvest

4.7.3 Interaction effect of sulphur sources and levels

The interaction between the sources and levels of sulphur did not show significant effect on gross returns, net returns and B: C ratio.

Discussion

V. DISCUSSION

The central theme of the investigation was to find out the effect of different sources and levels of sulphur on productivity and quality of rainfed sunflower (*Helianthus annuus* L.) The experiment was conducted on a vertisol under rainfed condition during the *kharif* season of 2016 at Main Agriculture Research Station, Raichur. In the light of various established physiological as well as biochemical processes, efforts has been made to explain and discuss pertinent findings in this chapter. Attempt is also being made to corroborate the findings of this investigation with those reported by other scientific workers in this field in the past. The results of the investigation are discussed in this chapter under various headings.

5.1 Effect of weather on crop performance

Raichur is situated in the North Eastern Dry Zone of Karnataka (Zone-2) at 16^{o} $15^{'}$ N and 75^{o} $20^{'}$ E longitude with an altitude of 389 meter above mean sea level. Crop was raised under rainfed condition of zone-2 at Main Agricultural Research Station, Raichur. Total annual rainfall was 868.7 mm. during crop growth period, July (143.2 mm), August (78.0 mm), September (292.5 mm) and October (39.2 mm) months of 2016 received higher rainfalls which were more than that of normal annual rainfall pattern. The mean maximum air temperature was higher in the month of April (41.8 ^{o}C) during 2016. During cropping period higher temperature was recorded in the month of August (32.4 ^{o}C). The mean minimum air temperature higher in the month of December (15.6 ^{o}C) and during cropping period higher mean minimum air temperature was recorded in the month of October (19.4 ^{o}C). The mean monthly relative humidity ranged from 48 to 92 per cent during 2016.

5.2 Growth parameters

The growth of sunflower was recorded from the day of sowing at regular intervals till maturity. Crop growth was measured in terms of plant height, number of leaves, leaf area, leaf area index and dry matter production. The results of the investigation revealed that different sources and levels of sulphur had significant influence on plant height, number of leaves, leaf area plant^{-1}, leaf area index and total dry matter production at different stages of the crop growth (Table 3,4,5,6, and 7).

Among different sources of sulphur, significantly higher plant height (184.10 and 185.66 cm) was observed with ammonium sulphate (S_1) as a source of sulphur at 60 DAS and at harvest over other sources of sulphur *viz*., SSP (S_4), gypsum (S_2) and elemental sulphur (S_1). Increase in plant height due to ammonium sulphate might be attributed to the supply of sulphur is more readily available form than the other sources like SSP, gypsum and elemental sulphur. This would have increased the metabolic processes in the plants and promoted the meristamatic activities causing apical growth and resulted in increased plant height (Intodia and Tomar, 1997). Improvement in plant growth could partly be attributed to the beneficial effect of sulphur fertilization as nutrient (Tandon, 1989). Superiority of ammonium sulphate over the other sources such as gypsum and SSP in respect to plant height was observed in soybean (Dhillon and Dev, 1980) and in sunflower (Sreemannarayana *et al*., 1994).

Significantly higher plant height (68.09, 188.07 and 187.04 cm) was recorded with 45 kg S ha^{-1} (L_3) at 30, 60 DAS and at harvest stage and superior to 30 kg S ha^{-1} (L_2) and 15 kg S ha^{-1} (L_1). Better growth and development of sunflower plants due to higher levels of sulphur dose would have been due to multiple role of sulphur in protein and carbohydrate metabolism of plants by activating a number of enzymes which participate in dark reaction of photosynthesis and hence increases the plant height by higher dose of sulphur application. The crop receiving higher dose of sulphur might have been helped in terms of vigorous root growth, formation of chlorophyll, resulting in higher photosynthesis (Ravi *et al*., 2010). Increase in plant height may be due to better nutritional environment for plant growth at active vegetative stages as a result of improvement in root growth, cell multiplication, elongation and cell expression in the plant body (Steffenson, 1954), which ultimately increased the plant height. Significant increase in plant height with sulphur application might be attributed to direct and indirect involvement of sulphur in the photosynthesis process of plants (Patil *et al*., 2014). Abbas *et al*. (1995) identified that increasing levels of sulphur increased the plant height significantly. These lines are in agreement with Baviskar *et al.* (2005) and Ravi *et al*. (2008) in safflower.

Sulphur sources showed significant influence on number of leaves per plant at all the growth stages except at 30 DAS, maximum being at 60 DAS and thereafter declined at harvest stage. Among the sources significantly higher number of leaves per plant (18.37, 22.37 and 17.68) was observed with application of sulphur through ammonium sulphate (S_3) at all the growth stages. The increased number of leaves due to ammonium sulphate might be attributed to the supply of sulphur which enhances cell division, cell elongation or expansion and chlorophyll synthesis. It is also important in the activity of meristematic tissues and development of shoots. Thus in adequate supply of sulphur, it will be expected that plants grow taller with more number of leaves having bigger size and higher chlorophyll content.

Differences in number of leaves per plant at all the stages of growth were significant due to different levels of sulphur. Leaf number increased up to 60 days and declined progressively later because of senescence and leaf fall. Application of 45 kg S ha^{-1} (L_3) recorded significantly higher number of leaves per plant. Number of leaves per plant increased with increasing levels of sulphur up to 45 kg S ha^{-1} at all the stages of growth possibly due to better growth environment leading to increased number of leaves. Also, higher leaf number indicates high mobilizable protein at the beginning of reproductive stage which helps the crop to put forth higher production as indicated by Boote *et al*. (1985). These results are in conformity with those of Sarkar *et al*. (1999).

Sources of sulphur failed to exert significant influence on leaf area $plant^{-1}$ and leaf area index at 30 DAS and had significant effect at 60 DAS and at harvest. At 60 DAS and at harvest, ammonium sulphate recorded significantly higher leaf area $plant^{-1}$ and leaf area index compared to SSP, gypsum and elemental sulphur. Higher LAI might be attributed to the higher supply of available sulphur through ammonium sulphate as compared to SSP, gypsum and elemental sulphur. This could have increased the metabolic processes in the plants and promoted the meristamatic activities causing apical growth and resulted in increased plant height and leaf area index (Intodia and Tomar, 1997).

Differences in leaf area and LAI $plant^{-1}$ at all the stages of growth were significant owing to different levels of sulphur. Significantly higher leaf area and LAI was noticed at 60 DAS and declined thereafter as the crop progressed towards physiological maturity.

