STUDIES ON THE EFFECT OF SULPHUR NUTRITION ON GOBHI SARSON (*Brassica napus* var. *oleracea*) IN MAIZE-GOBHI SARSON SEQUENCE UNDER RAINFED CONDITIONS

THESIS

BY

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Submitted to

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IN

Partial fulfilment of the requirements for the degree

OF

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(AGRONOMY)

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Dedicated

to

my

reverend

Grand Parents

Dr. R.C. Thakur
Director of Research

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CERTIFICATE I

This is to certify that the thesis entitled **"Studies on the effect of sulphur nutrition on gobhi sarson (*Brassica napus* var. *oleracea*) in maize-gobhi sarson sequence under rainfed conditions"** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Agronomy** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, is a bonafide research work carried out by **Subhash Chand** son of Sh. Prem Chand under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

(R.C. Thakur)
Chairman
Advisory Committee

Place : Palampur
Dated : 17 May, 2002

CERTIFICATE II

This is to certify that the thesis entitled **"Studies on the effect of sulphur nutrition on gobhi sarson (*Brassica napus* var. *oleracea*) in maize-gobhi sarson sequence under rainfed conditions"** submitted by **Subhash Chand** son of Sh. Prem Chand to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Agronomy** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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(Subhash Chaudhary)

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INTRODUCTION

Oilseeds crops contain 25-60% edible oil and play an important role in human nutrition and animal food. They occupy a key position in the diet of Indian masses as majority of our population is vegetarian (Ramanarayan, 1973). India is endowed with a wealth of vegetable oil resources in the form of cultivated annuals and perennial tree species. But it is paradoxical that India, which is one of the major oilseed growing countries of the world, has to import a huge quantity of edible oils to meet the requirement of its population. The per capita consumption of edible oils of 9.1 kg/annum is very low as compared to 20 kg/annum recommended by the Indian Council of Medical Research, New Delhi. At the same time, an improvement in standard of living has also increased the demand at the rate of 3.5 per cent per annum.

To increase the oilseed production and minimize the imports, oilseed technology mission was started in May, 1986 with a view to enhance the productivity and total production of major oilseeds, in the country. The results of the programme have been spectacular and country progressed rapidly towards self-sufficiency in oilseed production. At present, India is one of the major oilseed producing countries in the world, ranking first in acreage (26 million hectare) and third in production (25.68 MT) (Anonymous, 2002). They account for about 13 per cent of country's gross cropped area, about 5 per cent of national gross product and 10 per cent of value of all the agricultural products (Gill, 1993). The future projections reveal that oilseeds production would have to be increased to by about 40.2 million tonnes by 2010 AD. For achieving the targeted requirement, major share has to come from rapeseed-mustard.

Rapeseed-mustard group of oilseed crops occupy 6.23 million hectares of land, contributing 28 per cent of the total oilseed production in the country. In India, the total area under rapeseed and mustard, at the present moment, is 6230 thousand hectares with the production of 5884.1 thousand tonnes resulting in an average yield of 945 kg/ha (Anonymous, 1995). During 1985-86 to 1994-95; the average productivity has increased from 674 kg/ha to 945 kg/ha indicating, thereby, an increase of 40.21 per cent. In Himachal Pradesh, it is cultivated on an area of 8700 hectares with the production of 4000 tonnes giving an average yield of 460 kg/ha (Anonymous, 1996).

Among the sub-species of rapeseed and mustard group of crops, gobhi sarson or Swede rape or winter rape (*Brassica napus* var. *oleracea*) is an amphiploid between *Brassica campestris* and *Brassica oleracea* and introduced in India from Europe and Canada. It is gaining importance because of its higher yield potential, wider adaptability, suitability for early planting, and its capacity to exploit the residual moisture of *kharif* season, and to yield high oil content (46%) of a better quality. Being a photo and thermo-sensitive crop, it makes slow growth during early period of vegetative phase and follows the temperature trend as the season warms up in February and matures in about 200 days. It is a quite recent introduction in H.P. Because of exhaustive root system, it can withstand moisture stress better; as compared to other crops during the season. This specie has a well developed root and shoot system; it's nutritional requirements might be at a higher level. Use of optimum nutrition is the key to harvest potential yields of any crop on sustainable basis. However, the use of fertilizers to oilseed crop is very low in Himachal Pradesh and the information on fertilizer requirement of this oilseed crops is still lacking.

Ever increasing shortage has attracted the attention of policy makers, scientist and financing agencies and now the efforts are being made to augment production of oilseed crops such as groundnut, sesamum, Indian mustard, gobhi-sarson, linseed and soybean which are mainly grown in rainfed areas and face twin problems of low productivity and yield fluctuations from year to year. Adoption of good crop management practices can increase the yield of these crops by 50 to 100 per cent. Besides other management practices, these crops also respond to fertilizers, which may be substantial especially when good soil moisture is conserved in rainfed areas (Aulakh and Patel, 1988).

However, very little attention has been given towards the systematic research on fertilizer requirement of these crops with special reference to secondary and micro-nutrients. Introduction of high yielding varieties, increased use of high analysis fertilizers containing negligible amount of these nutrients as contaminants, increased cropping intensity and restricted recycle of farm wastes have resulted in wide spread deficiency of secondary and micro-nutrients. Sakal and Singh (1994) reported that at several places, normal yield of crops could not be achieved despite of judicious application of N, P and K. In years to come, the deficiency problems of micro and secondary nutrients will go on intensifying. Hence, there is a dire need to have continuous watch on these nutrients so that they may not limit crop production. Among secondary nutrients, 'S' is a key nutrient for oilseed production.

Brassica oilseed crops have a specially high S requirement as sulphur is involved in oil and protein synthesis and is a constituent of some fatty acids in mustard oils particularly glucosides components of oils. It also helps in formation of disulfide linkage such as sulfhydryl (SH group), which besides giving pungency to oils, also imparts resistance to draught and cold. Sulphur also influences the activity of ATP sulfurylase-an enzyme that helps in the metabolism of sulphur and production of ferrodoxin being the electron acceptor in the photosynthetic process of crop plants besides a role in the biological nitrogen fixation by microbes.

Zinc is involved in biosynthesis of a plant hormone Indole Acetic Acid (IAA) and is a component of variety of enzymes. It also helps in protein synthesis and in the utilization of N and P, besides it also maintains the membrane permeability. Dr. J.S. Kanwar, India's leading soil scientist wrote "In countries such as India vitally concerned with increasing food production, S is one element that must not be overlooked". Dr. N.N. Goswami, IARI, New Delhi wrote "Crops for example require as much S as they do P and S can therefore be rightly called the fourth major nutrient in Indian Agriculture".

Thus, S becomes a key member of balanced fertilizers team in areas where S deficiency is a problem. Neglect of S in such areas will lead to low yield, inferior crop quality and reduction in the efficiency of NPK. On an average, crops absorb 10-12 kg S to produce one tonne (1000 kg) of seed. S application to oilseed crop increases yield to the tune of 15-30 per cent and oil content by 4-9 per cent (Anonymous, 1994). Results from FAO trials have shown that each rupee spent on sulphur nutrition produces extra crop valued at Rs 8-9 (Tandon, 1994). Some micro-nutrients are needed for balanced fertilization and to increase the efficacy of NPK fertilizers, S plays a vital role. *Brassica* oilseeds also respond to zinc application as reported by many workers.

In Himachal Pradesh, 82 Per cent of the total cropped area is rainfed and in this area maize-wheat cropping system is followed year after year with very low productivity. The production of this system can be improved if wheat is replaced by an oil seed like gobhi sarson. Most of the studies conducted in past deal with gobhi sarson alone and information about gobhi sarson in maize-gobhi sarson sequence is not available.

Therefore, exploring the suitability of different levels of Zn in general and sulphur in particular, can lead to such cropping systems that provide the farmer maximum production as well as net profit per-unit area per unit time with minimum loss, if any, in soil productivity.

Considering the above principles and need of the farmers, the present study entitled, "**Studies on the effect of sulphur nutrition on gobhi sarson (*Brassica napus* var. *oleracea*) in maize-gobhi sarson crop sequence under rainfed conditions**" was undertaken with the following objectives :

1. To estimate the yield potential of maize-gobhi sarson crop sequence in the presence and absence of Zn and S,
2. to assess the magnitude of nutrient removal in the crop sequence, and
3. to study the fertility status and yield sustainability after each crop cycle.

REVIEW OF LITERATURE

Chapter-2

REVIEW OF LITERATURE

An effort has been made in this chapter to review the earlier work done on sulphur nutrition of gobhi sarson (*Brassica napus* var. *oleracea*) in maize (*Zea mays*) – gobhi sarson (*Brassica napus* var. *oleracea*) sequence. In cases, where information on this particular sequence is not available, related crop sequences have been included. The available literature has been discussed under the following headings:

2.1 Effect of sulphur and zinc nutrition on growth and development of gobhi sarson or related oilseed crops

2.2 Effect of sulphur and zinc nutrients on yield and yield attributes of gobhi-sarson or related oilseed crops

2.3 Yield potential of maize-gobhi sarson or related oilseed based crop sequences in presence and absence of S and Zn

2.4 Total nutrient uptake

2.5 Soil fertility status after each crop cycle

2.1 EFFECT OF SULPHUR AND ZINC NUTRITION ON GROWTH AND DEVELOPMENT OF GOBHI-SARSON OR RELATED OILSEED CROPS

Dixit and Shukla (1984) reported from Hissar that dry matter accumulation upto 50 days of early growth was just 5 per cent of the total at maturity in *Brassica juncea*. Yield of shoots increased with S and Zn application indicating response to these nutrients even at the early stage of growth @ 25 ppm S and 5 ppm Zn. Contrary to this, Verma and Ram (1985) reported no significant increase in height and seed yield of mustard due to application of sulphur.

Significant increase in leaves per plant of mustard was reported with application of 30 kg N and 90 kg S while significant increase in LAI was with 30 kg N and 60 kg S ha^{-1} (Upsani and Sharma, 1986).

Singh and Saran (198( ) reported from New Delhi that S application in *B. campestris* var. *toria* at lower rate of 30 kg S ha^{-1} produced taller plants. While, dry matter production $plant^{-1}$ increased significantly by both 30 and 60 kg S ha^{-1} when compared with control. The difference between these two levels, however, was not significant. Bhal *et al.* (1990) reported increase in growth parameters of mustard (*B. juncea* L.) with S application due to enhanced metabolic constituents of some amino acids. Similarly, Saran and Giri (1990) reported from New Delhi that application of S influences growth and yield of mustard. Significant increase in plant height, branches and dry matter was recorded with 60 kg S ha^{-1} and increase in leaf area was recorded with 30 kg S.

Mohan and Sharma (1992) reported from Bihar that application of S to *Brassica juncea* at lower rate (50 kg ha^{-1}) increased plant height and dry matter production significantly during both the years and at higher rate (75 kg ha^{-1}) it significantly increased the functional leaves, primary and secondary branches $plant^{-1}$ during both the years and LAI during one year. Khanpara *et al.* (1993) reported from Rajasthan that S applied either through elemental sulphur alone 21 days before sowing or 50 kg S ha^{-1} through gypsum and remaining S through elemental sulphur at sowing were found equally effective for all growth characters and seed yield of mustard (*Brassica juncea* L.).

et al. (1994) reported that plant height and number of branches plant^{-1} increased significantly with S application in Indian mustard (*Brassica juncea* L.). Subbiah and Mitra (1996) reported from West Bengal that growth component like plant height and dry matter accumulation increased significantly with zinc and boron application @ 500 ppm each in Indian mustard (*Brassica juncea* L.). Tomar *et al.* (1997) reported that plant height and dry matter accumulation per plant increased significantly with increasing levels of N, P and S upto 180, 80 and 80 kg ha^{-1}, respectively, in Indian mustard (*Brassica juncea* L.).

Similarly, Patel and Shelke (1998) reported significant increase in the plant height, leaf area per plant and primary branches per plant in Indian mustard with application of 60 kg S ha^{-1}.

With the application of 120, 60, 40, 10 and 90 kg ha^{-1} N, P, K, Zn and S, respectively, significant increase in plant height, branches and other growth and development components of mustard, was also reported by Singh *et al.* (1998).

Chaudhary (1998) reported that nitrogen, phosphorus (SSP 12% S and 112 ppm Zn) and potassium promoted growth, leaf size, leaf area, plant height dry matter accumulation, RGR and CGR in gobhi sarson (*B. napus* sub sp. *Oleifera* var. *annua*). On the contrary, Thakur and Chand (1998) reported from Kangra (HP) that application of 120 kg N and 40 kg P through SSP (12% S) did not significantly increase the growth and development of gobhi-sarson.

From the foregoing review of work done by different workers, it is seen that growth characters were significantly enhanced with the application of S and Zn in gobhi sarson or closely related oilseed crops with few exceptions.

2.2 EFFECT OF SULPHUR AND ZINC NUTRITION ON YIELD AND YIELD ATTRIBUTES OF GOBHI-SARSON OR RELATED OILSEED CROPS

The relevant responses of *Brassica species* to different level and sources of S and Zn with respect to yield and yield contributing characters have been reported by numerous scientists in India and abroad. In general though at variable levels, but all the *B. species* exhibited positive responses to fertilization in all the characters under study.

Chatterjee *et al.* (1985) reported that application of S, Zn and borax in Indian mustard (*Brassica juncea* L.) caused increase in siliquae per plant and test weight of seed. While, Rauth and Ali (1985) reported that number of siliquae per plant as well as seed yield were significantly influenced with S application (50 kg S ha^{-1} through gypsum) to mustard (*Brassica juncea* L.), in both years of study. Soil application of 250 kg gypsum ha^{-1} (50 kg S ha^{-1}) influenced the yield attributes and yield significantly over control. They further reported a close positive relationship of number of siliquae with seed yield under rainfed conditions.

Chatterjee *et al.* (1985) further reported from Kalyani, W.B. that application of S at 20 kg ha^{-1} through gypsum in conjunction with borax (10 kg ha^{-1}) caused increase in yield of mustard (*B. juncea*), mainly due to increase in siliqua per plant and test weight of the seed. They further reported that fertilization with nitrogen and phosphorus significantly increased the test weight, number of seeds per siliqua and number of siliquae per plant. Application of $CaSO_4$ and $ZnSO_4$ in all the years significantly increased the number of siliquae per plant and test weight of seed. However, the effect of $CaSO_4$, K_2SO_4 and Borax on the number of siliqua per plant, and on test weight of grains was more pronounced in late sown crop during 1982-83. They further reported that in sandy-loam soils of Gangetic plains applications of S at 20 kg ha^{-1} through gypsum in combination with borax @ 10 kg ha^{-1} caused 42 per cent increase in yield of mustard. Borax, Zinc sulphate (equivalent to 20 kg S ha^{-1}) and gypsum when applied singly caused 34, 26 and 30 per cent increase in yield, respectively. Combination of these nutrient products, however, did not show any additive effect.

Singh and Saran (1987) reported from New Delhi that S application at 30 and 60 kg ha^{-1} in *Brassica campestris* var. toria at lower rate of N (30 kg ha^{-1}) influenced significantly the yield attributes like pods per plant and 1000-seed weight. Likewise, Balayneh (1987) reported from Holetta, that application of S increased the seed yield of *Brassica napus* from 21.7 to 28.4 q ha^{-1}. Saran and Giri (1990) reported that in rainfed mustard, number of siliquae per plant, number of seeds per siliqua, number of siliquae per plant and 1000-seed weight were also increased significantly with 60 kg S ha^{-1}. Seed weight per plant was however, increased with 30 kg S but only in 1985-86. They further reported that in the absence of N and P, seed yield of mustard (*Brassica juncea* L.) increased significantly with increase in S levels upto 60 kg ha^{-1} while in presence of N (40 or 80 kg ha^{-1}) and P (11 kg ha^{-1}) the response to sulphur was recorded upto 30 kg S only. They also reported that neither N nor P application influenced the oil content of mustard while application of 60 kg S significantly increased oil content over control and 30 kg S ha^{-1}.

Walker and Booth (1990) reported that in rape varieties, Raftal and Tapidor, response to S was obtained at high N levels and the full response was not obtained even at 64 kg S ha^{-1} whereas at low level of N, the yield response to additional S flattened off at 32 kg S ha^{-1}.

Sharma *et al.* (1991) reported that increasing doses of S increased gradually the seed and oil yield of mustard (*Brassica juncea*) and 60 kg S ha^{-1} produced significantly higher seed and oil yield of 21.94 and 8.56 q ha^{-1}, respectively. An application of 50 kg S ha^{-1} significantly increased yield of rapeseed (*B. compestris)* by 10.7 per cent. Yield component analysis revealed that the number of fertile pods per plant was significantly increased by S application in these crops (Zhao *et al.,* 1991). Similarly, Khanpara *et al.* (1993) reported that fertilizing the mustard (*B. juncea* L.) with 100 kg S ha^{-1} was found beneficial as far as crop productivity is concerned. However, 100, 150 and 200 kg S ha^{-1} were largely comparable in both years of study in Rajasthan.

Mohan and Sharma (1992) reported from Bihar that in mustard (*Brassica juncea* L.), application of N @ 75 kg ha^{-1} and S @ 50 kg ha^{-1} significantly increased the number and size of siliqua, siliquae per plant, length of siliqua at harvest, seeds per siliqua and test weight of seed (1000-seed weight) during both years of study. Siliquae per plant were maximum with S application @ 75 kg ha^{-1} during 1985-86. Likewise, Kumar (1992) reported that mustard gave 14.78 q ha^{-1} grain yield with application of 20 kg S along with 10 kg Zinc ha^{-1} at Pantnagar, Kanpur, Hissar, Durgapur and Ludhiana. Similarly, Krishna and Singh (1992) reported that Zn application upto 30 kg ha^{-1} as $ZnSO_4$ in alluvial soils of Kanpur increased seed yield and oil content of mustard (*B. juncea* L.).

Patgiri and Baruah (1993) reported from Assam that seed yield of toria (*Brassica campestris* var. *toria*) receiving S was significantly higher than that of control. Seed yield was highest when S was applied @ 30 kg ha^{-1}, after which there was a decline in yield, the lowest being recorded at S application @ 60 kg ha^{-1}. Similarly, Dubey *et al.* (1994) reported that pods per plant, pod length, seeds per pod, 1000-seed weight, seed and stover yields increased significantly with sulphur application in Indian mustard. Mishra (1994) reported from Madhya Pradesh that highest dry pod yield of groundnut (*Arachis hypogaea*) was obtained under 60 kg P_2O_5 (SSP 12% S) ha^{-1} and lowest under control which was due to the increase in pod number per plant and 100-kernal weight.

Sen and Chatterjee (1994) reported from West Bengal that when yellow sarson (*Brassica campestris* var. sarson) was given 80 kg N + 40 kg P + 40 kg K ha^{-1} with or without 15 or 30 kg S ha^{-1} as elemental sulphur or 30 kg S through SSP, then seed yield increased with S application and was highest with S as SSP. N content in seeds was highest with 30 kg elemental S whereas S content in seed was highest with SSP. Varieties do differ in these responses to sulphur. As such, Sakal (1995) reported that out of 20 varieties of rapeseed and mustard, nine responded to 20 kg S ha^{-1} and the remaining 11 varieties responded upto 40 kg S ha^{-1}. The grain yield response ranged from 17 to 32 per cent in *Brassica campestris* group.

Kumar (1995) reported from Manipur that rape cv. M-27 when supplied with 0, 30 or 60 kg ha^{-1} each of S and P as elemental sulphur and DAP, respectively, then seed yield increased upto 30 kg S (1044 kg) and was highest with 60 kg P (1220 kg ha^{-1}). Seed oil and protein concentration were increased by S application. While, phosphorus application increased the protein concentration only. The N:S ratio was significantly lowered by S application. Likewise, Shakhela and Vyas (1995) reported from Jobner that on loamy-sand soils of Jobner (Rajasthan) effect of application of N, P and S were significant on seed and straw yield of mustard. Application of each nutrient at their higher level recorded significantly more seed yield. It was (17.6 per cent) higher with S application at the rate of 60 kg S ha^{-1} over S application at the rate of 30 kg ha^{-1}. The interaction effects (N x P x S) also produced significant impact on seed and straw yield of mustard.

Subbiah and Mitra (1996) reported from West Bengal that yield contributing characters in mustard (*B. juncea* L.) like siliquaeper plant, seeds per siliqua and 1000-seed weight were significantly increased by zinc and boron application each at the rate of 500 ppm. They further reported that application of Zn and B increased the seed yield by 26 and 18 per cent in the first year and 49 and 47 per cent, respectively in the second year over NPK alone in Indian mustard (*Brassica juncea* L.).

Tomer *et al.* (1997) working with different combinations of N, P and S in *B. juncea* observed that oil content of seed decreased with increased levels of N and P, whereas it increased with increasing levels of sulphur upto 60 kg S ha^{-1}.

Aulakh and Pasricha (1997) obtained a maximum of 914 kg oil ha^{-1} with 30 kg S and 100 kg N ha^{-1} in gobhi sarson (*Brassica napus* sub sp. *Oleifera* var. *annua*) and in toria (*B. campestris*) maximum seed yield of 600 kg ha^{-1} was obtained with 20 kg S ha^{-1}. They further reported from Punjab that the application of 100 kg N + 30 kg P_2O_5 + 20 kg S ha^{-1} influenced the seed protein (%), seed oil (%) and oil yield (q ha^{-1}) of gobhi sarson to the tune of 21.6 per cent, 43.7 per cent and 914 q ha^{-1}, respectively.

Solanki *et al.* (1998) reported that number of branches per plant, siliquae per plant, seeds per siliqua and test weight increased with increasing level of S upto 60 kg ha^{-1} over three years of experimentation with Indian mustard on sandy loam soils of Rajasthan. Similarly, Patel and Shelke (1998) reported from Maharashtra that in Indian mustard (*Brassica juncea*), sulphur application @ 60 kg ha^{-1} significantly increased the siliquae per plant, total dry matter per plant, length of siliqua, seeds per siliqua, weight of seeds per plant and 1000-seed weight. Similarly 30 kg S ha^{-1} was also significantly better than control. Similar trend was also noted in seed and straw yield, oil and protein content in seed of Indian mustard. On the other hand, Thakur and Chand (1998) reported from Kangra (H.P.) that application of 120 kg N and 40 kg P through

SSP did not increase growth, yield and yield attributes and yield significantly over control in gobhi sarson (*B. napus* sub sp. *Oleifera* var. *annua*) under rainfed conditions.

Jaggi (1998) reported from HPKV, Palampur (H.P.) that seed yield of Varuna varieties of Indian mustard (*B. juncea* L.) significantly increased with S application @ 60 kg ha^{-1}. With S addition @ 30, 60 and 90 kg ha^{-1}, the increase in seed yield over control were 121, 157 and 176 per cent, respectively. A significant positive interaction between S and P in increasing seed and straw yields was observed. Highest grain (21.5 q ha^{-1}) and straw (69.0 kg ha^{-1}) yields were obtained due to combined application of S at the rate of 90 kg ha^{-1} and P_2O_5 at the rate of 60 kg ha^{-1}. Highest seed:straw ratio (0.33) was evident from the treatments combinations of 60 kg S and 60 kg P_2O_5 ha^{-1}.

Singh *et al.* (1998) reported from Madhya Pradesh that seed yield and straw yield of Indian mustard (*B. juncea*) increased significantly with application of 120 kg N + 60 kg P_2O_5 + 10 kg Zn + 90 kg S ha^{-1}. Protein and oil contents were also found to increase significantly with S application. Likewise, Solanki *et al.* (1998) reported from Rajasthan that in Indian mustard (*Brassica juncea*), application of 60 kg S ha^{-1} gave significantly higher seed yield (26.47 q ha^{-1}) than 20 and 40 kg ha^{-1} by 15.5 and 7.2 per cent, respectively. Various sources of S had no significant effect on seed yield. Similarly, Sarmah and Debnath (1999) reported from Assam that gypsum and elemental sulphur application significantly improved most of the growth and yield attributes except plant height and number of seeds per siliqua in toria during 1995-96 and 1996-97. Increasing levels of S from 20 to 60 kg/ha increased the growth and yield attributes in both years, however differences were not significant statistically.

2.3 YIELD POTENTIAL OF MAIZE-GOBHI SARSON OR RELATED OILSEED BASED CROP SEQUENCES IN THE PRESENCE AND ABSENCE OF S AND Zn

This has been discussed under the following sub-headings:

2.3.1 Yield potential of gobhi-sarson or related oilseed crops due to direct effect of NPK in the absence of S and Zn.

2.3.2 Yield potential of gobhi sarson or related oilseed crops due to direct effect of NPK in the presence of S and Zn.

2.3.3 Yield potential of maize due to direct effect of NPK in the absence of S and Zn.

2.3.4 Residual effect of S and Zn applied to gobhi-sarson or related oilseed crops to succeeding maize or related crop in rotation.

2.3.5 Yield potential of oilseed based cropping system in the absence of S and Zn.

2.3.6 Yield potential of oilseed based cropping system in the presence of S and Zn.

2.3.1 Yield potential of gobhi-sarson or related oilseed crops due to direct effect of NPK in the absence of S and Zn

Singh (1984) reported that Indian mustard (*Brassica juncea*), var. 'Varuna' gave maximum yield when fertilized with 60 kg N, 40 kg P_2O_5 and 20 kg K_2O ha^{-1} under dryland condition on farmer's field in Rajasthan, whereas, Tomer and Tiwari (1990) reported that maximum seed yield of Indian mustard was 18.22 q ha^{-1} with recommended package of practices during 1984-85 from Morena, Madhya Pradesh. Similarly, soybean gave maximum average grain yield (1786 kg ha^{-1}) at Jabalpur (M.P.) when fertilized with 20 kg N, 60 kg P_2O_5 and 20 kg K_2O (Anonymous, 1991-92a). Kumar (1992) reported that standard variety of *B. juncea* gave maximum grain yield of (12.94 q ha^{-1}) with recommended dose of fertilizers under irrigated conditions in Punjab. However, under rainfed conditions of Uttar Pradesh Tomer *et al.* (1992) reported significantly higher yield of mustard (14.33 q ha^{-1}) when it was fertilized with 120, 60 and 60 kg ha^{-1} N, P_2O_5 and K_2O, respectively under rainfed conditions.

Gill *et al.* (1993) reported from Ludhiana that under rainfed conditions gobhi-sarson (*Brassica napus* sub sp. *Oleifera* var. *annua*) gave maximum grain yield (13.3 q ha^{-1}) when fertilized with 125, 45 and 30 kg ha^{-1} N, P and K, respectively. Similarly, highest seed yield of rapeseed (*B. napus*) (18.1 q ha^{-1}) was recorded with the application of 120 kg N and 60 kg P_2O_5 ha^{-1} Narang *et al.* (1993a).

Singh *et al.* (1994) reported that *Brassica juncea* cv. T-59 gave highest seed yield of 18 q ha^{-1} with the application of 90 kg N, 90 kg P_2O_5, 60 kg K_2O ha^{-1}, while Dubey *et al.* (1994) reported maximum seed yield (15.12 q ha^{-1}) from Madhya Pradesh when Indian mustard (*B. juncea*) was fertilized with 90, 60 and 40 kg ha^{-1}, N, P_2O_5 and K_2O, respectively. Similarly, Rajput *et al.* (1994) reported that maximum yield of Ethiopian mustard was 20.37 q ha^{-1} with the application of 100 and 75 kg ha^{-1} N and P; respectively. At Jabalpur soybean gave maximum mean grain yield (825 kg/ha) when fertilized with 20 kg N, 60 kg P_2O_5 and 20 kg K_2O (Anonymous, 1994-95a).

Sharma *et al.* (1999) reported from Delhi that mustard (*Brassica juncea)* gave 19.06 q ha^{-1} yield with 80, 40 and 40 kg ha^{-1} N, P and K, respectively whereas under farmer's practice (60 kg N + 57 kg P_2O_5 ha^{-1}) mustard gave 12.81 q ha^{-1} yield.

2.3.2 Yield potential of gobhi-sarson or related oilseeds crops due to direct effect of NPK in the presence of S and Zn

Shrivastava and Pathak (1980) reported that in Y.ai (*B. juncea*), application of 20 kg elemental sulphur ha^{-1} and 10 kg $ZnSO_4$ ha^{-1} along with 120, 30 and 30 kg ha^{-1} N, P_2O_5 and K_2O, respectively gave seed yield of 14.88 and 15.35 q ha^{-1}.

An improvement in seed yield, oil and protein contents of *Brassica juncea* (Rai) was observed with application of S, Zn and B either alone or in combination with recommended dose of NPK (Shukla *et al.,* 1983).

Singh and Sahu (1986) reported least response in Himachal Pradesh, where application of 100 kg S ha^{-1} increased seed yield of mustard by 18 per cent compared to 124 per cent in Punjab with application of 30 kg S ha^{-1}. They further reported that per cent increase in grain yield of mustard (*Brassica juncea*) with application of 30 kg S ha^{-1} was 124, 18 and 4 per cent in Punjab, Uttar Pradesh and Haryana, respectively. Under rainfed conditions of Orissa and Rajasthan increase in grain yield was 17 and 25.41 per cent, with 20 and 20-50 kg S ha^{-1}, respectively. Similarly, Pasricha *et al.* (1987) reported significant response to direct application of 20 kg S ha^{-1} applied through gypsum and pyrite to groundnut. However, grain yield of linseed was not influenced significantly by the direct application of graded levels of S supplied through pyrite with basal dose of NPK (Anonymous, 1987-88).

Pasricha

Aulakh and *(1988)* reported yield response of toria (*Brassica campestris* var. *toria*) to 20 kg S ha^{-1} ranging from 5.9 q ha^{-1} in Punjab to 1.2 q ha^{-1} in Uttar Pradesh. While, Kumar and Singh (1989) reported from Jaipur that mustard (*Brassica juncea*) gave maximum grain yield (14.78 q ha^{-1}) when applied with 20 kg S and 120 kg Zn ha^{-1}, per cent increase over control was 34.9 per cent.

Zhao *et al.* (1991) reported from U.K. that application of 50 kg S ha^{-1} increased the yield (4.57 t ha^{-1}) of rapeseed var. 'Colera' over no application (4.13 t ha^{-1}). Mohan and Sharma (1992) reported from Bihar that seed yield (18.38 q ha^{-1}) of Indian mustard increased significantly with an increase in level of S up to 50 kg ha^{-1}. However, further increase in the level of S decreased yield. At Jabalpur (M.P.) no significant effect of graded level of sulphur and Zn as ZnO and $ZnSO_4$ was observed when these treatments were given to soybean compared to control (NPK only), however, there was increasing trend with the application of Zn as $ZnSO_4$ (Anonymous, 1991-92a).

Asaduzzuman *et al.* (1993) reported that *B. juncea* cv. 'Daulat' gave the highest grain and biomass yield with 140, 80, 60 and 30 kg ha^{-1} N, P, K and S, respectively. Dubey *et al.* (1994) reported from Madhya Pradesh that maximum yield (16.96 q ha^{-1}) of mustard (*Brassica juncea*) was obtained with the application of 90 kg N and 40 kg S ha^{-1} over control (4.49 q ha^{-1}).

In frontline demonstration, maize-gobhi sarson, gobhi sarson gave 1413 to 2156 kg ha^{-1} grain yield under rainfed conditions with recommended NPK where the source of P was SSP (containing 12% S) (Anon., 1994-95). At

Sehore (M.P.), soybean gave maximum yield with application of Zn as $ZnSO_4$ at 10 kg Zn ha^{-1} and 50 kg sulphur ha^{-1} as basal application when applied every year and alternate year to soybean (Anonymous, 1994-95a).

Ghosh *et al.* (1995) reported that with application of N, P, K where P was applied through SSP containing 12% S, significantly increase in yield of *B. campestris* var. *Toria*. On the contrary, Patel *et al.* (1995) reported from Gujarat that seed and stalk yield of mustard var. 'Varuna' was not influenced with the application of 50 kg elemental sulphur ha^{-1}. Similarly, in case of groundnut, Hazara (1997) reported 30 per cent increase in yield of groundnut with application of 40 kg S per hectare. Cultivation of gobhi sarson with recommended NPK in maize-gobhi sarson sequence in Himachal Pradesh gave 1865 and 1500 kg ha^{-1} grain yield of gobhi sarson at Loonapani and Sundernagar, respectively where P was supplied through SSP cotaining12% S. (Anonymous, 1995-96).

Chaudhary (1998) reported that application of recommended dose of N, P, K where P was applied through SSP (containing 12% sulphur), gobhi sarson (*B. napus*) gave 18.65 q ha^{-1} seed yield under irrigated conditions of Himachal Pradesh.

Dhillon *et al.* (1999) reported that gobhi sarson yield was better with N, P, K and S application in Punjab. He further added that sulphur concentration in gobhi sarson also improve considerably in treated plots compared to control plots.

2.3.3 Yield potential of maize due to direct effect of NPK in the absence of Sulphur and Zinc

Palled *et al.* (1991) reported from Karnataka that under assured irrigation maize gave maximum grain yield (44.56 q ha^{-1}) with application of 120, 60 and 40 kg ha^{-1} N, P_2O_5 and K_2O, respectively while Verma *et al.* (1991) reported maximum grain yield (52.1 q ha^{-1}) of wheat from J & K with 135, 90 and 45 kg ha^{-1} N, P_2O_5 and K_2O. respectively. Maize gave average grain yield of 1205 kg/ha when fertilized with 60 kg N, 40 kg P_2O_5 and 40 kg K_2O at Banswara (Anonymous, 1991-92a). Similarly, Shah *et al.* (1992) reported maximum yield of 41.8 q ha^{-1} of maize with 120, 60 and 20 kg ha^{-1}, N, P_2O_5 and K_2O, respectively.

Mishra (1993) reported from Madhya Pradesh that maize var. Ganga-5 gave maximum grain yield (20.82 q ha^{-1}) when fertilized with 100, 60 and 40 kg ha^{-1} N, P_2O_5 and K_2O, respectively and resulted in 111.5 per cent increase in grain yield over the control. However. Gill *et al.* (1993) reported under constraint of irrigation, maximum maize grain yield of 22.9 q ha^{-1} with the application of 80, 40 and 40 kg ha^{-1} N, P_2O_5 and K_2O, respectively. Gill *et al.* (1994) further reported from Ludhiana that maize var. "Navjot" gave maximum grain yield (32.6 q ha^{-1}) when fertilized with 120. 60 and 30 kg ha^{-1} N, P_2O_5 and K_2O, respectively. Maize gave average grain yield of 1302 kg/ha when fertilized with 80 kg N and 40 kg P_2O_5 ha^{-1} at Banswara (Rajasthan) (Anonymous, 1994-95a).

Under rainfed conditions of Himachal Pradesh Suri *et al.* (1995) reported that application of 90, 45 and 20 kg ha^{-1} N, P and K gave maximum grain yield of maize (52.5 q ha^{-1}).

Maximum grain yield of maize (62.79, 41.27 q ha^{-1}) was obtained with 100 per cent NPK during 1993 and 1994 by Manuja and Chakor (1995). Kumar and Singh (1995) reported maximum yield (60.0 q ha^{-1}) of maize with 100 per cent recommended NPK without FYM, S and Zn.

Srinivas and Shrinivasa (1998) reported from Andhra Pradesh that maize gave mean yield of (51.3 q ha^{-1}) with recommended dose of fertilizers. While, Singh *et al.* (1999) reported that maize crop at New Delhi gave 20.37 q ha^{-1} grain yield and 27.11 q ha^{-1} stover yield with application of 120, 60 and 40 kg ha^{-1} N, P_2O_5 and K_2O, respectively. Similarly, 27.5 q ha^{-1} grain yield of maize was reported with the application of 120, 60, 40 kg N, P_2O_5 and K_2O, respectively by Saikia and Pandey (1999) from New Delhi.

Vats *et al.* (1999) reported that in maize, maximum response (21.3 q ha^{-1}) was obtained with profit maximizing dose of 150, 75 and 75 kg ha^{-1} N, P and K respectively at Ludhiana (alluvial soils) and at Coimbatore (medium black soils) maximum response (21.2 q ha^{-1}) was obtained with profit maximizing dose of 142, 71 and 37 kg ha^{-1} N, P and K, respectively.

2.3.4 Residual effects of S and Zn applied to gobhi sarson or related oilseed crops to succeeding maize or related crop in rotation

Many scientists reported that when sulphur was applied to one crop then it can take care of S requirements of succeeding crop in rotation. Takkar and Randhawa (1978) reported that wheat crop significantly responded to residual effect of zinc applied to groundnut crop at the rate of 112 kg Zn ha^{-1}. Similarly, Sakal *et al.* (1985) reported that there was residual effect of pyrites application to groundnut at 0.4 and 0.8 t ha^{-1} levels on wheat crop. The residual effect of pyrites increased wheat grain yield from 2560 to 3800 kg ha^{-1} whereas in press mud (1.64% S), FYM (0.76% S) application to groundnut, yield of wheat increased from 2480 to 3480 and 3280 kg ha^{-1}, respectively. Sulphur uptake was also increased due to residual effect.

Singh and Sahu (1986) reported residual effect in the following crop in rotation when mustard (*B. juncea*) was applied with elemental sulphur. Pasricha *et al.* (1987) reported that in groundnut-wheat sequence, wheat gave a significant response (6-8 q ha^{-1}) to residual S from both gypsum and pyrite applied to groundnut. Similarly, Biswas and Tewatia (1991) reported from Ludhiana that fertilizer S applied to one crop could be sufficient to meet S requirement of succeeding crop in groundnut-wheat rotation. At Jabalpur (M.P.) significant residual effect was observed in wheat due to sulphur and zinc (ZnO and $ZnSO_4$) when applied every year or alternate year to soybean (Anonymous, 1991-92a). However, Saarela and Hahtonen (1993) reported from pot experiment in Finland that residual effect of S applied to turnip rape (*B. campestris* var. *Oleifera*) was not significant. On the contrary, Patel *et al.* (1994) reported significant residual effect of S application to groundnut at 30 kg S ha^{-1} on the subsequent crops in groundnut-wheat rotation. At Sehore (M.P.) significantly maximum residual effect of zinc as $ZnSO_4$ @ 10 kg zinc ha^{-1} was observed in wheat when zinc as $ZnSO_4$ applied every year or alternate year to soybean in soybean-wheat rotation (Anonymous, 1994-95a). Saroa *et al.* (1995) also reported significant residual effect of sulphur applied to soybean upto 80 kg P_2O_5 ha^{-1} through SSP containing 12% S on wheat grain yield at Ludhiana in soybean-wheat rotation. Similarly, Tiwari (1995) reported from U.P. that residual effect of S (gypsum) applied to mustard increased the grain yield of rice by 710 kg ha^{-1}. Hazı (1997) reported 26 per cent increase in yield of wheat due to residual effect of 40 kg s ha^{-1} applied to groundnut in Bihar in groundnut-wheat rotation. In groundnut-oat sequence, the residual effect of S applied to groundnut increased the yield of oat by 21 per cent. Mankotia and Sharma (1998) reported non-significant residual effect of graded level of N, P (SSP) and FYM on maize in gobhi-sarson+toria-maize cropping system in Himachal Pradesh.