Significantly higher leaf area (1382.33, 3066.08 and 1642.83 cm^2) and LAI (0.77, 1.70 and 0.91) was recorded with 45 kg S ha^{-1} (L_3) at 30, 60 DAS and at harvesting stage. Superiority of ammonium sulphate over the other sources such as SSP and gypsum with respect to leaf area index (LAI) was observed in soybean (Dhillon and Dev, 1980) and in sunflower (Sreemannarayana *et al*., 1994).

The progressive increase in LAI was due to increased sulphur application which leads to increased nutrient uptake which enhanced rate of photosynthesis. Application of sulphur might have influenced the overall nutritional environment of rhizosphere and that might be the reason for increase in the growth parameters of the crop. Sulphur being a constituent of succinyl Co-A involved in chlorophyll synthesis in plant leaves and their activation at cellular level promotes greater photosynthates and meristamatic activity. This seemed to have promoted vegetative growth in terms of leaf area and leaf area index (Hocking *et al*., 1987). Better availability of nitrogen and sulphur in deficient soils at active growth stage of the crop increases cell division and cell elongation which probably led to more plants and increased leaf area index (Bhanurekha and Reddy, 1998). Similar results were reported by Poomurugesan and Poonkodi (2008) in sunflower.

The data on dry matter production in different parts of the plant of sunflower indicated significant variations due to sources of sulphur at all the growth stages except at 30 DAS. At 60 DAS and at harvest, ammonium sulphate (102.97 and 138.93 g) recorded significantly higher dry matter compared to gypsum and elemental sulphur but statistically on par with SSP. The significant improvement in dry matter production might have resulted from better sulphur nutrition of crop. Ammonium sulphate proved the most efficient source of sulphur for correcting sulphur deficiency in a standing crop as reported by Arora *et al*. (1983). Similar results were reported by Reddy and Reddy (2001) in soybean and Venkatesh *et al*. (2002) in safflower.

The dry matter production increased continuously up to maturity. The process of dry matter accumulation in sunflower was continuous due to its genetic ability to absorb inorganic materials for synthesizing carbohydrates until it matures (Sarkar *et al*., 1998). Application of sulphur significantly affected the dry matter accumulation in plants. At all the growth stages irrespective of sources, application of 45 kg S ha^{-1} produced significantly higher dry matter $plant^{-1}$ and however, there were no significant differences with the application of 15 and 30 kg S ha^{-1}. Application of sulphur significantly increased the N uptake, stimulated the photosynthetic activity and synthesis of chloroplast protein which might have resulted in higher dry matter production (Reddy and Reddy, 2001). Better sulphur nutrition to plants resulted in more height and number of branches and other growth parameters, which resulted in higher dry matter production (Harendra Kumar and Yadav, 2007). The increase in total dry matter with application of sulphur could be due to the release of sulphate ions immediately into the soil solution resulting in better availability and absorption of sulphur and resulted in vigorous crop growth and production of higher dry matter by the plant (Vishwanath *et al.*, 2006). Similar results were reported by Sreemannarayana and Raju (1993). Bhilegaonkar *et al*. (1995) observed significant increase in dry matter at all the growth stages only up to 30 kg S ha^{-1} in safflower. Dry matter production increased with crop growth *i.e.* height and number of branches plant^{-1} from its initial growth stage to harvest of the crop (Nandanwar *et al*., 2000). These results are in line with findings of Babhulkar *et al*. (2000), Venkatesh *et al*. (2002) and Baviskar *et al.* (2005).

5.3 Yield and yield attributes

The yield determining components such as head weight, head diameter, hundred seed weight, number of filled and unfilled grains and grain yield were significantly influenced by the sources and levels of sulphur (Table 10, 11 and 12).

Head weight and head diameter are the most important yield attributing characters, which improves the seed yield by providing maximum number of florets for higher seed set. Different sulphur sources showed significant influence on head weight of sunflower. Significantly higher weight of head plant^{-1} (60.21 g) and higher diameter of head (16.81cm) was recorded with the treatment receiving ammonium sulphate (S_3) as a source of sulphur compared to gypsum (S_2) and elemental sulphur (S_1) and however it was statistically on par with SSP (S_4).

Different levels of sulphur showed significant influence on head weight and head diameter of sunflower. Significantly higher weight of head plant^{-1} (63.86 g) and head diameter (18.13 cm) was recorded with the treatment receiving 45 kg S ha^{-1} (L_3) and it was significantly superior over 30 kg and 15 kg S ha^{-1}. This significant and positive influence of sulphur on head weight and head diameter was due to improved growth through increased nutrient assimilation which in turn accelerated the crop to put forth larger heads. Also, sulphur at 45 kg ha^{-1} was found favourable and economical to obtain larger heads. The influence of sulphur in enhancing the head diameter was also reported by Ajai Singh *et al.* (2000), Maity and Gajendra Giri (2003), Reddi Ramu and Maheswara Reddy (2003) and Thorat *et al.* (2007).

The data presented in Table 10 revealed that sources of sulphur cause significant variation in 100 seed weight at harvest stage of the crop. Among the sulphur sources, ammonium sulphate (S_3) application resulted in significantly higher 100 seed weight (5.16 g) compared to gypsum and elemental sulphur and however it was statistically on par with SSP (S_4). More number of bigger sized heads might have accommodated more number of seeds providing sufficient space for development of individual seed, leading to higher 100 seed weight. Similar findings were reported by Verma *et al*. (2012).

Variations in 100 seed weight owing to different levels of sulphur were found significant at harvest stage of the crop. 100 seed weight was significantly higher (5.45 g) with higher sulphur level (L_3) at 45 kg S ha^{-1} and it decreased with decrease in the sulphur levels and it was significantly superior over 30 kg S ha^{-1} (5.11 g). This might be due to the balanced system of nutrition and consequently producing healthy seeds (Mishra and Agrawal, 1994). These results are in conformity with the results of Dashora and Sharma (2006), Ravi *et al*. (2010) and Singh and Singh (2013).

Data obtained on number of filled grains $head^{-1}$ after harvesting differed significantly due to application of different sources of sulphur. Whereas there was no significant difference on number of unfilled and total grains $head^{-1}$. Among the sources, statistically higher filled grains $head^{-1}$ (660.53) was recorded with the application of ammonium sulphate (S_3) compared to gypsum (619.70) and elemental sulphur (601.41) and however it was on par with SSP (642.81).

With respect to levels, application of 45 kg S ha^{-1} recorded significantly higher number of total (823.90), filled grains (723.96) and lower unfilled grains $head^{-1}$ (99.93). The total and filled number of grains $head^{-1}$ increased with increasing levels of sulphur up to 45 kg ha^{-1}. Whereas number of unfilled grains decreased with increased levels of sulphur. Significantly higher number of unfilled grains head^{-1} (125.03) was recorded with sulphur application at 15 kg S ha^{-1}. Increase in the total and filled number of grains head^{-1} at higher levels of sulphur (45 kg ha^{-1}) might be due to larger heads with improved plant vigour and increased production and translocation of photosynthates which might have accommodated more number of filled seeds head^{-1}. Similar results were reported by Maity and Gajendra Giri (2003), Reddi Ramu and Maheswara Reddy (2003) and Thorat *et al.* (2007).

The data presented in Table 12 revealed that sources of sulphur caused significant variation in grain and stalk yield of sunflower at harvest stage of the crop. Among the sulphur sources, application of ammonium sulphate (S_3) recorded significantly higher grain and stalk yield (1648.0 and 2504.29 kg ha^{-1}) compared to elemental sulphur (S_1) and however, seed yield was on par with SSP and gypsum whereas, stalk yield was on par with SSP. The higher grain and stalk yield through ammonium sulphate might be due to better availability of sulphur as compared to other sources (SSP, gypsum and elemental sulphur) as it is more soluble and release the sulphate ions immediately into soil solution for absorption by the crop to produce better yields. The next best source of sulphur in terms of above parameter found to be SSP (Verma *et al*., 2012). Similar results have been reported by Hegde (2008).

Among the sulphur carriers, ammonium sulphate proved better for obtaining higher grain and stalk yield which might be due to its higher solubility (77.24 per cent by weight at 20 ^{o}C) (Venkatesh *et al.*, 2002). Similar observations were recorded by Patel *et al*. (2002) and Verma *et al*. (2012). Superiority of ammonium sulphate over other sources has been reported by Satish Kumar *et al*. (2011) and Tomar (2012) in other oilseed crops.

A perusal of data presented in Table 12 revealed that variations in grain and stalk yield due to levels of sulphur were found significant at harvest stage of the crop. The increase in levels of sulphur exhibited the increment in grain and stalk yield of sunflower up to 45 kg S ha^{-1}. Application of 45 kg S ha^{-1} registered significantly higher grain and stalk yield (1719.83 kg ha^{-1} and 2558.75 kg ha^{-1}) and showed statistical superiority over remaining sulphur levels of 15 and 30 kg S ha^{-1}. The favourable effect of sulphur fertilization at higher levels on yield components and finally on yield might be due to balanced nutritional environment, efficient and greater partitioning of metabolites and adequate translocation of nutrients towards reproductive site. The increase in grain and stalk yield might be due to stimulatory effect of applied sulphur on the synthesis of protein, which in turn might have accelerated photosynthesis and improved most of the yield contributing characters which resulted in significantly higher grain and stalk yield (Tulasi *et al*. 2014). This might be due to more accumulation of amino acids and amide substances and their translocation to the reproductive organs which influenced growth and yield due to application of sulphur Dongarkar *et al*. (2005). The results are in conformity with the findings of Patel *et al*. (2002), Tomar (2012) and Debnath and Basu (2013) in other oilseed crops.

Experimental data on harvest index (%) was analysed statistically and found non significant with various sources and levels of sulphur and shown in Table 12. These results were in conformity with the findings of Kapila Shekhawat and Shivay (2008) in sunflower and Santosh Kumar *et al*. (2011) in mustard.

5.4 Quality

The quality determining components such as oil content, oil yield, protein content and protein yield were significantly influenced by the sources and levels of sulphur (Table 13). Different sulphur sources showed significant influence on oil content and oil yield of sunflower. Among the sources, significantly higher oil content (37.84 %) and oil yield (624.84 kg ha^{-1}) was recorded with the application of ammonium sulphate (S_3) compared to gypsum (S_2) and elemental sulphur (S_1) and however, it was on par with SSP (36.23 %) and (593.35 kg ha^{-1}). The higher oil content and yield with ammonium sulphate might be due to better availability of sulphur as compared to other sources (SSP, gypsum and elemental sulphur). Ventakesh *et al*. (2002) and Patel *et al*. (2002) also found similar findings in safflower.

Different levels of sulphur showed significant influence on oil content and oil yield of sunflower. The treatment receiving 45 kg S ha^{-1} (L_3) resulted in significantly higher oil content (38.23 %) and oil yield (657.75 kg ha^{-1}). This was significantly superior over 15 kg S ha^{-1} (33.01 %) and (489.52 kg ha^{-1}) and however it was on par with 30 kg S ha^{-1} (36.84 %) with respect to oil content. The increased levels of sulphur showed positive effect on oil content of sunflower seeds. This might be due to the role of sulphur in synthesis of oil. Sulphur is involved in the formation of glucosides and glucosinolates (mustard oil) and sulphydril-linkage and activation of enzymes which aid in biochemical reaction within the plant (Ravi *et al*., 2008). This confirms the findings of Gangadhara *et al.* (1990) in sunflower and Mishra and Agarwal (1994) in soybean.

The increase in oil content with increase in sulphur might be due to the involvement of sulphur in electron-transport chain (Margatham and Chellamuthu, 2000). Highest oil content might be due to influence of sulphur in rapid conversion of nitrogen to crude protein and finally to oil. The acetic thiolinase, a sulphur based enzyme in the presence of sulphur converts acetyl Co A to melonyl Co A rapidly resulting in higher oil content (Krishnamurthi and Mathan, 1996 and Nagavani *et al*., 2001). In fatty acid synthesis, acetyl coenzyme A is converted to malonyl co-enzyme. The activity of this enzyme depends upon sulphur supply. Moreover, acetyl co-enzyme A itself contains sulphur and sulphohydryl group (Karle *et al*., 1985). This might be the reason for increasing the oil content of sunflower with sulphur application. Since, oil storage organs of oilseed crops including sunflower are mostly protein rich in sulphur, the supply of sulphur to these crops is of paramount importance (Subbaiah and Singh, 1970). About 50 to 80 per cent of total sulphur in oilseed crops goes for making sulphur containing amino acids and rest is required for other sulphur containing compounds Tisdale *et al.* (1985).

Oil yield is a function of oil content and grain yield, both the attributes increased with increasing the levels of sulphur resulting in a significant increase in oil yield (Santosh Kumar *et al*., 2011). Sulphur can be identified as a key element for increasing oil yield. The increase in oil content with sulphur application might be the role of sulphur in oil synthesis as sulphur is a constituent of amino acid that play a vital role in oil synthesis (Tulasi *et al*., 2014). These results are in agreement with Patel *et al*. (2002), Kubsad and Mallapur (2003) in safflower and in other oilseed crops by Saren *et al*. (2005), Sandeep Singh and Vinay Singh (2007) in linseed and Deshmukh *et al.* (2010) in sesame.