2.3.5 Yield potential of . seed based cropping system in the absence of S and Zn

Soni and Vats (1989) reported from Ludhiana that maximum grain yield (52.41 q ha^{-1}) was obtained in maize-mustard sequence on chestnut brown soils at 100 per cent NPK fertilization. Tomar and Tiwari (1990) reported from Morena that maize-mustard gave total grain yield of 39.07 q ha^{-1}, when fertilized with recommended dose of NPK. Raghuwansi *et al.* (1991) reported from JNKVV, Indore, Madhya Pradesh that wheat equivalent yield (q ha^{-1}) for soybean-wheat rotation was 87.1 and 55.8 q ha^{-1} during 1983-84 and 1984-85, respectively. Likewise, they further added that wheat equivalent yield of 69.7 and 48.3 q ha^{-1} with NPK application through urea, DAP and MOP, during 1983-84 and 1984-85, respectively to soybean (T-49) – wheat in Madhya Pradesh. At Jabalpur yield of soybean was significantly lower with the application of NPK only (Anonymous, 1991-92a).

Patil and Shinde (1992) reported from Jalgaon that in sesamum-sorghum cropping system, sesamum and sorghum gave 614 and 758 kg ha^{-1} grain yield, respectively with recommended NPK. They further reported that in groundnut-sorghum cropping system, groundnut and sorghum gave 1332 and 434 kg ha^{-1}yield respectively with recommended NPK.

Gill *et al.* (1994) reported from Ludhiana that with recommended NPK fertilization of maize – gobhi sarson (*B. napus* sub sp. *Oleifera* var. *annua*) cropping system resulted in maize grain yield of 30.27 and 38.28 q ha^{-1} and gobhi sarson yield of 16.96 and 19.39 q ha^{-1} in Hoshiarpur and Kapurthala, respectively. At Jabalpur (MP) soybean gave mean grain yield of 717 kg/ha and wheat gave 3258 kg/ha when fertilized with recommended dose of NPK (Anon., 1994-95). Reddy *et al.* (1996) reported from a study on maize and oil seed based cropping system in Andhra Pradesh that production efficiency of maize-Indian mustard rotation was 14.5 kg ha^{-1} day^{-1} whereas for maize-groundnut, it was 23.0 kg ha^{-1} day^{-1}. Maximum production efficiency was observed in maize-sunflower rotation (28.7 kg ha^{-1} day^{-1}) and minimum in maize-Indian mustard (14.5 kg ha^{-1} day^{-1}) rotation. Maize equivalent yield was 2991 kg ha^{-1} in maize-Indian mustard sequence, whereas maize-sunflower rotation gave maximum maize equivalent yield of 5,972 kg ha^{-1} with recommended NPK through urea, DAP and MOP.

Sahota *et al.* (1997) reported that maize-gobhi sarson (*B. napus*) sequence when fertilized with recommended NPK dose gave 52.60 q ha^{-1} total grain, out of which 20.2 q ha^{-1} is attributed to gobhi sarson (*B. napus*). Srinivas and Shrinivasa (1998) reported maximum maize grain equivalent yield was recorded in maize-groundnut cropping system (140.5 q ha^{-1}), whereas in maize-Indian mustard sequence, it was 81.3 q ha^{-1}. The production efficiency of maize-groundnut was also higher (34.7 kg ha^{-1} day^{-1}) compared to maize-mustard sequence (29.0 kg ha^{-1} day^{-1}) with recommended dose of NPK.

2.3.6 Yield potential of oilseed based cropping systems in the presence of sulphur and zinc

The beneficial effect of FYM which is also a source of micro and secondary nutrients along with 100 per cent NPK reflected in the highest production in soybean-wheat-potato crop sequence giving 4.1 t ha^{-1} grain yield of soybean and wheat and 7.6 t ha^{-1} of potato tubers at Ranchi on acidic red loam soil (Anonymous, 1984).

Among the four crop sequences tested under optimum NPK fertilization where source of P was SSP (12% S and 0.011% Zn), soybean-wheat and ground-wheat gave 48.80 and 55.42 q ha^{-1} wheat equivalent yield, respectively (Sahay, *et al.* 1989). At Sehore (MP) the yield of soybean and wheat improved significantly in the presence of sulphur and zinc in soybean-wheat sequence (Anonymous, 1991-92a). In Himachal Pradesh, maize-gobhi sarson sequence produced 3520 kg ha^{-1} of maize and 1867 kg ha^{-1} grain yield of gobhi sarson under rainfed conditions and 5040 kg ha^{-1} maize and 1734 kg ha^{-1} gobhi sarson grain under irrigated conditions with recommended levels of urea, SSP and MOP (Anonymous, 1994-95). As reported from Madhya Pradesh, grain yield of soybean and wheat increased significantly in the presence of sulphur and zinc when applied every year or alternate year to soybean in soybean-wheat crop sequence (Anonymous, 1994-95a).

Verma (1997) reported from Uttar Pradesh that with recommended NPK (P through SSP containing 12% S and 112 ppm Zn), maize-Indian mustard-green gram gave per hectare grain yield of 1867, 2676 and 440 kg during 1992-93 and 1955, 2684 and 375 kg per hectare during 1993-94, respectively. They further reported that in rice-Indian mustard-green gram crop rotation, maximum yield of rice was obtained (3.778 kg ha^{-1}) with 100 per cent NPK (P throughSSP) while Indian mustard and green gram gave grain yield to the tune of 2111 and 428 kg ha^{-1} respectively, during 1992-93. During 1993-94, grain yield of rice, Indian mustard and green gram was 2711, 2333 and 348 kg ha^{-1}, respectively.

Aulakh and Pasricha (1997) reported from Ludhiana that in soybean wheat rotation, application of 80 kg P ha^{-1} through SSP gave maximum yield of soybean 25.7 q ha^{-1} and wheat 24.1 q ha^{-1}. Gupta and Dubey (1998) reported from their study on soybean-wheat-maize (fodder) cropping system conduced at Jabalpur, (M.P.) that the grain yield was highest in soybean (25.2 q ha^{-1}), wheat (44.2 q ha^{-1}) and maize (69.2 q ha^{-1}) when fertilized with sulphur + FYM + 100 per cent NPK while 100 per cent NPK + Zn gave yield of 22.8 40.2 and 58.1 q ha^{-1}, respectively. Exclusion of Zn from the fertilizer schedule reduced the yield of soybean by 0.40 q ha^{-1}, wheat by 0.90 q ha^{-1} and maize fodder by 5.0 q ha^{-1} and exclusion of S reduced the yield of soybean by 1.4 q ha^{-1}, wheat by 2.1 q ha^{-1} and maize fodder by 7.6 q ha^{-1}. Similarly. Rao *et al.* (1998) reported from Madhya Pradesh that in soybean-wheat sequence, soybean gave maximum grain yield (2.31 t ha^{-1}) with recommended NPK fertilizers along with application of S and Zn 20 kg ha^{-1}, respectively and FYM @ 16 t ha^{-1}, respectively, while wheat gave maximum grain yield (3.25 t ha^{-1}) with recommended NPK fertilizer alongwith 20 kg S ha^{-1}, and 6 kg Zn ha^{-1} during first year (1992-93). With same fertilizer schedule, during second year (1993-94), the soybean and wheat yield was 1.84 and 3.93 t ha^{-1}, respectively. Mankotia and Sharma (1998) reported from HPKV, Palampur, Himachal Pradesh that in maize-gobhi sarson + toria sequence, gobhi sarson equivalent yield of 1391 kg ha^{-1} was obtained with application of 80 kg P through SSP (12% S, 112 ppm Zn).

From the foregoing review, it appears that there is significant increase in yield of maize and gobhi sarson or related oilseed crops due to application of sulphur and zinc. Application of S and Zn to a crop has sufficient residual effect also on succeeding crops. In different agro-climatic zones, different oilseed based crop sequences have been found to give higher yield in presence of S and Zn as compared to yield in absence of sulphur and Zn.

2.4 TOTAL NUTRIENT UPTAKE

The uptake of total nitrogen, phosphorus, potassium, sulphur and zinc has been discussed under following sub-heads:

2.4.1 Nitrogen, phosphorus, potassium, sulphur and zinc uptake by gobhi sarson/oilseed crop.

2.4.2 Nitrogen, phosphorus, potassium, sulphur and zinc uptake by maize/cereal crop

2.4.3 Nitrogen, phosphorus, potassium, sulphur and zinc uptake by maize-gobhi sarson sequence or related crop sequences.

2.4.1 Nitrogen phosphorus, potassium,sulphur and zinc uptake by gobhi sarson/oilseed crop

Aulakh *et al.* (1980) reported from Ludhiana that nitrogen uptake by yellow mustard and mustard was influenced by application of both N and S. Nitrogen rates had a larger effect than S rates on N uptake. Uptake of N was further improved when N and S were applied together and there was a significant positive N x S interaction. Generally there was increase of S uptake by grain of both crops with successive application of S rates. Similarly, successive N application significantly influenced N uptake. Shrivastava and Pathak (1980) reported that mustard (*B. juncea*) removed the nutrients as high as 144 kg N, 35 kg P_2O_5, 40 kg K_2O and 87 kg S ha^{-1}.

Shukla *et al.* (1983) reported that total uptake of N, S and Zn by rai (*Brassica juncea*) at 20 kg S ha^{-1} (through elemental S) was 68.45, 37.55 and 0.186 kg ha^{-1}, respectively. With application of 10 kg Zn ($ZnSO_4$), respective uptake was 69.40, 36.18 and 0.218 kg ha^{-1}. Combined application of elemental S (20 kg ha^{-1}) and Zn (10 kg $ZnSO_4$ ha^{-1}) to *B. juncea* (Rai) resulted in 72.14, 39.76 and 0.207 kg ha^{-1} uptake of N, S and Zn respectively.

Jain *et al.* (1984) reported that total uptake of N, P, K and S by mustard (*B. juncea*) producing 26.0 q ha^{-1} yield was 130.9. 25.3, 133.3 and 44.9 kg ha^{-1}, respectively. However, they further reported 130.9, 26.4, 141.3 and 44.9 kg ha^{-1} uptake of N, P, K and S, respectively with elemental S application at Jaipur. Without S application, respective values were 93.6, 16.4, 99.5 and 26.2 kg ha^{-1}.

Roy and Tripathi (1985) reported that nutrient uptake per tonne of mustard (*B. juncea*) seed was 33.29 to 40.22 kg N, 13.71 to 18.22 kg P_2O_5 and 32.11 to 41.08 kg K_2O. Aulakh *et al.* (1985) while studying the uptake of macro and micro nutrients by sarson and raya reported that total uptake by sarson grain was 83, 17, 71, 26 and 0.15 and by raya grain was 129, 18, 90, 32 and 0.117 kg ha^{-1} for N, P, K, S and Zn, respectively. This indicates that raya crop is heavy feeder of nutrients especially that of N, P, K and S. Nitrogen and phosphorus uptake by soybean was the highest among three crops taken in soybean-wheat-maize (fodder) cropping sequence at Jabalpur (Anonymous, 1988).

On the other hand, *B. campestris* var. *toria* removed about 110-116 kg N, 27.6 to 30 kgP_2O_5 and 12-13 kg S when fertilized with 120 kg N, 60 kg P and 50 kg S per ha (Narang *et al.*, 1993). In oilseed crop like sunflower (*Helianthus annuus L.*), application of S through gypsum, ammonium sulphate and SSP at the rte of 20 and 60 kg S ha^{-1} increased uptake of N, K, S and Zn (Sreemannaryana *et al.,* 1993). Dubey *et al.* (1994) reported from Madhya Pradesh that increasing levels of N upto 90 kg ha^{-1} and S upto 30 kg ha^{-1}, significantly increased the N and S contents as well as the uptake of these nutrients by mustard seeds. Since both, nitrogen and sulphur are closely linked with protein metabolism, their relationship is likely to be synergistic. Contrary to this, Patel *et al.* (1994) reported non-significant uptake of N, P and K by groundnut fertilized with SSP. Saroa *et al.* (1995) reported that in soybean-wheat rotation, mean P removal by soybean grains was significantly higher upto (40 kg P_2O_5 ha^{-1}).

Thakur and Chand (1998) reported from Kangra that with increasing levels of SSP, there was nominal increase in N, P and S uptake. however, S uptake increased significantly compared to control in gobhi-sarson (*B. napus* sub sp. *Oleifera* var. *annua*).

2.4.2 Nitrogen, phosphorus, potassium, sulphur and zinc uptake by maize/cereal crop

Rajgopal and Mehta (1971) reported that hybrid maize removed 222.2, 23.3, 203.5 and 808 mg N, P, K and Zn pot^{-1}, respectively when supplied with 100 kg P_2O_5 ha^{-1} and 5.0 ppm zinc along with uniform dose of 200 kg N $[(NH)_2SO_4]$ and 100 kg K (K_2SO_4). On the other hand in field with yield level of 113 q ha^{-1}, removed 142, 124, 156 and 12 kg ha^{-1} of N, P, K and S, respectively, alongwith removal of 113 gm Zn ha^{-1} (Anonymous, 1983). While, Jain *et al.* (1984) estimated that the removal of N, P, K and S in maize crop producing 51.4 q ha^{-1} was 300.6, 35.8, 180.7 and 18.7 kg ha^{-1}, respectively. Nad and Goswami (1984) reported that a cereal crop producing 4000 kg ha^{-1} grain removes 12-16 kg S. In a pot study, Singh and Singh (1984) reported that maize removed 1533.1 μg of zinc with yield level of 40.4 g pot^{-1} fertilized with 20 ppm zinc. At Jabalpur, K uptake was highest in case of fodder maize followed by wheat and soybean in soybean-wheat-maize (fodder) cropping sequence but P uptake by fodder maize was just half of the wheat (Anonymous, 1988). Maize crop removed 99.99, 18.46 and 28.92 kg ha^{-1} N, P_2O_5 and K_2O, respectively with 100 per cent NPK fertilization (Anonymous, 1989-90). Prasad and Kerketta (1991) reported that maize crop removed 162.0, 22.1 and 45.0 kg ha^{-1} N, P_2O_5 and K_2O, respectively under, 100 per cent NPK fertilization. In another study, maize removed 194.6, 36.0 and 57.1 kg ha^{-1} N, P and K, respectively when fertilized with 100 per cent NPK only and 24.2, 43.2 and 68.3 kg ha^{-1}, respectively in combination with 20 t ha^{-1} FYM (Anonymous, 199

Mishra (1993) reported from Madhya Pradesh that maize removed 66.5, 77.4 and 95.2 kg N ha^{-1} with application of 100, 150 and 200 kg N ha^{-1}, respectively. Similarly, Sawat and Dyanand (1994) reported from New Delhi that maize (*Zea mays*) removed maximum N (260.25 kg ha^{-1}) and K (92.96 kg ha^{-1}) with application of 225 kg N and 50 kg P. It was reported from Madhya Pradesh that sulphur application increase the uptake of N, P, K, S and Zn in wheat due to its residual effect and residual effect was maximum with sulphur, Zn as $ZnSO_4$ applied every year or alternate year to soybean in soybean-wheat crop sequence (Anonymous, 1994-95a). Tandon (1995) reported from New Delhi that range for S uptake by main produce of maize varied from 2.2-4.6 kg S t^{-1}, with mean value of 3.4. At Hyderabad, maize crop (*Zea mays*) producing 144 g dry matter $plant^{-1}$ removed 206.3, 40.3 and 183.2 kg ha^{-1} N, P_2O_5 and K_2O, respectively (Sreenivas and Satyanarayana, 1996).

2.4.3 Nitrogen, phosphorus, potassium, sulphur and zinc uptake by maize-gobhi sarson sequence or related crop sequences

Nair *et al.* (1973) reported from Pantnagar that out of five rice based multiple cropping sequences rice-Indian rape-soybean removed 489, 106.5 and 290 and rice-Indian mustard-wheat removed 335, 93 and 267 kg ha^{-1} N, P and K, respectively. Nambiar and Ghosh (1984) reported that under optimum NPK application, oilseed based cropping sequence like soybean-wheat and groundnut-wheat-guar removed 242 and 504 gm Zn ha^{-1}, respectively with yield level of 5.7 and 26.2 t ha^{-1}, respectively. Intensive cropping system may remove upto 70 kg S ha^{-1} $year^{-1}$ from the soil (Tandon, 1984a), while Nad and Goswami (1984) reported annual removal of 10 to 70 kg S ha^{-1}. Nambiar and Ghosh (1984) reported that soybean-wheat-maize cropping system removed about 49 kg S ha^{-1} $year^{-1}$. In the same rotation, when maize is taken as fodder crop, then S uptake varied from 36 to 43 kg ha^{-1} at optimal to super optimal NPK inputs with single super phosphate as S source. Manickam (1985) reported that of crop type yield level are the major determinants of S removal from soil. He further reported that under comparable conditions, oilseed-legume cropping sequence removed more S than a cereal dominated crop sequence, former removed 4-5 kg S whereas latter removed only 2 kg S per tonne dry matter production.

Sharma *et al.* (1987) reported from a study on oilseed based cropping sequences, that groundnut-bread wheat and groundnut-Indian mustard removed 193, 17.5, 106 and 27, 5.7 and 21 kg ha^{-1} N, P, K, respectively. Uptake of P and K by crops in acidic soils of Ranchi is generally very low as compared to N. The low P and K uptake by the crop sequence soybean-potato-wheat in these acid soils may be attributed to very high fixation capacity and low native source of K (Anonymous, 1988). Cereal based crop rotation having maize, potato and rice as one of the crop removed higher amount of NPK than oilseed based cropping systems. Groundnut-wheat rotation removed 115.1, 16.86 and 84.92 kg ha^{-1} $year^{-1}$ N, P, K, respectively (Thakur *et al.,* 1990).

Islam *et al.* (1997) reported that in rice-mustard crop rotation, rice removed 9.49 kg S ha^{-1} with 100 per cent NPK + 25 kg S (gypsum), 7.6 kg S with 4 kg Zn (ZnO), 11.51 kg ha^{-1} S with 25 kg S ha^{-1} + 4 kg Zn ha^{-1} (ZnO) as compared to control (6.23 kg S ha^{-1} with 100% NPK). Similarly Zn uptake was 0.200, 0.241 and 0.319 kg ha^{-1} with same treatments when compared to control (0.161 kg ha^{-1} Zn with 100% NPK). Following mustard crop removed 4.21, 3.56, 4.08 and 2.94 kg ha^{-1} S and 0.077, 0.082, 0.094 and 0.054 kg Zn ha^{-1} with same treatments as in rice indicating that rice is heavy feeder of nutrient compared to mustard.

From the foregoing review of work done by different workers it can be summarized, that uptake of major nutrients i.e. N, P and K increases with increase in S and Zn. Further, the cropping sequence removed higher amount of nitrogen followed by potassium and phosphorus. S and Zn uptake was generally higher in oilseed based cropping sequences than crop sequence without any oilseed crop, as gobhi sarson or closely related oilseed crop are heavy feeder of nutrients (N, P, K, S and Zn). In general, S and Zn improve the uptake of N, P and K but negative interaction between S x P and P x Zn was also observed.

2.5 SOIL FERTILITY STATUS AFTER EACH CROP CYCLE

Fertility status of soil after harvest of each crop has been discussed under following sub-heads:

2.5.1 Fertility status of soil after harvest of gobhi sarson/oilseed crops

2.5.2 Fertility status of soil after harvest of maize/cereal crops

2.5.3 Fertility status of soil after harvest of maize-gobhi sarson or related crop sequences

2.5.1 Fertility status of soil after harvest of gobhi sarson

From Himachal Pradesh, Kumar (1992) reported that available N, P and K of the soil after the harvest of gobhi sarson (*B. napus* sub sp. *Oleifera* var. *annua*) crop of 1990-91 was 316.5, 16.25, 182.59 kg ha^{-1}, respectively. The organic carbon and pH was 0.71 per cent and 5.63, respectively. The respective values were 329.31, 18.10, 198.12, 0.69 and 5.3 during 1991-92. On the other hand, Chaudhary (1998) reported that available nitrogen, phosphorus, potassium and sulphur was 374.65, 20.97, 294.91 and 34.33 kg ha^{-1} respectively when the gobhi sarson was fertilized with 100 kg N, 60 kg P_2O_5 (through SSP containing 12% S) and 45 kg K_2O ha^{-1}. With the application of above mentioned dose of fertilizer, the N, P and K status of soil was maintained while that of available S and organic carbon decreased by 0.11 per cent. Similarly, Mankotia and Sharma (1998) indicated a build up of nitrogen and phosphorus and slight decline in available potassium due to N, P and FYM fertilization of gobhi sarson. After the harvest of gobhi sarson, the available nitrogen was 294.5 and 292.1, available phosphorus was 19.77 and 21.70 and available potassium was 209.0 and 217.8 kg ha^{-1}.

2.5.2 Fertility status of soil after the harvest of maize

Sakal *et al.* (1985) reported that the soil available Zn after harvest of maize/cereal crops fertilized with 5 and 10 kg ha^{-1} as $ZnSO_4$ and ZnO was 1.60, 2.97 and 2.29, 3.61 ppm, respectively as against 0.48 ppm in control. Zinc frits did not improve soil available Zn as they are sparingly soluble material and release Zn very-very slowly. After harvest of maize crop, the available nitrogen, phosphorus and potassium contents of the soil were 507.8, 27.6 and 241.5 kg ha^{-1}, respectively (Anonymous, 1988-89). However, in another study the available nitrogen, phosphorus, potassium and contents after the harvest of maize were found to be 489.1, 14.3, 164.6 and 1.53 kg ha^{-1} respectively (Anonymous. 1988-89). Still another study reported that available nitrogen, phosphorus and potassium contents, after harvest of maize was 652.1, 31.5 and 129.1 kg ha^{-1}. respectively and organic carbon contents was 0.52 per cent (Anonymous, 1990-91). In another studies these value were 677.2, 33.9 and 162.8 kg ha^{-1} and organic carbon was 0.56 per cent after the harvest of maize crop (Anonymous. 1992-93).

Indulkar and Malewar. (1994) reported that the available Zn decreased in control by 0.08 ppm after the harvest of sorghum. This indicates that sorghum removes sufficient amount of Zn, the zinc content in soil decreases significantly if it is not added from out side.

2.5.3 Fertility status of soil after the harvest of maize-gobhi sarson or related crop sequences

Rao and Sharma (1976) reported from Pantnagar that in maize-rapeseed-wheat sequence there was slight increase during first year and appreciable increase during second year in soil pH, but organic carbon, total nitrogen, available phosphorus and potassium decrease after rape seed crop at 100 per cent NPK level However, decrease in organic carbon was non-significant during second year

Biswas *et al.* (1977) clearly indicated that application of organic manures enhances Zn availability for the entire cropping system and maintain the soil fertility level of Zn also.

Dhillon and Dev (1979) reported from Ludhiana that after two cycle of groundnut-wheat rotation, available N increased in both layers (0-15 and 15-30 cm) and this build up was more in the surface layer and in soil having low initial fertility level. However, the available P and K status of both the layers declined after two cropping cycles and this reduction was more in soil with high fertility status. Growing a groundnut crop resulted in increase and wheat resulted in a decrease in the available nutrient status of the soil.

Rao and Ghosh (1981) reported that continuous intensive cropping for seven years without S application reduced available S to about 50 per cent of the initial level. On the other hand S application sustained the initial level of S. Deka and Singh (1984) reported that in rice-mustard-green gram rotation, total soil N, available P, available K. Among different rice based crop sequences, maximum build up of N, P and K was with rice-mustard green gram sequence.

At Jabalpur, in soybean-wheat-maize fodder sequence, soil available Zn was 0.7 ppm with 100 per cent NPK, 1.0 ppm with 100 per cent NPK + FYM and 6.5 ppm with 100 per cent NPK + Zn whereas in control it was 0.9 ppm after 10 cropping cycles (Anonymous, 1985). While, in acidic red loam soil of Ranchi, there was slight decline in available Zn (9%) after soybean-wheat-potato cropping system when at 100 per cent NPK. Addition of FYM enhanced Zn contents in soil by 97 per cent and application of Zn recorded about three times the values obtained at 50 to 150 per cent NPK levels after six cropping cycles (Anonymous, 1985).

In medium black soils of Jabalpur, in soybean-wheat-maize fodder crop sequences there was increase in availability of nitrogen content by 84 per cent with 100 to 150 per cent NPK levels. Available P and K status also improved due to application of 150 per cent NPK with FYM (Anonymous, 1985). Under intensive cropping (1971-82), available Zn decreased by 45 per cent in light textured alluvial soils at Ludhiana. Addition of Zn enhanced the level of available Zn markedly in medium black soil of Coimbatore, Jabalpur and Bhubneswar (Anonymous, 1985).

Thakur *et al.* (1990) reported from Ranchi, Bihar that crop rotation (3 cycles) deplete organic carbon content of the sandy clay loam soil. However, sequences consisting of legumes had significantly higher organic carbon than that without legumes. Organic carbon content of soil after soybean-wheat rotation was found to be maximum (4.5 g ha^{-1}) and significantly higher than that obtained with other sequences. In general, available P status of soil during 1985-86 increased over the initial value irrespective of the crop sequence. Available K status of soil increased over the initial value under all sequences particularly after *rabi* crop.

Sharma and Gupta (1992) reported from JNKVV, M.P. that after two cropping seasons of soybean-wheat there was net depletion of available N, P, K and S in 30 cm soil layer of unfertilized plots. The plots treated with N and S showed a slight build up of N and S, probably due to symbiotic biological fixation of atmospheric N by soybean and oxidation of pyrites, respectively. Available P and K however, showed net depletion except at 100 kg S ha^{-1}.

Sanyal *et al.* (1993) reported that in potato-groundnut-rice-cropping sequence, the N content of soil slightly improved or remained constant at 100 or 150 per cent recommended fertilizer dose or at 75 per cent NPK + FYM or with incorporation of the crop residue. The P status of soil was improved by 2-19 per cent under different treatments. The K status of the soil also improved wherever K was applied to crop.

Sinha and Sakal (1993) reported that in groundnut-wheat rotation, availability of S in soil was increased by pyrite, FYM and press mud. Mishra (1994) reported from Orissa that after continuous cropping for 20 years, the available S in soil was 15.7 kg S ha^{-1} without S addition and 43.2 kg S ha^{-1} with S addition. Sudhir *et al.* (1997) reported from their studies on long term fertilization and continuous cropping at Bangalore that Zn concentration remain above critical limits, even without supplementary addition of this element from external source in alfisol.

Mankotia and Sharma (1998) reported from Himachal Pradesh that at the end of two years cropping system of gobhi sarson + toria – maize, the available N content did not register any change. While the available P was up by 5.2 kg P ha^{-1} and available K by 5.4 kg ha^{-1}

Srinivas and Shrinivasa (1998) reported that in maize-groundnut, available N, P and K contents were 208.56 and 482 kg ha^{-1} after the harvest of maize-groundnut rotation during 1994-95 and respective values were 220, 58 and 525 kg ha^{-1} during 1995-96 indicating slight build up of N, P and K during second year. They further reported from Andhra Pradesh that available nitrogen, phosphorus and potassium contents were 200, 51 and 475 kg ha^{-1} after the harvest of maize-Indian mustard during 1994-95 and these values were 188, 50 and 502 kg ha^{-1} during 1995-96. There was slight decline in N, P, K status of soil after the harvest of crops. Thakur *et al.* (1998) reported that after three years cycle in rice-linseed sequence, the available N, P and K content was 250, 28.1 and 90 kg ha^{-1}, respectively.

From the foregoing review, it was observed that soil available N, P, K, S and Zn levels found to be maintained with slight increase or decrease under different sequences when these nutrients (S and Zn) were supplied regularly either alone or with crop residue or FYM.

MATERIAL AND METHODS

Chapter-3

MATERIAL AND METHODS

The field experiment entitled **"Studies on the effect of sulphur nutrition on gobhi sarson (*Brassica napus* var. *oleracea*) in maize-gobhi sarson sequence under rainfed conditions"** was conducted for a period of two year 1997-98 and 1998-99 at the Experimental Farm of Department of Agronomy, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (H.P.). The detail of material used and methods employed have been presented in this chapter.

3.1 EXPERIMENTAL SITE

The Experimental Farm is situated at 32° 6' North latitude, 76° 3' East longitude and at an altitude of 1290.8 metres above mean sea level. The area represents the mid-hill sub-humid zone of Himachal Pradesh and is characterized by wet temperate climate.

3.2 CLIMATE AND WEATHER

The average annual rainfall received is about 2500 mm, out of which 80 per cent is received during peak monsoon months viz., June to September and remaining 20 per cent is received between October to May. Occasionally, the region also receives snow during winters.

Agro-climatically, Palampur region has been characterised by mid hill sub-humid temperate climate with severe winters and mild summers. The mean weekly meteorological parameters viz., maximum and minimum temperature, relative humidity, rainfall and sunshine hours pertaining to the period of experimentation (Oct., 1997 to Oct., 1999) recorded at the meteorological observatory of the Department of Agronomy, CSK HPKV, Palampur have been presented graphically in Fig. 3.1 & 3.2 and appended in Appendix-I & II.

The perusal of weekly data reveals that during first year of experimentation (October 29, 1997 to October 22, 1998), the mean maximum temperature ranged from 13.1 °C to 35.5 °C and mean minimum temperature ranged from 3.4 °C to 23.1 °C. The total rainfall received during the period was 2172.8 mm. The relative humidity ranged from 31 to 86 per cent. During the second year of experimentation (October 26, 1998 to October 8, 1999) the mean temperature ranged from 14.5 °C to 24.0 °C. The mean minimum temperature ranged from 3.8 °C to 21.3 °C. The total rainfall received during the period was 2109.6 mm. The relative humidity ranged from 26 to 88 per cent. Out of the total rainfall received during first and second year of experimentation, 73.29 and 90.00 per cent was received during monsoon months (June-September) of the respective year of experimentation. However, during *rabi* 1997-98 (Oct. 29, 1997 to May 1, 1998), maximum temperature ranged from 13.1 °C to 29.8 °C and minimum temperature ranged from 3.6 °C to 18.8 °C. Total rainfall received was 486.2 mm and relative humidity ranged from 40 to 75 per cent while during *rabi* 1998-99, the maximum temperature ranged from 14.5 °C to 34.0 °C and minimum temperature ranged from 3.8 °C to 21.3 °C. The total rainfall received during *rabi* 1998-99 was only 90.5 mm while relative humidity ranged from 26 to 62 per cent.

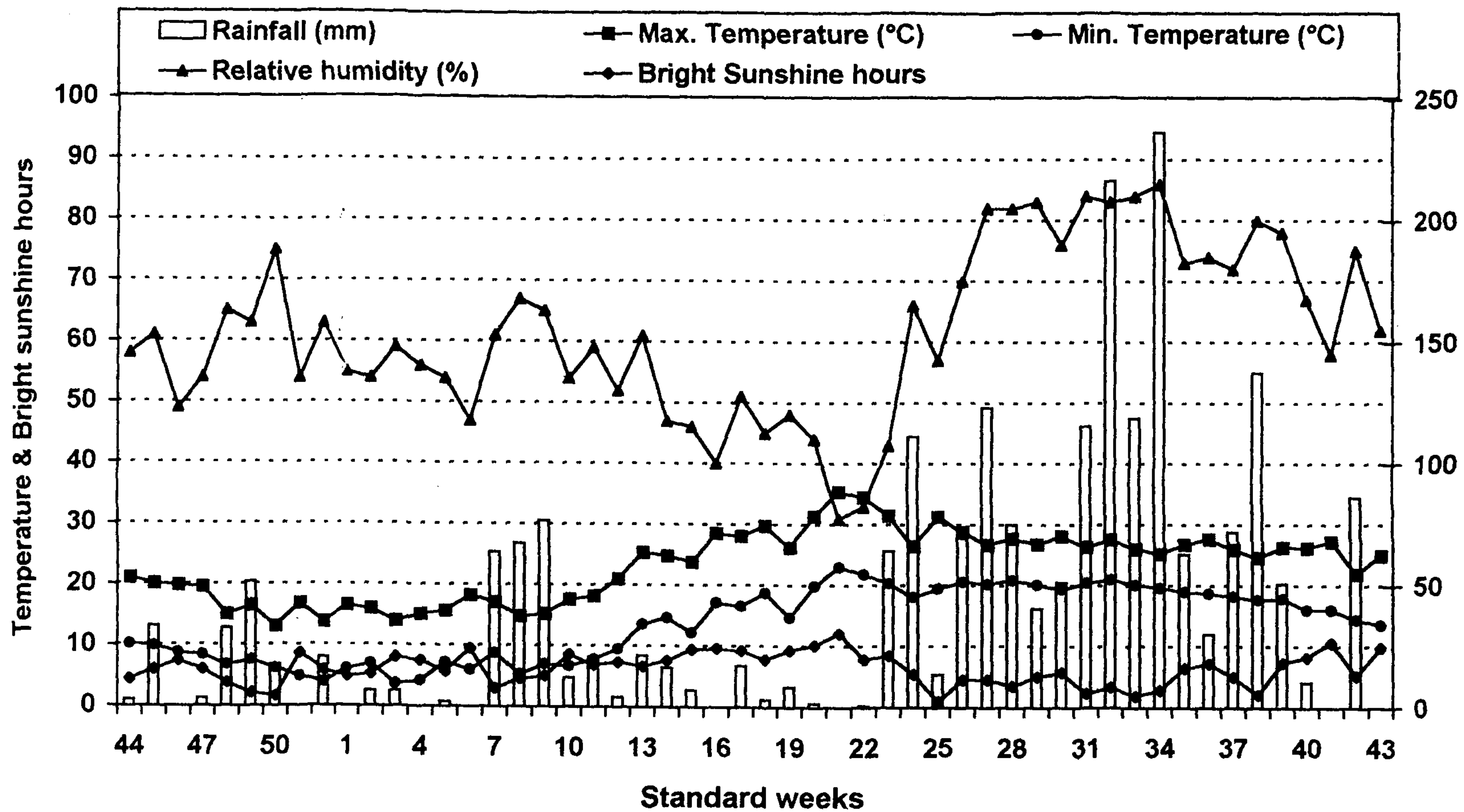

Fig. 3.1 Mean weekly meteorological data during 1997-98

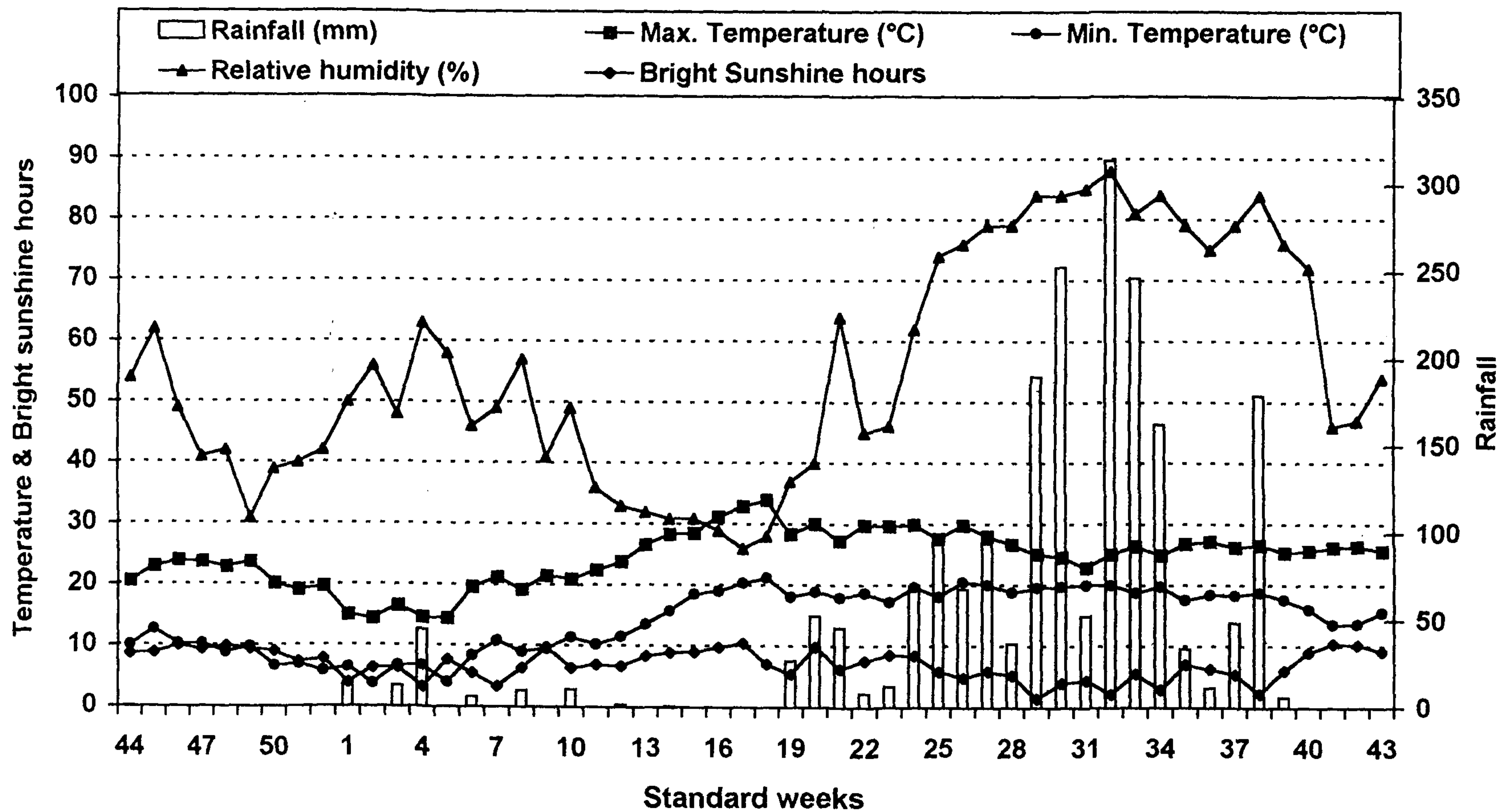

Fig. 3.2 Mean weekly meteorological data during 1998-99

3.3 PHYSICO-CHEMICAL PROPERTIES OF SOIL

Prior to sowing of crop, composite soil samples from 0 -15 cm depth were collected from experimental fields. The samples were analysed for physico-chemical properties of the soil, the results of which are presented in Table 3.1.

A perusal of data reveals that soil of experimental field was silt clay loam in texture and acidic in reaction. The soil was rated medium in respect of available nitrogen, high in available phosphorus and potassium, medium in available sulphur, zinc and organic carbon.

Table 3.1 Mechanical and chemical analysis of surface soil (0-15 cm) of the experimental site

Soil property	Value obtained	Method employed	References
A. Mechanical analysis			
Sand (%)	18.16	International Pipette method	Piper, 1966
Silt(%)	42.43		
Clay (%)	37.71		
Texture	Silty-clay loam		
B. Chemical analysis			
pH	5.70	1:2.5 soil water suspension using glass electrode pH meter	Jackson, 1967
OC (%)	0.65	Walkley and Black's rapid titration method	Walkley and Black's, 1934
Available N (kg/ha)	392.42	Alkaline permanganate method	Subbiah and Asija, 1956
Available P (kg/ha)	28.62	Olsen's method	Olsen *et al.*, 1954
Available K (kg/ha)	280.48	Neutral Normal Ammonium acetate extraction method	A.O.A.C., 1970
Available S (ppm)	12.70	Turbidimetry method	Chesnin and Yien, 1950
Available Zn (ppm)	0.62	DTPA-Zn method	Lindsay and Norvell, 1978

3.4 CROPPING HISTORY

The experimental site was under maize-wheat cropping system before the start of experiment. A maize crop was raised during *kharif* 1997 with recommended N, P_2O_5 and K_2O nutrients supplied through urea, DAP and muriate of potash (MOP). No FYM was used either to maize or to gobhi sarson during the course of study.

3.5 TREATMENTS, DESIGN AND LAYOUT

The field experiment comprised of application of 13 treatments combinations to gobhi sarson in maize-gobhi sarson cropping sequence as given below. Layout plan of these treatments has been shown in Fig. 3.3.

Treatments :

T_1 : Control (Recommended NPK only, S and Zn free)

T_2 : S at 25 kg ha^{-1} as elemental sulpur (ES) (EY)

T_3 : S at 25 kg ha^{-1} as elemental sulpur (ES) (AY)

T_4 : S at 50 kg ha^{-1} as elemental sulpur (ES) (EY)

T_5 : S at 50 kg ha^{-1} as elemental sulpur (ES) (AY)

T_6 : Zn at 5 kg ha^{-1} as ZnO (EY)

T_7 : Zn at 5 kg ha^{-1} as ZnO (AY)

T_8 : Zn at 10 kg ha^{-1} as ZnO (EY)

T_9 : Zn at 10 kg ha^{-1} as ZnO (AY)

T_{10} : Zn at 5 kg ha^{-1} as $ZnSO_4$ (EY)

T_{11} : Zn at 5 kg ha^{-1} as $ZnSO_4$ (AY)

T_{12} : Zn at 10 kg ha^{-1} as $ZnSO_4$ (EY)

T_{13} : Zn at 10 kg ha^{-1} as $ZnSO_4$ (AY)

Fig. 3.3 LAYOUT PLAN OF EXPERIMENT

BLOCK \ PLOT	1	2	3	4
I	T_{11}	T_6	T_9	T_3
II	T_4	T_8	T_3	T_{12}
III	T_{12}	T_{13}	T_{11}	T_{10}
IV	T_2	T_5	T_8	T_{11}
V	T_7	T_8	T_9	T_{10}
VI	T_4	T_5	T_6	T_{10}
VII	T_1	T_5	T_9	T_{12}
VIII	T_3	T_5	T_7	T_{13}
IX	T_1	T_2	T_3	T_{10}
X	T_2	T_4	T_9	T_{13}
X1	T_1	T_4	T_7	T_{11}
XII	T_1	T_6	T_8	T_{13}
XIII	T_2	T_6	T_7	T_{12}

N
E

Design: Balanced Incomplete Block Design (BIBD)

Frequency of application :

EY : Every year

AY : Alternate year

Note : Only 100 per cent recommended NPK were given to maize every season in the sequence. Treatments were imposed on *Gobhi sarson* *(Brassica napus* var. *oleracea*) in every and alternate years as shown above.

3.6 CULTURAL OPERATIONS

Schedule of culture operations carried out during the period of experimentation have been given in Table 3.2. Maize and gobhi sarson were raised with their recommended package of practices. The variety used, seed rates, row spacing, net plot size as well as recommended dose of fertilizers in case of each crop have been given in Table 3.3. In both the crops, nitrogen, phosphorus and potassium were supplied through urea, IFFCO (12:32:16) and muriate of potash, respectively. In both the crops, whole of P and K and 1/3rd of nitrogen were applied at the time of sowing, while remaining nitrogen was applied in two splits; at knee high stage and pre-tasseling stages in maize and at flowering and siliqua development stages in gobhi sarson coinciding with rains.

Table 3.2 Schedule of culture operations

Operation	Gobhi sarson	
	1997-98	1998-99
Preparatory tillage	Oct. 28, 97	Oct. 26, 98
Layout	Oct. 28, 97	Oct. 26, 98
Application of basal fertilizers	Oct. 29, 97	Oct. 28, 98
Sowing	Oct. 29, 97	Oct. 28, 98
Thinning	Nov. 27 & Nov. 28, 97	Nov. 27 & Nov. 28, 98
Earthing up	Dec. 30, 97	Dec. 30, 98
Herbicide application	Dec. 15, 97	Dec. 16, 98
Top dressing of fertilizer N	(i) Dec. 20, 97 (ii) Jan. 27, 98	(i) Dec. 25, 98 (ii) Jan. 29, 99
Insecticide spray	Mar. 17 & Mar. 24, 98	Mar. 15, 99
Harvesting	April 30, 98	May 1, 99
Threshing and winnowing	May 7, 98	May 8, 99

Operation	Maize	
	1998	1999
Preparatory tillage	May 5, 98	May 12, 99
Layout	May 5, 98	May 13, 99
Application of basal fertilizers	May 6, 98	May 14, 99
Sowing	May 6, 98	May 14, 99
Herbicide application	May 7, 98	May 17, 99
Thining and filling	June 8 and 9, 98	June 20, 99
Earthing up	June 11, 98	June 22, 99
Top dressing of fertilizer N	i) June 15, 98 ii) July 21, 98	i) June 24, 99 ii) July 24, 99
Insecticide spray	Aug. 18, 98	July 27 & 28, 99
Harvesting	Oct. 22, 98	Oct. 8, 99

Table 3.3 Details of the varieties, seed rates, row spacings, fertilizer doses (N, P_2O_5 and K_2O) and net plot area for maize and gobhi sarson

Crop	Variety	Seed rate	Row spacing	Fertilizers (kg ha^{-1})			Net plot size (m^2)
		(kg ha^{-1})	(cm)	N	P_2O_5	K_2O	
Maize	Hybrid -3438	25	60	120	60	40	4.8x4.6
Gobhi sarson	Sheetal	8	45	120	60	40	6.3x4.6

3.7 OBSERVATIONS RECORDED

The following observations were recorded on gobhi sarson and maize crop.

3.7.1 Gobhi sarson (*B. napus* var. *oleracea*)

3.7.1.1 Growth studies

3.7.1.1.1 Plant height

Five plants were randomly selected and tagged for making studies on plant height, number of primary and secondary branches, number of siliquae per plant and number of seeds per siliqua. The height of these randomly selected plants was measured from the base of the plants to the tip of the plants at maturity. The mean of five plants was recorded as plant height in cm.

3.7.1.1.2 Number of primary branches and secondary branches per plant

The total number of primary and secondary branches was counted from the five randomly selected and tagged plants. It was averaged to get the number of primary and secondary branches per plant.

3.7.1.2 Yield and yield contributing characters

3.7.1.2.1 Number of plants per metre row length

In each net plot, the number of plants in three randomly selected metre row length was counted and the mean value was recorded as number of plants per metre row length.

3.7.1.2.2 Number of siliquae per plant

Number of siliquae per plant were counted from the five tagged plants and averaged to get the number of siliquae per plant.

3.7.1.2.3 Number of seeds per siliqua

Five siliquae from each of five tagged plants were taken. Seeds from these 25 siliquae were counted after threshing and cleaning. The number so obtained was averaged to get the number of seeds per siliqua.

3.7.1.2.4 Thousand seed weight

The seed sample from the dry produce of each net plot was taken and thousand seeds were counted. The weight was recorded as 1000-seed weight in gram.

3.7.1.2.5 *Biological yield*

The harvested produce from each net plot was sun-dried, weighed and then converted into kg/ha.

3.7.1.2.6 Seed yield

After threshing and cleaning the produce from each net plot, grains were sun-dried thoroughly, weighed and then computed as kg/ha.

3.7.1.2.7 Straw yield

The straw yield was worked out by subtracting the seed yield from the biological yield of each net plot and recorded as kg/ha.

3.7.2 Maize (*Zea mays*)

3.7.2.1 Grain yield

The cobs were removed from each net plot. The grain yield per net plot was calculated after shelling the grains. The grain yield so obtained was adjusted at 15 per cent moisture and recorded as grain yield in kg/ha.

3.7.2.2 Stover yield

The stover from each net plot was harvested after decobing, sun-dried for 6-8 days and then the weight was recorded after conversion to kg/ha.

3.8 CHEMICAL STUDIES

3.8.1 Soil samples

Composite soil samples were collected from 0-15 cm depth before the start and after the completion of each crop cycle. Soil was collected from three randomly selected places within the net plot with the help of tube auger, composited plot-wise, air-dried and processed. Chemical studies were then made as detailed below :

(a) Soil pH

Soil pH was recorded by using 1:2.5 soil water suspension with glass electrode pH meter as discussed by Jackson (1967).

(b) Organic carbon content

It was estimated by rapid titration method of Walkley and Black's (1934).

(c) Available nitrogen content

Available nitrogen content was determined by alkaline permanganate method as described by Subbiah and Asija (1956).

(d) Available phosphorus content

Available phosphorus content was determined by soil extraction with 0.5 N sodium bicarbonate at pH 8.5 (Olsen *et al.,* 1954) and colour development was done as described by Murphy and Riley (1962).

(e) Available potassium content

Available potassium content was determined by neutral normal ammonium acetate method as described by Jackson (1967).

(f) Available sulphur content

Available S content in soil was determined by turbidimetric method as outlined by Chesnin and Yien (1950).

(g) Available zinc content

Available Zn content was determined by DTPA method as outlined by Lindsay and Norvell (1978).

3.8.2 Plant chemical studies

Representative samples of grain and stover/straw were collected from each net plot, dried in an oven till constant weight, processed and analysed for total nitrogen, phosphorus, potassium, sulphur and zinc content as per procedure detailed in Table 3.4.

Table 3.4 Chemical analysis of grain and straw/stover of Gobhi sarson and Maize crop

Chemical analysis	Method employed	References
1. Total nitrogen	Nessler's reagent	Snell and Snell (1955)
2. Total phosphorus	Molybdo-vanado phosphoric acid yellow colour	Jackson (1967)
3. Total potassium	Flame-emission spectro-photometry	Jackson (1967)
4. Total sulphur	Turbidimetric method	Chesnin and Yen (1950)
5. Total zinc	Atomic absorption spectro-photometer after digestion in di-acids mixture (Nitric acid : Perchloric acid) in 9:4	Lindsay and Norvell (1978)

Total uptake of nutrients by crops

Total uptake of nutrients i.e. nitrogen, phosphorus, potassium, sulphur and zinc by each crop was calculated by multiplying the percentage of each nutrient with respective dry matter of grains and stover/straw separately and then summed up for total uptake.

3.9 STATISTICAL ANALYSIS

The data recorded on various parameters were subjected to statistical analysis, following analysis of variance technique for Balanced Incomplete Block Design. The significance of the treatment differences was judged by 'F' test as outlined by Cochran and Cox (1970). To evaluate the significance of difference between treatment means, critical difference (CD) at 5% level of probability was worked out.

RESULTS

RESULTS

The results obtained from the present investigation have been presented in this chapter through data tables and depicted graphically wherever necessary. The analyses of variance have been appended in Appendix section.

4.1 GOBHI SARSON

4.1.1 Growth studies

Data on growth parameters viz.. plant height, primary and secondary branches per plant have been presented in Table 4.1 and the corresponding analyses of variance have been appended in Appendix III and IV.

4.1.1.1 Plant height

A critical perusal of data in Table 4.1 reveals that plant height was significantly influenced during 1997-98 by every year (EY) treatments and during 1998-99, both by EY as well as AY treatments. During both the years, frequent application (EY) of sulphur through elemental sulphur at all the levels produced significantly taller plants. Similarly AY application of sulphur through elemental sulphur (ES) at all levels also produced significantly taller plants during the year of their application (1998-99). Zinc application at 10 kg Zn ha^{-1} (ZnO) applied EY increased the plant height significantly over control during 1997-98 but it was at par with the treatments where it was accompanied by sulphur as $ZnSO_4$ at 10 kg Zn ha^{-1}, indicating thereby that the increase in plant height through EY application of 10 kg Zn ha^{-1} ($ZnSO_4$) was not due to sulphur alone. EY application of 5 kg Zn ha^{-1} ($ZnSO_4$) increased plant height significantly compared to control while application of 5 kg Zn ha^{-1} through ZnO was not able to increase the plant height significantly over control but 5 kg Zn ha^{-1} as $ZnSO_4$ and 5 kg Zn ha^{-1} through ZnO did not differ significantly with each other. This indicates that increase in plant height at 5 kg Zn ha^{-1} ($ZnSO_4$) was due to the combined effect of sulphur and zinc.

Table 4.1 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on plant height (cm), number of primary branches and secondary branches per plant in gobhi sarson at maturity

Treatment	Plant height (cm)		Primary branches per plant		Secondary branches per plant	
	1997-98*	1998-99	1997-98*	1998-99	1997-98*	1998-99
Control (NPK) EY	133.80	129.78	7.18	9.14	14.21	9.39
25 kg S ha^{-1} (ES) EY	146.25	139.16	7.62	9.58	14.66	12.32
25 kg S ha^{-1} (ES) AY	136.96	139.10	7.30	9.42	14.23	12.98
50 kg S ha^{-1} (ES) EY	145.45	137.84	7.76	9.53	14.57	14.40
50 kg S ha^{-1} (ES) AY	135.17	140.16	7.20	9.71	14.27	14.45
5 kg Zn ha^{-1} (ZnO) EY	138.55	132.18	7.50	9.18	14.33	11.15
5 kg Zn ha^{-1} (ZnO) AY	136.14	129.52	7.13	9.39	14.24	11.50
10 kg Zn ha^{-1} (ZnO) EY	143.07	131.26	7.62	9.23	14.47	10.56
10 kg Zn ha^{-1} (ZnO) AY	134.00	131.25	7.21	9.23	14.14	10.45
5 kg Zn ha^{-1} (Zn SO_4) EY	144.77	130.36	7.30	9.47	14.37	16.52
5 kg Zn ha^{-1} (Zn SO_4) AY	136.27	134.55	7.25	9.46	14.32	15.44
10 kg Zn ha^{-1} (Zn SO_4) EY	147.02	136.59	7.23	9.50	14.33	14.20
10 kg Zn ha^{-1} (Zn SO_4) AY	136.24	135.79	7.13	9.52	14.60	14.65
SEd	3.63	2.78	0.16	0.18	0.25	0.47
CD 5%	7.44	5.70	0.33	NS	NS	0.96

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Likewise, 10 kg Zn ha^{-1} through $ZnSO_4$ whether applied EY or AY increased plant height significantly compared to control during 1998-99. However, EY or AY application of 10 kg Zn ha^{-1} through ZnO was not able to increase plant height significantly over control indicating that the increase was due to the application of sulphur and zinc supplied through $ZnSO_4$ at higher level (10 kg Zn ha^{-1}).

4.1.1.2 Number of primary branches per plant

A keen observation of data in Table 4.1 shows that EY treatments had a significant effect on the number of primary branches per plant of gobhi sarson during 1997-98 alone. Here too, number of primary branches per plant increased significantly over control by different levels of sulphur (ES) and Zn (ZnO) but Zn as $ZnSO_4$ had no effect on number of primary branches per plant. This indicates that both zinc and sulphur can improve branching only when they were supplied independently of each other. On the other hand, their combined application as $ZnSO_4$ proved counterproductive on influencing branching.

4.1.1.3 Number of secondary branches per plant

Data on number of secondary branches per plant (Table 4.1) reveal that during 1997-98, treatments had no significant effect on branching. However, during 1998-99 they were significantly influenced by different treatments. Here too, EY or AY application of increasing levels of sulphur through elemental sulphur (ES) increased secondary branching significantly over control. Also, zinc application as ZnO increased secondary branches significantly over control but was significantly lower than the treatments where it was accompanied by sulphur as $ZnSO_4$ at 5 or 10 kg Zn ha^{-1} levels applied EY as well as AY. It indicates that increase in secondary branches through application of zinc as $ZnSO_4$ was due to sulphur. It was further seen that application of $ZnSO_4$ at lower level (5 kg Zn ha^{-1}) significantly increased secondary branches over 25 kg and 50 kg sulphur ha^{-1} (ES) applied either EY or AY. This indicates that at lower level, zinc might have improved the effect of sulphur through $ZnSO_4$ on number of secondary branches. It was also noticed that frequency of application of different treatments did not affect secondary branches per plant except application of 5 kg zinc as $ZnSO_4$ where number of branches increased significantly with EY application than with AY application.

4.1.2 Yield contributing characters

Observations recorded on the effect of different treatments on yield contributing characters viz., number of plants per metre row length, number of siliquae per plant, number of seeds per siliqua and 1000-seed weight have been presented in Table 4.2. The corresponding analyses of variance have been given in Appendix V and VI.

4.1.2.1 Number of plants per metre row length

Data presented in Table 4.2 show that the different levels of application of sulphur (ES), Zn (ZnO) and Zn as $ZnSO_4$ did not influence significantly the number of plants per metre row length during both the years. Likewise, frequency of each level of sulphur (ES) and Zn (ZnO and $ZnSO_4$) also had no significant effect on number of plants per metre row length.

Table 4.2 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on yield attributing characters in gobhi sarson at maturity

Treatments	Number of plants per metre row length		Number of siliqua per plant		Number of seeds per siliqua		1000-seed weight (g)	
	1997-98*	1998-99	1997-98*	1998-99	1997-98*	1998-99	1997-98*	1998-99
Control (NPK) EY	7.97	13.30	205.90	156.04	16.35	15.36	3.50	3.48
25 kg S ha^{-1} (ES) EY	8.43	14.00	223.98	269.19	20.96	23.06	3.61	3.49
25 kg S ha^{-1} (ES) AY	8.63	14.42	220.52	262.65	18.58	20.29	3.35	3.49
50 kg S ha^{-1} (ES) EY	8.58	14.23	225.98	278.11	22.42	24.90	3.52	3.48
50 kg S ha^{-1} (ES) AY	8.61	13.92	209.29	276.65	17.81	24.90	3.48	3.48
5 kg Zn ha^{-1} (ZnO) EY	8.07	13.73	218.36	215.27	18.42	18.90	3.47	3.49
5 kg Zn ha^{-1} (ZnO) AY	8.48	14.42	193.60	211.19	15.19	15.67	3.50	3.49
10 kg Zn ha^{-1} (ZnO) EY	8.53	14.30	224.83	208.11	20.11	16.52	3.52	3.48
10 kg Zn ha^{-1} (ZnO) AY	8.20	13.96	199.98	211.88	17.58	16.98	3.48	3.48
5 kg Zn ha^{-1} (Zn SO_4) EY	8.20	13.92	199.29	278.27	20.35	30.21	3.51	3.50
5 kg Zn ha^{-1} (Zn SO_4) AY	8.04	13.46	208.83	281.65	17.27	26.52	3.50	3.48
10 kg Zn ha^{-1} (Zn SO_4) EY	8.51	14.30	214.83	281.19	18.42	25.44	3.52	3.48
10 kg Zn ha^{-1} (Zn SO_4) AY	8.33	14.00	197.36	272.27	18.04	25.98	3.49	3.50
SEd	0.39	0.57	24.75	9.70	1.98	1.60	0.09	0.01
CD 5%	NS	NS	NS	19.90	NS	3.29	NS	NS

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

4.1.2.2 Number of siliquae per plant

Data on number of siliqua (Table 4.2) show that EY application of different levels of sulphur (ES) and Zn (ZnO and $ZnSO_4$) did not influence significantly the number of siliqua per plant during first year (1997-98). However, during subsequent year (1998-99), EY as well as AY application of different treatments significantly increased the number of siliqua per plants compared to control. Levels of application of sulphur through elemental sulphur (ES) and Zn through $ZnSO_4$ had not significant effect on number of siliqua per plant when applied EY or AY. Frequency of application of these treatments had no effect on number of siliqua per plant. Likewise, frequency of application of zinc as ZnO did not affect number of siliqua per plant. It was further observed that EY as well as AY application of Zn supplemented with sulphur as $ZnSO_4$ at 5 and 10 kg Zn ha^{-1} resulted in significantly more number of siliqua per plant compared to the application of zinc through ZnO at their respective levels. It clearly indicates that increase in the number of siliqua per plant was due to sulphur alone supplied through $ZnSO_4$ at 5 and 10 kg Zn ha^{-1} levels. It was also seen that number of siliqua per plant with application of sulphur through $ZnSO_4$ at any level was statistically similar to the number obtained with sulphur (ES) at any level. This indicates that zinc did not affect number of siliqua per plant.

4.1.2.3 Number of seeds per siliqua

Data on seeds per siliqua presented in Table 4.2 reflect that levels of sulphur application (ES) as well as levels of Zn application as ZnO and $ZnSO_4$ were unable to influence the number of seeds per siliqua significantly during first year (1997-98). However, in the subsequent year (1998-99), EY as well as AY application of sulphur as elemental sulphur (ES) and Zn ($ZnSO_4$) resulted in significantly more number of seeds per siliqua compared to control. EY application of lower level of Zn as ZnO also produced significantly more number of seeds as compared to control. An increase in number of seeds per siliqua was observed with increase in level of sulphur as elemental sulphur (ES), whether applied EY or AY. However, this increase was significant only in case of AY application of sulphur through elemental sulphur. On the contrary, a decrease in number of seeds per siliqua was observed with increase in level of zinc as ZnO, when applied EY, however, the decrease was not significant. It was also seen that Zn application (ZnO) at the rate of 5 kg Zn ha^{-1} when applied EY then it significantly increased number of seeds per siliqua as compared to control. Zinc application further increased these significantly when it was supplemented with sulphur as $ZnSO_4$ at 5 and 10 kg Zn ha^{-1}. It clearly show that more number of seeds per siliqua due to application of $ZnSO_4$ @ 5 or 10 kg Zn ha^{-1} were due to the application of sulphur and not due to zinc. It may further be seen that EY application at lower level of Zn as $ZnSO_4$, resulted in significantly more number of seeds compared to AY application. Further, Zn as $ZnSO_4$ at 5 kg ha^{-1} when applied EY produced significantly more number of seeds per siliqua than produced by Zn as $ZnSO_4$ at 10 kg ha^{-1} given AY. This indicates that frequent application of lower level of Zn as $ZnSO_4$ applied EY is more beneficial than AY application either at same level or at higher level.(EY & AY).

4.1.2.4 Thousand seed weight

A perusal of data pertaining to 1000-seed weight presented in Table 4.2 reveals that the different levels of sulphur (ES) and Zn (ZnO and $ZnSO_4$) did not influence significantly 1000-seed weight during both the years. It also shows that frequency of application at each level of sulphur (ES) and Zn as ZnO or $ZnSO_4$ also had not significant effect on 1000-seed weight during 1998-99.

4.1.3 Seed and straw yield

During 1997-98, only EY treatments of sulphur (ES) application were imposed. The data presented in Table 4.3 reveal that none of the treatments had a significant effect on the seed yield of gobhi sarson. The corresponding analyses of variance have been given in Appendix VII.

In the following year i.e. 1998-99, both EY and AY treatments were imposed and data reveal that application of sulphur as ES whether EY or AY increased gobhi sarson yield significantly as compared to control. It may further be seen that yield levels were higher with all the levels of sulphur when it was applied EY, however, differences between EY and AY application were not significant. Also, Zn application as ZnO though increased the yield significantly over control but was significantly lower than the treatments where it was accompanied by sulphur as $ZnSO_4$ at 5 or 10 kg ha^{-1} applied EY as well as AY showing thereby that the increase in yield due to application of $ZnSO_4$ @ 5 or 10 kg Zn ha^{-1} was due to sulphur and not due to zinc.

Table 4.3 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on seed and straw yield (kg/ha) of gobhi sarson

Treatments	Seed yield		Straw yield	
	1997-98*	1998-99	1997-98*	1998-99
Control (NPK) EY	1284	1058	5336	5518
25 kg S ha^{-1} (ES) EY	1327	1397	5527	6340
25 kg S ha^{-1} (ES) AY	1057	1363	4551	6296
50 kg S ha^{-1} (ES) EY	1236	1623	5118	7156
50 kg S ha^{-1} (ES) AY	1126	1451	5050	6322
5 kg Zn ha^{-1} (ZnO) EY	1260	1241	4299	6435
5 kg Zn ha^{-1} (ZnO) AY	1015	1309	4630	6540
10 kg Zn ha^{-1} (ZnO) EY	1298	1296	4807	6655
10 kg Zn ha^{-1} (ZnO) AY	1036	1299	4079	7049
5 kg Zn ha^{-1} (Zn SO_4) EY	1093	1783	4671	6546
5 kg Zn ha^{-1} (Zn SO_4) AY	1101	1653	4500	6222
10 kg Zn ha^{-1} (Zn SO_4) EY	1017	2035	4701	7599
10 kg Zn ha^{-1} (Zn SO_4) AY	1040	1817	5289	6930
SEd	120	109	404	325
CD 5%	NS	223	830	668

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Straw yield data reveal that EY application of sulphur either with or without Zn decreased gobhi sarson straw yield, though not significant as compared to control, however, application of 25 kg sulphur (ES) increased it again though the increase was not significant. Application of Zn as ZnO though decreased straw yield compared to control, however, decrease was significant only with application of 5 kg Zn ha^{-1} as ZnO. During the following year i.e. 1998-99, EY application of sulphur either as ES or $ZnSO_4$ increased straw yield compared to AY application, though the difference was significant when sulphur was applied either through 50 kg S ha^{-1} (ES) or through 10 kg Zn ha^{-1} as $ZnSO_4$. Reverse trend was noticed in ZnO treatments where yield was higher in AY, though the difference was not significant. Irrespective of the frequency of application, Zn application as ZnO though increased the straw yield significantly over control but in case of EY treatment, it was lower than the treatments where it was accompanied by sulphur as $ZnSO_4$ at 5 or 10 kg Zn ha^{-1}, however, the difference was significant only at 10 kg level of application. On the contrary, in AY, treatment ZnO produced higher yield though not significant compared to $ZnSO_4$ at both the levels. It indicates that frequent application of higher level of Zn as $ZnSO_4$ increased straw yield due to the effect of sulphur alone.

4.1.4 Total nutrient uptake in gobhi sarson

The total uptake data of different nutrients by gobhi sarson is presented in Table 4.4 and shown graphically in Fig. 1 to 5. The corresponding analyses of variance have been given in Appendix VIII and IX for 1997-98 and 1998-99, respectively.

4.1.4.1 Total nitrogen uptake

Data presented in Table 4.4 and Fig. 1 reveal that total N uptake was not influenced by varying levels of sulphur as elemental sulphur and Zn as ZnO and $ZnSO_4$ application during first year (1997-98), However, during 1998-99 it was significantly influenced by different treatments. Every year (EY) as well as alternate year (AY) treatments of sulphur as elemental sulphur and Zn as ZnO and $ZnSO_4$ resulted in significantly higher uptake of total N as compared to control. Though AY application of sulphur as elemental sulphur as

Table 4.4 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on total N, P, K, S and Zn uptake (kg/ha) in gobhi sarson during both the years (1997-98 and 1998-99)

Treatments	Total uptake (kg/ha)									
	1997-98*					1998-99				
	N	P	K	S	Zn	N	P	K	S	Zn
Control (NPK) EY	76.24	12.70	61.30	14.09	0.157	56.32	10.93	43.29	10.52	0.121
25 kg S ha^{-1} (ES) EY	79.95	13.94	61.05	15.51	0.262	85.38	16.45	62.94	19.42	0.282
25 kg S ha^{-1} (ES) AY	67.24	12.02	50.85	12.16	0.166	82.43	15.85	60.35	16.53	0.278
50 kg S ha^{-1} (ES) EY	89.74	12.14	67.83	16.23	0.269	94.05	18.41	66.22	19.89	0.311
50 kg S ha^{-1} (ES) AY	69.37	12.95	53.76	13.21	0.199	84.41	16.40	56.39	17.92	0.279
5 kg Zn ha^{-1} (ZnO) EY	70.90	12.58	59.43	14.27	0.253	78.58	15.10	57.79	15.11	0.317
5 kg Zn ha^{-1} (ZnO) AY	66.70	11.92	49.03	12.50	0.194	82.08	15.22	58.12	15.68	0.325
10 kg Zn ha^{-1} (ZnO) EY	86.03	12.80	67.93	15.36	0.271	81.78	15.67	60.26	15.88	0.327
10 kg Zn ha^{-1} (ZnO) AY	62.12	11.87	45.06	12.44	0.150	84.60	16.09	62.62	16.03	0.342
5 kg Zn ha^{-1} (Zn SO_4) EY	65.27	10.42	49.10	12.56	0.239	94.98	18.39	61.45	20.07	0.348
5 kg Zn ha^{-1} (Zn SO_4) AY	55.79	9.90	38.88	10.72	0.126	87.36	17.14	57.80	19.08	0.325
10 kg Zn ha^{-1} (Zn SO_4) EY	54.60	9.85	45.12	11.74	0.131	100.41	19.58	68.36	21.44	0.366
10 kg Zn ha^{-1} (Zn SO_4) AY	55.00	9.07	37.52	10.66	0.152	93.60	18.71	61.03	20.31	0.335
SEd	13.77	1.98	10.87	1.98	0.030	4.95	1.05	3.35	1.43	0.021
CD 5%	NS	NS	NS	NS	0.061	10.16	2.16	6.87	3.97	0.043

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

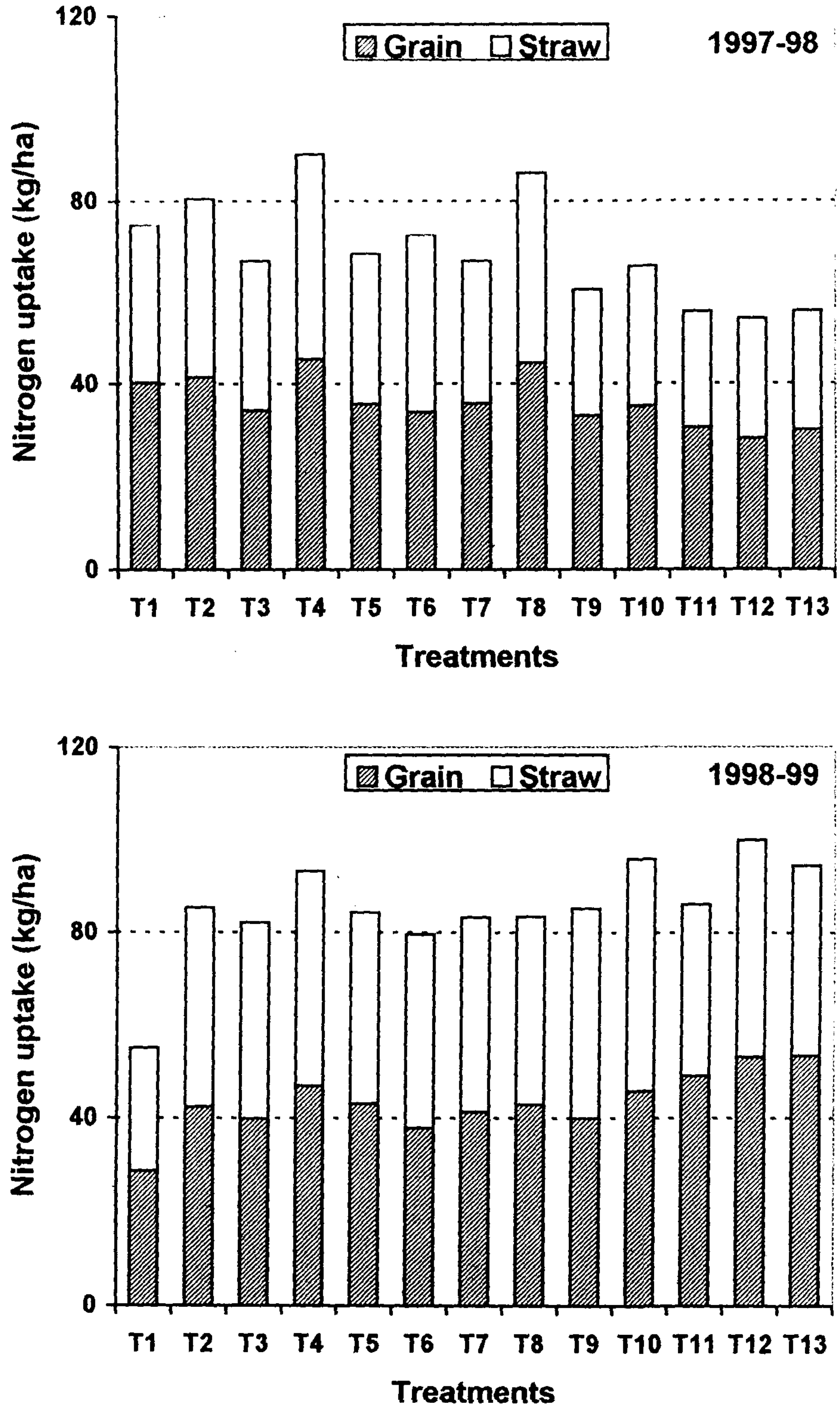

Fig. 4.1 Nitrogen uptake (grain + straw) by gobhi sarson crop

well as Zn as $ZnSO_4$ decreased uptake compared to every year application of the respective treatments but the difference were not significant. It may further be seen that uptake levels were higher with increased levels of sulphur application through ES and $ZnSO_4$ whether applied every year or AY. Irrespective of the frequency of application, Zn application as ZnO though increased the N uptake significantly over control but it was significantly lower than the treatments where EY application of Zn was accompanied by sulphur as $ZnSO_4$ at 5 or 10 kg ha^{-1}. It indicates clearly that the increase in nitrogen uptake due to every year application of Zn as $ZnSO_4$ @ 5 or 10 kg ha^{-1} was due to sulphur and not due to zinc.

4.1.4.2 Total phosphorus uptake

Like N uptake, P uptake by gobhi sarson (Table 4.4 and Fig. 2) also remained unaffected by different treatments during first year (1997-98) and was significantly influenced in the subsequent year by different treatments. EY as well as AY application of sulphur as ES and Zn (ZnO and $ZnSO_4$) resulted in significantly higher uptake of phosphorus as compared to control. However, decrease in frequency of sulphur application through elemental sulphur or as $ZnSO_4$ decreased P uptake though the decrease was not significant statistically. It may further be seen that P-uptake though increased with increase in levels of sulphur application as ES and Zn as $ZnSO_4$, but increase was not significant. Also Zn application through ZnO increased the P-uptake significantly over control but was significantly lower than the EY treatments of Zn accompanied by sulphur as $ZnSO_4$ at both 5 and 10 kg ha^{-1} levels and AY treatment of Zn supplemented by sulphur as $ZnSO_4$

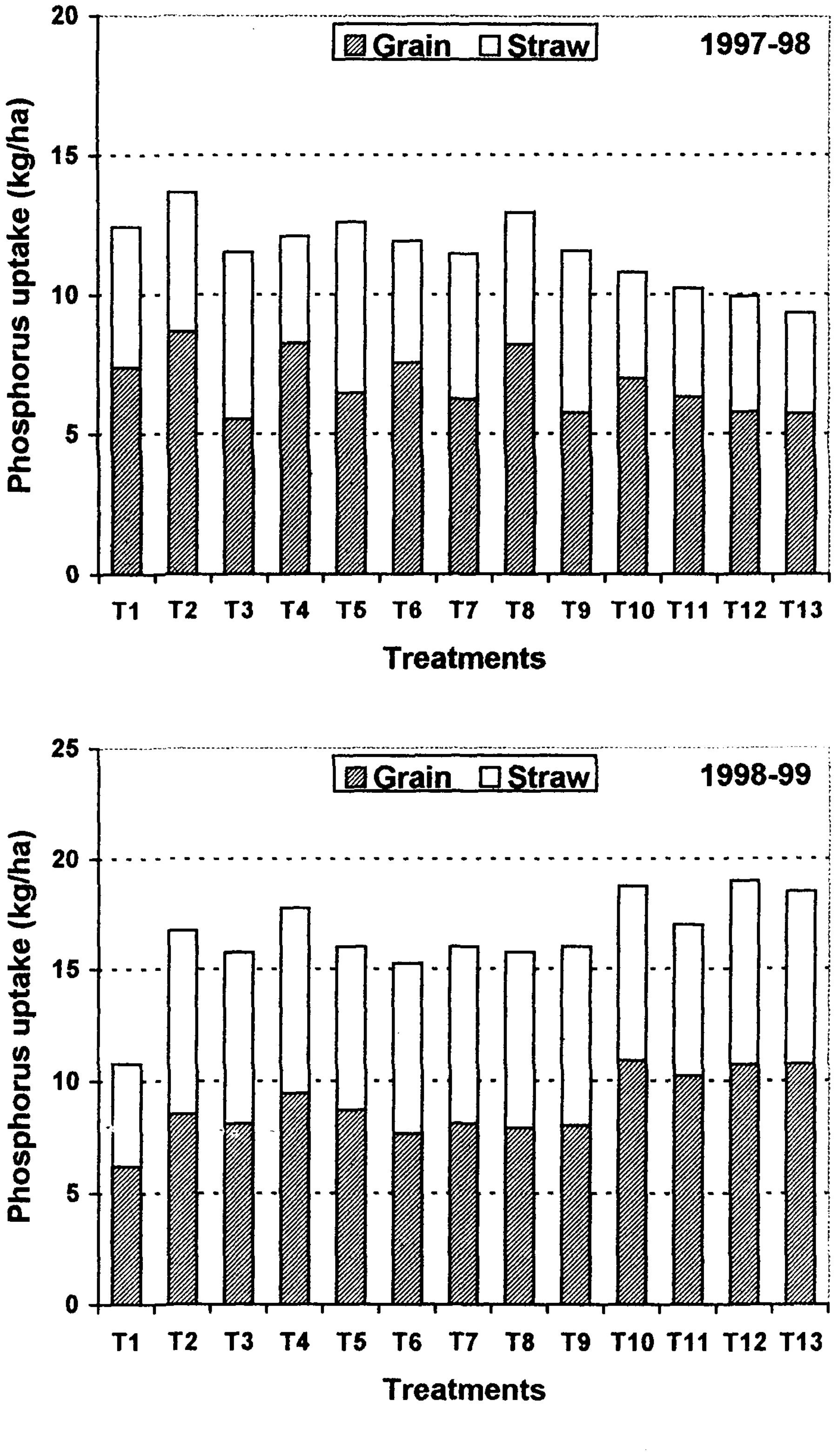

Fig. 4.2 Phosphorus uptake (grain + straw) by gobhi sarson crop

at only 10 kg Zn ha^{-1} level. It indicates that frequent application (EY) of $ZnSO_4$ at lower level or through AY or EY application of it at higher rate, increased the P uptake due to the effect of sulphur.