Effect of different sources of sulphur influenced significantly on protein content and protein yield of sunflower. Among the sources application of ammonium sulphate (S_3) gave significantly higher protein content and protein yield (16.22 % and 268.68 kg ha^{-1}) and it was significantly higher than elemental sulphur (14.57 % and 225.82 kg ha^{-1}) and however it was statistically on par with gypsum (15.60 % and 249.56 kg ha^{-1}) and SSP (15.76 % and 258.33 kg ha^{-1}). This might be due to higher solubility of sulphur present in ammonium sulphate than that is sparingly soluble in gypsum or SSP. Although, the three sources are containing SO_4^-, when gypsum is applied to soils, the presence of free Ca^{++} ions in soil solution reduces its solubility as a result of common ion effect (Sreemannarayana *et al.,* 1994).

Protein yield is a function of protein content and grain yield, both the attributes increased due to application of ammonium sulphate resulting in a significant increase in protein yield. Similar increase in protein content and protein yield due to sulphur application through ammonium sulphate was observed by Ventakesh *et al.* (2002) in safflower and in other oilseed crops by Reddy and Reddy (2001).

The increased levels of sulphur showed positive effect on protein content and protein yield. Among the levels of sulphur, significantly higher protein content (17.08 %) and yield (294.23 kg ha^{-1}) was recorded with 45 kg S ha^{-1} (L_3) and it was statistically superior to 30 kg S ha^{-1} (15.32 % and 246.87 kg ha^{-1}) and 15 kg S ha^{-1} (14.22 % and 210.69 kg ha^{-1}). The protein content and protein yield was increased significantly with increased levels of sulphur up to 45 kg ha^{-1} (L_3) and with decrease in the sulphur levels the protein content and protein yield was decreased. Kumar *et al.* (1981) reported an increase in protein content with the application of sulphur. Sulphur is a constituent of essential amino acids *viz.*, methionine, cystein and cystine and it helps in conversion of these amino acids into high quality protein (Chopra and Kanwar, 1996, Harkal *et al.*, 1993). Appropriate structure is essential for protein formation and sulphur provides di-sulphide (S-S) bonds for cross linkage of two polypeptide chains and thus helps in the formation of proteins (Allaway and Thompson, 1966). These results are in support with the findings of Babhulkar *et al.* (2000) in safflower. Increase in protein content is by virtue of sulphur being a constituent of amino acids which are the building blocks of protein (Tandon, 1991). Protein yield is a function of protein content and seed yield, both the attributes increased with increasing the levels of sulphur resulting in a significant increase in the protein yield.

The increase in protein content and protein yield with sulphur application is due to involvement of sulphur directly in protein metabolism (Chitkala and Reddy, 1991). Futher sulphur being an integral part of sulphur containing amino acids (Gangadhara *et al*., 1990), protein content and yield would increase on sulphur addition (Kalaiyarasan, 2007). The beneficial effect of sulphur levels on protein content and protein yield might be due to increase in cation exchange capacity of the roots which would enable the plant to extract more nutrients from soil (Tomar, 2012).

5.5 Nutrient uptake

Nutrients play a major role in increasing growth and ultimately the yield. The data on nutrient uptake increased the uptake of nitrogen, phosphorus, potassium and sulphur significantly with respect to application of different sources and levels of sulphur at all the stages of growth.

5.5.1 Nitrogen

The data on uptake of N in different parts of the plant of sunflower indicated significant variations due to sources of sulphur at 60 DAS and at harvest. Among the different sources of sulphur ammonium sulphate (S_3) recorded significantly higher N uptake (15.74 and 23.20 kg ha^{-1}), (18.17 and 27.36 kg ha^{-1}) and (33.91 and 93.55 kg ha^{-1}) in leaf, stalk, and total at 60 DAS and after harvest compared to gypsum (S_2) and elemental sulphur (S_1) respectively and however it was on par with SSP (S_4). At harvest highest N uptake was recorded in grain (42.99 kg ha^{-1}). Tomar (2012) also found similar results in linseed.

The data on nitrogen uptake by leaf, stalk, seed and total nitrogen (kg ha^{-1}) of sunflower indicated significant variations due to different levels of sulphur at all the growth stages. Among different levels of sulphur, significantly higher N uptake was recorded with 45 kg S ha^{-1} (6.70, 11.13 and 17.83 kg ha^{-1}) and (15.68, 19.41 and 35.09 kg ha^{-1}) in leaf, stalk and total at 30 and 60 DAS, respectively compared to 15 kg S ha^{-1} and 30 kg S ha^{-1}. At harvest higher N uptake was recorded with 45 kg S ha^{-1} (24.13, 28.13, 47.08 and 99.34 kg ha^{-1}) in leaf, stalk seed and total respectively, followed by 15 kg and 30 kg S ha^{-1}. The increase in nutrient uptake was mainly due to better nutrition which resulted in better growth and yield and ultimately higher uptake of nitrogen (Singh and Meena, 2004). The higher level of sulphur application to the crop resulted in profused vegetative and root growth and might have activated the absorption of N from the soil (Patel *et al*., 1992). Nutrient uptake increased due to higher dry matter accumulation. These results are in conformity with the findings of Girish and Reddy (2005) in soybean and Ravi *et al.* (2008) in safflower.

5.5.2 Phosphorus

The experimental data on nutrient uptake of P in different parts of the plant of sunflower indicated significant variations due to different sources of sulphur at all the stages of growth. At 30 and 60 DAS among the different sources of sulphur used, significantly higher uptake of P was recorded with ammonium sulphate (1.30, 4.32 and 5.60 kg ha^{-1}) and (1.34, 4.02 and 5.36 kg ha^{-1}) in leaf, stalk and total uptake respectively which was significantly superior over application of elemental sulphur (S_1) and gypsum (S_2) and however, it was on par with SSP at 30 DAS and uptake in leaf at 60 DAS was on par with SSP. After harvest of sunflower higher uptake of P was recorded with ammonium sulphate (3.21, 8.03, 9.43 and 20.66 kg ha^{-1}) in leaf, stalk, seed and total respectively over gypsum (S_2) and elemental sulphur (S_1) and however it was on par with SSP (S_4). Superiority of ammonium sulphate over other sources could be due to precipitation of $PO_4^{=}$ by the Ca present in gypsum and SSP rendering the phosphate unavailable to plant (Sreemannarayana *et al.*1994). The results were in agreement with those of Sharma and Bansal (1998) in safflower.

The increase in the levels of sulphur increased the uptake of P in leaf, seed, stalk and total at all the growth stages. At 30 and 60 DAS, application of 45 kg S ha^{-1} recorded significantly higher P uptake (1.25, 4.22 and 5.59 kg ha^{-1}) and (1.35, 4.54, 5.88 kg ha^{-1}) in leaf, stem and total respectively. At harvest higher P uptake (3.29, 8.82, 9.47 and 21.58 kg ha^{-1}) was recorded with 45 kg S ha^{-1} in leaf, stem seed and total respectively.

Application of sulphur had synergistic effect on P showing significant increase in its uptake with increase in level of applied sulphur. However, in seeds at harvest, P showed antagonistic relationship with sulphur. The antagonism of sulphur with phosphorus might be due to likely competition between these two nutrients for the same absorption sites on root surface (Aulakh and Pasricha, 1977). Maximum P content might be due to increased sulphur content in sulphur levels and accelerated metabolic activity of the plants resulting in increased nutrient absorbing power of root system (Agrawal and Verma, 1998). This finding was in line with that of Ravi *et al*. (2008) in safflower.

5.5.3 Potassium

There was a significant increase in the uptake of K in leaf, seed, stalk and total with the application of different sources of sulphur at all the growth stages of sunflower. Among different sources of sulphur at 30 and 60 DAS significantly higher K uptake was recorded with ammonium sulphate (15.84, 51.31 and 67.15 kg ha^{-1}) and (24.36, 89.73 and 114.09 kg ha^{-1}) in leaf, stem and total, respectively which was superior over gypsum, elemental sulphur and it was on par with SSP. At harvest stage, significantly higher K uptake was noticed with the application of ammonium sulphate (31.16, 136.58, 14.28 and 182.03 kg ha^{-1}) in leaf, stalk, seed and total uptake, respectively compared to gypsum (S_2) and elemental sulphur (S_1) and however it was on par with SSP (S_4). The superiority of ammonium sulphate in increasing the uptake of cationic nutrient K might be due to replacement of these nutrients from the exchange complex by NH_4^+ ions present in the source there by increasing their availability to the crop (Sreemannarayana *et al.,* 1994). These results are in agreement with Tomar (2012) in linseed.

Different levels of sulphur improved the uptake of K in the leaf, seed, stalk and total at all the growth stages. The rate of increase in uptake was higher at higher levels of sulphur than at the lower application rates. At 30, 60 DAS among different levels application of sulphur at 45 kg ha^{-1} recorded significantly higher uptake of potassium (16.38, 56.46 and 72.83 kg ha^{-1}) and (24.99, 92.78 and 117.78 kg ha^{-1}) in leaf, stem and total respectively which was significantly superior over L_1 and L_2. At harvest similar results were noticed as obtained in 60 DAS, where 45 kg S ha^{-1} recorded significantly higher uptake of potassium (131.65, 15.05 and 178.46 kg ha^{-1}) in leaf, stalk, seed and total, respectively. It is a well known fact that if a plant nutrient is involved in improving the vegetative growth, it would certainly improve the uptake of all nutrients, which are required to maintain the growth (Kapila Shekhawat and Shivay, 2008). Similar results were observed by Babhulkar *et al*. (2000) in safflower**.**

5.5.4 Sulphur

There was a significant increase in the uptake of S in leaf, seed, stalk and total with the application of different sources of sulphur at all the growth stages of sunflower.

At 30 and 60 DAS among the sources of sulphur significantly higher uptake of S was recorded with ammonium sulphate (2.33, 3.28 and 5.6 kg ha^{-1}) and (3.08, 5.08, and 8.16 kg ha^{-1}) in leaf, stalk and total compared to gypsum (S_2) and elemental sulphur (S_1) and however it was on par with SSP (S_4). At harvest stage significantly higher S uptake was recorded with ammonium sulphate (3.66, 7.37 and 4.53 kg ha^{-1}) in leaf, stalk, seed and total compared to gypsum (S_2) and elemental sulphur (S_1) and however it was on par with SSP (S_4). It might be the reason that sources other than ammonium sulphate used in present study are sparingly soluble and do not contain easily available form of sulphur like ammonium sulphate (Venkatesh *et al*., 2002). Similar results were also reported by Baviskar *et al.* (2005) in safflower.

The sulphur uptake by the crop at 30, 60 DAS and at harvest increased significantly with each increment in sulphur application and reached to highest when 45 kg S ha^{-1} (L_3) was applied. The uptake of S was significantly increased with increasing sulphur level (15 to 45 kg S ha^{-1}). At 30 DAS significantly higher uptake of sulphur (2.81, 4.06 and 6.88 kg ha^{-1}) was recorded in leaf, stalk and total with 45 kg S ha^{-1} statistically superior to 30 (L_2) and 15 kg S ha^{-1} (L_1). At 60 DAS significantly higher uptake of sulphur (3.60, 5.82 and 9.42 kg ha^{-1}) in different parts of the plant was recorded with 45 kg S ha^{-1} compared to 30 and 15 kg S ha^{-1}. At harvest significantly higher S uptake (4.63, 8.25, 5.33 and 18.07 kg ha^{-1}) was recorded with 45 kg S ha^{-1} in leaf, stalk, seed and total respectively compared to 30 kg S ha^{-1} and 15 kg S ha^{-1}. The increase in removal of the nutrients under sulphur application might be the outcome of increased contents of these nutrients in seed and stalk coupled with increased seed and stalk yield ha^{-1} (Singh *et al*., 2013). The higher level of sulphur application to the crop resulted in profused vegetative and root growth and might have activated the absorption of sulphur from the soil (Patel *et al*., 1992). These results were in line with the findings of Singh and Singh (2013) and Baviskar *et al.* (2005) in safflower, Najar *et al*. (2011) in soybean, Santosh Kumar *et al.* (2011) in mustard and Satish Kumar *et al*. (2011) in sunflower.

5.6 Chemical properties

Effect of different sources and levels of sulphur during the period of study had not influenced significantly on soil reaction, electrical conductivity and organic carbon. In general pH of the soil ranged from 7.51 to 7.82 with respect to sources and 7.56 to 7.73

with respect to levels of sulphur, electrical conductivity of soil ranged from 0.14 to 0.16 dSm^{-1} with respect to sources and levels of sulphur and organic carbon content of the soil ranged from 4.16 to 4.57 g kg^{-1} with respect to sources and 4.09 to 4.49 g kg^{-1} with respect to levels of sulphur.