4.1.4.3 Total potassium uptake

Data presented in Table 4.4 and Fig. 3 show that during 1997-98, none of the treatments influenced potassium uptake in gobhi sarson. However, during 1998-99, it was significantly influenced by different treatments. EY as well as AY application of sulphur as elemental sulphur and Zn as ZnO and $ZnSO_4$ resulted in significantly higher K uptake as compared to control. It was further seen that alternate year application of sulphur as elemental sulphur (ES) and Zn as $ZnSO_4$ decreased K uptake compared to every year, application but the difference was significant only at higher levels of application viz., 50 kg S (ES) and 10 kg Zn ha^{-1} as $ZnSO_4$. It was further observed that K uptake increased with increase in the levels of EY application of sulphur as Elemental sulphur and every year as well as AY application levels of Zn as ZnO and $ZnSO_4$, respectively, however, difference was significant only in case of EY application of Zn as $ZnSO_4$. It indicates that at this level increase was due to synergistic effect of sulphur with zinc. Zinc application as ZnO though increased the K uptake significantly over control but in case of EY treatment it was lower than the treatments where Zn was accompanied by sulphur as $ZnSO_4$ at both 5 and 10 kg ha^{-1} levels and in case of AY treatments it was higher than the treatments where Zn was accompanied by sulphur at both the levels. However, difference between ZnO

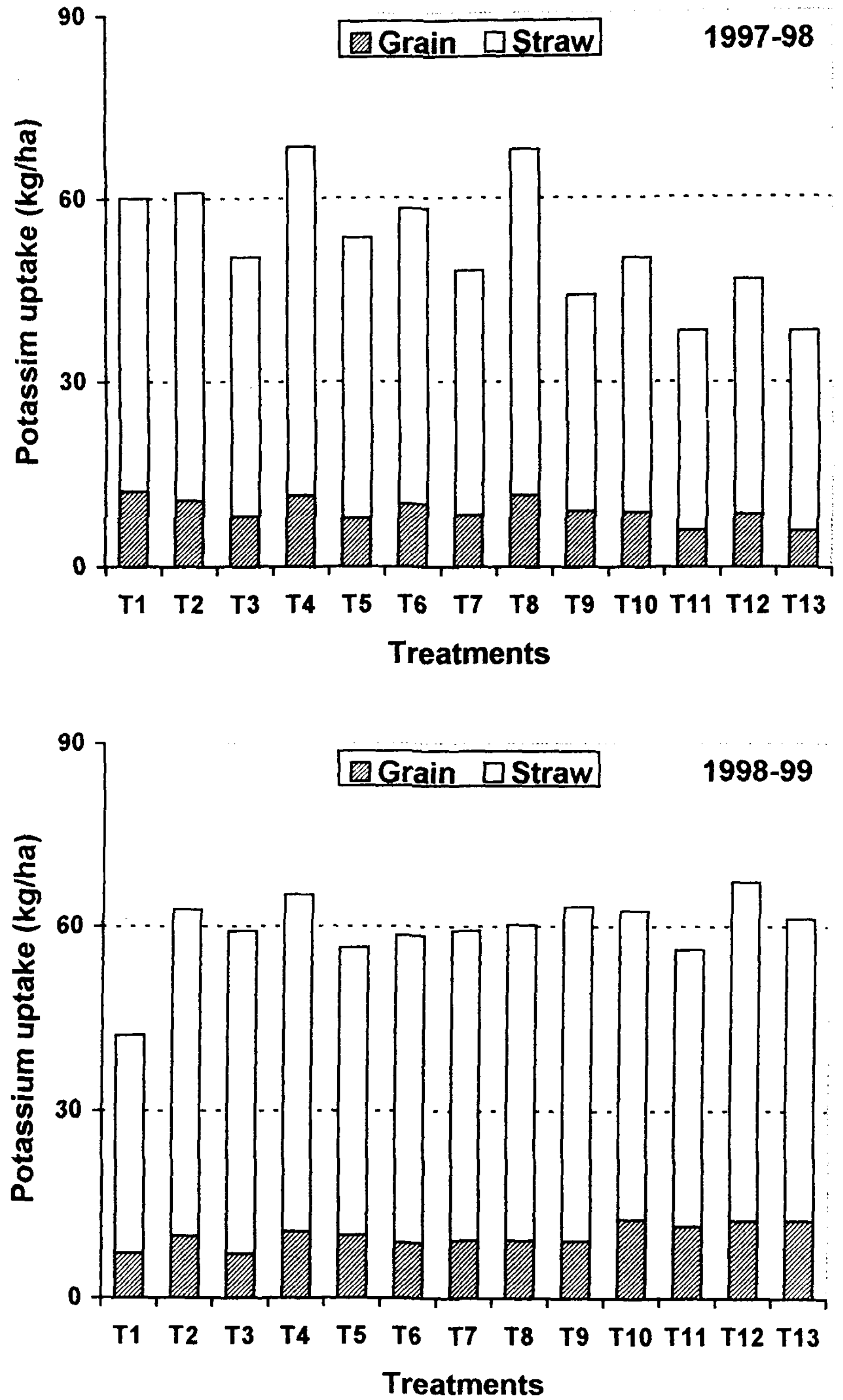

Fig. 4.3 Potassium uptake (grain + straw) by gobhi sarson crop

and $ZnSO_4$ treatments was significant only at 10 kg level and that too in EY treatments alone. This indicates that effect of this treatment was due to the effect of sulphur alone.

4.1.4.4 Total sulphur uptake

Like, N, P and K uptake, the sulphur uptake (Table 4.4 and Fig. 4) too, could not reach to the level of significance during first year (1997-98). However, it was significantly influenced by different treatments during subsequent year (1998-99). Here, EY as well as AY application of sulphur as elemental sulphur and Zn as ZnO and $ZnSO_4$ resulted in significantly higher uptake of sulphur over control. Though AY application of sulphur as elemental sulphur and Zn as $ZnSO_4$ decreased uptake compared to their EY application but the difference was not significant. On the contrary, AY application of Zn as ZnO increased S uptake over its EY application though the increase was not significant. It may further be seen that uptake was higher though not differed significantly statistically with increasing levels of sulphur application as elemental sulphur and Zn as ZnO and $ZnSO_4$, respectively, whether applied every year or AY. Also Zn application as ZnO though increased the total S uptake significantly over control but was significantly lower than the treatments where EY application of Zn was accompanied by sulphur as $ZnSO_4$ at 5 or 10 kg ha^{-1} and where AY application of Zn was accompanied by sulphur as $ZnSO_4$ at 10 kg ha^{-1} level only. It indicates that increase in sulphur uptake due to EY application of 5 and 10 kg and AY application of 10 kg Zn ha^{-1} as $ZnSO_4$ was due to sulphur alone.

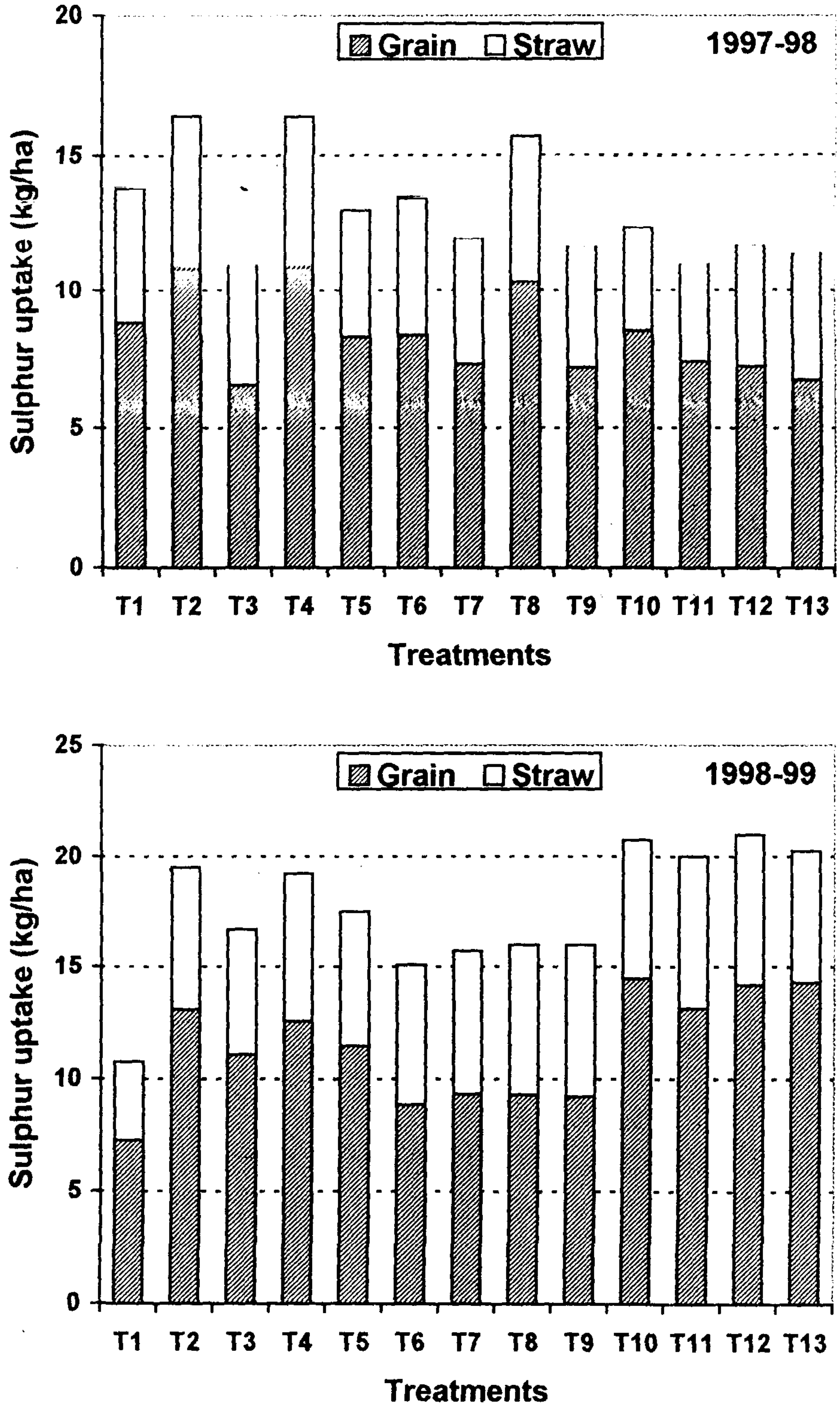

Fig. 4.4 Sulphur uptake (grain + straw) by gobhi sarson crop

4.1.4.5 Total uptake of zinc

A close examination of data pertaining to Zn uptake in gobhi sarson as presented in Table 4.4 and Fig. 5, reveal that with the exception of 10 kg Zn ha^{-1} as $ZnSO_4$, EY application of different levels of all other treatments resulted in significantly, higher Zn uptake as compared to control during 1997-98. Though application of 10 kg Zn ha^{-1} as $ZnSO_4$ resulted in significantly lower uptake as compared to rest of the treatments but it was statistically at par with control. Further, during 1997-98, levels of sulphur application as ES and Zn as $ZnSO_4$ and ZnO did not differ significantly among themselves. However, increase in level of Zn application as $ZnSO_4$ significantly decreased zinc uptake. As expected, Zn application as ZnO increased Zn uptake significantly over control which was significantly higher than the treatments where EY application of Zn was accompanied by sulphur as $ZnSO_4$ at 10 kg ha^{-1} level. During second year (1998-99) EY as well as AY application of different treatments resulted in significantly higher uptake of zinc as compared to control. It was further seen that though AY application of sulphur as elemental sulphur or Zn as $ZnSO_4$ decreased uptake compared to EY application of respective treatments but the differences were not significant. It was also observed that Zn uptake increased with increase in level of sulphur application through elemental sulphur (ES) or Zn as $ZnSO_4$ whether applied EY or AY. As expected every year Zn application as ZnO though increased Zn uptake significantly over control but it was not significantly lower than the treatments where Zn was accompanied by sulphur

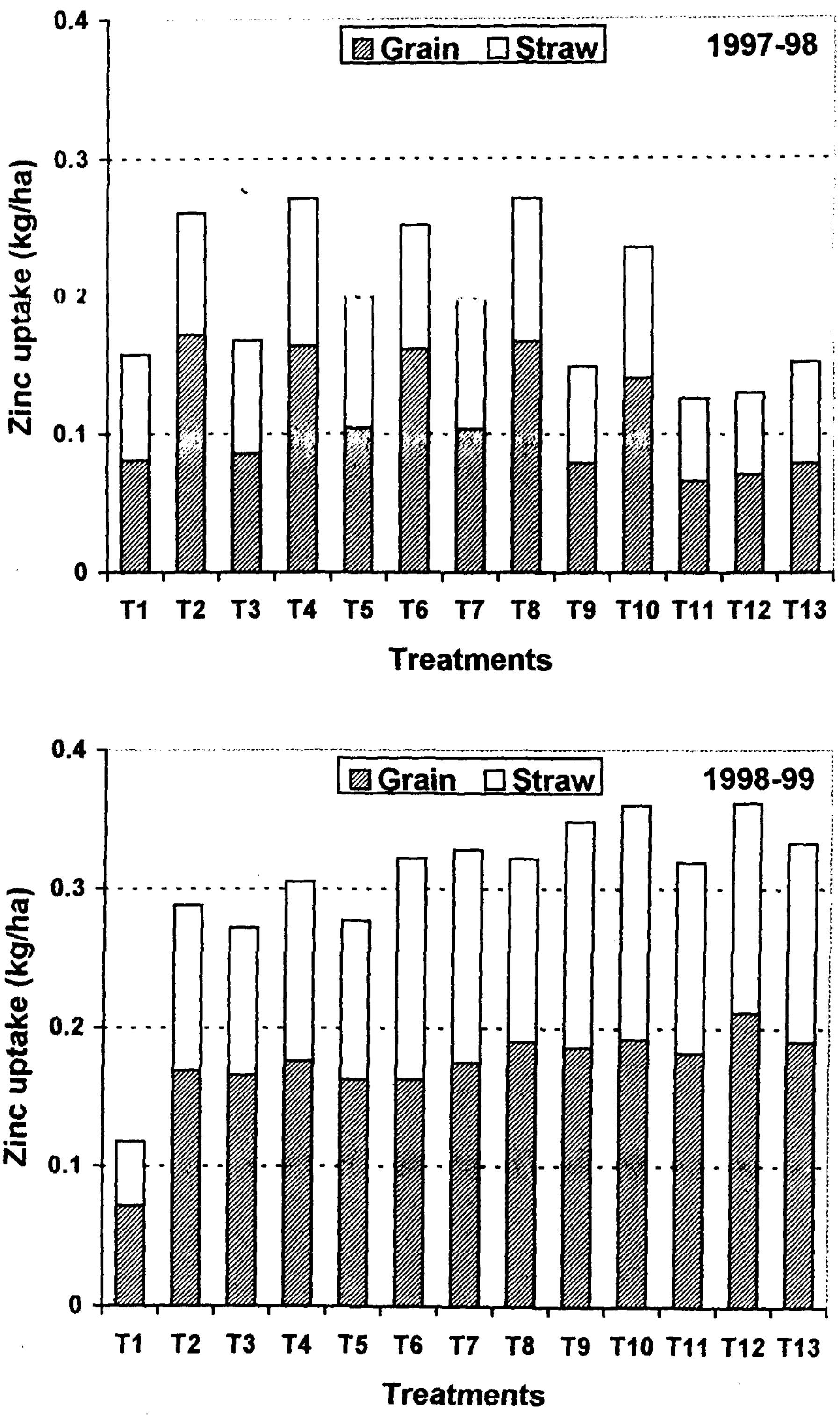

Fig. 4.5 Zinc uptake (grain + straw) by gobhi sarson crop

as $ZnSO_4$ at 5 kg and 10 kg ha^{-1}, respectively. It indicates that the increase in Zn uptake was due to zinc and not due to sulphur. The data in Table 4.4 also reveal that neither the different levels nor the frequencies of their application differed significantly with each other. In alternate year treatments reverse trend was observed. In AY treatments also, Zn application as ZnO increased Zn uptake significantly over control, but when zinc was accompanied by sulphur as $ZnSO_4$ at 5 or 10 kg ha^{-1}, then Zn uptake dropped, though not significantly. It again indicates that sulphur had no influence on the uptake of zinc.

4.2 MAIZE

4.2.1 Grain and stover yield

The data on maize grain and stover yield have been presented in Table 4.5. The analyses of variance have been given in Appendix X.

During 1997, general crop of maize was raised with recommended NPK (Sulphur and Zn free). The treatments were imposed on gobhi sarson during 1997-98. Here also (1997-98), every year (EY) treatments were imposed to gobhi sarson. Hence, no grain and stover yield data of maize for 1997 have been reported. Maize grain yield data for 1998 presented in Table 4.5 reveal that the yield of maize was not affected significantly by the application of suphur (ES) and Zn (ZnO or $ZnSO_4$) at any level applied to gobhi sarson during 1997-98. This shows that there was no residual effect of sulphur on grain yield of maize due to sulphur application to previous crop of gobhi sarson during 1997-98.

Table 4.5 Residual effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on grain and stover yield (kg/ha) of maize

Treatments	Grain yield		Stover yield	
	1998*	1999	1998*	1999
Control (NPK) EY	5586	4635	11401	7377
25 kg S ha^{-1} (ES) EY	5673	5477	11655	8824
25 kg S ha^{-1} (ES) AY	6175	5217	12641	8603
50 kg S ha^{-1} (ES) EY	5799	5597	12103	8475
50 kg S ha^{-1} (ES) AY	5628	5548	12093	8874
5 kg Zn ha^{-1} (ZnO) EY	5523	5064	11385	8099
5 kg Zn ha^{-1} (ZnO) AY	5819	4933	12014	8146
10 kg Zn ha^{-1} (ZnO) EY	5595	5099	11843	8397
10 kg Zn ha^{-1} (ZnO) AY	5692	5033	11613	8384
5 kg Zn ha^{-1} (Zn SO_4) EY	5476	5194	11504	7957
5 kg Zn ha^{-1} (Zn SO_4) AY	5498	5291	11885	7991
10 kg Zn ha^{-1} (Zn SO_4) EY	5582	5376	11484	8256
10 kg Zn ha^{-1} (Zn SO_4) AY	5805	5333	12052	7918
SEd	175	242	367	319
CD 5%	359	496	753	654

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Every year or alternate year application of sulphur through elemental sulphur @ 25 or 50 kg S ha^{-1} (ES) to gobhi sarson (1998-99) significantly increased the grain yield of maize compared to control during 1999. Every year treatments gave slightly higher yield than alternate year treatments at each level of sulphur application, though the increase was not significant. Further at each frequency, higher level of sulphur application gave slightly higher yield than its lower level, however, the differences between levels were not significant as shown in Table 4.5. At each frequency of application, Zn application as ZnO at both levels though increased grain yield of maize as compared to control, but the increase was not significant. However, when every year zinc application was supplemented with sulphur as $ZnSO_4$ at 5 & 10 kg level or alternate year Zn application was supplemented with sulphur as $ZnSO_4$ at both the levels, then maize yield increased significantly as compared to ZnO. This clearly indicates that increase in maize yield in response to every year application of 5 and 10 kg Zn as $ZnSO_4$ and alternate year application of 5 or 10 kg Zn as $ZnSO_4$ to gobhi sarson was due to the combined effect of residual sulphur and zinc, though not significant.

The stover yield data presented in Table 4.5 show that every year application of sulphur (ES), Zn ($ZnSO_4$ or ZnO) at both the levels to gobhi sarson did not affect stover yield of maize compared to control during 1998. Hence there was no residual effect of these treatments on stover yield of maize during 1998. During 1999, application of 25 and 50 kg S (ES) applied every year or alternate year to gobhi sarson significantly influenced the stover yield of maize as compared to control. Every year treatments recorded slightly higher stover yield than alternate year treatments at lower level of sulphur application (25 kg S) while reverse was true at higher level of S application through elemental sulphur. However, the differences between every and alternate year at each level of sulphur as elemental sulphur (ES) application was not significant. With the abrasion of 10 kg Zn as $ZnSO_4$ (every year) the stover yield of maize was not influenced significantly as compared to control by application of Zn ($ZnSO_4$) at any level applied to gobhi sarson during 1998-

99. However, this treatment i.e. 10 kg Zn ha^{-1} as $ZnSO_4$ (every year) also did not differ significantly as compared to remaining treatments. At each frequency of application, Zn as ZnO at both levels increased significantly stover yield of maize as compared to control. However, supplementing zinc with sulphur as $ZnSO_4$ decreased maize stover yield, however, differences were not significant statistically. This indicates that application of zinc as ZnO to gobhi sarson have residual effect on stover yield of maize however, this beneficial effect of zinc is neutralized by application of sulphur along with zinc as $ZnSO_4$.

4.2.2 Nutrient uptake

The total nutrient uptake data of different nutrients by maize have been presented in Table 4.6 to 4.10 and depicted graphically in Fig. 6 to 10. The corresponding analyses of variance have been given in Appendix XI and XII.

4.2.2.1 Total nitrogen uptake

Data, presented in Table 4.6 and shown graphically in Fig. 6. reveal that total N uptake by maize crop with the abrasion of 25 kg ES (AY), was not influenced by varying levels of sulphur (ES) and Zn (ZnO and $ZnSO_4$) during 1998, where only every year treatments were imposed to gobhi sarson during 1997-98. However, sulphur application through ES at both the levels as well as Zn as $ZnSO_4$ at both levels resulted in higher uptake of N compared to control. It was further seen that where only Zn (ZnO) was applied every year at both levels also resulted in higher N uptake compared to control but when it was supplemented with sulphur as $ZnSO_4$, it decreased uptake of N at both the respective levels of Zn as ZnO and $ZnSO_4$.

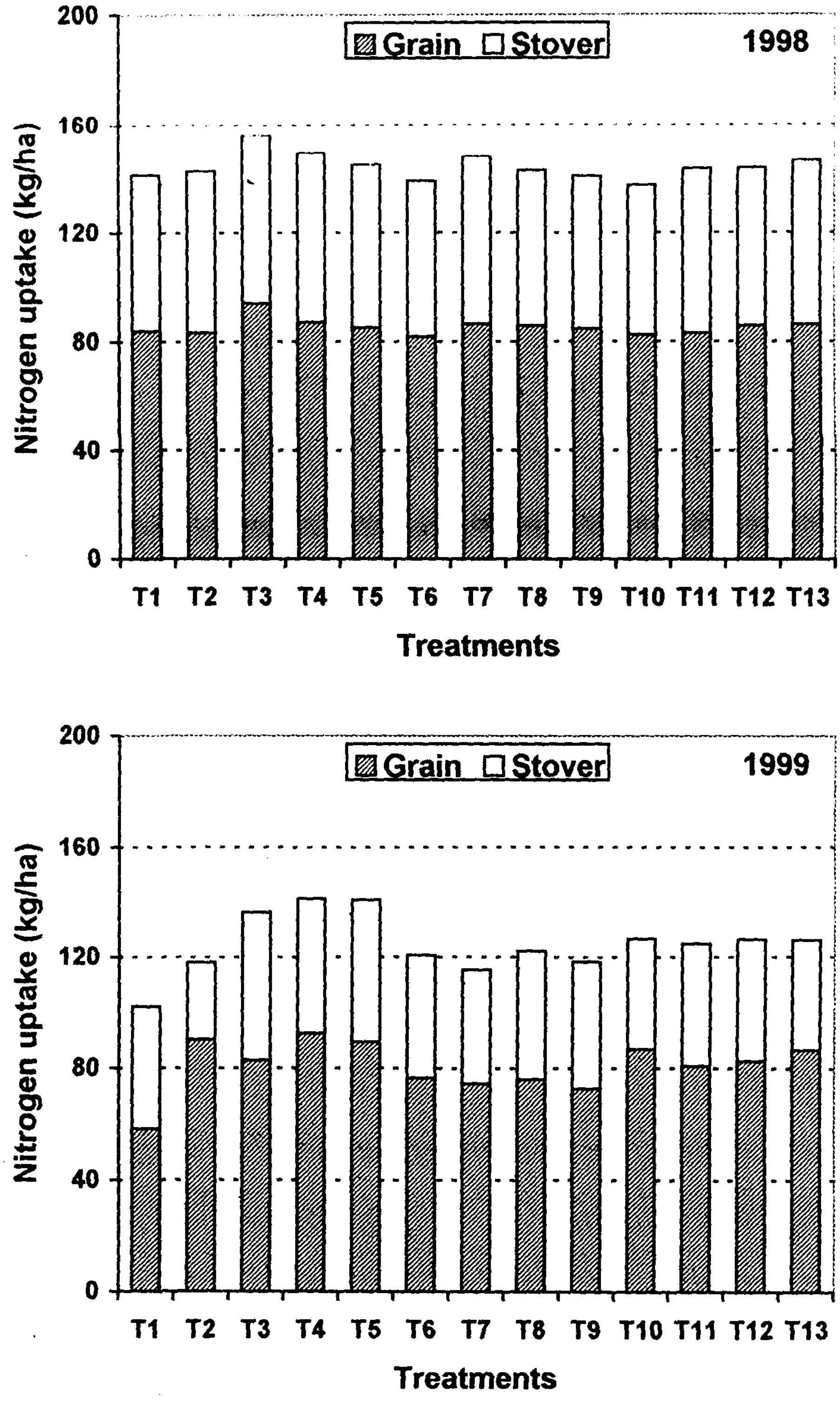

Fig. 4.6 Nitrogen uptake (grain + stover) by maize crop

Table 4.6 Residual effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on total nitrogen uptake (kg/ha) in maize

Treatments	Total N uptake (kg/ha)	
	1998*	1999
Control (NPK) EY	139.82	103.08
25 kg S ha^{-1} (ES) EY	143.21	138.27
25 kg S ha^{-1} (ES) AY	155.38	138.54
50 kg S ha^{-1} (ES) EY	148.14	141.63
50 kg S ha^{-1} (ES) AY	145.24	141.01
5 kg Zn ha^{-1} (ZnO) EY	139.92	119.06
5 kg Zn ha^{-1} (ZnO) AY	148.08	114.91
10 kg Zn ha^{-1} (ZnO) EY	142.95	122.01
10 kg Zn ha^{-1} (ZnO) AY	141.96	117.85
5 kg Zn ha^{-1} (Zn SO_4) EY	139.89	126.06
5 kg Zn ha^{-1} (Zn SO_4) AY	143.24	124.78
10 kg Zn ha^{-1} (Zn SO_4) EY	142.48	126.80
10 kg Zn ha^{-1} (Zn SO_4) AY	147.49	126.79
SEd	4.21	10.14
CD 5%	8.64	20.81

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

In the following year (1999) application of sulphur (EY) to gobhi sarson as ES or Zn as $ZnSO_4$, resulted in higher uptake of N in maize compared to control. However, neither levels nor frequency of sulphur application to gobhi sarson influenced N uptake in maize. At each frequency of application, zinc as ZnO at both levels to gobhi sarson did not influence N uptake in maize as compared to control but when Zn was supplemented with sulphur as $ZnSO_4$, then N uptake in maize increased significantly as compared to control but remained at par with Zn as ZnO. This clearly indicates that increasing N uptake in maize through EY and AY application of Zn as $ZnSO_4$ to gobhi sarson was due to combined residual effect of residual sulphur and zinc.

4.2.2.2 Total phosphorus uptake

The data on P uptake has also been presented in Table 4.7 and shown graphically in Fig. 4.7.

Table 4.7 Residual effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on total phosphorus uptake (kg/ha) in maize

Treatments	Total P uptake (kg/ha)	
	1998*	1999
Control (NPK) EY	23.12	14.07
25 kg S ha^{-1} (ES) EY	23.64	21.24
25 kg S ha^{-1} (ES) AY	25.26	20.02
50 kg S ha^{-1} (ES) EY	24.66	21.82
50 kg S ha^{-1} (ES) AY	25.60	21.50
5 kg Zn ha^{-1} (ZnO) EY	23.36	17.95
5 kg Zn ha^{-1} (ZnO) AY	22.54	16.23
10 kg Zn ha^{-1} (ZnO) EY	24.13	18.15
10 kg Zn ha^{-1} (ZnO) AY	23.91	17.86
5 kg Zn ha^{-1} (Zn SO_4) EY	23.38	18.62
5 kg Zn ha^{-1} (Zn SO_4) AY	23.43	19.01
10 kg Zn ha^{-1} (Zn SO_4) EY	23.64	19.83
10 kg Zn ha^{-1} (Zn SO_4) AY	25.72	19.49
SEd	1.45	0.93
CD 5%	NS	1.91

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Data presented in Table 4.7 indicate that total uptake of P in maize (grain + stover) was not influenced by varying levels of sulphur as ES or Zn as $ZnSO_4$ during the year 1998. However, during 1999, it was significantly

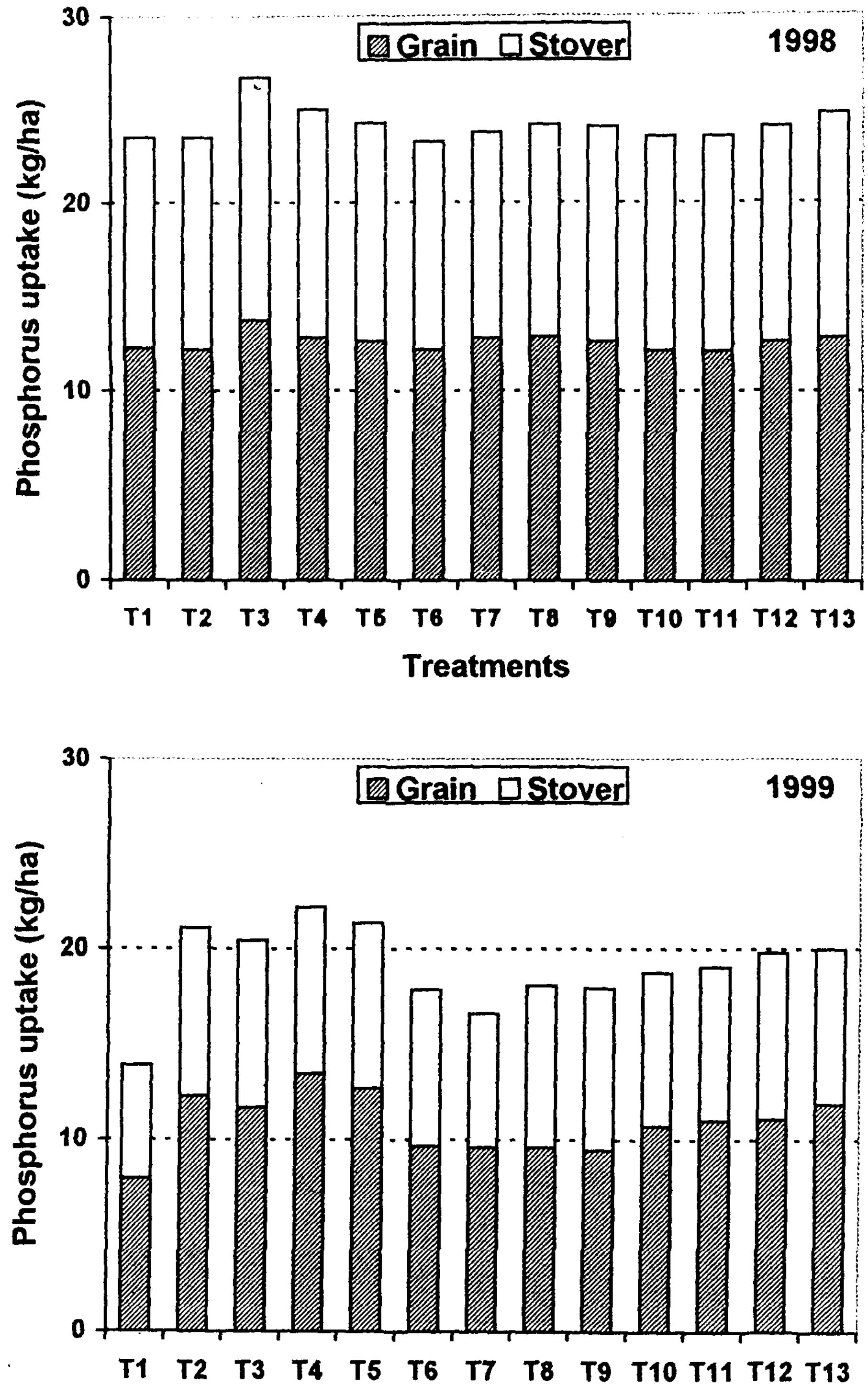

Fig. 4.7 Phosphorus uptake (grain + stover) by maize crop

influenced by different treatments. Here, EY as well as AY application of sulphur as ES and Zn as ZnO and $ZnSO_4$ resulted in significantly higher uptake of total P as compared to control. Though AY application of sulphur (ES) and Zn through ZnO and $ZnSO_4$ except 5 kg Zn ha^{-1} ($ZnSO_4$) decreased uptake compared to EY application of respective treatments but the differences were not significant while the reverse trend was observed with 5 kg Zn ha^{-1} through $ZnSO_4$. It may further be seen that though P uptake was higher with higher levels of sulphur whether applied EY or AY, it was also seen that application of Zn through ZnO resulted in significantly higher uptake of P over control but the P uptake was lower than the treatment where EY and AY application of Zn was accompanied by sulphur as $ZnSO_4$ at their respective levels but the difference was significant at 5 kg Zn ha^{-1} (ZnO) applied in AY. It indicates that the total P uptake in maize was not influenced significantly both by sulphur and zinc. Frequencies of application had no effect on P uptake.

4.2.2.3 Total potassium uptake

The total K uptake data have been presented in Table 4.8 and shown graphically in Fig. 4.8.

Data presented in Table 4.8 indicate that total K uptake in maize was higher with application of sulphur as ES and Zn as $ZnSO_4$ treatments compared to control during 1998. Also, total K uptake was higher with Zn as ZnO as compared to control but it was lower as compared to Zn as $ZnSO_4$ applied every year.

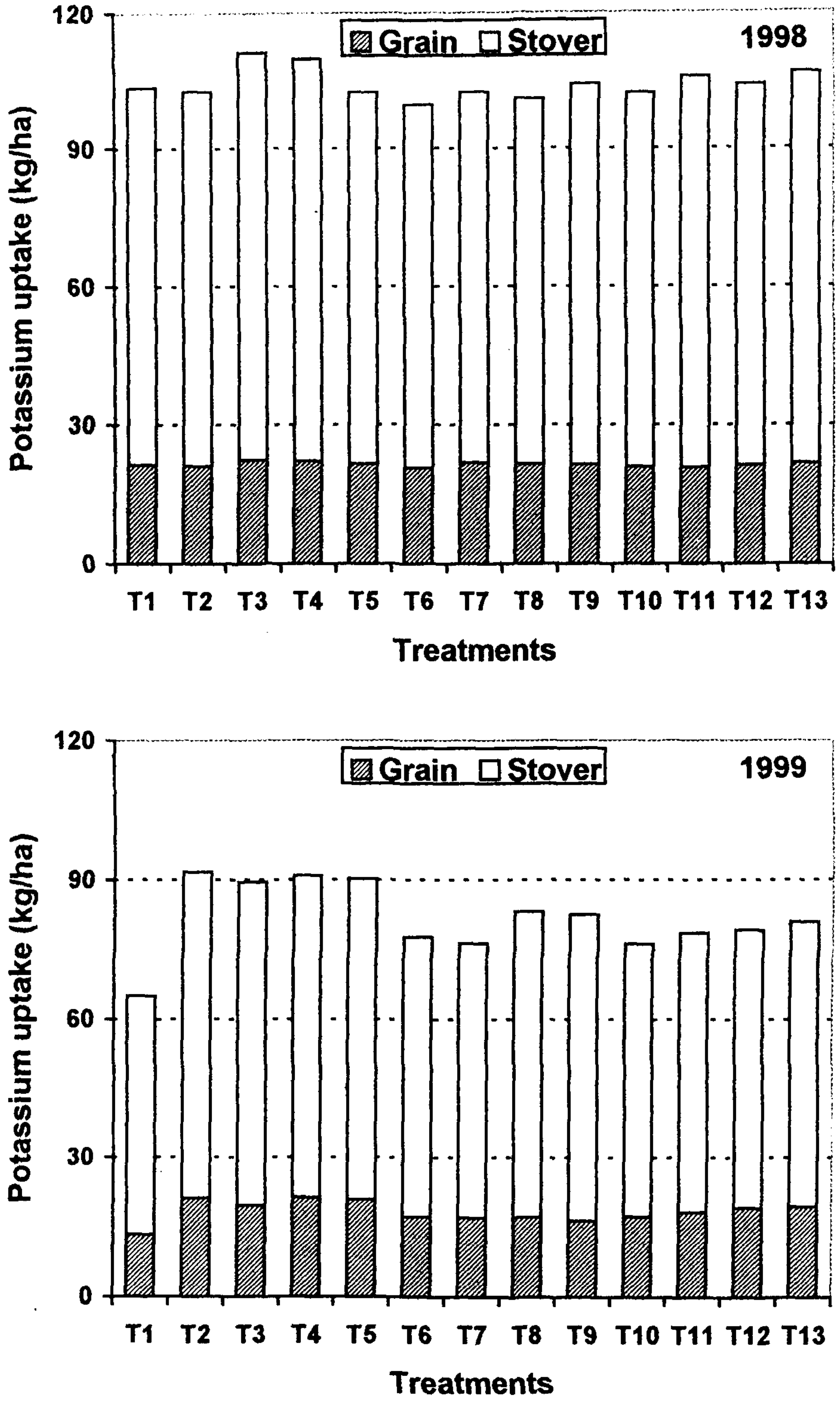

Fig. 4.8 Potassium uptake (grain + stover) by maize crop

Table 4.8 Residual effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on total potassium uptake (kg/ha) in maize

Treatments	Total K uptake (kg/ha)	
	1998*	1999
Control (NPK) EY	103.05	65.61
25 kg S ha^{-1} (ES) EY	103.83	91.42
25 kg S ha^{-1} (ES) AY	111.16	88.07
50 kg S ha^{-1} (ES) EY	110.10	89.09
50 kg S ha^{-1} (ES) AY	102.36	91.96
5 kg Zn ha^{-1} (ZnO) EY	100.92	77.01
5 kg Zn ha^{-1} (ZnO) AY	103.43	78.37
10 kg Zn ha^{-1} (ZnO) EY	100.40	84.65
10 kg Zn ha^{-1} (ZnO) AY	103.40	82.32
5 kg Zn ha^{-1} (Zn SO_4) EY	102.98	75.79
5 kg Zn ha^{-1} (Zn SO_4) AY	106.13	78.31
10 kg Zn ha^{-1} (Zn SO_4) EY	103.43	81.22
10 kg Zn ha^{-1} (Zn SO_4) AY	107.13	78.36
SEd	3.12	3.06
CD 5%	6.40	6.28

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

However, only 50 kg S ha^{-1} (ES) applied every year resulted in significantly higher total K uptake in maize compared to control while rest of the treatments did not differ significantly as compared to control. This indicates that total K uptake was significantly higher with higher levels of sulphur applied through ES. During 1999, it was significantly influenced by different treatments. Every year as well as alternate year application of sulphur as ES and Zn as ZnO and $ZnSO_4$ resulted in significantly higher total uptake of K in maize as compared to control. It was also seen that ES and

$ZnSO_4$ treatments did not differ significantly with respect to their respective levels as well as their frequencies of application. However, application of Zn as ZnO at 10 kg Zn ha^{-1} (EY) differed significantly to 5 kg Zn ha^{-1} applied EY and AY but both the levels resulted in significantly higher total K uptake over control. It was also seen that higher level of Zn through ZnO and $ZnSO_4$ resulted in higher uptake of K and lower level of Zn through ZnO and $ZnSO_4$ resulted in lower uptake of K while reverse trend was observed with sulphur as elemental sulphur levels applied every year and alternate year to previous crop of gobhi sarson but the differences were not-significant. Therefore, it can be concluded that K uptake was influenced both by sulphur and zinc.