5.7 Available N, P, K and S content (kg ha^{-1}) in soil after harvest of sunflower

The results of the experimental data indicated that there was significant influence on available nitrogen content in soil after harvest of the crop. Significantly higher available N content (79.11 kg ha^{-1}) in the soil was recorded with ammonium sulphate (S_3) treated plot compared to gypsum (74.69 kg ha^{-1}) and elemental sulphur (71.95 kg ha^{-1}) and however it was on par with SSP (76.80 kg ha^{-1}). This might be the reason that application of ammonium sulphate not only supplies sulphur but also releases nitrogen into the soil in the form of ammonium ions which increases the N content of the soil. Similar results were reported by Tomar (2012).

Data pertaining to available N (kg ha^{-1}) in the soil after harvest of sunflower was analyzed statistically and significantly differed due to levels of sulphur. Among the different levels, application of 45 kg S ha^{-1} (L_3) significantly increased available nitrogen (82.85 kg ha^{-1}) content in the soil after harvest of sunflower compared to 30 kg S ha^{-1} (L_2) and 15 kg S ha^{-1} (L_1). The available N content in the soil decreases with decrease in the sulphur levels. Similar findings were observed with Venkatesh *et al*. (2002) in safflower, Tomar (2012) in linseed and Jadhao *et al*. (2014) in soybean. Data pertaining to available P_2O_5 in soil after harvest of the crop was not significantly influenced by various sources and levels of sulphur and interaction of sulphur source and levels. These findings were in conformity with Tomar (2012). Data pertaining to available K_2O in soil after harvest of the crop was not significantly influenced by various sources and levels of sulphur and interaction of sulphur sources and levels. These findings were substantiating with Tomar (2012).

Data pertaining to available S in soil after harvest of the crop was influenced significantly due to various sources of sulphur. Among the different sources of sulphur application of ammonium sulphate (S_3) increased the S content in the soil after harvest of sunflower compared to SSP (S_4), gypsum (S_2) and elemental sulphur (S_1). Significantly higher available S content of 16.35 kg ha^{-1} was recorded with ammonium sulphate (S_3) compared with that of 14.54 kg ha^{-1}, 14.15 kg ha^{-1} and 13.62 kg ha^{-1} of SSP (S_4), gypsum (S_2) and elemental sulphur (S_1) respectively. It might be attributed to the supply of sulphur in more readily available form from ammonium sulphate compared to SSP and gypsum. Tomar (2012) in linseed also found similar result.

Effect of different sources levels of sulphur during the period of study had influenced significantly on available S in soil. At harvest stage, the available sulphur content in soil increased from its initial status in all the treatments with increase in sulphur levels. However, significantly higher available sulphur content in soil was recorded with 45 kg S ha^{-1} and the lower with 15 kg S ha^{-1}. The higher S content of 17.55 kg ha^{-1} was recorded with L_3 (45 kg S ha^{-1}) which was significantly superior over rest of the sulphur levels. Increased levels of S influenced the S status in the soil. This may be due to more vegetative as well as root growth with the application of sulphur which oxidized the reduced sulphur to sulphate by microbial activity in association with the roots in the rhizosphere and in the oxidized layers of the soil (Ravi *et al.*, 2010). Addition of fertilizer S known to increase available S status of soils as cropping without S input will decrease (Intodia and Sahu, 1999). Similar results were found by venkatesh *et al*. (2002) and Murthy and Muralidharudu (2003) in safflower, Tomar (2012) in linseed and Jadhao *et al*. (2014) in soybean.

5.8 Economics

Among the different sources of sulphur used, application of sulphur through ammonium sulphate (S_3) recorded significantly higher gross returns (₹ 65,920 ha^{-1}), net returns (₹ 45,962 ha^{-1}) and B: C ratio (3.25) as compared to other sources *viz*., SSP (S_4), gypsum (S_2) and elemental sulphur (S_1). Elemental sulphur (S_1) recorded the lower gross returns, net returns and B: C ratio. This might be due to more availability of sulphur through ammonium sulphate (S_3) which has increased the seed yield, stalk yield and quality of safflower. These results are in accordance with the findings of Patel e*t al*. (2002) and Verma *et al*. (2012).

Among the different levels of sulphur, higher gross returns (₹ 68,793.33 ha^{-1}) and net returns (₹ 47,617.58 ha^{-1}) were recorded with the application of 45 kg S ha^{-1} (L_3)

which was significantly higher than application of 30 kg S ha^{-1} (L_2) and 15 kg S ha^{-1} (L_1). Each increasing level of sulphur increased the economic yield significantly which ultimately resulted in increased gross and net returns ha^{-1}. The higher B:C ratio (3.19) was observed with the application of 45 kg S ha^{-1} (L_3) followed by 30 kg S ha^{-1} (3.06) and 15 kg S ha^{-1} (2.96). This might be due to increase in the doses of sulphur that increases the seed yield, stalk yield and quality of sunflower. These results were in accordance with the findings of Patel *et al*. (2002), Kubsad and Mallapur (2003), Dashora and Sharma (2006) and Ravi *et al.* (2008).

Summary and Conclusion

VI. SUMMARY AND CONCLUSION

An investigation entitled "Studies on different sources and levels of sulphur on productivity and quality of rainfed sunflower (*Helianthus annuus* L.)" was conducted under rainfed condition during the *kharif* season of 2016 at Main Agriculture Research Station, Raichur. The experiment was laid out in factorial randomized block design with four sulphur sources (S_1: elemental sulphur, S_2: gypsum S_3: ammonium sulphate and S_4: single super phosphate) as factor one and three sulphur levels (L_1: 15 kg S ha^{-1}, L_2: 30 kg and L_3: 45 kg S ha^{-1}) as second factor comprising twelve treatment combinations and replicated thrice. Observations on growth parameters, yield and yield attributes, quality, nutrient uptake, soil available nutrient status and economics were recorded for different sources and levels of sulphur and also interaction effect of sulphur sources and levels was also recorded. The salient features of the experimental findings are summarized as below

- Growth parameters *viz*., plant height, number of leaves, leaf area, leaf area index (LAI) and dry matter production were significantly influenced by varying sulphur sources and levels at 30, 60 DAS and at harvest except at 30 DAS with respect to sources of sulphur.

- Among sulphur sources, application of ammonium sulphate recorded significantly higher plant height (184.10 and 185.66 cm), number of leaves (22.37 and 17.68), leaf area plant^{-1} (2919.11 and 1585.44 cm^2), LAI (1.62 and 0.88) and total dry matter production (102.97 and 138.93 g plant^{-1}) over SSP, gypsum and elemental sulphur at 60 DAS and at harvest stage, respectively.