4.2.2.4 Total sulphur uptake

The total S uptake by maize crop during 1998 and 1999 have been presented in Table 4.9 and shown graphically in Fig. 4.9.

Data presented in Table 4.9 reveal that application of sulphur to gobhi sarson as ES and Zn as (ZnO and $ZnSO_4$) significantly influenced the total S uptake in maize during 1998 when applied every year. Application of S @ 25 and 50 kg ha^{-1} through ES resulted in significantly higher total S uptake compared to control but the difference in the levels of application was not significant. Similarly, application of 5 and 10 kg Zn ha^{-1} through ZnO and $ZnSO_4$, respectively resulted in significantly higher total S uptake as compared to control. However, lower level of zinc as ZnO and $ZnSO_4$ applied every year was significantly lower when compared to 50 kg S ha^{-1} (ES) applied every year during 1998, however, the difference between two respective levels of Zn

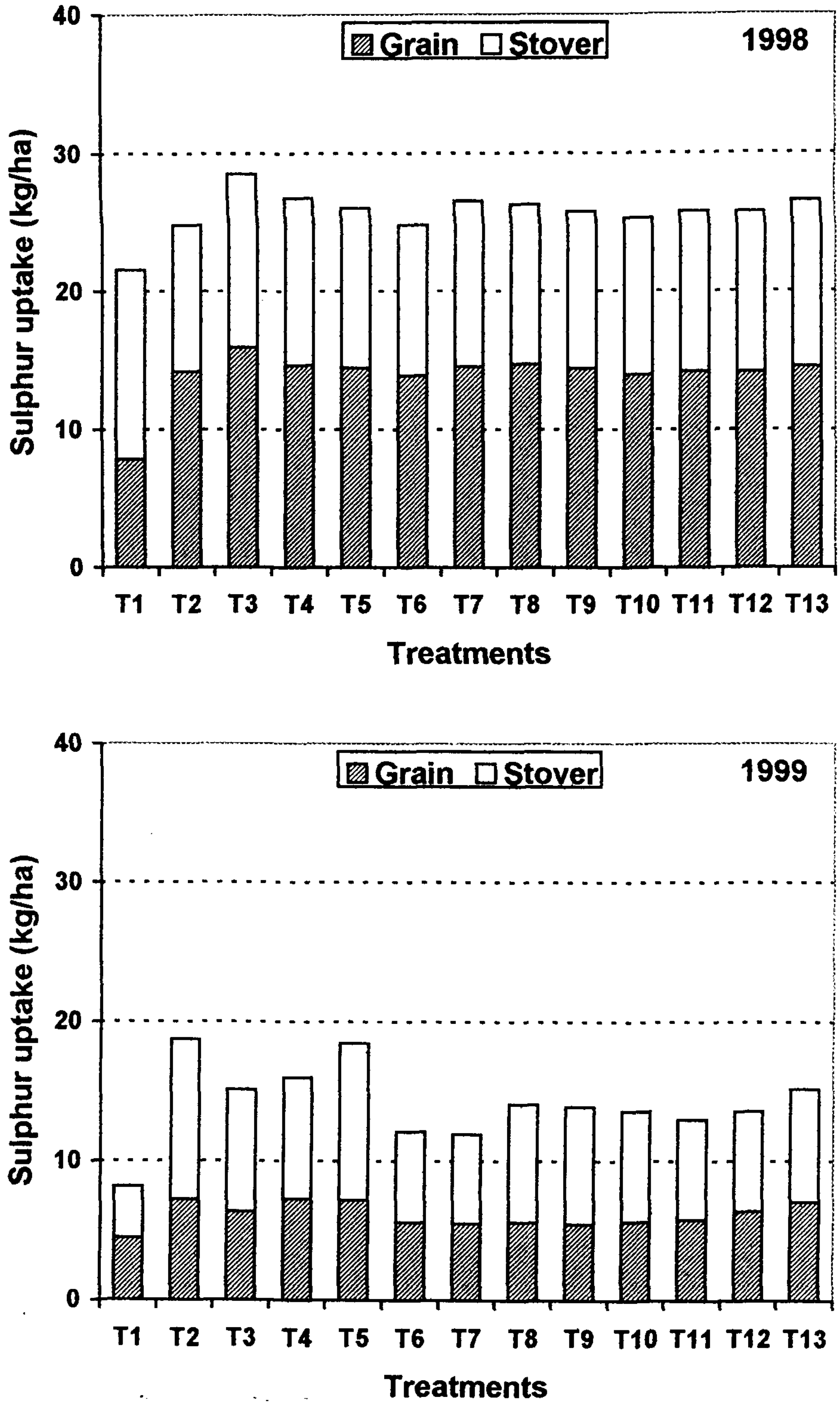

Fig. 4.9 Sulphur uptake (grain + stover) by maize crop

as ZnO and $ZnSO_4$ was not significant. Though, zinc application as ZnO at both levels to gobhi sarson increased sulphur uptake in maize as compared to control but when zinc was supplemented with sulphur as $ZnSO_4$, sulphur uptake did not change significantly. It indicates clearly that the increase in S uptake in maize due to application of $ZnSO_4$ at either rate to gobhi sarson was due to residual effect of sulphur and zinc.

Table 4.9 Residual effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on total sulphur uptake (kg/ha) in maize

Treatments	Total S uptake (kg/ha)	
	1998*	1999
Control (NPK) EY	21.41	8.37
25 kg S ha^{-1} (ES) EY	25.78	18.63
25 kg S ha^{-1} (ES) AY	28.13	14.83
50 kg S ha^{-1} (ES) EY	26.89	15.78
50 kg S ha^{-1} (ES) AY	26.49	18.68
5 kg Zn ha^{-1} (ZnO) EY	25.57	12.01
5 kg Zn ha^{-1} (ZnO) AY	27.07	11.97
10 kg Zn ha^{-1} (ZnO) EY	26.14	14.18
10 kg Zn ha^{-1} (ZnO) AY	25.91	13.96
5 kg Zn ha^{-1} (Zn SO_4) EY	25.20	13.55
5 kg Zn ha^{-1} (Zn SO_4) AY	26.00	13.07
10 kg Zn ha^{-1} (Zn SO_4) EY	25.60	13.94
10 kg Zn ha^{-1} (Zn SO_4) AY	26.57	14.79
SEd	0.59	0.57
CD 5%	1.21	1.17

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

During 1999 application of sulphur to gobhi sarson as ES and Zn as ZnO and $ZnSO_4$ resulted in significantly higher S uptake as compared to control. Application of S @ 25 kg and 50 kg ha^{-1} through ES when applied every year to gobhi sarson resulted in significantly higher total S uptake compared to control. However, these two levels of sulphur with their frequencies of application were also found significant. Alternate year application of sulphur (ES) @ 25 kg ha^{-1} resulted in significantly lower uptake of S compared to its EY application whereas reverse trend was observed with 50 kg S ha^{-1} (ES). In all other treatments frequency of application has not significant effect on S uptake. Similarly, 5 and 10 kg Zn ha^{-1} through ZnO resulted in significantly higher S uptake as compared to control applied every year and alternate year. Data in Table 4.9 further reveal that the difference in S uptake between EY and AY application was not significant, when 5 or 10 kg Zn ha^{-1} (ZnO) were applied every year and alternate year to gobhi sarson.

There was significant increase in S uptake with increase in levels of zinc application as ZnO whether applied every year or alternate year. It is further seen that though at each frequency Zn application to gobhi sarson as ZnO at both levels increased S uptake in maize in comparison to control but supplementation of zinc with sulphur increased S uptake significantly only in case of every year of 5 kg Zn as $ZnSO_4$ ha^{-1}. This clearly indicates that increase in S uptake in maize through EY application of 10 kg Zn ha^{-1} as $ZnSO_4$ and alternate year application of 5 and 10 kg Zn as $ZnSO_4$ ha^{-1} was due to combined effect of residual zinc and sulphur, whereas with EY application of 5 kg Zn ha^{-1} as $ZnSO_4$, it was due to residual effect of sulphur and not due to residual zinc.

4.2.2.5 Total zinc uptake

Data on total Zn uptake by maize crop (grain + stover) during 1998 and 1999 have been presented in Table 4.10 and shown graphically in Fig. 4.10.

Table 4.10 Residual effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on total zinc uptake (kg/ha) in maize

Treatments	Total Zn uptake (kg/ha)	
	1998*	1999
Control (NPK) EY	0.224	0.108
25 kg S ha^{-1} (ES) EY	0.344	0.188
25 kg S ha^{-1} (ES) AY	0.366	0.182
50 kg S ha^{-1} (ES) EY	0.359	0.245
50 kg S ha^{-1} (ES) AY	0.347	0.191
5 kg Zn ha^{-1} (ZnO) EY	0.333	0.284
5 kg Zn ha^{-1} (ZnO) AY	0.353	0.280
10 kg Zn ha^{-1} (ZnO) EY	0.401	0.289
10 kg Zn ha^{-1} (ZnO) AY	0.342	0.284
5 kg Zn ha^{-1} (Zn SO_4) EY	0.332	0.225
5 kg Zn ha^{-1} (Zn SO_4) AY	0.339	0.230
10 kg Zn ha^{-1} (Zn SO_4) EY	0.344	0.242
10 kg Zn ha^{-1} (Zn SO_4) AY	0.352	0.294
SEd	0.011	0.009
CD 5%	0.022	0.018

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Data presented in Table 4.10 reveals that Zn uptake in maize was significantly influenced by the application of sulphur as ES and Zn as ZnO and $ZnSO_4$ to gobhi sarson during 1998 where only EY treatments were imposed to gobhi sarson (1997-98). Application of 25 and 50 kg S ha^{-1} through ES resulted in significantly higher uptake of Zn compared to control, however

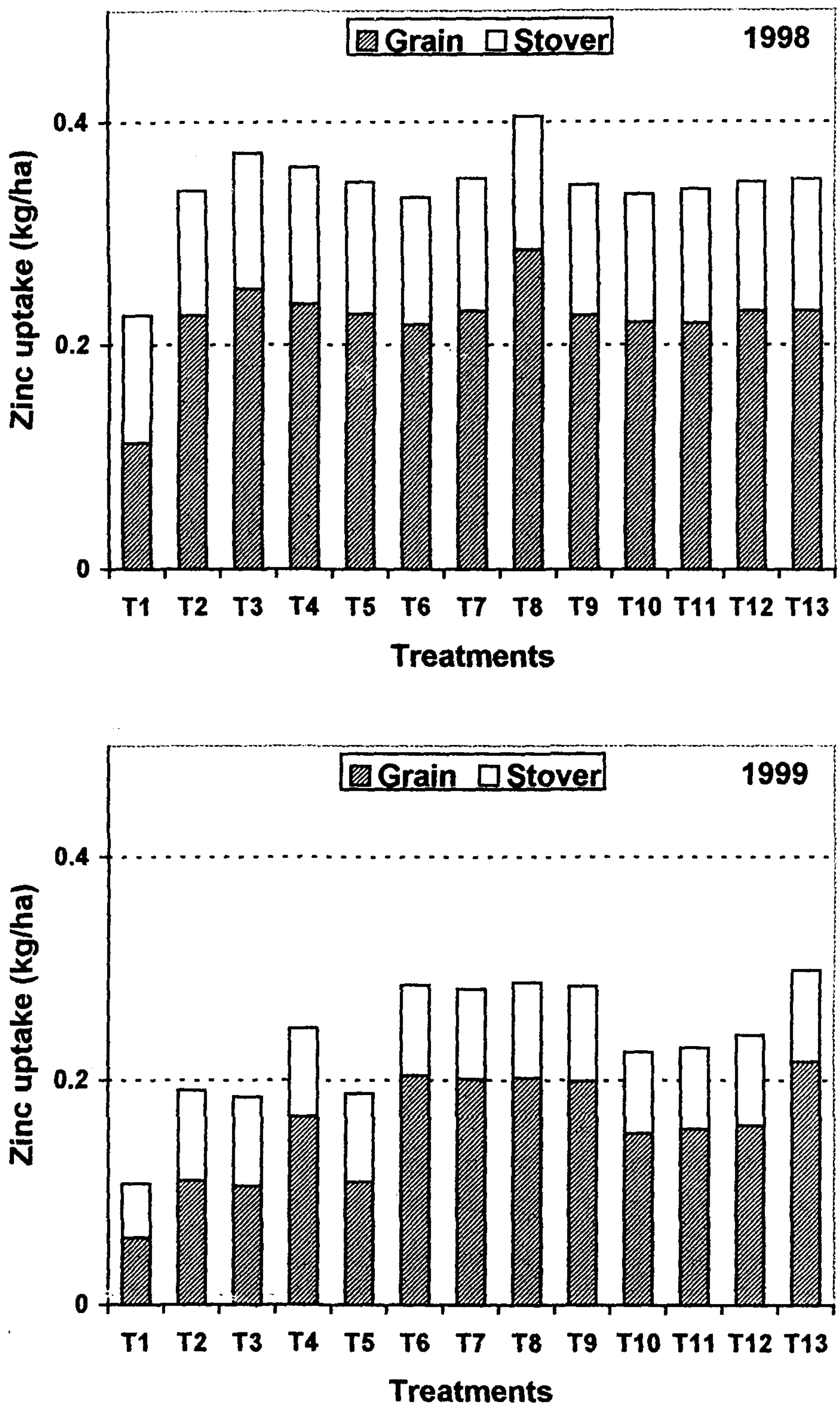

Fig. 4.10 Zinc uptake (grain + stover) by maize crop

levels did not differ significantly with each other. Data further show that application of 5 and 10kg Zn ha^{-1} ($ZnSO_4$) resulted in significantly higher Zn uptake as compared to control but levels of application did not differ significantly among themselves. The above mentioned treatments did not differ significantly at their respective levels. However, application of 10 kg Zn ha^{-1} (ZnO) resulted in significantly higher Zn uptake by maize crop (1998) compared to control and other treatments given to gobhi sarson (1997-98). Application of 5 kg Zn ha^{-1} (ZnO) resulted in significantly higher Zn uptake compared to control but uptake was significantly lower than that obtained by application of 10 kg Zn ha^{-1} (ZnO) applied every year to gobhi sarson. It was also seen that Zn uptake in maize was higher where only Zn (ZnO) was applied and was lower where Zn was accompanied with sulphur as $ZnSO_4$, however significant difference was observed with 10 kg Zn ha^{-1} applied through ZnO during 1998. During second year (1999), data presented in Table 4.10 reveal that application of sulphur as elemental sulphur and Zn as ZnO and $ZnSO_4$ to gobhi sarson (1998-99) significantly influenced the Zn uptake compared to control whether applied every year and alternate year. Application of 25 and 50 kg S ha^{-1} (ES) resulted in significantly higher Zn uptake compared to control when applied every year or alternate year. Increase in levels of sulphur application as elemental sulphur increased zinc uptake but the increase was significant only in case of every year application. Also, EY application of 50 kg S ha^{-1} (ES) resulted in significantly higher Zn uptake compared to its alternate year application. Similarly, application of 10 kg Zn ha^{-1} ($ZnSO_4$) to gobhi sarson (1998-99) in AY resulted in significantly higher Zn uptake by maize (1999) as compared to EY and two levels of S application applied EY and AY. Also increase in levels of zinc application as zinc sulphate increased zinc uptake but the increase was significant only in case of alternate year application. It is further seen that at each frequency zinc application as ZnO at both the levels increased zinc uptake in maize in comparison to control, however, significant decrease in zinc uptake was observed when EY zinc application at both levels to gobhi sarson was supplemented with sulphur as $ZnSO_4$ and AY zinc application to gobhi sarson was supplemented with sulphur at 5 kg level as $ZnSO_4$. This clearly indicates that residual effect of sulphur as $ZnSO_4$ decreased zinc uptake in maize.

4.2.3 Nutrient uptake by maize-gobhi sarson cropping sequence

Data pertaining to N, P, K, S and Zn uptake by maize-gobhi sarson cropping sequence have been given in Table 4.11 and the corresponding analyses of variance have been given in Appendix XIII and XIV.

4.2.3.1 Total nitrogen uptake

Data presented in Table 4.11 reveal that total N uptake of sequence was neither influenced significantly by application of different levels of Zn to gobhi sarson applied through ZnO and $ZnSO_4$ nor by sulphur (ES) during 1997-98. However, during second year (1998-99), it was significantly improved by different treatments as compared to control. It may further be seen that application of sulphur through elemental sulphur and Zn through $ZnSO_4$ resulted in significantly higher N uptake compared to control but

Table 4.11 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on total N, P, K, S and Zn uptake (kg/ha) in maize-gobhi sarson sequence

Treatments	Total uptake (kg/ha)									
	1997-98*					1998-99				
	N	P	K	S	Zn	N	P	K	S	Zn
Control (NPK) EY	215.06	34.54	167.62	35.50	0.381	153.91	24.99	109.27	18.97	0.228
25 kg S ha^{-1} (ES) EY	226.88	37.80	165.16	41.29	0.606	227.40	37.71	154.75	38.13	0.472
25 kg S ha^{-1} (ES) AY	221.26	36.47	162.32	40.29	0.533	215.49	35.82	148.80	31.13	0.456
50 kg S ha^{-1} (ES) EY	228.15	36.94	177.17	43.08	0.628	237.51	40.25	155.70	35.44	0.556
50 kg S ha^{-1} (ES) AY	213.32	37.98	156.38	39.72	0.546	227.22	37.88	148.74	36.69	0.459
5 kg Zn ha^{-1} (ZnO) EY	211.55	36.27	160.59	39.85	0.586	199.46	33.05	135.16	27.21	0.600
5 kg Zn ha^{-1} (ZnO) AY	215.65	37.32	151.70	39.57	0.547	198.83	31.61	135.87	27.76	0.605
10 kg Zn ha^{-1} (ZnO) EY	[illegible]	37.29	168.58	41.50	0.672	205.61	33.85	145.30	29.84	0.620
10 kg Zn ha^{-1} (ZnO) AY	[illegible]	36.14	148.71	38.35	0.493	204.27	33.94	145.33	30.07	0.625
5 kg Zn ha^{-1} (Zn SO_4) EY	200.31	33.93	152.23	37.77	0.571	215.58	37.04	136.10	33.40	0.572
5 kg Zn ha^{-1} (Zn SO_4) AY	197.69	33.46	144.25	36.72	0.465	212.98	36.16	141.35	32.23	0.558
10 kg Zn ha^{-1} (Zn SO_4) EY	199.00	33.82	148.29	37.35	0.476	229.06	39.42	148.44	36.38	0.608
10 kg Zn ha^{-1} (Zn SO_4) AY	203.01	34.22	144.90	37.22	0.504	223.15	38.18	138.22	35.18	0.626
SEd	14.27	2.08	11.67	2.08	0.032	8.20	1.47	5.67	1.82	0.025
CD 5%	NS	NS	NS	4.27	0.066	16.83	3.01	11.65	3.73	0.052

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

increase in their respective levels whether applied EY or AY did not increase uptake significantly. It was also seen that with decrease in their frequency of application though decreased uptake but the decrease was not significant. With application of zinc as ZnO, data also reveal that N uptake was higher in EY as compared to AY application of Zn through ZnO but the difference was not-significant. Also, Zn application as ZnO increased N uptake significantly over control but was significantly lower than the treatment where every year or AY application of Zn was accompanied by sulphur as $ZnSO_4$ at 10 kg ha^{-1}. Application of 5 kg Zn ha^{-1} through ZnO and 5 kg Zn ha^{-1} through $ZnSO_4$, did not differ significantly with each other whether applied EY or AY. Thus, it is clear that higher uptake of N was due to sulphur alone when $ZnSO_4$ was applied at higher level, whereas at lower level, it was due to S and Zn.

4.2.3.2 Total phosphorus uptake

Data pertaining to total uptake of phosphorus by maize-gobhi sarson sequence presented in Table 4.11 reveal that neither levels of sulphur (ES) nor levels of zinc as ZnO and $ZnSO_4$ influenced P uptake significantly during 1997-98. However, during second year (1998-99), it was significantly influenced by sulphur application through elemental sulphur (ES) and Zn through both ZnO and $ZnSO_4$, whether applied every year or alternate year to gobhi sarson. It may be seen from the same table that all the levels of sulphur through elemental sulphur whether applied EY or AY resulted in significantly higher P uptake compared to control but remained statistically at par among themselves. More frequent application of sulphur through elemental sulphur

(ES) though resulted in higher uptake compared to its AY application, but differences were not significant at each level of elemental sulphur application. Neither increase in levels nor increase in frequency of application of Zn as ZnO and $ZnSo_4$ increased P uptake significantly compared to their AY application. Data in Table 4.11 further reveal that every year or alternate year application of Zn through ZnO at both levels resulted in significantly higher uptake of P compared to control but was significantly lower when it was accompanied by sulphur as $ZnSO_4$ at both the levels applied EY or AY. It clearly indicates that higher P uptake noticed in Zn as $ZnSO_4$ treatments was due to sulphur alone.

4.2.3.3 Total potassium uptake

A critical examination of total K uptake data of crop sequence (Table 4.11) shows that neither the levels of sulphur as ES nor the levels of zinc either alone as ZnO or in combination with sulphur as $ZnSO_4$ influenced K uptake during first year (1997-98). However, during second year (1998-99), it was significantly influenced by the application of different treatments. Every year as well as AY application of sulphur as ES at both the levels though resulted in significantly higher K uptake compared to control but differences within levels of alternate or every year treatments were not significant Likewise, application of Zn alone through ZnO or with sulphur as $ZnSO_4$ at both the levels though resulted in significantly higher uptake than control but differences within levels of respective nutrient elements were not-significant whether applied every year or AY. It was also observed that the K uptake increased though not significantly with frequent application of sulphur through elemental sulphur (ES) at both the levels or through Zn as $ZnSO_4$ at higher level only compared to their less frequent application (AY). On the other hand frequent application of Zn as ZnO decreased K uptake at both the levels however, differences between every year and alternate year were not significant at each level of application. Data further, revealed that Zn as ZnO whether applied EY or AY resulted in significantly higher K uptake compared to control but was not significantly lower than the treatments where it was accompanied by sulphur as $ZnSO_4$ at 5 or 10 kg ha^{-1}. It indicates clearly that the increase in K uptake in response to $ZnSO_4$ application to gobhi sarson was not due to sulphur but it was due to the combined effect of sulphur and zinc. but the increase was not significant.

4.2.3.4 Total sulphur uptake

Total uptake of sulphur embodied in same table (Table 4.11) revealed that during first year (1997-98) where only EY treatments were applied, application of both levels of sulphur as elemental sulphur and Zn as ZnO resulted in significantly higher sulphur uptake compared to control. However, increase in level of each resulted in non-significant increase in sulphur uptake. On the contrary when Zn and sulphur were applied in combinations through $ZnSO_4$ at 5 or 10 kg ha^{-1}, the uptake did not differ significantly as compared to ZnO control. Thus S uptake of crop sequence was improved only by individual application of S (ES) and Zn (ZnO) and when applied together as $ZnSO_4$ then zinc and sulphur counteract the effect of each other. During second year (1998-

99), sulphur uptake by crop sequence was significantly influenced by the frequencies as well as level of application of sulphur as ES and Zn (ZnO and $ZnSO_4$). Data presented in Table 4.11 further reveal that different treatments whether applied EY or AY resulted in significantly higher S uptake as compared to control. However, uptake did not differ significantly with increase in level of Zn as ZnO and $ZnSO_4$, whether applied every year or AY. It may further be seen that there was significant difference in the levels of sulphur when applied in alternate year, where 50 kg S ha^{-1} through elemental sulphur (ES) resulted in significantly higher sulphur uptake as compared to 25 kg S ha^{-1} (ES). Alternate year application of sulphur resulted in significantly lower sulphur uptake compared to EY application when applied at the rate of 25 kg S ha^{-1} as elemental sulphur. Further, alternate application of Zn at the both levels and sulphur (ES) at 50 kg S ha^{-1} through elemental sulphur improved sulphur uptake but not significantly compared to every year application of respective treatments. On the contrary, alternate year application of Zn and sulphur as $ZnSO_4$ at both the levels reduced sulphur uptake again not significantly compared to every year application of respective level. Though EY as well as AY application of zinc as ZnO resulted in significantly higher sulphur uptake compared to control but when Zn was supplemented with sulphur as $ZnSO_4$, that it resulted in significantly higher sulphur uptake by crop sequence whether applied every year or AY at 5 or 10 kg Zn ha^{-1} level. It clearly shows that increase in sulphur uptake was due to sulphur alone.

4.2.3.5 Total zinc uptake

Total Zn uptake data (Table 4.11) reveal that during 1997-98, Zn uptake in maize gobhi sarson sequence was significantly improved over control by the EY application of S as ES, Zn as ZnO and $ZnSO_4$ at both levels. As expected, there was significant increase in Zn uptake with increase in level of Zn alone as ZnO. When Zn application was supplemented with sulphur as $ZnSO_4$, then Zn uptake decreased, however, decrease was significant only at higher level of zinc application (10 kg Zn ha^{-1}). It indicates that sulphur may have antagonistic effect on Zn uptake, which becomes prominent at higher level of sulphur application. Data pertaining to second year (1998-99) indicate that either every year or AY application of sulphur through elemental sulphur and Zn as $ZnSO_4$ as well s application of Zn alone as ZnO resulted in significantly higher Zn uptake as compared to control. It was also seen that increase in every year levels of sulphur application as elemental sulphur and alternate year level of Zn application as $ZnSO_4$ significantly improved Zn uptake. Frequent (EY) application of sulphur at both levels as elemental sulphur increased Zn uptake compared to its alternate year of application, however, the increase was significant only at higher level of sulphur (ES) application. Frequent zinc application as $ZnSO_4$ had no significant effect on Zn uptake compared to alternate year application at both the levels of application. Likewise frequent Zn application ZnO also had no significant effect on Zn uptake compared to AY of application at both the levels. It is also seen that application of Zn as ZnO applied EY or AY increased zinc uptake significantly over control, however, when zinc was accompanied by sulphur as $ZnSO_4$ at 5 or 10 kg Zn ha^{-1}; then a drop in zinc uptake was observed in gobhi sarson, which was not significant. It can be inferred that sulphur may have some antagonistic effect on Zn uptake in maize-gobhi sarson crop sequence.

4.3 SOIL STUDIES

4.3.1 Soil pH

Data pertaining to pH changes after each crop cycle due to levels and frequencies of application of sulphur through elemental sulphur and Zn as ZnO and $ZnSO_4$ have been given in Table 4.12. A close examination of data reveal that pH of soil after the harvest of gobhi sarson remained unaffected by every year application of Zn as ZnO or $ZnSO_4$, however, EY application of sulphur as elemental sulphur decreased it slightly as compared to control. It was also observed that increase in the level of sulphur as elemental sulphur (ES) and Zn as $ZnSO_4$ decreased the soil pH. On the contrary during 1998-99 every year application of Zn as ZnO and $ZnSO_4$ increased soil pH, however EY application of sulphur as elemental sulphur (ES) decreased it slightly as compared to control. Increase in the level of sulphur (ES) and zinc as $ZnSO_4$ decreased soil pH. During the same year AY application of sulphur (ES), Zn as $ZnSO_4$ (at lower level) and ZnO (at both the levels) increased the soil pH as compared to control. It was also observed that different treatments whether applied EY or AY did not affect soil pH substantially as compared to initial soil pH.

Table 4.12 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on soil pH after each crop cycle

Treatments	Soil pH			
	1997-98*		1998-99	
	After gobhi sarson	After maize	After gobhi sarson	After maize
Control (NPK) EY	5.68	5.69	5.68	5.68
25 kg S ha^{-1} (ES) EY	5.68	5.68	5.66	5.66
25 kg S ha^{-1} (ES) AY	5.70	5.70	5.69	5.68
50 kg S ha^{-1} (ES) EY	5.66	5.65	5.65	5.66
50 kg S ha^{-1} (ES) AY	5.69	5.70	5.68	5.68
5 kg Zn ha^{-1} (ZnO) EY	5.68	5.69	5.70	5.69
5 kg Zn ha^{-1} (ZnO) AY	5.69	5.69	5.69	5.69
10 kg Zn ha^{-1} (ZnO) EY	5.69	5.70	5.70	5.70
10 kg Zn ha^{-1} (ZnO) AY	5.69	5.68	5.69	5.68
5 kg Zn ha^{-1} (Zn SO_4) EY	5.[illegible]	5.68	5.69	5.[illegible]
5 kg Zn ha^{-1} (Zn SO_4) AY	5.69	5.69	5.69	5.69
10 kg Zn ha^{-1} (Zn SO_4) EY	5.69	5.68	5.68	5.68
10 kg Zn ha^{-1} (Zn SO_4) AY	5.69	5.69	5.69	5.68
Initial	5.70			

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Further examination of the soil reaction data after the harvest of maize presented in Table 4.12 indicate that every year application of sulphur as elemental sulphur and Zn as $ZnSO_4$ and ZnO at both the levels to gobhi sarson, decreased soil pH even after the harvest of maize as compared to control during 1997-98. The increase in level of sulphur as ES decreased soil pH substantially. But Zn as $ZnSo_4$, there was no decrease in soil pH in the subsequent year (1998-99).

Every year application of sulphur (ES) to gobhi sarson decreased pH after the harvest of maize when compared with control. All other treatments whether applied every year or alternate year to gobhi sarson did not affect the soil pH after the harvest of maize. Levels of sulphur whether applied EY or AY as elemental sulphur (ES) and Zn as $ZnSO_4$ did not affect the pH of soil after the harvest of maize. When compared to initial value, the application of different treatments decreased the soil pH.

4.3.2 Organic carbon content

Data on organic carbon contents have been presented in Table 4.13 and the corresponding analyses of variance have been given in Appendix XV.

Organic carbon content of the soil increased after the harvest of gobhi sarson over the initial value (0.65%) during 1997-98 and was further improved during 1998-99. However, overall build up of organic carbon was marginal. A keen observation of data on soil organic carbon (%) after the harvest of gobhi sarson revealed that every year application of sulphur through elemental sulphur (ES) and Zn through ZnO to gobhi sarson significantly increased the organic carbon content in the soil as compared to control during 1997-98. However, no change in soil organic carbon content was observed when both Zn and S were applied simultaneously through $ZnSO_4$. It was further noticed that organic carbon content of soil decreased significantly with increase in level of sulphur (ES) while reverse was true in case of Zn as ZnO.

Table 4.13 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on soil organic carbon contents

Treatments	Soil organic carbon (%)			
	1997-98*		1998-99	
	After gobhi sarson	After maize	After gobhi sarson	After maize
Control (NPK) EY	0.67	0.68	0.68	0.66
25 kg S ha^{-1} (ES) EY	0.70	0.69	0.71	0.69
25 kg S ha^{-1} (ES) AY	0.66	0.68	0.70	0.69
50 kg S ha^{-1} (ES) EY	0.69	0.70	0.71	0.70
50 kg S ha^{-1} (ES) AY	0.68	0.68	0.71	0.69
5 kg Zn ha^{-1} (ZnO) EY	0.68	0.68	0.69	0.68
5 kg Zn ha^{-1} (ZnO) AY	0.68	0.67	0.70	0.67
10 kg Zn ha^{-1} (ZnO) EY	0.69	0.67	0.70	0.68
10 kg Zn ha^{-1} (ZnO) AY	0.67	0.68	0.71	0.67
5 kg Zn ha^{-1} (Zn SO_4) EY	0.67	0.67	0.72	0.68
5 kg Zn ha^{-1} (Zn SO_4) AY	0.67	0.67	0.71	0.68
10 kg Zn ha^{-1} (Zn SO_4) EY	0.67	0.68	0.72	0.68
10 kg Zn ha^{-1} (Zn SO_4) AY	0.67	0.68	0.72	0.68
SEd	0.005	0.004	0.005	0.004
CD 5%	0.01	0.01	0.01	0.01
Initial	0.65			

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

During 1998-99, every year as well as AY application of sulphur (ES) and zinc through ZnO and $ZnSO_4$ significantly improved organic carbon content of the soil as compared to control. In case of AY treatments ES and Zn (ZnO and $ZnSO_4$) significantly improved organic carbon content of the soil after the harvest of gobhi sarson while in case of every year treatments, only increase in level of zinc as ZnO increased organic carbon significantly. It may be seen that application of zinc as ZnO at both the levels significantly increased organic carbon as compared to control but it was further increased significantly when it was accompanied by sulphur as $ZnSO_4$ at 5 or 10 kg ha^{-1} whether applied EY or AY. This indicates that increase in organic carbon due to application of $ZnSO_4$ is because of [illegible] sulphur. Frequent application of sulphur and zinc at lower level either as ES or $ZnSO_4$ significantly increased organic carbon content of the soil significantly compared to their alternate year application. Reverse trend was observed at both levels of Zn (ZnO) application where organic carbon was significantly higher in AY than in EY treatments.

Keen observation of the organic carbon status of the soil after the harvest of maize (Table 4.13) indicates that EY application of sulphur as ES in gobhi sarson significantly improved the organic carbon content of the soil after the harvest of maize as compared to control during *kharif* 1997-98. Organic carbon content of the soil after maize was also improved significantly with increase in level of sulphur application as elemental sulphur to gobhi sarson. Rest of the treatments had not clear-cut effect on organic carbon content of soil. During 1998-99 data on soil organic carbon content after maize from the same table (Table 4.13) indicate that varying levels of sulphur (ES) and Zn as ZnO and $ZnSO_4$ whether applied EY or AY to gobhi sarson significantly influenced the organic carbon content in soil after the harvest of maize compared to control. Increase in the level of EY application of sulphur as elemental sulphur significantly improved soil organic carbon, but increase in AY application of sulphur as elemental sulphur (ES) levels had no significant effect on soil organic carbon. Similarly change in level of zinc ($ZnSO_4$) or Zn (ZnO) whether applied EY or AY to gobhi sarson had no significant effect on organic carbon content of the soil after the harvest of maize. It was also observed that application of both Zn and sulphur as $ZnSO_4$ increased organic carbon content significantly as compared to Zn (ZnO) application alone when applied in alternate year. It indicates that both residual Zn and sulphur are responsible for increased soil organic content after the harvest of maize in AY treatments.

4.3.3 Available nitrogen

Data pertaining to available nitrogen in soil have been given in Table 4.14 and corresponding analyses of variance have been appended in Appendix XVI.

Data embodied in Table 4.14 show that EY application of sulphur as elemental sulphur (ES) and Zn as ZnO and $ZnSO_4$ significantly influenced the available nitrogen status in the soil after the harvest of gobhi sarson (1997-98). Data embodied in Table 4.14 also show that EY application of sulphur as elemental sulphur (ES) resulted in significant decrease in the soil available nitrogen after the harvest of gobhi sarson (1997-98) compared to control. Level of sulphur (ES) had no significant effect on available nitrogen in soil after the harvest of gobhi sarson (1997-98).

Table 4.14 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on soil available nitrogen

Treatments	Available nitrogen (kg/ha)			
	1997-98*		1998-99	
	After gobhi sarson	After maize	After gobhi sarson	After maize
Control (NPK) EY	386.36	393.71	445.19	391.12
25 kg S ha^{-1} (ES) EY	373.76	395.70	413.09	382.36
25 kg S ha^{-1} (ES) AY	435.06	380.81	398.45	382.29
50 kg S ha^{-1} (ES) EY	377.99	379.80	400.74	380.30
50 kg S ha^{-1} (ES) AY	391.63	396.37	417.72	382.65
5 kg Zn ha^{-1} (ZnO) EY	387.22	395.33	430.07	384.79
5 kg Zn ha^{-1} (ZnO) AY	421.79	383.19	421.91	384.92
10 kg Zn ha^{-1} (ZnO) EY	378.92	389.40	419.77	385.09
10 kg Zn ha^{-1} (ZnO) AY	429.85	395.57	419.24	390.72
5 kg Zn ha^{-1} (Zn SO_4) EY	391.86	387.66	393.68	384.60
5 kg Zn ha^{-1} (Zn SO_4) AY	428.28	398.21	399.44	384.86
10 kg Zn ha^{-1} (Zn SO_4) EY	439.66	397.33	395.17	383.99
10 kg Zn ha^{-1} (Zn SO_4) AY	436.16	391.67	394.08	383.80
SEd	2.09	7.61	1.29	0.15
CD 5%	4.29	NS	3.58	0.32
Initial	392.42			

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Data also reveal that EY application of zinc at higher level (10 kg Zn ha^{-1}) as ZnO significantly decreased available nitrogen in soil after the harvest of gobhi sarson compared to control. However, application of zinc (ZnO) at lower level (5 kg Zn ha^{-1}) was statistically at par with control. When zinc was supplemented with sulphur as $ZnSO_4$, there was significant increase in available nitrogen in soil as compared to application of Zn (ZnO) at their respective levels. Also, increase in levels of Zn as $ZnSO_4$ improved significantly available nitrogen status of the soil. It indicates that observed effect of Zn through $ZnSO_4$ on available nitrogen in the soil after the harvest of gobhi sarson (1997-98) is due to sulphur alone.

Data presented in Table 4.14 indicate that different treatments significantly influenced the soil available nitrogen after the harvest of gobhi sarson during second year of experimentation (1998-99). EY or AY application of sulphur through elemental sulphur and zinc through ZnO and $ZnSO_4$ significantly decreased available nitrogen of the soil after the harvest of gobhi sarson as compared to control. Here, EY application of sulphur (ES) at lower level significantly, improved the soil available nitrogen as compared to AY application. However, reverse trend was observed at higher level of sulphur (ES) application where AY application proved beneficial Data presented in same table (Table 4.14) also reveal that EY application of Zn through ZnO (5 kg Zn ha^{-1}) significantly improved the soil available nitrogen compared to AY application. However, at higher level of zinc (ZnO) application, frequency of application had not significant effect on available soil nitrogen. It may further be seen that when zinc was supplemented with sulphur as $ZnSO_4$ and application of Zn through it at 5 or 10 kg ha^{-1} significantly decreased soil available nitrogen whether applied EY or AY compared to Zn as ZnO. Further, it was also observed that increase in the level of EY sulphur (ES) application and AY zinc application with sulphur as $ZnSO_4$ significantly decreased the available soil nitrogen. On the contrary increase in level of AY sulphur (ES) application increased significantly the available nitrogen. Similarly, EY increase in the level of Zn (ZnO) application significantly decreased available nitrogen status in the soil after harvest of gobhi sarson. It indicates that observed effect of Zn as $ZnSO_4$ on available nitrogen in soil after harvest of gobhi sarson was due to sulphur alone in $ZnSO_4$ treatments.