- Among sulphur levels, application of sulphur at 45 kg ha^{-1} recorded significantly higher plant height (188.07 and 187.04 cm), number of leaves (23.89 and 18.66), leaf area plant^{-1} (3066.08 and 1642.83 cm^2), LAI (1.70 and 0.91) and total dry matter production (110.68 and 146.61 g plant^{-1}) compared to 30 kg S ha^{-1} and 15 kg S ha^{-1} at 60 DAS and at harvest stage, respectively.

- Sulphur sources and levels did not show any significant interaction effect on growth, yield and yield attributes at different stages of sunflower.

- Significantly higher head weight, head diameter, 100 seed weight, and number of filled grains head^{-1} were noticed with ammonium sulphate as a source of sulphur compared to single super phosphate, gypsum and elemental sulphur.

- Among different levels of sulphur, application of sulphur at 45 kg ha^{-1} recorded significantly higher head weight, head diameter, 100 seed weight, and number of filled grains head^{-1} over 30 kg S ha^{-1} and 15 kg S ha^{-1}.

- Significantly higher grain (1648 kg ha^{-1}) and stalk yield (2504.29 kg ha^{-1}) was registered with ammonium sulphate as a source of sulphur compared to SSP, gypsum and elemental sulphur. Application of 45 kg S ha^{-1} recorded significantly higher stalk (1719.83 kg ha^{-1}) and stalk yield (2558.75 kg ha^{-1}) over 30 kg S ha^{-1} and 15 kg S ha^{-1}.

- Significantly higher oil content (37.84%), oil yield (624.84 kg ha^{-1}), protein content (16.22%) and protein yield (268.68 kg ha^{-1}) were noticed with ammonium sulphate as a source of sulphur compared to SSP, gypsum and elemental sulphur. Among sulphur levels, application of sulphur at 45 kg ha^{-1} recorded significantly higher oil content (38.23%), oil yield (657.75 kg ha^{-1}), protein content (17.08%) and protein yield (294.23 kg ha^{-1}) over 30 kg S ha^{-1} and 15 kg S ha^{-1}.

- Significantly higher nitrogen, phosphorus, potassium and sulphur uptake by leaf, stalk, seed and total was observed with ammonium sulphate as a source of sulphur compared to SSP, gypsum and elemental sulphur. Significantly higher nitrogen, phosphorus, potassium and sulphur uptake by leaf, stalk, seed and total uptake at different growth stages of sunflower was observed with application of 45 kg S ha^{-1} over 30 kg S ha^{-1} and 15 kg S ha^{-1}.

- The soil available nutrients *viz.*, N and S increased significantly with application of ammonium sulphate compared to SSP, gypsum and elemental sulphur. Soil available P_2O_5 and K_2O did not show significant effect with application of different sulphur sources. After harvest of crop, N and S soil availability increased with increase in the sulphur level from 15 to 45 kg ha^{-1} and found higher with 45 kg S ha^{-1} over 30 kg S ha^{-1} and 15 kg S ha^{-1}. The soil availability of P_2O_5 and K_2O was found non significant with application of different sulphur levels.

- Gross returns, net returns and benefit cost (B: C) ratio were increased with various sources of sulphur. However, significant increase in net returns (₹ 45,962 ha^{-1}) and B: C ratio (3.25) was observed with ammonium sulphate as sulphur source compared to SSP, gypsum and elemental sulphur. Linear increase in net returns (₹ 47,617.58 ha^{-1}) and B:C ratio (3.19) were observed up to 45 kg S ha^{-1} over 30 kg S ha^{-1} and 15 kg S ha^{-1}.

CONCLUSION

From the results of the present study, it can be concluded that there was significant response of sulphur fertilization on sunflower crop. Application of S through ammonium sulphate at the level of 45 kg ha^{-1} could be the best source of sulphur as compared to SSP, gypsum and elemental sulphur for enhancing the growth, yield, quality and nutrient uptake of sunflower because of its higher solubility and availability of sulphur for plants. Ammonium sulphate was also found economical in obtaining higher yield with high B: C ratio.

FUTURE LINE OF WORK

1. To study the sulphur fertilizers in combination with different organic manures.

2. Use of microbial consortia with elemental sulphur for early availability and effective uptake of sulphur by sunflower and its interactions are need to be studied.

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Appendix

APPENDIX – I

Prices of inputs and output

Sl. No.	Particulars	Prices (Rs.)
I. Inputs		
1.	Sunflower seeds (KBSH-44)	200 kg^{-1}
2.	FYM	500 t^{-1}
3.	Fertilizer	
	a) Urea	1,072 q^{-1}
	b) Diammonium phosphate (DAP)	2,600 q^{-1}
	c) Murate of potash (MOP)	1,200 q^{-1}
	d) Elemental sulphur	100 kg^{-1}
	e) Gypsum	500 q^{-1}
	f) Ammonium sulphate	1,300 q^{-1}
	g) SSP	1,250 q^{-1}
4.	Labour wages	
	a) Labour	200 day^{-1}
	b) Bullock pair with men	800 day^{-1}
II. Output		
	a) Sunflower seeds	4,000 q^{-1}

APPENDIX – II

Detailed cost of cultivation of sunflower (Rs. ha^{-1})

Sl. No.	Particulars	Cost of Cultivation (Rs. ha^{-1})											
		S_1L_1	S_1L_2	S_1L_3	S_2L_1	S_2L_2	S_2L_3	S_3L_1	S_3L_2	S_3L_3	S_4L_1	S_4L_2	S_4L_3
1.	**Land preparation**												
	Ploughing	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
	Harrowing	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
2.	**Inputs**												
	FYM	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
	Seeds	700	700	700	700	700	700	700	700	700	700	700	700
3.	**Fertilizers**												
	Urea	1284	1284	1284	1284	1284	1284	963	653	342	1391	1477	1616
	DAP	5070	5070	5070	5070	5070	5070	5070	5070	5070	3978	2236	1352
	MOP	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
	Elemental sulphur	1500	3000	4500	0	0	0	0	0	0	0	0	0
	Gypsum	0	0	0	420	835	1250	0	0	0	0	0	0

Contd….

Sl. No.	Particulars	Cost of Cultivation (Rs. ha^{-1})											
		S_1L_1	S_1L_2	S_1L_3	S_2L_1	S_2L_2	S_2L_3	S_3L_1	S_3L_2	S_3L_3	S_4L_1	S_4L_2	S_4L_3
	Ammonium sulphate	0	0	0	0	0	0	845	1690	2535	0	0	0
	SSP	0	0	0	0	0	0	0	0	0	1725	3437.5	5163
	Plant protection chemicals (PPC)	600	600	600	600	600	600	600	600	600	600	600	600
	Application charges for FYM, fertilizers and PPC	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
	Sowing and gap filling	1620	1620	1620	1620	1620	1620	1620	1620	1620	1620	1620	1620
	Inter-cultivation	800	800	800	800	800	800	800	800	800	800	800	800
	Hand weeding	1650	1650	1650	1350	1650	1650	1650	1650	1650	1650	1650	1650
	Harvesting and threshing	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
	Marketing and handling	150	150	150	150	150	150	150	150	150	150	150	150
	Total	**20724**	**22224**	**23724**	**19344**	**20059**	**20474**	**19748**	**20283**	**20817**	**19964**	**20020.5**	**21001**

APPENDIX – III

Nitrogen balance sheet in soil (kg ha^{-1}) as influenced by different sources and levels of sulphur

Treatments	Initial N in soil	Applied N through FYM/fertilizers	Total N	Uptake of N by crop	Estimated N	Soil N status after harvest	Net gain/ loss (+/-) of N in soil
	1	**2**	**3=1+2**	**4**	**5=3-4**	**6**	**7=6-5**
S_1L_1	238.8	120	358.8	62.16	296.6	63.22	-233.4
S_1L_2	238.8	120	358.8	80.71	278.1	71.42	-206.7
S_1L_3	238.8	120	358.8	92.12	266.7	81.22	-185.5
S_2L_1	238.8	120	358.8	74.31	284.5	66.00	-218.5
S_2L_2	238.8	120	358.8	83.11	275.7	76.25	-199.4
S_2L_3	238.8	120	358.8	95.11	263.7	82.16	-181.5
S_3L_1	238.8	120	358.8	78.18	280.6	71.14	-209.5
S_3L_2	238.8	120	358.8	91.82	267.0	80.16	-186.8
$S3L_3$	238.8	120	358.8	110.66	248.1	82.70	-165.4
S_4L_1	238.8	120	358.8	79.41	279.4	70.26	-209.1
S_4L_2	238.8	120	358.8	85.74	273.1	78.83	-194.2
S_4L_3	238.8	120	358.8	99.46	259.3	82.30	-177.0

APPENDIX – IV

Phosphorus balance sheet in soil (kg ha^{-1}) as influenced by different sources and levels of sulphur

Treatments	Initial P in soil	Applied P through FYM/fertilizers	Total P	Uptake of P by crop	Estimated P	Soil P status after harvest	Net gain/ loss (+/-) of P in soil
	1	**2**	**3=1+2**	**4**	**5=3-4**	**6**	**7=6-5**
S_1L_1	23.5	102	125.5	15.74	109.8	32.04	-77.7
S_1L_2	23.5	102	125.5	18.30	107.2	29.73	-77.5
S_1L_3	23.5	102	125.5	20.19	105.3	28.60	-76.7
S_2L_1	23.5	102	125.5	17.54	108.0	29.79	-78.2
S_2L_2	23.5	102	125.5	18.94	106.6	30.61	-75.9
S_2L_3	23.5	102	125.5	21.24	104.3	32.86	-71.4
S_3L_1	23.5	102	125.5	18.42	107.1	31.36	-75.7
S_3L_2	23.5	102	125.5	20.69	104.8	33.17	-71.6
$S3L_3$	23.5	102	125.5	22.88	102.6	38.10	-64.5
S_4L_1	23.5	102	125.5	18.10	107.4	28.58	-78.8
S_4L_2	23.5	102	125.5	19.97	105.5	34.42	-71.1
S_4L_3	23.5	102	125.5	22.02	103.5	36.26	-67.2

APPENDIX – V

Potassium balance sheet in soil (kg ha^{-1}) as influenced by different sources and levels of sulphur

Treatments	Initial K in soil	Applied K through FYM/fertilizers	Total K	Uptake of K by crop	Estimated K	Soil K status after harvest	Net gain/ loss (+/-) of K in soil
	1	**2**	**3=1+2**	**4**	**5=3-4**	**6**	**7=6-5**
S_1L_1	387.4	90	477.4	127.15	350.3	256.33	-93.9
S_1L_2	387.4	90	477.4	154.98	322.4	238.33	-84.1
S_1L_3	387.4	90	477.4	175.62	301.8	241.67	-60.1
S_2L_1	387.4	90	477.4	156.01	321.4	234.00	-87.4
S_2L_2	387.4	90	477.4	149.26	328.1	249.33	-78.8
S_2L_3	387.4	90	477.4	169.61	307.8	274.00	-33.8
S_3L_1	387.4	90	477.4	166.20	311.2	252.00	-59.2
S_3L_2	387.4	90	477.4	183.27	294.1	268.67	-25.5
$S3L_3$	387.4	90	477.4	196.62	280.8	277.00	-3.8
S_4L_1	387.4	90	477.4	159.36	318.0	255.67	-62.4
S_4L_2	387.4	90	477.4	178.49	298.9	252.00	-46.9
S_4L_3	387.4	90	477.4	172.00	305.4	266.00	-39.4

APPENDIX – VI

Sulphur balance sheet in soil (kg ha^{-1}) as influenced by different sources and levels of sulphur

Treatments	Initial S in soil	Applied S through FYM/fertilizers	Total S	Uptake of S by crop	Estimated S	Soil S status after harvest	Net gain/ loss (+/-) of S in soil
	1	**2**	**3=1+2**	**4**	**5=3-4**	**6**	**7=6-5**
S_1L_1	18.6	27	45.6	8.40	37.2	11.40	-25.8
S_1L_2	18.6	42	60.6	12.46	48.1	13.41	-34.7
S_1L_3	18.6	57	75.6	16.61	59.0	16.06	-42.9
S_2L_1	18.6	27	45.6	9.57	36.0	11.54	-24.5
S_2L_2	18.6	42	60.6	13.48	47.1	13.66	-33.5
S_2L_3	18.6	57	75.6	17.35	58.2	17.25	-41.0
S_3L_1	18.6	27	45.6	11.35	34.2	14.63	-19.6
S_3L_2	18.6	42	60.6	15.46	45.1	15.28	-29.9
$S3L_3$	18.6	57	75.6	19.86	55.7	19.14	-36.6
S_4L_1	18.6	27	45.6	11.17	34.4	11.58	-22.9
S_4L_2	18.6	42	60.6	14.25	46.4	14.29	-32.1
S_4L_3	18.6	57	75.6	18.47	57.1	17.76	-39.4