A critical observation of the data of available nitrogen after the harvest of maize (Table 4.14) indicate that EY application of different levels of sulphur as elemental sulphur (ES) and zinc as ZnO and $ZnSO_4$ to gobhi sarson did not affect the available nitrogen of the soil after the harvest of maize during 1997-98. However, in the succeeding season (1998-99), frequency as well as different level of sulphur (ES) and zinc, as $ZnSO_4$ whether applied EY or AY significantly decreased soil available nitrogen as compared to control. It was further observed that AY application at higher level application of sulphur (ES) @ 50 kg S ha^{-1} to gobhi sarson resulted in significant improvement in soil available nitrogen in soil as compared to EY application at the same level. However, at lower level of sulphur application as ES frequency of application did not affect available N. On the contrary, AY application of zinc at higher level of Zn as ZnO to gobhi sarson resulted in significant increase in soil available nitrogen compared to EY application at the same level. Rest of the treatments whether applied EY or AY to gobhi sarson did not influence the available soil nitrogen after the harvest of maize. Data presented in Table 4.14 also indicate that increasing the level of sulphur as elemental sulphur (ES) to gobhi sarson resulted in significant decrease in soil available nitrogen when applied EY. However, AY increase in level of sulphur as elemental sulphur (ES) had no significant effect on available soil nitrogen. Also increasing level of [illegible] AY application of Zn (ZnO) to gobhi sarson resulted in significant increase the soil available nitrogen after the harvest of maize. But it decreased available nitrogen significantly compared to control. It was further decreased when EY and AY application of zinc was supplemented with sulphur as $ZnSO_4$, however, the decrease was significant only in case of higher level of zinc application as $ZnSO_4$. It indicates that observed effect of higher level of zinc application as $ZnSO_4$ on available nitrogen status of the soil after the harvest of the maize was due to sulphur alone.

4.3.4 Available phosphorus

Data pertaining to available phosphorus in the soil after each crop cycle due to levels and frequencies of application of sulphur through elemental sulphur (ES) and Zn through ZnO and $ZnSO_4$ have been given in Table 4.15 and corresponding analysis of variance have been given in Appendix XVII.

A keen observation of data presented in Table 4.15 reveals that EY application of different levels of sulphur (ES) and zinc through ZnO and $ZnSO_4$ to gobhi sarson significantly influenced the soil available phosphorus after its harvest during 1997-98. It may be seen that application of sulphur (ES) applied EY to gobhi sarson resulted in significant decrease in soil available phosphorus compared to control. However, increase in the levels of sulphur (ES) had no effect on available phosphorus.

Table 4.15 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on soil available phosphorus

Treatments	Available phosphorus (kg/ha)			
	1997-98*		1998-99	
	After gobhi sarson	After maize	After gobhi sarson	After maize
Control (NPK) EY	32.25	37.71	43.82	36.19
25 kg S ha^{-1} (ES) EY	30.10	37.69	38.67	36.59
25 kg S ha^{-1} (ES) AY	33.53	32.68	38.80	36.53
50 kg S ha^{-1} (ES) EY	30.11	34.40	37.65	36.22
50 kg S ha^{-1} (ES) AY	32.58	35.12	39.10	36.25
5 kg Zn ha^{-1} (ZnO) EY	33.92	37.70	40.01	38.17
5 kg Zn ha^{-1} (ZnO) AY	33.84	35.31	39.82	38.63
10 kg Zn ha^{-1} (ZnO) EY	32.00	35.26	39.56	37.70
10 kg Zn ha^{-1} (ZnO) AY	33.41	36.07	39.66	37.79
5 kg Zn ha^{-1} (Zn SO_4) EY	32.30	37.59	34.15	37.50
5 kg Zn ha^{-1} (Zn SO_4) AY	34.26	36.81	37.58	37.32
10 kg Zn ha^{-1} (Zn SO_4) EY	34.78	35.63	34.71	37.56
10 kg Zn ha^{-1} (Zn SO_4) AY	33.36	35.27	34.54	36.20
SEd	0.13	0.095	0.38	0.09
CD 5%	0.27	0.19	0.77	0.19
Initial	28.62			

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Application of 5 kg Zn ha^{-1} (ZnO) and 10 kg Zn ha^{-1} ($ZnSO_4$) resulted in significant increase in soil available phosphorus after the harvest of gobhi sarson while 10 kg Zn ha^{-1} (ZnO) and 5 kg Zn ha^{-1} ($ZnSO_4$) remained statistically at par with control. Data further show that with increase in the level of zinc as ZnO, there was significant decrease in soil available phosphorus in soil after harvest of gobhi sarson. On the contrary, when Zn was supplemented with sulphur as $ZnSO_4$, then soil available phosphorus was significantly improved with increasing levels of zinc. Data on available phosphorus after the harvest of gobhi sarson crop of 1998-99 (Table 4.15) reveal that it considerably improved as compared to 1997-98. However, all the treatments whether applied EY or AY resulted in significant decrease in available phosphorus as compared to control. Data further reveal that AY application of sulphur (ES) at higher level (50 kg S ha^{-1}) to gobhi sarson significantly improved soil available phosphorus compared to its EY application. It may further be seen that zinc application at lower level through $ZnSO_4$ significantly improved available phosphorus when applied AY. In rest of the treatments frequency of application had no significant effect on available phosphorus in the soil after the harvest of gobhi sarson. Further examination of data reveal that EY increasing the levels of sulphur (ES) and AY increasing the levels of zinc through $ZnSO_4$ significantly decreased the available phosphorus status of soil after the harvest of gobhi sarson. In all other cases, increase in level of sulphur (ES) or zinc had not significant effect on available soil phosphorus whether applied EY or AY. It may further be seen from the same table (Table 4.15) that when zinc was supplemented with sulphur as $ZnSO_4$ at 5 or 10 kg Zn ha^{-1} applied EY or AY, it decreased significantly the soil available phosphorus after the harvest of gobhi sarson. The observed effect of zinc as $ZnSO_4$ application to gobhi sarson in respect to available phosphorus of the soil was due to sulphur alone.

Data on available phosphorus after the maize crop harvest presented in Table (4.15) reveal that in general EY application of sulphur (ES) and zinc through ZnO or $ZnSO_4$ to gobhi sarson decreased the available phosphorus as compared to control after the harvest of succeeding crop of maize (1997-98). However, this decrease was significant only at higher level of application of respective nutrient element during 1997-98 when EY treatments were imposed to gobhi sarson. It was also seen that increase in the levels of sulphur through elemental sulphur (ES) and Zn through ZnO and $ZnSO_4$ application to gobhi sarson resulted in significant decrease in soil available phosphorus after the harvest of succeeding maize crop of 1997-98. Further, at higher level of zinc application, supplementing Zn with sulphur as $ZnSO_4$ significantly improved the soil available phosphorus after the harvest of succeeding maize whereas at lower level (5kg Zn ha^{-1}), it did not show any significant change in available phosphorus. It indicate that observed effect of higher level of zinc application as $ZnSO_4$ to gobhi sarson on available phosphorus of the soil after the harvest of the succeeding crop of maize was due to sulphur alone. Data on soil available phosphorus after the harvest of maize crop of 1998-99 given in Table 4.15 indicate that all the treatments whether applied EY or AY to gobhi sarson improved the soil available phosphorus after the harvest of maize crop as compared to control. However differences were not significant in case of 50 kg S ha^{-1} as elemental sulphur (ES) applied EY as well as AY and 10 kg Zn ha^{-1} through $ZnSO_4$ applied AY compared to control. It may be further seen from the same table that at lower

(5 kg ha^{-1}) of zinc through ZnO applied in AY to gobhi sarson significantly improved the soil available phosphorus after succeeding maize crop compared to EY application. Whereas at higher level (10 kg ha^{-1}), zinc application as $ZnSO_4$ to gobhi sarson resulted in significant decrease in soil available phosphorus status compared to its EY application. In rest of the treatments, frequency of their application to gobhi sarson did not affect the soil available phosphorus after the harvest of maize. Further examination of data in the same table reveal that increase in the level of sulphur as elemental sulphur (ES) and zinc as ZnO to gobhi sarson whether applied EY or AY significantly decreased the soil available phosphorus after harvest of succeeding maize crop. However, when zinc was supplemented with sulphur as $ZnSO_4$, and applied EY as well as AY at 5 kg Z ha^{-1} to gobhi sarson, then it resulted in significant decrease in soil available phosphorus after the harvest of maize. Similar trend was observed when Zn was supplemented with sulphur as $ZnSO_4$ at higher level of zinc application to gobhi sarson, decreased in soil available phosphorus, however, difference was significant with supplementing of Zn application of AY alone. It again indicates that both levels of AY zinc application and lower level of EY zinc application as $ZnSO_4$ to gobhi sarson, the observed effect was due to sulphur alone.

4.3.5 Available potassium

Data pertaining to available potassium in soil after the harvest of each crop have been presented in Table 4.16 and corresponding analyses of variance have been appended in Appendix XVIII.

Table 4.16 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on soil available potassium

Treatments	Available potassium (kg/ha)			
	1997-98*		1998-99	
	After gobhi sarson	After maize	After gobhi sarson	After maize
Control (NPK) EY	280.59	287.76	288.15	290.48
25 kg S ha^{-1} (ES) EY	278.36	288.07	284.61	287.94
25 kg S ha^{-1} (ES) AY	283.13	278.07	286.84	289.94
50 kg S ha^{-1} (ES) EY	280.90	280.00	279.92	290.01
50 kg S ha^{-1} (ES) AY	281.05	288.00	287.76	288.01
5 kg Zn ha^{-1} (ZnO) EY	282.67	290.00	287.69	296.94
5 kg Zn ha^{-1} (ZnO) AY	283.59	288.00	287.53	296.09
10 kg Zn ha^{-1} (ZnO) EY	277.98	287.00	284.69	292.01
10 kg Zn ha^{-1} (ZnO) AY	283.36	286.00	280.84	292.48
5 kg Zn ha^{-1} (Zn SO_4) EY	284.05	288.02	283.61	296.01
5 kg Zn ha^{-1} (Zn SO_4) AY	283.90	284.92	286.53	295.01
10 kg Zn ha^{-1} (Zn SO_4) EY	284.98	285.23	279.53	294.32
10 kg Zn ha^{-1} (Zn SO_4) AY	286.13	284.92	285.23	293.94
SEd	0.35	0.16	1.13	0.24
CD 5%	0.71	0.32	2.32	0.49
Initial	280.48			

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Data on available potassium after gobhi sarson harvest embodied in Table 4.16 show that EY application of sulphur (ES) at lower level (25 kg S ha^{-1}) resulted in significant decrease in soil available potassium whereas the higher level of sulphur as ES application had no effect on available potassium when compared to control. It was also seen from the same table that Zn application at lower level (5 kg Zn ha^{-1}) through ZnO to gobhi sarson significantly improved the soil available potassium compared to control. On the other hand, reverse trend was observed at higher level (10kg Zn ha^{-1}) of zinc application through ZnO where significant decrease in available potassium was observed compared to control. It may further be seen that when Zn application to gobhi sarson was supplemented with sulphur as $ZnSO_4$, it resulted in significant improvement in soil available potassium compared to control and both the level of zinc ($ZnSO_4$) application. However, increase in level of zinc ($ZnSO_4$) had not significant effect on available potassium. Data in Table 4.16 further reveal that increasing the levels of sulphur (ES) resulted in significant increase in the soil available potassium after the harvest of gobhi sarson as reverse trend was observed with increasing levels Zn as ZnO, where available potassium decreased significantly with increasing level of Zn. It indicates that observed effect was due to sulphur alone. A perusal of the data on soil available potassium after the harvest of gobhi sarson during 1998-99 (Table 4.16) reveal that AY application of graded levels of sulphur (ES) and EY and AY application of Zn as ZnO at lower level (5 kg Zn ha^{-1}as ZnO) to gobhi sarson did not affect the soil available potassium as compared to control. Rest of the treatments, whether applied EY or AY to gobhi sarson resulted in significant decrease in available potassium in soil compared to control. Data further reveal that AY application of 50 kg S ha^{-1} through elemental sulphur and 5 or 10 kg Zn ha^{-1} through $ZnSO_4$ to gobhi sarson resulted in significant improvement in soil available potassium compared to their EY application. On the contrary AY application of

10 kg Zn ha^{-1} as ZnO to gobhi sarson resulted in significant decrease in soil available potassium compared to its EY application. In rest of the treatments frequency of application did not show any effect on available potassium.

EY application of higher levels of sulphur as ES and zinc as $ZnSo_4$ to gobhi sarson significantly decreased available potassium in the soil after harvest of maize in 1997-98 as compared to control. Rest of the treatments did not reach the level of significance as compared to control. It was also seen that increase in (Table 4.16) level of sulphur as ES and Zn as ZnO as well as $ZnSo_4$ to gobhi sarson resulted in significant decrease in available potassium after the harvest of maize. It may further be seen that when zinc application to gobhi sarson was supplemented with sulphur as $ZnSO_4$ at both the levels, then it resulted in significant decrease in available potassium in soil after the harvest of maize. It indicates that observed decrease in available K after harvest of maize in response to $ZnSO_4$ treatment application at both the levels to gobhi sarson was due to the effect of sulphur alone. Data presented in Table 4.16 indicate that there was improvement in available soil potassium in the soil after the harvest maize during *kharif*, 1998-99 compared to *rabi* season 1998-99 after the harvest of gobhi sarson. Here also treatments were imposed in gobhi sarson during *rabi* season 1998-99 only. A close examination of data in the same table (Table 4.16) indicated that with the exception of EY application of 50 kg S ha^{-1} through elemental sulphur (ES), different levels of sulphur as elemental sulphur (ES) and zinc as ZnO and $ZnSO_4$ to gobhi sarson whether applied EY or AY significantly influenced the soil available potassium status of soil after the harvest of *Kharif* maize crop as compared to control. A close perusal of data indicated that AY application of sulphur through elemental sulphur (ES) to gobhi sarson significantly improved available potassium of the soil when applied at lower level but at higher level AY application reduced available potassium significantly in soil after maize harvest as compared to EY application of respective level. Also, it is clear from the table that alternate year application of zinc as ZnO to gobhi sarson at lower levels resulted in significant decrease whereas at higher level of application, it had no effect on available potassium when compared with EY application at respective level. Similar type of trend was also observed when zinc was applied through $ZnSO_4$. Here too, AY application to gobhi sarson at lower level significantly reduced available potassium in soil after maize harvest whereas at higher level, AY application had no effect on available potassium in the soil when compared with EY application at respective levels. However, when EY as well as AY zinc application at lower level to gobhi sarson was supplemented with sulphur as $ZnSO_4$, it resulted in significantly decrease in soil available potassium after the harvest of maize. On the contrary, reverse trend was observed when zinc at higher level was supplemented with sulphur as $ZnSO_4$, here supplementing EY or AY zinc application to gobhi sarson with sulphur resulted in significant improvement in soil available potassium after the harvest of succeeding maize crop. It is also evident from the table that increase in the level of sulphur as elemental sulphur (ES) significantly increased available potassium in soil when applied

EY. On the contrary, in case of AY application increase in level of sulphur (ES) significantly decreased available potassium after the harvest of maize. Similarly, increase in level of application of zinc as ZnO or $ZnSO_4$ given EY or AY to gobhi sarson significantly reduced available potassium in the soil after the harvest of succeeding maize crop, indicating thereby that observed decrease in available K after harvest of maize in response to $ZnSO_4$ treatments application at lower level to gobhi sarson and observed increased in available K after maize harvest in response to $ZnSO_4$ treatment application at higher level was due to the effect of sulphur alone.

4.3.6 Available sulphur

Data pertaining to available sulphur in the soil after the harvest of individual crop have been given in Table 4.17 and corresponding analyses of variance have been appended in Appendix XIX.

A close examination of data given in Table 4.17 show that EY application of sulphur (ES) and zinc through ZnO and $ZnSO_4$ to gobhi sarson influenced the available sulphur status of the soil significantly as compared to control after the harvest of gobhi sarson during 1997-98. All treatments resulted in significant increase in available sulphur after the harvest of gobhi sarson except the treatments involving application of 5 kg Zn ha^{-1} as ZnO (EY), which resulted in significant decrease in available sulphur as compared to control. It was also noticed that with increase in level of sulphur (ES) or zinc (ZnO or $ZnSO_4$) application to gobhi sarson, the available sulphur in the soil after the harvest of gobhi sarson, was improved significantly. It was further observed that when zinc application to gobhi sarson at respective level was supplemented with sulphur as $ZnSO_4$, then it resulted in significant increase in available sulphur after the harvest of gobhi sarson. It is clear, therefore that observed increase in available sulphur after harvest of gobhi sarson in response to $ZnSO_4$ treatment application at both the levels was due to sulphur alone.

Table 4.17 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on soil available sulphur

Treatments	Available sulphur (ppm)			
	1997-98*		1998-99	
	After gobhi sarson	After maize	After gobhi sarson	After maize
Control (NPK) EY	7.08	5.28	4.17	4.16
25 kg S ha^{-1} (ES) EY	11.50	10.51	12.70	10.55
25 kg S ha^{-1} (ES) AY	8.41	4.04	10.86	7.67
50 kg S ha^{-1} (ES) EY	16.45	15.45	20.92	16.54
50 kg S ha^{-1} (ES) AY	6.95	4.40	10.81	10.43
5 kg Zn ha^{-1} (ZnO) EY	6.95	4.78	3.42	3.35
5 kg Zn ha^{-1} (ZnO) AY	8.02	4.08	3.10	3.46
10 kg Zn ha^{-1} (ZnO) EY	7.75	4.03	3.14	3.43
10 kg Zn ha^{-1} (ZnO) AY	8.29	4.73	3.57	3.11
5 kg Zn ha^{-1} (Zn SO_4) EY	7.80	6.27	5.23	5.06
5 kg Zn ha^{-1} (Zn SO_4) AY	8.37	5.54	5.21	5.18
10 kg Zn ha^{-1} (Zn SO_4) EY	8.36	6.07	5.37	5.36
10 kg Zn ha^{-1} (Zn SO_4) AY	8.31	5.89	5.34	5.15
SEd	0.04	0.04	0.06	0.04
CD 5%	0.08	0.09	0.13	0.08
Initial	12.70			

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

Data on available sulphur after the harvest of gobhi sason during 1998-99 (Table 4.17) reveal that EY as well as AY application of different level of sulphur (ES) and zinc through $ZnSO_4$ resulted in significant improvement in soil available sulphur as compared to control. On the contrary, EY as well as AY application of different levels of zinc through ZnO resulted in significant decrease in available sulphur in the soil as compared to control. It may be seen from the same table that EY application of sulphur (ES) to gobhi sarson resulted in significant increase in available soil sulphur compared to AY application at respective levels of sulphur application. Similarly, EY application of zinc through ZnO to gobhi sarson at lower level (5 kg Zn ha^{-1}) resulted in significant increase in available sulphur compared to AY application at the same level. However reverse trend was seen with higher level (10kg Zn ha^{-1}) of zinc application through ZnO. It was further seen that frequency of application of zinc as $ZnSo_4$ at different levels had no effect on available sulphur in the soil after harvest of gobhi sarson.

It may further be seen that increasing the level of every year as well as AY application of sulphur (ES) and Zn through [illegible] $ZnSO_4$ to gobhi sarson resulted in significant improvement in soil available sulphur after the harvest of gobhi sarson. Also, increase in level of EY zinc application through ZnO significantly decreased the available sulphur in the soil. However, increase in level of AY zinc application through ZnO significantly improved available sulphur in the soil. When EY as well as AY zinc application was supplemented with sulphur as $ZnSO_4$, then significant improvement in soil available sulphur was observed after the harvest of gobhi sarson. It indicate that observed effect of EY or AY application of Zn as $ZnSO_4$ at both the levels to gobhi sarson on available sulphur after the harvest of the gobhi sarson was due to the effect of sulphur alone and not due to the effect of zinc.

It may further be seen from the same table that different levels of sulphur (ES) and zinc as $ZnSO_4$ applied EY to gobhi sarson resulted in significant improvement in soil available sulphur after succeeding maize harvest compared to control. But EY application of zinc through ZnO at both levels resulted in significant decrease in soil available sulphur after the harvest of succeeding maize during 1997-98. Data further reveal that increasing levels of sulphur (ES) application to gobhi sarson resulted in significant improvement in soil available sulphur. However, reverse trend was observed with increasing levels of zinc through ZnO as well as through $ZnSO_4$, where increase in level of zinc application to gobhi sarson resulted in significant decrease in available sulphur after the harvest of succeeding maize crop (1997-98). It may further be seen that when zinc application to gobhi sarson though decreased available sulphur after of succeeding maize but when zinc was supplemented with sulphur as $ZnSO_4$ then significant improvement in available sulphur status of the soil was observed after harvest of maize. Data for available sulphur after harvest of maize crop of 1998-99 presented in Table 4.17 indicate that EY as well as AY application of sulphur (ES) and zinc ($ZnSO_4$) at different levels to gobhi sarson resulted in significant increase in available sulphur in soil after the harvest of succeeding maize compared to control. However, EY as well as AY application of zinc through ZnO to gobhi sarson resulted in significant decrease in soil available sulphur after the harvest of *kharif* season maize during 1998-99 as compared to control. Data further indicate that EY application of sulphur through elemental sulphur (ES) at either levels resulted in significant improvement in soil available sulphur compared to AY application. Similarly EY application of zinc at higher level of zinc either through ZnO or $ZnSO_4$ to gobhi sarson resulted in significant improvement in soil available sulphur compared to AY application. Whereas reverse was true at lower level of zinc (5 kg Zn ha^{-1}) application to gobhi sarson through ZnO or $ZnSO_4$. Here, AY application proved significantly better than EY application. Increase in the levels of sulphur (ES) to gobhi sarson whether applied EY or AY resulted in significant increase in soil available sulphur after the harvest of succeeding maize. It may be further seen that increase in level of EY zinc application to gobhi sarson either through ZnO or $ZnSO_4$ resulted in significant improvement in soil available sulphur after the harvest of succeeding maize crop. However, trend was reversed in case of alternate year application, where increase in level of zinc as ZnO application to gobhi sarson resulted in significant fall in soil available sulphur after harvest of maize. Although zinc application to gobhi sarson significantly reduced available sulphur in soil after maize harvest compared to control but available sulphur status was significantly improved when zinc was supplemented with sulphur as $ZnSO_4$ at 5 or 10 kg Zn ha^{-1} whether applied EY or AY. This indicates that observed effect of $ZnSO_4$ treatment on available sulphur after the harvest of maize was due to sulphur alone.

4.3.7 Available zinc

Data pertaining to available zinc after the harvest of each crop have been given in Table 4.18 and corresponding analyses of variance have been appended in Appendix XX.

A close examination of data on soil available zinc after the harvest of gobhi sarson 1997-98 presented in Table 4.18 indicate that EY application of sulphur through elemental sulphur (ES) at either levels to gobhi sarson did not affect soil available zinc compared to control. However, EY application of Zn at different levels either Zn through ZnO or through $ZnSO_4$ resulted in significant improvement in soil available zinc as compared to control. Further insight in data indicates that increase in levels of sulphur (ES) had no significant influence on soil available zinc after the harvest of gobhi sarson. Whereas increase in levels of Zn either through ZnO or through $ZnSO_4$ resulted in significant increase in available zinc.

Although EY zinc application at both the levels to gobhi sarson significantly improved soil available zinc as compared to control but when it was supplemented with sulphur as $ZnSO_4$ at 5 or 10 kg Zn ha^{-1}, then a significant decrease in available zinc was observed. Thus, it is evident that decrease in available zinc due to $ZnSO_4$ application was because of sulphur alone.

Table 4.18 Effect of different levels and frequencies of application of sulphur (ES) and zinc (ZnO and $ZnSO_4$) on soil available zinc

Treatments	Available zinc (ppm)			
	1997-98*		1998-99	
	After gobhi sarson	After maize	After gobhi sarson	After maize
Control (NPK) EY	0.58	0.56	0.45	0.57
25 kg S ha^{-1} (ES) EY	0.57	0.57	0.45	0.56
25 kg S ha^{-1} (ES) AY	0.57	0.58	0.46	0.55
50 kg S ha^{-1} (ES) EY	0.55	0.58	0.46	0.56
50 kg S ha^{-1} (ES) AY	0.58	0.58	0.47	0.57
5 kg Zn ha^{-1} (ZnO) EY	1.06	0.96	1.89	1.52
5 kg Zn ha^{-1} (ZnO) AY	0.58	0.58	0.98	0.92
10 kg Zn ha^{-1} (ZnO) EY	1.97	1.88	2.72	2.25
10 kg Zn ha^{-1} (ZnO) AY	0.59	0.58	1.80	1.60
5 kg Zn ha^{-1} (Zn SO_4) EY	0.87	0.68	0.88	0.82
5 kg Zn ha^{-1} (Zn SO_4) AY	0.58	0.58	0.75	0.84
10 kg Zn ha^{-1} (Zn SO_4) EY	0.87	0.75	0.90	0.85
10 kg Zn ha^{-1} (Zn SO_4) AY	0.57	0.56	0.92	0.67
SEd	0.02	0.02	0.69	0.03
CD 5%	0.04	0.04	1.42	0.07
Initial	0.62			

ES – Elemental sulphur; EY – Every year; AY – Alternate year
ZnO – Zinc Oxide; $ZnSO_4$ – Zinc sulphate
* Alternate year treatments skipped

All the levels of sulphur applied through elemental sulphur (ES) and zinc as $ZnSO_4$ whether applied EY or AY to gobhi sarson during 1998-99 remained statistically at par with control in respect of available Zn in soil. However, EY as well as AY application of zinc through ZnO at both the levels to gobhi sarson resulted in significant increase in soil available zinc after the harvest of gobhi sarson during 1998-99. A close perusal of data in same table shows that every year application of zinc through ZnO to gobhi sarson increased the available zinc status of soil after the harvest of gobhi sarson as compared to AY application of respective levels. Frequency of application of sulphur as elemental sulphur (ES) and zinc as $ZnSO_4$ at either level had no effect on the available zinc after the harvest of gobhi sarson. Increase in the level of sulphur (ES) and zinc as $ZnSO_4$ whether applied EY or AY had no significant effect on available zinc after the harvest of gobhi sarson. However, when zinc was applied as ZnO then significant increase in available zinc was observed with increase in level of EY or AY application. Though EY or AY zinc application at both the levels to gobhi sarson significantly improved the available status of Zn as compared to control but when it was supplemented with sulphur as $ZnSO_4$ at 5 or 10kg Zn ha^{-1} a decrease in available Zn was observed, however, the decrease was not significant in case of alternate year application of lower level. Thus, it is evident that decrease in available Zn with application of $ZnSO_4$ is due to sulphur alone.

A close examination of data on soil available zinc after the harvest of maize presented in table (Table 4.18) reveal that all the levels of EY sulphur application to gobhi sarson through elemental sulphur (ES) remained statistically at par with control in respect of available Zn status after succeeding maize crop of 1997-98. However, level of EY Zn application either through ZnO or through $ZnSO_4$ resulted in significant improvement in available Zn status of soil after harvest of succeeding maize crop. Data further show that increase in level of Zn either through ZnO or through $ZnSO_4$ to gobhi sarson resulted in significant increase in available zinc status of soil after the harvest of succeeding maize. However, increase in level of sulphur (ES) did not have significant effect on available zinc after maize during 1997-98.

Though, EY zinc as ZnO application at both the levels to gobhi sarson significantly improved the available status of zinc after the harvest of maize as compared to control but when it was supplemented with sulphur as $ZnSO_4$ then a significant decrease was observed as compared to Zn as ZnO. Thus, it is evident that decrease in available zinc was due to sulphur alone and not due to zinc. Further examination of data on available zinc after harvest of maize crop of 1998-99 presented in Table 4.18 indicate that different levels of sulphur as elemental sulphur (ES) whether applied EY or AY to gobhi sarson had no significant effect on available zinc after maize harvest as compared to control. However, different level of Zn either as ZnO or $ZnSO_4$ whether applied EY or AY significantly improved the Zn status of the soil as compared to control. Further insight into this data reveal that AY application of Zn as ZnO or $ZnSO_4$ to gobhi sarson significantly decreased the available Zn in soil after harvest of succeeding maize compared to EY application at respective levels However, frequency of sulphur application to gobhi sarson had no significant effect on available zinc after the harvest of succeeding maize. The data embodied in Table 4.18 further indicate that increase in level of elemental sulphur (ES) whether applied EY or AY to gobhi sarson did not effect available zinc status after the harvest of succeeding maize crop. As expected, increase in level of zinc as ZnO as well as $ZnSO_4$ whether applied EY or AY to gobhi sarson improved significantly the soil available zinc after harvest of succeeding maize crop. Though the EY or AY application of zinc at both levels to gobhi sarson significantly improved available zinc status after harvest of maize but when zinc was supplemented with sulphur as $ZnSO_4$ at 5 kg or 10 kg ha^{-1} level than a significant drop in available zinc in soil was observed after the harvest of succeeding maize. It clearly indicate that fall in available zinc after the harvest of maize in response to EY and AY application of Zn as $ZnSO_4$ at both the levels was due to sulphur alone and not due to zinc.

Chapter-5

DISCUSSION

The results obtained from present investigation entitled **"Studies on the effect of sulphur nutrition on gobhi sarson (*Brassica napus* var. *oleracea*) in maize-gobhi sarson crop sequence under rainfed conditions"** conducted during *rabi* 1997-98 to *rabi* 1998-99 at Research Farm of Department of Agronomy, CSK HPKV, Palampur to assess the effect of different levels and frequencies of sulphur application through elemental sulphur and zinc as $ZnSO_4$ on yield and yield attributes of gobhi sarson in maize-gobhi sarson cropping sequence under rainfed conditions have been presented in preceding chapter. Additional treatment of zinc as ZnO at varying levels and frequencies of zinc application was also imposed to gobhi sarson to isolate the effect of $ZnSO_4$ treatment, to see whether the response with Zn as $ZnSO_4$ treatment is due to sulphur alone or due to combined effect of sulphur and zinc. The residual effect of these treatments on succeeding maize crop was also assessed. In this chapter, important findings have been discussed and an attempt has been made to establish cause and effect relationship on scientific basis and forward possible explanations based on available evidences, wherever applicable.

5.1 WEATHER IN RELATION TO CROP PERFORMANCE

Agroclimatically, the experimental site, represents the mid hill sub-humid temperate zone. A cursory glance of mean weekly meteorological data during the experimentation period in Fig. 3.1 & 3.2 and Appendix I & II indicates that *rabi* season of 1998-99 was comparatively dry as the rainfall recorded was only 96.5 mm as against 486.2 mm during *rabi* 1997-98. Consequently mean weekly maximum temperature was lower (13.1 °C to 29.8 °C) in first year than second year (14.5 °C to 34.0 °C). Likewise, minimum temperature was also lower during *rabi* 1997-98 (3.6 °C to 18.8 °C) compared to *rabi* 1998-99 (3.8 °C to 21.3 °C). Mean temperature during growth period of gobhi sarson crop ranged between 9.60 °C to 20.93 °C during 1997-98. Thus temperature limit was by and large favourable for production of gobhi sarson and other *Brassica* spp. as reported by Maiti *et al.* (1989). During 1998-99, though the initial temperature, as well as soil moisture was sufficiently enough for germination and growth but in the latter stages i.e. reproductive stages of gobhi sarson (126 DAS) crop suffered due to moisture stress as there was almost negligible rainfall (Appendix II). Here, only a life saving light irrigation was given during the flower initiation stage, even then yield levels were much lower during 1998-99. Total rainfall during *kharif* season of 1998 and 1999 was 1702 and 2012.1 mm with weekly mean maximum temperature range of 22.0 °C to 35.5 °C and 23.0 °C to 30.1 °C while, weekly mean minimum temperature ranged from 13.6 °C to 23.1 °C and 13.6 °C to 20.6 °C during *kharif* 1998 and 1999, respectively. These temperature limits were by and large favourable for maize production.

5.2 GOBHI SARSON

5.2.1 Growth contributing characters

In general, crop plants were taller during 1997-98 as compared to 1998-99 (Table 4.1). The limited moisture supply during early vegetative phase might have resulted in poor root growth and development leading to less nutrients absorption from native reserve of soil. Hence, there was lower shoot length during latter year (1998-99). However, primary branches were the maximum during 1998-99 but secondary branches were more or less same during both years. This might be attributed to the fact that at the latter vegetative phase roots might have extracted the applied nutrients due to less moisture stress, which ultimately improved the branching. It was observed that sulphur (elemental sulphur) (Table 4.1) significantly improved the plant height during both years. However, levels as well as frequencies of application of sulphur had no effect on plant height during both the years. It was also observed that Zn as ZnO at 10 kg Zn ha^{-1} significantly increased plant height over control but it was at par with $ZnSO_4$ treatment at same rate. This indicates that plant height was influenced due to sulphur and zinc at 10 kg Zn ha^{-1} as $ZnSO_4$ given every year to gobhi sarson. Likewise, application of ZnO @ 5 kg ha^{-1} did not give significant difference as compared to control and also remained at par with $ZnSO_4$ treatment at same level, when applied every year. This indicates that plant height increased due to combined effect of sulphur and Zn in $ZnSO_4$ treatment at its lower level (5 kg Zn ha^{-1}). However, during 1998-99, 10 kg Zn ha^{-1} as ZnO remained at par with control when applied every year and alternate year whereas $ZnSO_4$ treatment at same level produced significantly taller plants whether applied every year as well as alternate year as compared to control. However, it did not differ significantly as compared to Zn as ZnO. This indicates that increase in plant height was due to sulphur and zinc supplied through $ZnSO_4$ at 10 kg Zn ha^{-1} level. Frequencies of application of different treatments had no significant effect on plant height.

Every year application of sulphur (elemental sulphur) and zinc (ZnO) at all levels significantly influenced the primary branches per plant whereas zinc as $ZnSO_4$, had no effect, indicating that both zinc and sulphur improved branching only when they were supplied independently of each other. On the other hand combined application of S and Zn as $ZnSO_4$ proved counterproductive on influencing branching, when applied every year to gobhi sarson during 1997-98. This might be due to the reason that zinc might have slight antagonistic effect with sulphur leading to imbalance ratio of nutrient concentrations in the plant system. This might have adversely affected the plant metabolism leading to lower number of branches. In subsequent year, none of the treatments could influence the number of primary branches per plant. This might be due to the limited moisture supply, which forced the plant to complete life cycle as early as possible. During 1997-98, EY application of different treatments had not significant effect on secondary branches. This might be attributed to the fact that plant might have fulfilled their sulphur nutrient requirement from the native reserve of the soil. However, in the subsequent year application of sulphur (elemental sulphur) at all levels and frequencies of application significantly increased the secondary branches (Table 4.1). Also, zinc as ZnO (5 and 10 kg Zn ha^{-1}) produced significantly more number of secondary branches over control but it was significantly lower than $ZnSO_4$ treatment at same rate of application whether applied every year as well as alternate year. It reveals that increase in number of secondary branches through application of Zn as $ZnSO_4$ treatment was due to sulphur and not due to zinc. It was also observed that 5 kg Zn as

$ZnSO_4$ produced significantly more number of secondary branches compared to 25 and 50 kg S ha^{-1} (elemental sulphur) at all frequencies of application. This might be attributed to the fact that at lower level, zinc might have improved the effect of sulphur on influencing branching. Also, every year application of $ZnSO_4$ proved better as compared to its alternate year application in gobhi sarson during 1998-99. These observations are in conformity with the results obtained by Khanpara *et al.* (1993) who also reported that levels of sulphur (elemental sulphur) though significantly increased the growth characters, however, sulphur application did not attain the level of significance for all growth characters. Similarly, Saran and Giri (1990) also reported that sulphur and Zn as $ZnSO_4$ increased seed and straw yield but at the same time, reported non-significant variation in plant height and number of branches per plant. While, Dixit and Shukla (1984) reported increase in primary and secondary branches by sulphur and zinc application in mustard crop.

5.2.2 Yield contributing characters

As expected, neither different levels of sulphur application sulphur (elemental sulphur) and zinc as ZnO and $ZnSO_4$ nor their frequencies of application had significant effect on number of plants per metre row length and 1000-seed weight during both the years (Table 4.2). Similarly, siliquae per plant and seeds per siliqua were not influenced significantly due to different treatments effects when applied every year to gobhi sarson during 1997-98. This might be attributed to the reason that plant might have fullfilled their requirement of sulphur and zinc from native reserve of the soil and no response to applied nutrients (sulphur and zinc) was observed during 1997-98. In the subsequent year (1998-99), sulphur as elemental sulphur (ES) significantly improved the number of siliqua at both levels. Also, Zn as $ZnSO_4$ when applied every year as well alternate year at 5 and 10 kg Zn ha^{-1} resulted in significantly more number of siliqua when compared to zinc as ZnO at their respective levels. This indicates that significant increase in number of siliqua per plant with application of Zn as $ZnSO_4$ treatment was due to the effect of sulphur alone. It was also seen that number of siliqua per plant with application of zinc as $ZnSO_4$ at any level was statistically similar to number obtained with sulphur as elemental sulphur at any level of application. This again clearly indicates that sulphur nutrition significantly improved the number of siliqua per plant. This might be due to the reason that zinc through $ZnSO_4$ might have improved the effect of sulphur resulting in increased number of siliqua per plant, on the other hand zinc alone as ZnO might have moderate antagonistic effect with soil available phosphorus. This might be due to the imbalanced ratio of nutrients in the plant system which ultimately adversely affected the plant metabolism. Thus, lower number of siliqua per plant. were observed. It was observed that an increase in number of seeds per siliqua (Table 4.2) was observed with increase in level of sulphur (elemental sulphur) whether applied every year as well as alternate year, however, this increase was significant with alternate year application of sulphur (elemental sulphur). Zinc through ZnO whether applied every year or alternate year to gobhi sarson also increased number of seeds per siliqua over control. Zinc application further increased this character significantly when it was supplemented with sulphur as

$ZnSO_4$ at 5 and 10 kg zinc ha^{-1} as compared to Zn as ZnO. It clearly shows that more number of seeds per siliqua obtained with application of Zn as $ZnSO_4$ were due to effect of sulphur. Every year application at lower level of zinc as $ZnSO_4$ resulted in significantly more number of seeds compared to alternate year application. Further zinc as $ZnSO_4$ at 5 kg Zn ha^{-1} when applied every year produced significantly more number of seeds per siliqua than its higher level (10 kg Zn ha^{-1}) given in alternate year. It indicate that frequent application of lower level of zinc as $ZnSO_4$ applied every year is more beneficial than alternate year application either at same level or at higher level. It is evident from the same table that most of the yield attributes were better during 1998-99 compared to 1997-98. This improvement in yield attributes might be because of the light live saving irrigation (1998-99) given to gobhi sarson somewhere during flowering stage which resulted in more uptake of applied nutrients due better moisture supply. Likewise, limited rainfall and bright sunshine hours (Appendix II) during reproductive phase of crop might have improved some of the yield attributes, resulting in better yield of crop. Similar observations in gobhi sarson were also observed by Thakur and Chand (1998). Similarly, Chatterjee *et al.* (1985) and Mohan and Sharma (1992) also reported that sulphur (elemental sulphur) and zinc as $ZnSO_4$ significantly influenced the yield attributes in mustard crop. The improvement in some of growth and yield contributing characters due to sulphur and zinc might be due to fact that there might have better photosynthetic activity and better root growth, nutrient uptake and better nitrogen metabolism due to sulphur and zinc. Sulphur also enhances cell division, multiplication elongation and expansions, imparts deep colour to leaves due to better chlorophyll synthesis, which ultimately improves photosynthesis activity. Improvement in some of yield attributes due to S may also be attributed to the fact that with increased supply of N and S, the process of tissue differentiation from somatic to reproductive, merismatic activity and development of floral primordia might have increased resulting in more number of flowers, siliqua and seeds per plant. Also, zinc application help in protein synthesis, many enzymatic activity in plant nitrogen metabolism and chlorophyll formation for enhanced photosynthesis activities due to better root growth and nutrient absorption and more leaf expansion. This may have improved the growth and yield contributing characters (Mohan and Sharma, 1992). .

5.2.3 Yield

Better growth of crop in very beginning due to the effect of applied nutrients and their interaction effects provide a larger frame in terms of plant height and branches on which more flowers and eventually more siliqua can develop (Holmes, 1980). Also, yield is a function of growth and yield contributing characters, which are ultimately reflected in yield level of the crop. It was observed that during 1997-98 (Table 4.3) application of sulphur (elemental sulphur) and zinc through ZnO and $ZnSO_4$ when applied every year to gobhi sarson did not influence the grain yield of it significantly. Since most of the growth and all the yield contributing characters were not influenced significantly due to every year application of different treatments. Therefore, different treatments could not effect grain yield of gobhi sarson. This might be due to the reason that gobhi sarson plants might have taken the nutrients from the native source of soil. Hence, no response was observed to the applied nutrients during 1997-98. Immediate effect of secondary and micronutrients may not be observed since more than 60 per cent of micronutrients get fixed in the high content of organic matter present in heavy texture type of soils in mid-hill sub-humid temperate climate. Also due to low temperature oxidation process is very slow which is further depressed if high rainfall is there which reduces the microbial activity. Therefore, due to very slowly release of secondary and micronutrients during winter, may not be available to plants, therefore, no response was observed to the applied nutrients during 1997-98.

Only EY application of zinc as ZnO at lower level resulted in significantly lower straw yield compared to control, while rest of the treatments remained at par with control. This might be due to the fact that very less Zn from ZnO is available to plant at its lower rate (5 kg Zn ha^{-1}) due to its less solubility and mobility in soil complex. Its availability is further depressed due to high level of available phosphorus in the soil. This might have caused Zn deficiency in plants system and adversely affected the plant metabolism resulting in lower straw yield. Nil or negative response to zinc alone or marginal response to zinc at higher levels was also reported by Rattan *et al.* (1997) whereas Ankineedu *et al.* (1983) reported that excessive moisture or limited moisture during growth and development period caused poor response to applied nutrients. Similar type of observations were also reported from Jabalpur, (M.P.) where every year application of sulphur and zinc as ZnO and $ZnSO_4$ did not have any significant effect on grain and straw yield of soybean in soybean-wheat rotation (Anonymous, 1994-95a). However, in the subsequent year (1998-99), different treatments significantly influenced the grain yield of gobhi sarson. Most of the growth and yield contributing characters were influenced significantly due to different treatments. Therefore, yield was also affected significantly by every year as well as alternate year application of these treatments at varying levels. Further every year application of sulphur (ES) at higher level (50 kg S ha^{-1}) resulted in significantly higher grain yield compared to its lower level applied in alternate year during 1998-99 (Table 4.3). Similarly, increase in levels of sulphur increased the yield significantly at higher level of sulphur application as elemental sulphur. It was also seen that alternate year application of 5 kg Zn ha^{-1} and every year as well as alternate year application of 10 kg Zn ha^{-1} (ZnO) to gobhi sarson resulted in significantly higher grain yield compared to control but was significantly lower when supplemented with sulphur as $ZnSO_4$ at 5 or 10 kg Zn ha^{-1} applied every year or alternate year. It indicates that increase in grain yield was due to sulphur and not due to zinc in $ZnSO_4$ treatments. It was also observed that (Table 4.3) Every year application of higher level of Zn as $ZnSO_4$ remained at par with its alternate year application at the higher level (10 kg Zn ha^{-1}). However, 10 kg Zn ha^{-1} as $ZnSO_4$ given in alternate year remained at par with lower level of Zn (5 kg Zn ha^{-1}) as $ZnSO_4$ at all frequencies and higher level of sulphur (50 kg S ha^{-1}) as elemental sulphur. Likewise, higher level of sulphur (50 kg ha^{-1}) applied every year remained at par alternate year but resulted in significantly higher grain yield over lower level of sulphur (25 kg S ha^{-1}) whether applied every year as well as alternate year. The increase in grain yield may be due to the fact that sulphur help in photosynthetic activity, protein synthesis, oil synthesis and better utilization of nitrogen and nitrogen metabolism which ultimately increased the yield of gobhi sarson. Also higher rate of elemental sulphur is required because microbial oxidation process is slow during winter and very lower amount of sulphur is available at lower rate. So high rate might have released more amount of SO_4 ion, which might have slight positive interaction with available P in soil. This may have resulted in better root and shoot development causing increased uptake of nutrients. This, in turn, increased the total biomass of the plants resulting in higher grain yield. Straw was not affected significantly due to sulphur and zinc during 1997-98. However, straw yield data given in Table 4.3 indicates that there was significant increase in straw yield of gobhi sarson with EY application of sulphur at the rate of 50 kg S ha^{-1} (elemental sulphur). It was also observed that yield was significantly lower when zinc was supplemented with sulphur as $ZnSO_4$ at both levels applied in AY and increased with EY application. However, difference was significant only at 10 kg Zn ha^{-1} level applied EY through $ZnSO_4$, indicating thereby that increase in straw yield was due to sulphur alone at higher rate of Zn as $ZnSO_4$ given every year during 1998-99. Increase in straw yield due to sulphur is very clear that it resulted in higher total biological yield and ultimately there was increase in straw yield due to more photosynthetic activity. Straw yield almost followed the grain yield trend in gobhi sarson during 1998-99. Frequent application of 50 kg S ha^{-1} (elemental sulphur) also increased straw yield significantly. On the other hand at higher level of $ZnSO_4$, zinc might have improved the effect of sulphur resulting in increased total dry matter production and ultimately straw yield of gobhi sarson during 1998-99. plant population per unit area was more, hence more straw yield. Sulphur as elemental sulphur is not readily available to plants. There is time lag between the time of application and oxidation of sulphur to its available form. Hence, plants might not received sufficient sulphur when its demand was high, especially in early vegetative phase. Therefore, higher rate might have fulfilled the requirements. Also, sulphur is responsible for chlorophyll synthesis, which helped in better photosynthesis process, resulting in more dry matter production. Zinc also helped in the protein and chlorophyll formations and zinc is needed for various metabolic process, which results in high dry matter production. Similar observations were also made by Singh *et al.* (1998) where seed and straw yield of mustard increased significantly due to $ZnSO_4$.

These results are also in conformity with the results obtained by Mohan and Sharma (1992) who also reported significant increase in seed yield owing to S application upto 50 kg S ha^{-1}. Similar observations were also made from Sehore, Sub. Centre (M.P.) where every year as well as alternate year application at 50 kg S ha^{-1} as pure sulphur and 10 kg Zn ha^{-1} as $ZnSO_4$ increased significantly the yield of soybean in soybean-wheat rotation (Anonymous, 1994-95a).

5.2.4 Nutrient uptake

Total uptake of nitrogen, phosphorus potassium and sulphur in gobhi sarson (seed + straw) was not affected significantly by varying levels of sulphur through elemental sulphur and zinc as ZnO and $ZnSO_4$ (Table 4.4) during 1997-

98. Since yield levels were also not affected significantly due to these treatments. Therefore, uptake remained unaffected due to sulphur and zinc when applied every year to gobhi sarson during 1997-98. It may be seen from the Table 4.4 that uptake pattern did not follow the yield pattern which was mainly due to variation in the actual per cent concentrations of the nutrients in seed and straw of gobhi sarson (Data not reported). This may attributed to the fact that interaction among the nutrients in the plant system as well as in the soil system might have of greater importance including total nutrient uptake and balanced ratio of nutrient concentration in plant system which may not affect plant metabolism adversely. The another major reason was continuous rains coupled with more number of rainy days and lower number of bright sun-shine hours during whole of the growth period (Appendix I) which might have effected the total nutrient uptake in gobhi sarson grain and straw due to poor physical conditions of the soil. Similar observations were also reported by Ankineedu *et al.* (1983), who reported that limited or high moisture supply is responsible for poor response of nutrients as well as their uptake. Also in heavy textured soils, rich in organic matter, applied micro and secondary nutrients get fixed in these soils in organic form during winter and available to plant in the subsequent years and no immediate effect can be observed.

Therefore, crop might have taken or fulfilled their requirement from native reserve of soil which resulted in lower yield level, though with inconsistent pattern of total nutrient uptake during 1997-98. Thus, overall, presence of medium to high organic matter in heavy textured type of soils, prevailing cool temperature in winter and erratic rainfall pattern at experimental site were responsible for non-significant uptake of N, P, K, and S in the start of experiment (1997-98) without affecting the yield level during 1997-98.

These results are in agreement with those reported by Patel *et al.* (1994) who also observed that nitrogen, phosphorus, potassium and sulphur uptake was not significant due to sulphur (SSP, 12% S) when given to groundnut. Similar type of observations were also reported from Jhabua (M.P.) that varying levels of sulphur and zinc as ZnO and $ZnSO_4$ resulted in nominal increase in uptake of sulphur and zinc along with other macro-nutrients when sulphur, ZnO and $ZnSO_4$ treatments were given every year to soybean in soybean-wheat rotation (Anonymous, 1994-95a). During subsequent year (1998-99) sulphur as elemental sulphur and zinc as $ZnSO_4$ at all levels and frequencies of application resulted in significantly increased in nitrogen uptake due to sulphur. This might be due to the reason that sulphur might have synergistic effect with available nitrogen status of soil resulting in increased nitrogen uptake, since both are linked with photosynthesis and protein formation.

It was further seen that zinc application as ZnO though increased the nitrogen uptake significantly compared to control but was significantly lower where every year application of zinc was supplemented by sulphur as $ZnSO_4$ at 5 or 10 kg Zn ha^{-1}, indicating thereby that increase in nitrogen uptake was due to sulphur in these treatments. This might be due to fact that there might have synergistic interaction of sulphur with nitrogen, which resulted in increased uptake of nitrogen since both are linked with proteins synthesis and photosynthesis. Also uptake trend follow the yield trend. Also, if there is more sulphur absorptions, therefore more nitrogen is also needed for protein synthesis. Similarly sulphate from $ZnSO_4$ is readily soluble in soil after dissociation into Zn^{++} and SO_4^{-} ion and both these ions do not compete for each other in absorption process. This ultimately might have resulted in more absorption of SO_4^{-} ion. In the subsequent (1998-99), it was observed from Table 4.4 that sulphur (ES) significantly increased the uptake of phosphorus, however, levels and frequencies did not differ significantly. Also zinc as ZnO increased P uptake significantly over control but significantly lower than every year treatments of zinc with sulphur as $ZnSO_4$ at both levels i.e. 5 and 10 kg Zn ha^{-1}. It was further seen that alternate year application of zinc as $ZnSO_4$ at higher level resulted in significant increase in P uptake compared to Zn as ZnO. It indicates that either through frequent application of $ZnSO_4$ at a lower level or through alternate year application of it at higher rate, the increase in P uptake was due to sulphur. It might be due to the fact that with frequent application of $ZnSO_4$ to gobhi sarson, zinc might have improved the effect of sulphur on total uptake of P. On the other hand when it was applied in alternate year, it is required at high rate just to keep in nutrient concentration in soil in balanced ratio so that absorption is not affected. It is also obvious that when there is more growth and development of gobhi sarson due to increased uptake of nitrogen, it also creates demands for other nutrients and so increased uptake of phosphorus might have there, since it is also required for various metablic functions and is a source of energy.

It was further seen that during 1998-99 significantly more uptake of total K was observed at higher level of application of sulphur @ 50 kg S ha^{-1} (elemental sulphur) and 10 kg Zn ha^{-1} ($ZnSO_4$) when applied every year as compared to alternate year application, indicate that only at 10 kg Zn ha^{-1} as $ZnSO_4$ level, increase was due to sulphur alone which increased K uptake due to synergistic effect of sulphur with potassium but at 5 kg Zn ha^{-1} as $ZnSO_4$, uptake was influenced both by sulphur and zinc. Therefore, more dry matter production results in higher K uptake. Every year treatments of both levels of sulphur as elemental sulphur and zinc as $ZnSO_4$ resulted in increased uptake of sulphur compared to alternate year application of these treatments, though the difference in alternate year was not significant but significantly better than control during 1998-99. Data further showed that when zinc was supplemented with sulphur as $ZnSO_4$, it resulted in significantly higher sulphur uptake compared to zinc as ZnO when applied every year or alternate year at their respective levels indicating thereby that increase in sulphur uptake was due to sulphur and not due to zinc in these treatments. Decreased uptake of sulphur due to Zn as ZnO may be due to the fact that ZnO is sparingly soluble and immobile in soil solution and whatever zinc is available from ZnO might have further depressed due to high available P status in soil. Therefore, lower concentrations of zinc in the plant system might have caused imbalance of nutrients in the plant systems leading to lower yield and consequently, lower uptake of sulphur might have occurred in this treatment. On the other hand, sulphur as elemental sulphur and through $ZnSO_4$ might have helped in chlorophyll formation and therefore increased photosynthetic activity and protein synthesis resulting in more dry matter production. This, in turn, increased the total S uptake. It was also seen from the same table that all the treatments applied every year resulted in significantly higher Zn uptake during both years except application of Zn as $ZnSO_4$ at 10 kg Zn ha^{-1} which remained at par with control, but significantly lower over rest of the treatments given every year. Every year application of zinc as ZnO resulted in significant increase in zinc uptake compared to zinc accompanied by sulphur as $ZnSO_4$ at 10 kg ha^{-1} level. It may be due to the fact that at higher level Zn as ZnO might have also mobilized the organically bound zinc in the soil and may have acted synergistically with soil available level of phosphorus and resulted in higher zinc uptake, whereas in $ZnSO_4$ treatment, sulphur may have some antagonistic effect with Zn resulting to lower uptake of Zn.

In the subsequent year 1998-99, all the treatments resulted in significant increase in zinc uptake compared to control, whether applied every year or alternate year. As expected every year Zn application as ZnO increased Zn uptake significantly over control, however, when zinc was supplied as $ZnSO_4$ at the rate of 5 or 10 kg ha^{-1}, respectively decrease in zinc uptake was observed but was not significant compared to ZnO application. This shows that increase in zinc uptake was mainly due to Zn and sulphur had no effect. Similar trend was also observed during alternate year treatments.

Increased uptake of these nutrients might be due to fact that N and S are closely related to each other for formation of chlorophyll and protein synthesis in plants. So increasing rate of sulphur as elemental sulphur or through $ZnSO_4$ might have increased photosynthetic activity leading to vigorous growth, which ultimately increased the total uptake of nitrogen. This in turn further influenced the uptake of phosphorus, potassium and zinc in balanced proportions due to cumulative effect of increased seed and straw yield. Zinc also help in chlorophyll formation and protein synthesis and activator of many enzymes in plants system. This might have increased the total biomass which resulted in higher uptake of other nutrients. These results on total uptake of nutrients are in conformity with the results obtained by many workers who observed that N, K, S and Zn uptake increased with increase in levels of S in sunflower (Sreemannaryana *et al.*, 1994) N, P and S in mustard (Shakhela and Vyas, 1995). N, P, K, S in mustard (Tomar *et al.*, 1997, Sharma and Bansal, 1998). Similar type of observations were also reported from Jabalpur where sulphur and zinc improve the uptake of sulphur and zinc along with N, P, K in soybean when sulphur and zinc (ZnO and $ZnSO_4$) were given every year as well as alternate year in soybean wheat-rotation (Anonymous, 1994-95a). However, total zinc and sulphur uptake was significantly more where ZnO and $ZnSO_4$ or any sulphur or zinc source was applied. Similar type of observations were also made by Rattan *et al.,* (1997) who also reported that where zinc source is applied, uptake of Zn was also more and Singh and Saran (1986) also reported that sulphur uptake is more where sulphur source is applied to the crop.

5.3 MAIZE

5.3.1 Yield

Maize grain and stover yield data (Table 4.5) reveals that the maize grain yield was not influenced significantly by the application of sulphur (ES) and Zn (ZnO and $ZnSO_4$) every year [illegible] at any level applied to previous crop of gobhi season during 1997 –1998. This indicates that there was no residual effect on grain yield of maize due to residual sulphur during *kharif* 1997-98. Similarly, stover yield also remained unaffected due to the residual effect of the treatments at all levels when applied every year to gobhi sarson. This may be due to fact that maize crop might have fulfilled its requirement of sulphur from native reserve of soil, which was already rich in sulphur. Hence no response was observed due to residual sulphur application during 1998. These results are in conformity with those reported from Jabalpur that when sulphur (elemental sulphur) and Zn (ZnO and $ZnSO_4$) applied every year to soybean no residual effect was observed on succeeding wheat crop (Anonymous, 1991-92a). Similar results were also reported by Mankotia and Sharma (1998) who observed that sulphur application through SSP (12% S) to gobhi sarson did not show any residual effect on succeeding maize crop. However, during *Kharif* 1999, significantly higher grain yield of maize was obtained with residual sulphur through 50 kg S ha^{-1} (elemental sulphur) and remained at par with 25 kg ha^{-1} level of sulphur as elemental sulphur (ES) applied every year as well as alternate year to gobhi sarson. This might be due to reason that there might have enhancement of SO_4 contents of soil due to residual sulphur, which showed significant residual effect on maize grain. Further, Zn as $ZnSO_4$ applied every year at 10 kg Zn ha^{-1} and in alternate year at 5 and 10 kg Zn ha^{-1} levels gave significantly higher yield as compared to Zn as ZnO. This clearly indicates that increase in maize grain yield is due to the combined effect of residual sulphur and zinc. This may be attributed to the fact that there might have increased contents of SO_4 contents of soil and more availability of zinc due to acidifying effect of sulphur. These available SO_4 and zinc contents do not compete for absorptions due to their anionic and cationic nature but they act synergistically, which showed a significant residual effect on maize grain. No residual effect on stover yield of maize was observed due to different treatment effect during 1998.

In the subsequent year both the levels of sulphur as elemental sulphur significantly increased the stover yield over control. This indicates that observed effect on stover yield was due to residual sulphur alone at low and high level of sulphur (elemental sulphur). Zn as ZnO at both the levels significantly increased the stover yield over control. But when it was supplemented with sulphur as $ZnSO_4$, there was decrease in stover yield compared to Zn as ZnO at all the levels. However, only 10 kg Zn ha^{-1} as $ZnSO_4$ could increase the stover yield. It indicate that application of every year zinc at 10 kg Zn ha^{-1} level as $ZnSO_4$, observed effect on stover yield of maize was due to combined effect of residual sulphur and zinc.

The residual effect due to zinc might be attributed to the fact that inorganic Zn get fixed either on clay complex or humus complex and immobilized Zn due to high organic matter and further get desorbed after lapse of time and available to succeeding maize crop. Similar type of observation were also reported from Indore (M.P.) when sulphur and zinc (ZnO and $ZnSO_4$) were given to soybean either every year as well as alternate year, showed a significant residual effect on succeeding wheat crop (Anonymous, 1991-92a). These results are also in conformity with the results obtained by Singh and Sahu (1986) who also reported that when sulphur (elemental sulphur) was given to mustard crop, residual effect was also observed on succeeding crop.

Since sulphur and zinc help in the formation of chlorophyll which ultimately increased the photosynthesis process resulting in more dry matter production in maize. Also carbohydrates and protein synthesis might have also affected by residual zinc by activating the enzyme activity and protein synthesis in maize plant which results in increased grain and stover yield of maize.

5.3.2 Total nutrient uptake

Total nutrient uptake of any nutrient by crop depends on total dry matter production (seed + stover) and percent concentration of that particular nutrient in the plant (seed + straw). Data given in Tables 4.6 to 4.10 showed that every year application of sulphur (elemental sulphur) and zinc (ZnO and $ZnSO_4$) to gobhi sarson (1997-98) at all levels did not show residual effect on total nitrogen, phosphorus and potassium uptake by succeeding maize crop during 1998. however, only 50 kg S ha^{-1} (elemental sulphur) applied every year resulted in significant increase in total K uptake by succeeding maize crop during 1998 indicating that increase was due to residual sulphur at 50 kg S ha^{-1} (elemental sulphur). Since K is taken up through out the growth and development of crop which results in significant uptake of K. During the same year (1998), both levels of sulphur (elemental sulphur) resulted in significant uptake of total sulphur due to residual sulphur over control. It indicates that where sulphur source was applied every year to gobhi sarson (1997-98) resulted in higher uptake of total sulphur by succeeding maize crop.

The mean per cent contents of N, P, K in grain and stover of maize were not influenced by sulphur application except with higher level of sulphur (50 kg S ha^{-1}) with respect to K uptake (though not reported) as well as yield level was also non-significant due to residual sulphur application, therefore uptake of N, P, K remained unaffected, though K uptake remained unaffected at lower level of sulphur (elemental sulphur) only.

It was further seen that every year application of Zn as ZnO at both levels resulted in significant uptake of sulphur but when it was supplemented with sulphur as $ZnSO_4$, did not change sulphur uptake significantly, however, remained at par with ZnO treatment at all levels. It indicates that sulphur uptake was influenced due to combined effect of residual sulphur and zinc. This may be attributed to the fact that sulphur and zinc may have synergistic effect at both levels, which resulted in increased uptake of sulphur in these treatments. Thus residual zinc might have improved the effect of residual sulphur in $ZnSO_4$ treatment at both the levels due to positive interaction. Similar trend was observed with every year application of zinc as ZnO at both levels in maize due to residual zinc with respect to zinc uptake in maize during 1998.

Similar type of observations were also reported from Jabalpur where every year application of sulphur and zinc (ZnO and $ZnSO_4$) given to soybean resulted in increased uptake of S and Zn due to residual effect of S and Zn in succeeding wheat crop without affecting the yield as well as uptake of N, P and K level (Anonymous, 1994-95a)

In the subsequent year (1999), there was significant increase in sulphur uptake at 25 kg S ha^{-1} (elemental sulphur) which further increased significantly at 50 kg S ha^{-1} as ES applied in alternate year to gobhi sarson. Reverse trend was observed in every year application at same levels of sulphur as elemental sulphur (elemental sulphur). Every year application of sulphur at 25 kg S ha^{-1}

resulted in significant higher uptake of total sulphur over alternate year application at the same level while reverse was true at higher level of sulphur. It indicates that total S uptake was more with every year application of 25 kg S ha^{-1} and 50 kg S ha^{-1} given alternate year to gobhi sarson (1998-99) in maize. It was further observed that though at each frequency of Zn application to gobhi sarson as ZnO at both the levels increased S uptake over control but supplementation of zinc with sulphur as $ZnSO_4$, increased S uptake significantly only in case of every year application of 5 kg Zn ha^{-1} as $ZnSO_4$ over ZnO at the same level. It clearly reveals that increase in S uptake in maize with every year application of zinc at lower level (5 kg Zn ha^{-1}) and every year as well as alternate year application of zinc at both levels as $ZnSO_4$ given to gobhi sarson, was due to the combined effect of residual sulphur and zinc. But at 5 kg Zn ha^{-1} as $ZnSO_4$ (every year) applied to gobhi sarson, the observed effect was due to sulphur alone. Decreased uptake of S at every year application of 50 kg S ha^{-1} might be attributed to the fact that too high level of sulphur may have antagonistic effect with high level of P in soil resulting in lower uptake of sulphur. Hence, too low level of sulphur (25 kg S ha^{-1}) given AY might have not increased yield due to applied nitrogen. This might have affected the nutrient concentration in plant leading to lower uptake of sulphur. Improvement in sulphur uptake due to sulphur alone at 5 kg Zn ha^{-1} as $ZnSO_4$ (every year) and due to residual S and Zn observed with rest of levels of $ZnSO_4$ may be attributed to fact that residual zinc might have improved the effect of residual sulphur in $ZnSO_4$ treatment on sulphur uptake. It was also observed that where sulphur sources were given to gobhi sarson during 1998-99, the uptake of sulphur as well as its availability in soil increased. Similar trend was also observed with residual zinc during 1999 in maize. Similar type of observations were also made by Sharma and Gupta (1992) also reported that increased uptake of nitrogen, phosphorus potassium and sulphur, with S application, [illegible] Nad and Goswami (1984) who reported that total N, S and Zn uptake increased with sulphur or sulphur with zinc as $ZnSO_4$ and Rattan *et al.* (1997) reported that where zinc sources is applied, uptake of zinc is also more.

It was also observed that both levels of sulphur (elemental sulphur) applied every year to gobhi sarson showed a significant residual effect on zinc uptake due to residual sulphur. Every year application $ZnSO_4$ at 10 kg Zn ha^{-1} decreased significantly the uptake of zinc as compared to ZnO at same level during 1998. It indicates that increase uptake of zinc was due to the effect of residual zinc.

Similar type of observations were also made from Thanjavur (Tamil Nadu) and Sehore (M.P.) where N, P, K, S and Zn uptake increased due to every year application of residual sulphur and zinc due to sulphur and zinc (ZnO and $ZnSO_4$) (Anonymous 1994-95a). Also sulphur as elemental sulphur at both levels might have improved the uptake of zinc due to more dry matter production owing to residual sulphur.

In subsequent year (1999) total uptake of Zn in maize was significantly more when 50 kg S ha^{-1} was applied to gobhi sarson every year as compared to alternate year. It indicates that increase in uptake of zinc in maize crop was due to the effect of residual sulphur applied to gobhi sarson. Further Zn as ZnO resulted in significantly maximum uptake of Zn at all levels and frequencies. However supplementation of Zn with sulphur as $ZnSO_4$ decreased the uptake of Zn and this decrease was significant at all levels of Zn as $ZnSO_4$. This indicates that residual sulphur decreased the uptake of zinc. This might be due to fact that residual sulphur might have antagonistic effect on zinc absorption so uptake was decreased.

5.4 TOTAL UPTAKE BY MAIZE-GOBHI SARSON SEQUENCE

The total N, P, K, S and Zn uptake by maize-gobhi sarson sequence presented in Table 4.11 showed that total N, P and K uptake by crops in sequence was not influenced significantly due to every year application of sulphur (elemental sulphur) and zinc (ZnO and $ZnSO_4$). However, total S and Zn uptake by crops in sequence was influenced significantly due to every year application of different treatments given to gobhi sarson during 1997-98. It was seen that total S and Zn uptake was improved significantly due to sulphur as elemental sulphur compared to control. Increasing levels of sulphur as elemental sulphur increased total S and Zn uptake significantly but this increase was not significant at both levels of sulphur as elemental sulphur. Similarly, every year application of Zn as ZnO to gobhi sarson increased total uptake of S and Zn significantly over control at both levels. Increasing levels of Zn as ZnO increased the total S and Zn uptake by crops in sequence but this increase was significant only with respect to total Zn uptake at higher level of Zn as ZnO when applied every year to gobhi sarson. However, when zinc was supplemented with sulphur as $ZnSO_4$, then it was seen that Zn uptake improved significantly over control but total S uptake remained statistically at par with control. On the contrary, total S and Zn uptake decreased with application of Zn as $ZnSO_4$ as compared to Zn as ZnO at their respective levels, but, this decrease was significant only at higher level of Zn as $ZnSO_4$ (10 kg Zn ha^{-1}) when applied every year to gobhi sarson during 1997-98. This indicates that S uptake was improved only by individual application of S as elemental sulphur and Zn as ZnO whereas combined application of S and Zn might have counter act the effect of each other leading to decreased uptake of sulphur. While in case of total Zn uptake by crops in sequence, S may have antagonistic effect on Zn uptake, which became prominent at higher level Zn as $ZnSO_4$ (10 kg Zn ha^{-1}) during 1997-98. In the subsequent year (1998-99), total N, P, K, S and Zn uptake by the crops in sequence increased significantly by every year as well as alternate year application of sulphur as elemental sulphur to gobhi sarson at 25 and 50 kg S ha^{-1} as elemental sulphur.

However, levels and frequencies of application of sulphur as elemental sulphur with respect to total N, P and K uptake by crops in sequence was not significant when applied to gobhi sarson during 1998-99. On the other hand, every year increase in the levels of sulphur application as elemental sulphur decreased the total S-uptake but decrease was not significant whereas alternate year application of increasing levels of sulphur as elemental sulphur increased total S uptake significantly. Reverse was seen with respect to Zn uptake but significantly higher uptake was only observed with every year application of sulphur as elemental sulphur. It was further seen that every year application of 25 kg S ha^{-1} resulted in higher uptake of S and Zn compared to alternate year application but significant difference was observed with respect to S-uptake. It was further seen that every year application of higher level of sulphur as elemental sulphur (50 kg S ha^{-1}) decreased S uptake, though not significant while significantly higher total Zn uptake was observed with every year application of higher level of sulphur as elemental sulphur over alternate year application to gobhi sarson during 1998-99. Increasing levels of Zn as ZnO increased total N, P, K, S and Zn by the crops in sequence but this increase was not significant at any level and frequency of application of Zn as ZnO to gobhi sarson during 1998-99. Also increased the total uptake of N, P, K S and Zn over alternate year application, but the increase was not significant at any level of application to gobhi sarson during 1998-99. But when, Zn was supplemented with S as $ZnSO_4$, total N, P and K uptake further improved significantly. Total N uptake improved significantly at 10 kg Zn ha^{-1} as $ZnSO_4$ when applied every year as well alternate year but 5 kg Zn ha^{-1} as ZnO remained at par with 5 kg Zn ha^{-1} as $ZnSO_4$ whether applied every year and alternate year to gobhi sarson during 1998-99. This indicates that higher total N uptake was due to S and Zn when $ZnSO_4$ treatment was applied at higher level whereas at lower level, it was due to Zn alone. Total P uptake increased significantly due to Zn as $ZnSO_4$ at both the levels. It indicates that higher P uptake in Zn as $ZnSO_4$ treatment was due to sulphur alone. Whereas in case of total K uptake, Zn as ZnO remained at par with Zn as $ZnSO_4$ at both levels, when applied every year as well as alternate year to gobhi sarson. It indicates that increase in total K uptake by crops in sequence was due to combined effect of sulphur and zinc. Levels as well as frequencies of application of all treatments had no effect on total N, P and K uptake in sequence. It was also observed that Zn as ZnO increased the total S uptake significantly as compared to Zn as $ZnSO_4$ at their respective levels, however levels as well as frequencies of application had no effect on total S uptake. Where total Zn uptake decreased slightly, though not significant at any level and frequency of application over Zn as ZnO when applied every year as well as alternate year to gobhi sarson during 1998-99. This clearly indicate that increase in S uptake in response to sulphur application of $ZnSO_4$ to gobhi sarson was due to sulphur alone and with respect to drop in total Zn uptake in response to sulphur application as well as $ZnSO_4$ indicating that sulphur might have some antagonistic effect on zinc uptake by crops in sequence during 1998-99. When Zn as $ZnSO_4$ was given to gobhi sarson during 1998-99. Similar observations were also made by Khistaria *et al.* (1998).

5.5 SOIL STUDIES

5.5.1 Soil pH

There was slight decrease in soil pH at every level and frequency of S application (ES) as compared to initial soil pH (5.7) at the start of experiment during *kharif*, 1997 (Table 4.12). In general, there was more decrease in soil pH at 50 kg S ha^{-1} over 25 kg S ha^{-1} as ES when S as ES was applied EY to gobhi sarson in both the *rabi* seasons whereas, maximum pH value was observed with 10 kg Zn ha^{-1} as ZnO when applied EY. It was also observed that when EY and AY application of Zn was supplement with sulphur as $ZnSO_4$, at higher level the drop in soil pH was seen after *rabi* and *kharif* season during 1998-99 only. This decrease in soil pH was due to sulphur, which have acidifying effect on soil reaction. In general, there was no substantial change in soil pH due to different treatment effects compared to initial soil pH. The reason for this might be that soil high in organic matter have high buffering action to resist the change in soil pH. (Chaudhary *et al.,* 1981 and Prasad *et al.,* 1983).

5.5.2 Organic carbon

Organic carbon content was not influenced much either by varying level of S as ES and Zn as $ZnSO_4$ application or by different frequencies of S application (Table 4.13). However, significantly higher organic carbon contents were observed with 25 and 50 kg S ha^{-1} as ES after *rabi* and *kharif* seasons of 1997-98. Zinc as ZnO did not influence organic carbon too much compared to initial level but when it was supplemented with sulphur as $ZnSO_4$, there was marginal decrease in organic carbon contents at both levels of zinc as $ZnSO_4$ only after *rabi* and *kharif* season of 1997-98 though not significant. The increase was to the tune of 0.1% over control with EY sulphur as ES during 1997-98. In the subsequent year there was significant increase in organic carbon content of soil with all the levels and frequencies of application of sulphur as ES when applied EY or AY after every *rabi* and *kharif* season. Similarly zinc as $ZnSO_4$ when applied EY and AY also increased organic carbon content compared to Zn as ZnO after every *rabi* and *kharif* season of 1998-99, though increase was not significant. The increase in organic carbon content of soil with application of Zn as $ZnSO_4$ was very marginal to be considered as increase in organic carbon content.

In general, organic carbon contents increased after every *rabi* and *kharif* season of 1997-98 and 1998-99 as compared to initial value (0.65%). This might be attributed to the fact that more root biomass, above ground portions, plant remains and residues add to organic carbon. Also, crop residue, leaf litter add considerable amount to the soil, thus increase the organic carbon contents of soil. These results are in conformity with those of Rao and Sharma (1976).

5.5.3 Available nitrogen

Data presented in Table 4.14 show that EY application of Zn as $ZnSO_4$ at all levels after *rabi* 1997-98 and Zn as ZnO at all levels and frequencies of application to gobhi sarson after *rabi* 1998-99 resulted in significant increase in soil available N in soil after harvest of gobhi sarson. Though not significant but available N in soil increased with increasing levels of S as ES when applied EY after *rabi* 1997-98 and with AY application after *rabi* 1998-99. However, after *rabi* 1998-99 every year application of increasing levels of S as ES decreased available N in the soil. Levels had no effect on available N after *rabi* 1997-98, however, levels as well as frequencies of application of S (ES) had significant effect on available soil N after *rabi* 1998-99. The decrease was significantly more in AY treatments of S as ES. Every year application of S as ES resulted in significant increase over AY applications at lower level of S while reverse was true at higher level of S as ES. Further Zn as ZnO significantly decreased available N with increasing level of Zn as ZnO during both the season EY. When zinc was supplemented with S as $ZnSO_4$ significantly maximum available N was observed with 10 kg Zn as $ZnSO_4$ applied EY to gobhi sarson compared to Zn as

ZnO at same level after *rabi* 1997-98 whereas, significant decrease was seen with Zn as $ZnSO_4$ over ZnO at all the levels after *rabi* 1998-99 (EY and AY). This indicate that increase in available N after *rabi* 1997-98 was due to sulphur and decrease in available N after *rabi* 1998-99 was again due to sulphur in $ZnSO_4$ treatment.

It was further observed that only increasing levels of EY application of sulphur as ES resulted in significant drop in available N after *rabi* 1998-99. Frequencies of application at lower level of S (ES) had no effect on available N after harvest of maize during *kharif* 1998-99. Similarly after *kharif* season of 1998-99 significant drop in available N at higher level of Zn as $ZnSO_4$ applied EY or AY to gobhi sarson was observed. The decrease in available N due to sulphur may be attributed to the fact that both S and N are linked with photosynthesis, protein and oil synthesis. So more uptake of N due to S may have decreased the availability of nitrogen in the soil after every year season of 1998-99 whereas, increased available N after *rabi* season of 1997-98 after the harvest of gobhi sarson, may be attributed to the fact that yield level was lower. Therefore, uptake of N was also lower, resulting in increased availability of soil N. However, in general, it was seen that there was slight decrease or increase in soil available N at the end of experiment which is in agreement with the results obtained by Chaudhary *et al.* (1981). Data presented in same table show that both levels of S (ES) and 10 kg Zn ha^{-1} as ZnO during 1997-98 and all the treatments with their levels and frequencies of application during *rabi* 1998-99 resulted in significant decrease in available N after harvest of gobhi sarson during both the years.

5.5.4 Available phosphorus

With increasing levels of zinc as ZnO, there was significant decrease in soil available phosphorus after harvest of gobhi sarson during 1997-98. On the contrary, when Zn was supplemented with sulphur as $ZnSO_4$, then soil available phosphorus was improved with increasing level of zinc, however, significant improvement was observed at higher level of Zn as $ZnSO_4$ applied EY to gobhi sarson. Data further revealed that after *rabi* 1998-99 available P considerably improved as compared to 1997-98. It was further seen that AY application of sulphur (ES) at higher level significantly improved soil available phosphorus compared to its EY application. Also EY application of increasing level of S as ES and EY as well as AY application of increasing levels of ZnO decreased available phosphorus status of soil after the harvest of gobhi sarson during 1998-99. When zinc was supplemented with sulphur as $ZnSO_4$ at 5 or 10 kg Zn ha^{-1} applied EY or AY, it again decreased significantly the soil available phosphorus after the harvest of gobhi sarson indicating that observed decrease was due to sulphur. Data presented in Table 4.15 also indicate that in general EY application of sulphur as ES and zinc through ZnO decreased the available phosphorus as compared to control after the harvest of succeeding crop of maize 1997-98. It was also seen that in the higher level of sulphur through elemental sulphur and Zn as ZnO resulted in significant decrease in soil available phosphorus after the harvest of succeeding maize crop of 1997-98. Further at higher level as zinc application supplemented with sulphur as $ZnSO_4$ significantly improved the soil available phosphorus after the harvest of succeeding maize. Data in same table further show that all the treatments whether applied EY or AY to gobhi sarson improved the soil available phosphorus after the harvest of maize crop as compared to control during *kharif* 1998-99. However, differences were not significant in case of 50 kg S ha^{-1} as elemental sulphur applied EY as well as AY to gobhi sarson. Increase in level of sulphur as elemental sulphur (ES) and zinc as ZnO to gobhi sarson whether applied EY or AY significantly decreased the soil available phosphorus. At lower levels of Zn as $ZnSO_4$, when given EY and AY resulted in significant decrease in soil available phosphorus after the harvest of maize. However, similar trend was observed when Zn was supplemented with sulphur as $ZnSO_4$ at higher level only when applied in AY. Overall build up in the available phosphorus may be attributed to the fact that more than 80 per cent P get fixed in clay contents or with Al and Fe compounds in acidic soils. Build up in available P was also reported by Chaudhary *et al.* (1981).

5.5.5 Available potassium

Data presented in Table 4.16 show that after *rabi* 1997-98 EY application of sulphur as ES at lower level (25 kg S ha^{-1}) resulted in significant decrease in soil available potassium whereas the higher level of ES application had no effect on available potassium when compared to control. It was also seen from the same table that when Zn was supplemented with sulphur as $ZnSO_4$, then it resulted in significant improvement in soil available potassium compared to Zn as ZnO at both the levels. It indicates that increase in available K was due to sulphur alone after *rabi* 1997-98.

After *rabi* 1998-99, data reveal that AY application of graded level of sulphur (ES) as well as application of Zn at lower level (5 kg Zn ha^{-1}) through ZnO to gobhi sarson did not affect the soil available potassium as compared to control. But, when Zn was supplemented with sulphur as $ZnSO_4$ there was significant decrease in available K when applied EY and it increased significantly when applied in AY, which was due to sulphur application alone. Data given in same table further reveals that application of sulphur (ES) EY at higher level resulted significant decrease in available potassium after the harvest of maize during *kharif* 1997-98. It may further, be seen that when zinc application to gobhi sarson was supplemented with sulphur as $ZnSO_4$ at both the levels than it resulted in significant decrease in available potassium in soil compared to Zn as ZnO after the harvest of maize. This indicates that the decrease was due to sulphur. There was improvement in available soil potassium after the harvest of maize during *kharif* 1998-99 when compared to *kharif* 1997-98 which indicates that with the exception of EY application of 50 kg S ha^{-1} through elemental sulphur, different levels of sulphur as elemental sulphur to gobhi sarson whether applied EY or AY significantly decreased the available potassium status of soil after the harvest of *kharif* maize crop as compared to control. However, when EY as well as AY zinc application at lower level to gobhi sarson was supplemented with sulphur as $ZnSO_4$ it resulted in significant decrease in soil available potassium after harvest of maize due to sulphur. On the contrary, reverse trend was observed when zinc at higher level was supplemented with sulphur as $ZnSO_4$. Here supplementing EY or AY zinc application to gobhi sarson with sulphur resulted in significant improvement in soil available potassium after the harvest of succeeding maize crop due to sulphur. It is also evident from the table that increase in the level of sulphur as elemental sulphur (ES) significantly increased available potassium in soil when applied EY. On the contrary in case of AY application increase in level of sulphur (ES) significantly decreased available potassium after the harvest of maize during 1998-99. This may be attributed to the fact that S and K interaction is positive and K also helps in translocation and opening of stomata, which help in photosynthesis. So more uptake of K might have reduced its availability in the soil due to sulphur. However, there was marginal build up in available K. Chaudhary *et al.* (1981) also reported build up in available K.

5.5.6 Available sulphur

Every year application of sulphur (ES) and zinc as ZnO and $ZnSO_4$ to gobhi sarson during 1997-98 significantly improved the available sulphur after the harvest of gobhi sarson except application of 5 kg Zn ha^{-1} as ZnO, which significantly decreased available sulphur over control (Table 4.17). The improvement in available S was due to sulphur in $ZnSO_4$ treatment compared to zinc (ZnO). It was further observed that EY increasing levels of sulphur (ES), Zn as ZnO application to gobhi sarson significantly improved the available sulphur. When zinc was supplemented with sulphur as $ZnSO_4$ given every year to gobhi sarson, it resulted in significant build up in available sulphur. It indicates that observed effect was due to EY application of sulphur. This may be due to fact that more sulphur through elemental sulphur and $ZnSO_4$ was added to soil in addition to already present high amount of organically bound native sulphur of soil. On the other hand, only Zn from ZnO was added and more removal of sulphur by the crop might have resulted in lower build up in available sulphur after the harvest of gobhi sarson during 1997-98. In the subsequent year (1998-99), there was significant improvement in available soil sulphur over control after the harvest of gobhi sarson with every year as well as alternate year application of sulphur (ES). And also every year application of sulphur to gobhi sarson significantly increased soil available sulphur over alternate year application at respective levels of sulphur (ES). In general, build up in available soil sulphur was more during 1998-99 compared to 1997-98 after the harvest of gobhi sarson. Increasing levels of sulphur (ES), and zinc supplemented with sulphur as $ZnSO_4$ at all the levels of frequencies of application significantly improved available sulphur in the soil after harvest of gobhi sarson during the 1998-99 as compared to Zn as ZnO. This shows that improvement in available S was due to sulphur alone.

It was further observed that significant build up in soil available sulphur after the harvest of maize crop during 1998 due to residual effect of EY application of sulphur (ES) and zinc as $ZnSO_4$ to gobhi sarson at all the levels during 1997-98 was observed. This improvement in available sulphur in $ZnSO_4$ treatment was due to sulphur alone. at both the levels.

Increasing levels of sulphur (ES) at all frequencies showed significantly better available sulphur due to its residual effect after the harvest of maize crop during 1999. However, available sulphur was significantly improved when zinc was supplemented with sulphur as $ZnSO_4$ at all levels and frequencies of application as compared to Zn (ZnO) indicating that available sulphur was affected due to residual sulphur (ES) after the harvest of maize during 1999. More build up in available S in soil might be due to fact that where sulphur was applied through ES or $ZnSO_4$, more sulphur might have bound organically to the organic matter. Build up in available S was also reported by Shakhela and Vyas (1995) due to sulphur application in mustard.

5.5.7 Available zinc

It was observed from Table 4.18 that EY application of sulphur (ES) at both the levels did not affect the available zinc after the harvest of gobhi sarson during 1997-98 over control. Every year application of Zn as ZnO to gobhi sarson resulted in significant improvement in available zinc as compared to control but when it was supplemented with sulphur as $ZnSO_4$, there was significant drop in available zinc compared to Zn as ZnO at their respective levels indicating that decrease was due to sulphur. In general, there was build up in available zinc where it was applied through ZnO or $ZnSO_4$ compared to initial level (0.62 ppm). Data further reveals that application of sulphur as elemental sulphur (ES) at all levels and phases of application, did not affect the available zinc significantly as compared to control. Whereas Zn through ZnO at all levels and frequencies resulted in significant improvement in available zinc as compared to control after the harvest of gobhi sarson during 1998-99. Supplementation of Zn with sulphur as $ZnSO_4$ resulted in significant drop in available zinc at all levels and frequencies of application indicating that S may have some antagonistic effect on

Zn. It was further observed that available zinc after the harvest of maize during 1998 remained statistically at par with control due to residual effect of increasing levels of sulphur (ES) given EY to gobhi sarson during 1997-98. However, available zinc was significantly improved after the harvest of succeeding maize crop during 1998 over control due to residual effect of both the levels of zinc as ZnO given every year to gobhi sarson during 1997-98. Also, increase in the level of these treatments, significantly increased available zinc due to residual effect after the harvest of maize during 1998. It was further observed that available zinc in the soil after the harvest of maize during 1999 was not affected significantly over control due to the residual effect of all the levels and phases of application of sulphur (ES) given to gobhi sarson during *kharif* season of 1998-99. Moreover, increase in levels of sulphur (ES) did not have any residual effect on soil available zinc. However, available zinc was significantly improved after the harvest of succeeding maize crop during 1999 as compared to control due to residual effect of both the levels of zinc as ZnO EY and AY given to gobhi sarson during 1998-99. Also significantly lower available zinc status was there with AY application of Zn as ZnO compared to EY of these treatments at their respective levels of application. An increase in levels at all frequencies of application of these treatments to gobhi sarson during 1998-99 significantly improved available zinc due to their residual effect after the harvest of succeeding maize crop However, when zinc was supplemented with sulphur as $ZnSO_4$, there was significant drop in available zinc status of soil after the harvest of succeeding maize crop during 1999 at the respective levels of 5 and 10 kg Zn ha^{-1} given to gobhi sarson during

1998-99. This indicate that fall in available zinc was due to residual sulphur alone supplied through $ZnSO_4$ at all levels and phases of application after the harvest of succeeding maize crop during 1998-99. Availability of zinc increased where Zn was applied. More build up of Zn where Zn was applied through ZnO or $ZnSO_4$ was due to the fact that recovery percent of Zn was very less and it got fixed in the organic matter in organic form or some extent in clay. Similar type of observation were also reported from Jabalpur (M.P.) where Zn as ZnO and $ZnSO_4$ was applied EY and AY to soybean, there was build up in zinc in soybean-wheat rotation (Anonymous, 1994-95a). However, overall, there was no appreciable change in soil fertility status at the end of experiments. Similar observations were also made by Nair *et al.* (1973).

SUMMARY

SUMMARY

Field experiment on **"Studies on the effect of sulphur nutrition on gobhi sarson in maize-gobhi sarson crop sequence under rainfed conditions"** was carried out during 1997-98 and 1998-99 at the Experimental Farm of Department of Agronomy, CSK HPKV, Palampur (H.P.). The experiment conducted with the following broad objectives:

1. To estimate the yield potential of maize-gobhi sarson crop sequence in presence and absence of Zn and S,
2. to assess the magnitude of nutrient removal in the crop sequence, and
3. to study the fertility status and the yield sustainability after each crop cycle.

The experimental area was situated about 1290.8 m above mean sea level in North-Western Himalayas and had mid-hill sub-humid temperate type of climate. The soil of the experimental field was silty clay loam in texture and acidic in reaction. The soil was classified as high in available phosphorus and potassium and medium in respect of available nitrogen, sulphur, zinc and organic carbon. The experiment was laid out in Balanced Incomplete Block Design (BIBD) with two levels of sulphur as elemental sulphur (25 and 50 kg S ha^{-1}) and two levels of zinc (5 and 10 kg Zn ha^{-1} as ZnO and $ZnSO_4$) and two frequencies of application (EY - every year and AY - alternate year). All the treatments were imposed in gobhi sarson crop every year during 1997-98 and every year as well as alternate year during 1998-99, replicated four times along with control (NPK only, S and Zn free). In all there were thirteen treatments including control.

The significant findings obtained from the present investigation are summarized as under:

1. Significantly taller plants were obtained with both levels of Zn as $ZnSO_4$ mainly due to S and Zn during both years when 5 and 10 kg Zn as $ZnSo_4$ was applied EY (1997-98) or EY and AY (1998-99) to gobhi sarson and it remained at par with all the levels of sulphur as ES during 1997-98 (EY) and 1998-99 (EY and AY). Similarly primary branches increased significantly independently due to sulphur (ES) all the levels and Zn (ZnO) at higher level (10 kg Zn ha^{-1}). Zinc as $ZnSO_4$ did not influence primary branches as compared to control during 1997-98 when sulphur as ES and Zn (ZnO and $ZnSO_4$) were given EY to gobhi sarson. However, significantly maximum number of secondary branches were obtained due to sulphur through $ZnSO_4$ at 5 kg Zn ha^{-1} (EY) followed by 5 kg Zn ha^{-1} as $ZnSO_4$ (AY) during second year. It was further followed by 10 kg Zn ha^{-1} as $ZnSO_4$ which remained at par with higher level of S as ES when applied EY as well as AY to gobhi sarson during 1998-99.
2. Number of siliqua per plant were significantly maximum with sulphur when applied through 5 and 10 kg Zn ha^{-1} as $ZnSO_4$ (EY and AY) and remained at par with 25 and 50 kg S ha^{-1} as elemental sulphur (EY and AY) during second year (1998-99). Similarly, significantly maximum number of seeds per siliqua were obtained with sulphur alone when supplied through 5 kg Zn ha^{-1} as $ZnSO_4$ given every year to gobhi sarson followed by 5 kg Zn ha^{-1} as $ZnSO_4$ given alternate year 10 kg Zn ha^{-1} as $ZnSO_4$ (EY and AY) and higher (50 kg S ha^{-1}) level of sulphur (ES) applied every year and alternate year to gobhi sarson during 1998-99, while Zn had no effect on siliqua and seeds per siliqua during the same year.
3. None of the treatment when applied every year could influence the seed yield as well as straw yield of gobhi sarson during 1997-98. Significantly

higher seed yield of gobhi sarson was obtained with sulphur supplied through 10 kg Zn ha^{-1} as $ZnSO_4$ (EY and AY) followed by 5 kg Zn ha^{-1} as $ZnSO_4$ (EY and AY). Application of 50 kg S ha^{-1} as elemental sulphur (EY) produced significantly higher seed yield of gobhi sarson which remained at par with 10 kg Zn ha^{-1} as $ZnSO_4$ given AY to gobhi sarson during 1998-99. Significantly higher straw yield was also obtained with sulphur supplied through 10 kg Zn ha^{-1} as $ZnSO_4$ (EY and AY) and 50 kg S ha^{-1} as elemental sulphur (EY) followed by 10 kg Zn ha^{-1} as ZnO (AY) where straw yield increase due to Zn alone during 1998-99 and remained at par with each other. All these treatments were given to gobhi sarson during 1998-99.

4. Total uptake of N, P, K and S remained unaffected due to every year application of S and Zn to gobhi sarson during 1997-98. However, significantly higher total Zn uptake was observed with Zn as ZnO at 10 kg Zn ha^{-1} which remained at par with 5 kg Zn ha^{-1} as ZnO and $ZnSO_4$ treatment and 25 and 50 kg S ha^{-1} as elemental sulphur indicating that Zn uptake increase due to sulphur supplied through ES. In the subsequent year (1998-99), significantly higher uptake of N, P, K, and S was observed due to sulphur supplied through 10 kg Zn ha^{-1} ($ZnSO_4$) followed by 25 and 50 kg S ha^{-1} as elemental sulphur but zinc uptake was more with Zinc supplied through 5 and 10 kg Zn ha^{-1} as ZnO applied every year as well as alternate year to gobhi sarson. This indicates that total N, P, K and S uptake increased significantly in the presence of S while sulphur had no effect on Zn uptake.

5. Maize grain yield was not influenced significantly due to residual effect of S as elemental sulphur and Zn as ZnO and $ZnSO_4$ when applied every year to gobhi sarson during first year (1997-98). During second year (1998-99),

significantly higher grain yield of maize was obtained due to residual sulphur with 50 kg S as elemental sulphur (EY) and same yield can be obtained with rest of the levels of sulphur as elemental sulphur and all levels of Zn as $ZnSO_4$ at all frequencies of application when these treatments were applied every year and alternate year to previous crop of gobhi sarson during 1998-99 indicating that maize grain yield increased significantly due to combined effect of residual S as ES and S and Zn ascribed to $ZnSO_4$ treatment. No significant residual effect on stover yield of maize was observed due to residual sulphur and zinc during 1997-98, when different treatments were imposed to previous crop of gobhi sarson during 1997-98 In the subsequent year (1998-99), there was significant residual effect due to residual S on stover yield of maize when sulphur through elemental sulphur was given every year and alternate year to gobhi sarson followed by residual zinc supplied through 10 kg Zn ha^{-1} as ZnO (EY and AY). 10 kg Zn ha^{-1} as $ZnSO_4$ given every year had a significant residual effect remaining at par among themselves, whereas residual sulphur through $ZnSO_4$ at 5 and 10 kg Zn ha^{-1} given every year and in alternate year and 5 kg Zn ha^{-1} (AY) as $ZnSO_4$ neutralized the residual effect due to zinc by reducing the stover yield again.

6. Total N and P uptake (grain + stover) in maize was not influenced significantly residual sulphur or zinc or both when applied every year to gobhi sarson during 1997-98 through different treatments. However, residual sulphur @ 50 kg S ha^{-1} as elemental sulphur resulted in significantly maximum total uptake of K in maize. Total S uptake was significantly higher with every year application of different treatments of

sulphur as elemental sulphur while Zn uptake was significantly higher with residual Zn through 10 kg Zn ha^{-1} as ZnO It was observed that residual sulphur as $ZnSO_4$ did not change S uptake but it decreased total Zn uptake in $ZnSO_4$ treatment. However, total sulphur uptake increased significantly due to both residual sulphur and Zn in $ZnSO_4$ treatment.

During second year (1998-99), total N, P, K and S uptake in maize increased significantly due to residual sulphur as elemental sulphur (EY and AY) and due to combined effect of residual S and Zn in $ZnSO_4$ treatment except 5 kg Zn as $ZnSO_4$ (EY) where sulphur uptake increased due to sulphur. Total Zn uptake increased due to residual S as elemental sulphur Total zinc uptake decreased significantly due to residual sulphur in $ZnSO_4$ treatment but Zn uptake increased due to residual sulphur only at 10 kg Zn ha^{-1} $ZnSO_4$ (AY) during 1998-99 in maize.

7. Total N, P and K uptake by crops in sequence remained unaffected due to S and Zn applied through different treatments during 1997-98. Total S uptake increased significantly due to every year application of residual S as elemental sulphur and Zn as ZnO at both the levels. But, it dropped when Zn as $ZnSO_4$ was applied. It indicates that increase in S and Zn uptake was due to independent application of S and Zn. Total Zn uptake was also maximum significantly with S as elemental sulphur and Zn as ZnO at all levels but it decreased with residual S through $ZnSO_4$ treatments at both the levels. In the subsequent year 1998-99, total N, P, K, S and Zn increased significantly due to every year as well as alternate year application of residual sulphur as elemental sulphur. Zinc as ZnO also increased N, P, K, S and Zn significantly as compared to control but uptake further increased

with residual S through $ZnSO_4$ treatment. However, it decreased Zn uptake. This indicates that increased uptake of N was due to S at high level of Zn as $ZnSO_4$, (EY and AY), P uptake increased due to sulphur alone at both the levels of $ZnSO_4$, K uptake increased due to combined effect of S and Zn, S uptake due to S as $ZnSO_4$ at both the levels whereas Zn uptake increased due to sulphur as elemental sulphur but it decreased due to sulphur alone in $ZnSO_4$ treatment at higher level of Zn as $ZnSO_4$ (EY) and due to S and Zn at rest of the levels and frequency of application of Zn as $ZnSO_4$.

8. In general, there was more decrease in soil pH due to S @ 50 kg S ha^{-1} as elemental sulphur over 25 kg S ha^{-1} as elemental sulphur. Lowest value of soil pH was observed with S at 50 kg S ha^{-1} as elemental sulphur when applied every year after every crop season whereas, maximum pH was observed with Zn @ 10 kg Zn ha^{-1} as ZnO when given every year (1997-98) and every year and alternate year to gobhi sarson during 1998-99. Similary 10 kg Zn ha^{-1} as $ZnSO_4$ decreased soil pH after every *rabi* and *Kharif* season of 1997-98 and 1998-99 mainly due to sulphur.

9. Organic carbon content were significantly more with sulphur as elemental sulphur at both levels after *rabi* and *kharif* season of 1997-98. Organic carbon increased to the tune of 0.05 per cent with 25 kg S ha^{-1} as elemental sulphur and 0.04 per cent with 50 kg S ha^{-1} as elemental sulphur over initial value due to sulphur and minimum OC (%) was observed with 5 kg Zn ha^{-1} as $ZnSO_4$ (EY) after *rabi* and *kharif* season of 1997-98 mainly due to sulphur. In subsequent yea organic carbon increased to the tune 0.05 to 0.06 per cent with 25 kg S ha^{-1} as elemental sulphur and 0.06 per cent at 50 kg S ha^{-1} as elemental sulphur when applied EY and AY to gobhi sarson.

Sulphur through 50 kg S ha^{-1} ES resulted in more OC (%) after *rabi* and *kharif* season of 1998-99 applied EY and AY. Further, it increased by 0.07 per cent with 5 and 10 kg Zn as $ZnSO_4$ when applied every year as well as alternate year which was mainly due to sulphur alone after *rabi* season of 1998-99 and to the tune of 0.04 to 0.05 per cent with 25 and 50 kg S ha^{-1} as elemental sulphur when applied every year and alternate year after *kharif* season of maize when compared to initial value (0.65%). While, Zn as $ZnSO_4$, it increased to the tune of 0.03 per cent over initial value but it decreased significantly as compared to control. It indicates that S decreased the organic carbon content in $ZnSO_4$ treatment. Minimum OC (%) was observed due to sulphur and Zn supplied through 5 kg Zn ha^{-1} as $ZnSO_4$ and ZnO, respectively.

10. Available soil N content significantly decreased with graded levels of sulphur as elemental sulphur compared to control but S through Zn as $ZnSO_4$ increased the available N contents which increased significantly with increasing levels of Zn as $ZnSO_4$ applied every year to gobhi sarson. However, available N content remained unaffected after *kharif* season of 1997-98. Similarly there was significantly more build up of soil N content with S supplied through 10 kg Zn ha^{-1} as $ZnSO_4$ and lower N content were observed with EY application of 5 kg Zn ha^{-1} as ZnO after *rabi* season of 1998-99 when applied EY to gobhi sarson. Likewise, significantly maximum build up in soil N content was observed with Zn @ 5 kg Zn ha^{-1} (ZnO) when applied every year where minimum soil N contents were seen with S through 5 kg Zn ha^{-1} as $ZnSO_4$ given every year after *rabi* season of 1998-99. After *kharif* season of 1998-99 control or 10 kg Zn ha^{-1} as ZnO (EY)

treatment resulted in significantly maximum soil N contents and significantly minimum soil N contents were observed with sulphur at 50 kg S ha^{-1} as elemental sulphur applied in alternate year to gobhi sarson Sulphur through $ZnSO_4$ significantly improved soil available N after *rabi* 1997-98 also sulphur through $ZnSO_4$ decreased available N at all levels and frequencies of application after each season of 1998-99.

11. Significantly maximum build up of soil P content observed due to S @ 10 kg Zn ha^{-1} ($ZnSO_4$) after *rabi* season and with Zn as 5 kg Zn ha^{-1} as ZnO after *kharif* season of 1997-98 when applied EY to gobhi sarson while minimum was observed with S @ 25 kg S ha^{-1} and 50 kg S ha^{-1} as elemental sulphur after *rabi* and *kharif* season of 1997-98, respectively when given EY. During 1998-99, maximum available soil P was observed with Zn as 5 kg Zn ha^{-1} as ZnO and minimum was observed with S through 5 kg Zn ha^{-1} as $ZnSO_4$ applied every year after *rabi* season of 1998-99 whereas maximum available soil P was observed with Zn at 5 kg Zn ha^{-1} as ZnO given in every year to gobhi sarson where as minimum available soil P was observed with alternate year application due to S through 10 kg Zn ha^{-1} as $ZnSO_4$ after *kharif* 1998-99. In general, there was more build up in soil P after *kharif* season of 1998-99 compared to initial soil status. However, there was more build up in available soil P after each crop cycle over initial value at the end of the experiment.

12. Significantly maximum available K was observed due to S, Zn and S (ES) at Zn at 10 kg Zn ha^{-1} ($ZnSO_4$), 5 kg Zn ha^{-1} (ZnO) given every year and 50 kg S ha^{-1} as elemental sulphur (AY) and 5 kg Zn as ZnO (EY), respectively after each crop cycle during both the years, whereas minimum

K was observed with every year application of Zn and S at 10 kg Zn ha^{-1} as ZnO and 25 kg S ha^{-1} as elemental sulphur after each *rabi* and *kharif* season of 1997-98, respectively. Similarly significantly minimum soil available K was observed with S at 10 kg Zn ha^{-1} as $ZnSO_4$ when applied every year after *rabi* season and again due to sulphur (ES) at 25 kg S ha^{-1} given every year after *kharif* season of 1998-99.

13. Significantly maximum soil available sulphur was seen with S at 50 kg S ha^{-1} as elemental sulphur after each crop cycle and in general minimum was observed with Zn at 10 kg Zn ha^{-1} levels as ZnO given every year as well as alternate year to gobhi sarson after each crop cycle during 1997-98. Similarly maximum soil S was observed due to S at 50 kg S ha^{-1} (ES) after *rabi* and *kharif* season of 1998-99.

14. Significantly maximum available Zn was observed with Zn at 10 kg Zn ha^{-1} (ZnO) applied every year after each crop cycle whereas minimum soil Zn was observed with S @ 25 and 50 kg S ha^{-1} as elemental sulphur after *rabi* and *kharif* season of 1997-98, respectively when applied EY to gobhi sarson. Similarly, minimum available Zn was observed with S @ 25 kg S ha^{-1} EY and AY as ES given to gobhi sarson after *rabi* and *kharif* season of 1998-99, respectively. While maximum soil available Zn was observed due to Zn at 5 and 10 kg ha^{-1} as ZnO after *rabi* and *kharif* season of 1998-99 when applied AY to previous crop of gobhi sarson.

CONCLUSIONS

The foregoing summary of the results reveals that yield of gobhi sarson increased significantly in the presence of sulphur or zinc or both supplied through ES, Zn as ZnO and $ZnSO_4$ during second year (1998-99). Similarly maize yield also increased in the presence of residual S or S and Zn both when ES and $ZnSO_4$ treatment was given to gobhi sarson in maize-gobhi sarson crop sequence only during 1998-99. Every year and alternate year application of Zn alongwith S as $ZnSO_4$ at 10 kg Zn ha^{-1} resulted in significantly maximum yield of gobhi sarson. Similarly yield of maize was significantly maximum due to residual effect of S supplied through 50 kg S ha^{-1} as ES when applied in EY to gobhi sarson in maize-gobhi sarson crop sequence and same yield can be obtained with rest of the levels of sulphur as ES and due to S and Zn as $ZnSO_4$ at all the levels and frequencies of application. Total uptake of N, P, K and Zn was maximum with S @ 50 and 25 kg S ha^{-1} as elemental sulphur in maize gobhi sarson sequence while total sulphur uptake was maximum with 25 kg S ha^{-1} as ES. Sulphur (ES) slightly decreased the soil pH and but there was an improvement in organic carbon with the application of sulphur (ES) or through $ZnSO_4$ applied in alternate year at the end of experiment. There was slight decrease in available nitrogen and build up in soil available phosphorus due to sulphur (ES and $ZnSO_4$) but build up in available potassium was due to application of Zn as ZnO. More build up of available S was with S sources application, whereas more build in available Zn was observed where Zn sources were applied to gobhi sarson.

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APPENDIX

APPENDIX - I

Mean weekly meteorological data for the period of experimentation during 1997-98

Standard week	Period	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative humidity (%)	Bright Sunshine hours	Rainfall (mm)
44	29-04 Nov.	21.1	10.2	58	4.4	2.6
45	05-11	20.1	9.9	61	6.0	33.0
46	12-18	19.8	8.8	49	7.4	0.0
47	19-25	19.5	8.4	54	6.0	3.0
48	26-02 Dec.	15.1	6.8	65	3.8	32.0
49	03-09	16.5	7.5	63	2.1	51.1
50	10-16	13.1	6.2	75	1.6	16.9
51	17-23	16.9	4.9	54	8.7	0.0
52	24-31	13.8	3.9	63	5.9	20.1
01	01-07 Jan.	16.6	6.1	55	4.9	0.0
02	08-14	16.0	7.0	54	5.2	6.1
03	15-21	14.0	3.6	59	8.0	6.2
04	22-28	15.2	4.2	56	7.5	0.0
05	29-04 Feb.	15.7	7.2	54	5.7	2.0
06	05-11	18.3	6.0	47	9.5	0.0
07	12-18	17.2	8.8	61	3.0	63.6
08	19-25	14.9	5.3	67	4.6	67.3
09	26-04 Mar.	15.3	7.0	65	5.1	76.4
10	05-11	17.6	6.7	54	8.6	11.8
11	12-18	18.2	7.8	59	6.9	20.4
12	19-25	21.1	9.5	52	7.3	4.0
13	26-01 Apr.	25.5	13.6	61	6.7	21.2
14	02-08	24.9	14.7	47	7.6	16.2
15	09-15	23.8	12.2	46	9.4	6.8
16	16-22	28.6	17.2	40	9.6	0.0
17	23-29	28.1	16.6	51	9.2	17.0
18	30-06 May	29.8	18.8	45	7.8	3.0
19	07-13	26.3	14.8	48	9.3	8.4
20	14-20	31.5	19.9	44	10.2	1.6
21	21-27	35.5	23.1	31	12.1	0.0
22	28-03 Jun.	34.6	21.9	33	7.9	0.6
23	04-10	31.6	20.4	43	8.5	64.4
24	11-17	26.5	18.1	66	5.4	111.4
25	18-24	31.4	19.5	57	1.0	13.6
26	25-01 Jul.	28.9	20.7	70	4.6	69.8
27	02-08	26.8	20.3	82	4.6	123.1
28	09-15	27.8	21.0	82	3.5	75.4
29	16-22	26.9	20.2	83	5.1	40.7
30	23-29	28.2	19.4	76	5.7	51.5
31	30-05 Aug.	26.4	20.5	84	2.3	115.5
32	06-12	27.6	21.1	83	3.3	216.4
33	13-19	26.1	20.2	84	1.9	119.0
34	20-26	25.4	19.7	86	2.9	236.4

35	27-02 Sep.	26.9	19.1	73	6.5	63.2
36	03-09	27.7	18.8	74	7.2	30.2
37	10-16	26.0	18.3	72	5.1	72.2
38	17-23	24.7	17.7	80	2.1	137.5
39	24-30	26.4	17.9	78	7.3	51.0
40	01-07 Oct.	26.3	16.1	67	8.3	10.6
41	08-14	27.4	16.1	58	10.7	0.0
42	15-21	22.0	14.5	75	5.2	86.5
43	22-28	25.1	13.6	62	9.9	0.0

APPENDIX - II

Mean weekly meteorological data for the period of experimentation during 1998-99

Standard week	Period	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative humidity (%)	Bright Sunshine hours	Rainfall (mm)
44	29-04 Nov.	20.6	10.1	54	8.7	0.4
45	05-11	23.0	12.7	62	8.9	0.0
46	12-18	23.9	10.3	49	10.0	0.0
47	19-25	23.7	10.3	41	9.3	0.0
48	26-02 Dec.	22.9	8.9	42	9.9	0.0
49	03-09	23.7	9.8	31	9.4	0.0
50	10-16	20.2	6.7	39	9.1	0.0
51	17-23	19.2	7.0	40	7.3	0.0
52	24-31	19.7	5.8	42	7.8	0.0
01	01-07 Jan.	15.1	6.5	50	3.9	12.2
02	08-14	14.5	3.8	56	6.4	0.0
03	15-21	16.6	6.8	48	6.4	12.0
04	22-28	14.7	6.8	63	3.2	44.3
05	29-04 Feb.	14.5	4.0	58	7.7	0.0
06	05-11	19.6	8.4	46	5.5	5.8
07	12-18	21.3	10.9	49	3.3	0.0
08	19-25	19.3	9.1	57	6.4	9.5
09	26-04 Mar.	21.5	9.5	41	9.8	0.0
10	05-11	21.0	11.4	49	6.4	10.0
11	12-18	22.5	10.3	36	7.0	0.0
12	19-25	23.8	11.5	33	6.7	1.5
13	26-01 Apr.	26.7	13.6	32	8.4	0.0
14	02-08	28.4	15.8	31	9.0	0.8
15	09-15	28.6	18.6	31	9.1	0.0
16	16-22	31.3	19.1	29	9.8	0.0
17	23-29	33.0	20.4	26	10.5	0.0
18	30-06 May	34.0	21.3	28	7.1	0.0
19	07-13	28.4	18.1	37	5.4	26.8
20	14-20	30.1	19.0	40	9.9	52.5
21	21-27	27.4	18.0	64	6.3	45.7
22	28-03 Jun.	29.9	18.8	45	7.6	8.0
23	04-10	29.7	17.3	46	8.6	12.0
24	11-17	30.0	19.7	62	8.5	70.2
25	18-24	27.7	18.2	74	5.9	99.3
26	25-01 Jul.	29.9	20.6	76	4.9	68.0
27	02-08	28.1	20.1	79	5.9	94.4
28	09-15	26.8	18.9	79	5.2	36.8
29	16-22	25.2	19.6	84	1.4	190.0
30	23-29	24.7	19.8	84	4.0	253.0
31	30-05 Aug.	23.0	20.1	85	4.5	52.7
32	06-12	25.2	20.1	88	2.2	314.4
33	13-19	26.5	18.9	81	5.5	246.6
34	20-26	25.0	19.8	84	3.0	162.6

35	27-02 Sep.	26.9	17.6	79	7.1	33.8
36	03-09	27.3	18.5	75	6.3	11.4
37	10-16	26.3	18.4	79	5.4	48.7
38	17-23	26.7	18.9	84	2.3	179.2
39	24-30	25.5	17.7	76	6.1	6.0
40	01-07 Oct.	25.7	16.1	72	9.1	0.0
41	08-14	26.3	13.6	46	10.5	0.0
42	15-21	26.5	13.7	47	10.3	0.0
43	22-28	25.7	15.6	54	9.2	0.0

Appendix - III

Analysis of variance for growth attributes of gobhi sarson during 1997-98

Sources	d.f.	Mean sum of squares		
		Plant height	Primary branches per plant	Secondary branches per plant
Block (unadjusted)	12	25.12	0.0739	0.1993
Treatment (adjusted)	12	81.06*	0.1438*	0.0863
Error	27	21.38	0.0413	0.0989

* Significant at 5 per cent level

Appendix - IV

Analysis of variance for growth attributes of gobhi sarson during 1998-99

Sources	d.f.	Mean sum of squares		
		Plant height	Primary branches per plant	Secondary branches per plant
Block (unadjusted)	12	35.72	0.0507	4.33
Treatment (adjusted)	12	49.49*	0.0951	15.65*
Error	27	12.54	0.0545	0.35

* Significant at 5 per cent level

Appendix - V

Analysis of variance for yield attributing character of gobhi sarson during 1997-98

Sources	d.f.	Mean sum of squares			
		Number of plants per metre length	No. of siliquae per plant	No. of seeds per siliqua	1000-grain weight
Block (unadjusted)	12	0.20	1008.35	6.02	0.008
Treatment (adjusted)	12	0.52	412.92	12.47	0.010
Error	27	0.75	995.17	6.40	0.012

*Significant at 5 per cent level

Appendix - VI

Analysis of variance for yield attributing character of gobhi sarson during 1998-99

Sources	d.f.	Mean sum of squares			
		Number of plants per metre length	No. of siliquae per plant	No. of seeds per siliqua	1000-grain weight
Block (unadjusted)	12	0.33	1073.23	16.23	0.0003
Treatment (adjusted)	12	0.79	5382.53*	77.24*	0.0001
Error	27	1.06	152.84	4.18	0.0002

*Significant at 5 per cent level

Appendix - VII

Analysis of variance for grain and straw yield of gobhi sarson

Sources	d.f.	Mean sum of squares			
		Grain yield (kg/ha)		Straw yield (kg/ha)	
		1997-98	1998-99	1997-98	1998-99
Block (unadjusted)	12	15.60	661	39.51	3562
Treatment (adjusted)	12	13.55	2478*	59.44*	8675*
Error	27	32.40	1922	26.56	1720

* Significant at 5 per cent level

Appendix - VIII

Analysis of variance for N, P, K, S and Zn uptake by gobhi sarson during 1997-98

Sources	d.f.	Mean sum of squares				
		N	P	K	S	Zn
Block (unadjusted)	12	511.46	5.40	376.67	13.66	0.006
Treatment (adjusted)	12	446.89	6.81	329.84	10.41	0.010*
Error	27	308.33	6.40	192.17	6.36	0.001

* Significant at 5 per cent level

Appendix - IX

Analysis of variance for N, P, K, S and Zn uptake by gobhi sarson during 1998-99

Sources	d.f.	Mean sum of squares				
		N	P	K	S	Zn
Block (unadjusted)	12	118.33	5.05	49.27	7.37	0.004
Treatment (adjusted)	12	376.06*	15.67*	117.07*	28.57*	0.012*
Error	27	39.87	1.81	18.24	3.34	0.001

** Significant at 5 per cent level*

Appendix - X

Analysis of variance for grain and stover yield of maize

Sources	d.f.	Mean sum of squares			
		Grain yield (kg/ha)		Stover yield (kg/ha)	
		1998	1999	1998	1999
Block (unadjusted)	12	13.69	21.39	59.00	21.39
Treatment (adjusted)	12	11.35	23.47	55.17	23.47*
Error	27	4.97	9.49	21.87	9.49

* Significant at 5 per cent level

Appendix - XI

Analysis of variance for N, P, K, S and Zn uptake by maize (grain + stover) during 1998

Sources	d.f.	Mean sum of squares				
		N	P	K	S	Zn
Block (unadjusted)	12	91.74	8.04	37.69	4.57	0.0015
Treatment (adjusted)	12	75.14	3.21	34.64*	7.86*	0.0051*
Error	27	28.80	3.44	15.81	0.57	0.0002

* Significant at 5 per cent level

Appendix - XII

Analysis of variance for N, P, K, S and Zn uptake by maize (grain + stover) during 1999

Sources	d.f.	Mean sum of squares				
		N	P	K	S	Zn
Block (unadjusted)	12	443.04	1.66	87.58	7.37	0.0028
Treatment (adjusted)	12	393.15	20.11	178.82*	23.94*	0.0099*
Error	27	167.21	1.40	15.24	0.53	0.0001

* Significant at 5 per cent level

Appendix - XIII

Analysis of variance for N, P, K, S and Zn uptake by maize-gobhi sarson sequence during 1997-98

Sources	d.f.	Mean sum of squares				
		N	P	K	S	Zn
Block (unadjusted)	12	415.02	9.41	358.01	15.10	0.007
Treatment (adjusted)	12	398.75	8.75	339.48	15.31*	0.019*
Error	27	330.77	7.00	221.33	7.05	0.002

* Significant at 5 per cent level

Appendix - XIV

Analysis of variance for N, P, K, S and Zn uptake by maize-gobhi sarson sequence during 1998-99

Sources	d.f.	Mean sum of squares				
		N	P	K	S	Zn
Block (unadjusted)	12	520.48	17.15	186.53	24.13	.012
Treatment (adjusted)	12	1452.68*	52.81*	463.03*	87.39*	.041*
Error	27	109.27	3.50	52.35	5.38	.001

* Significant at 5 per cent level

Appendix - XV

Analysis of variance for soil organic carbon (%)

Sources	d.f.	Mean sum of squares			
		1997-98	1998	1998-99	1999
Block (unadjusted)	12	0.0001	0.0001	0.0002	0.0001
Treatment (adjusted)	12	0.0006*	0.0002*	0.0004*	0.0004*
Error	27	0.00004	0.00002	0.00005	0.00003

* Significant at 5 per cent level

Appendix - XVI

Analysis of variance for available nitrogen

Sources	d.f.	Mean sum of squares			
		1997-98	1998	1998-99	1999
Block (unadjusted)	12	515.00	106.61	208.67	7.21
Treatment (adjusted)	12	2177.84*	133.81	833.30*	31.62
Error	27	7.11	94.23	2.72	0.04

* Significant at 5 per cent level

Appendix - XVII

Analysis of variance for available phosphorus

Sources	d.f.	Mean sum of squares			
		1997-98	1998	1998-99	1999
Block (unadjusted)	12	1.60	1.83	0.1511	0.6003
Treatment (adjusted)	12	6.52*	7.54*	28.0156*	2.2898*
Error	27	0.03	0.015	0.2303	0.0136

* Significant at 5 per cent level

Appendix - XVIII

Analysis of variance for available potassium

Sources	d.f.	Mean sum of squares			
		1997-98	1998	1998-99	1999
Block (unadjusted)	12	5.31	0.035	12.62	6.79
Treatment (adjusted)	12	19.41*	46.125*	30.29*	31.04*
Error	27	0.19	0.040	2.07	0.09

* Significant at 5 per cent level

Appendix - XIX

Analysis of variance for available sulphur

Sources	d.f.	Mean sum of squares			
		1997-98	1998	1998-99	1999
Block (unadjusted)	12	22.53	17.38	75.961	60.223
Treatment (adjusted)	12	96.44*	74.14*	331.209*	262.809*
Error	27	0.003	0.003	0.0061	0.0027

* Significant at 5 per cent level

Appendix - XX

Analysis of variance for available zinc

Sources	d.f.	Mean sum of squares			
		1997-98	1998	1998-99	1999
Block (unadjusted)	12	0.745	0.641	2.161	2.288
Treatment (adjusted)	12	3.163*	2.761*	8.198*	10.363*
Error	27	0.0008	0.0006	0.780	0.002

* Significant at 5 per cent level