REVIEW OF LITERATURE

Although lentil is one of the oldest food crops yet very meagre scientific work has been done on various aspects of its cultivation. However, an attempt has been made in this chapter to review whatever information is available on cultural and varietal aspects. Wherever necessary, mention has been made of other legumes pertinent to this study to substantiate the findings recorded during the course of present investigation. Hence, whatever information is available on this crop in India and abroad, has been collected and reviewed in the following pages:

EFFECT OF VARIETIES

It is well known fact that systematic collection and evaluation of genetic stock have never been thoroughly examined. In this regard, some work has been done at Pantnagar from 1971-75 and as a result of that varieties like Pant L-406 and Pant L-209 and Pant L-639 have been evolved. The varieties Pant L-209 and Pant L-406 entered in the All India Co-ordinated varietal trials carried out during 1972-73 at different locations. The average yields of these selections for 4 years (1972-73 to 1975-76) was about 14.0 q/ha at number of locations representing different agro-climatic conditions in the country (Saxena, 1977). Lentil T-36 had
the highest yield of about 13.0 q/ha at Kanpur (Pannikkar, 1960). In eastern states of the country, where large areas are grown after late varieties of paddy, it has been recommended that high yielding varieties of lentil (B-77, B-25 Pusa-1 and Pusa-6) should replace the low yielding ones (Jeswani, 1970). According to Singh (1979), recommendations in case of lentil crop must be made carefully for each agro-climatic situation and cropping system.

The low production of pulses in India is mainly due to the existing available varieties of pulses taking long time to mature, resulting in low productivity per unit of time. As such, development of high yielding varieties is a pre-requisite for yield break through in any crop. Of late, there has been emphasis for development of disease resistant, short duration and high yielding varieties of lentil. As a result of judicious screening at various research stations, a number of varieties viz. Pant L-406, Pant L-639, Pant L-538, Pant L-209, L-9-12 and Pant L-234 have been developed (Pandaya et al., 1976) that yielded nearly 20% higher than T-36.

Like other crops, the growth pattern of lentil also differs from variety to variety. The rate of dry matter production in a crop increases with the increase in the leaf area index (LAI). In accordance with the age of the crop it reaches to maximum and declines thereafter. The
production of dry matter subsequently depends on day length, sunshine hours affecting the photosynthesis and length of growing season. It was observed that in many region the vegetation reached a dynamic equilibrium, where there is a maximum exploitation of incoming radiation to produce dry matter (Blackman and Black, 1959). Jain (1975) indicated that the number of branches per plant, seed clusters per plant and pods per plant were higher in the hybrids than in their parents.

Wilson and Teare (1972) working with three lines (small, medium and large seeded) of lentil observed that small seeded varieties had more branches followed by medium and large seeded varieties. They further observed that large seeded lines were taller than small seeded ones. In trials with 17 lentil cultivars, the seed yield was positively correlated with number of pods and clusters per plant. The contribution of height and number of branches per plant was negligible (Malhotra et al., 1973). However, Dixit (1974) observed in 21 lentil cultivars that seed yield was correlated with number of primary and secondary branches per plant. The number of primary and secondary branches were associated with number of pods per plant.

In studies with several lentil varieties at Pantnagar Kumar (1974) reported that among all the yield components, higher number of pods per plant and number of grain per pod were responsible for higher yield in...
L-209; while these components were the lowest in Pant L-234 and Pant L-220, which resulted ultimately, in lower grain yield. He further indicated that Plant L-234 took minimum period while Bombay-18 took maximum period for flowering. Dixit and Singh (1975) observed positive but non-significant correlation of seed yield of lentil with number of primary branches and pods per plant while all these characters were negatively correlated with plant height.

The growth rate of any crop is influenced by leaf area index, besides the light intensity. Thus, most of the early and medium duration varieties, add towards total dry matter production in the tune of 75 to 85 per cent at harvest. The studies on crop growth on ten lentil genotypes under Pantnagar conditions observed that mean crop growth rate was very slow during early stages but it increased with the onset of reproductive stage (Kumar et al. 1977). In a field trial in Washington, Wilson (1977) observed that seed yield was inversely related to seed size and plant height. However, Narsinghni et al. (1978) observed that seed yield per plant in 36 lentil cultivars was positively correlated with days to flowering and number of pods per plant. Tikka and Asawa (1981) reported that number of primary branches and pods per plant were the important yield-components. The primary branches, pods per plant and days to flowering had direct correlation to yield, whereas secondary branches had a direct negative effect on yield. The factors affecting these
traits were accounted for 65% of the variations.

From studies made at Vivekand Laboratory (Almora) and at Central Rice Research Institute, Cuttack, Chauhan and Sinha (1982) reported correlation and Path analysis carried out in 30 genotypes of lentil for seven characters. In this study, the grain yield was significantly correlated with pod numbers, secondary branches, and plant height. The path analysis revealed that secondary branches had the maximum direct or indirect effect on the grain yield followed by days to maturity. Pods per plant also had a direct effect on grain yield. The direct and indirect effects of 100 grain weight on yield were very high and negative except in number of pods per plant. The plant height and days in flowering had low and negative direct as well as indirect effects. Similarly, Sarwar et al. (1982) from correlation studies made on lentil crop in Bangladesh with a view to ascertain that grain yield is a function of several yield plants components, it may be more efficient to select on the basis of yield-contributory characters rather than yield per unit area. The inference from this study revealed positive association between the time of maturity and number of pods per plant. Number of pods per plant was positively correlated with seeds per pod and plant height. Plant height was significantly and positively correlated with seeds per pod and yield per plant.

Existence of varietal differences in grain yield
is well known, but, precise knowledge of the basis of difference is in fact, lacking. Bryssine (1955) made a general recommendation that in legume plants having large seeded varieties grew longer and yielded significantly more than those plants obtained from small seeded ones. Studies made by Dimitrov (1964) indicated that small seeded varieties of lentil yielded more than large seeded varieties in dry conditions of North Bulgaria. Jewiss (1966) stated that clear understanding of these basis of varietal differences in grain yield is necessary to improve the species and varieties and also to provide guidance for practical crop husbandry. Similarly, Singh and Jolly (1966) reported that cultivar L 9-12 gave, on an average, 49.2 per cent higher grain yield than local variety. From a study made under Bulgarian conditions, Roev (1969) revealed that the highest seed yield of 12.5 q/ha was obtained from a local red seeded lentil. Jain (1975) indicated that hybrids gave significantly higher yields than their parents.

An investigation was undertaken on cultivators plot of Bikramganj (Rihar) during rabi season of 1971-72 to identify the relative performance of 4 varieties, viz. L-9-12, T.T.3, T-36 and local. Variety, L 9-12 hereby out-yielded the other varieties significantly (Ojha et al., 1977). Singh et al., (1979) concluded that average yield of lentil could be increased by using improved agronomic practices, studying 4 lentil cultivars at Ranchi Agricultural
College (Bihar). Srivastava (1979) reported that L 9-12, Pant L-406, Pant L-209 and BR-25 yielded 1.69, 1.55, 1.55 and 1.38 tonnes grain/ha, respectively. Similar studies made at the Regional Research Station, Assam revealed that significantly higher yield was recorded with Pant L-406 over BR-25, BR-77, and Pant L-209 (Saharia, 1980). However, Sen (1981) reported that the new lentil lines S-226 and S-235 and the standard cultivar B-77 grown during 1977-80 gave average yields of 2.28, 2.31 and 1.95 tonnes per ha respectively. Lal (1985) recommended Pant L-406 for all the lentil growing areas, but, Pant L-209 and Pant L-639 had been suitable for U.P. and M.P. K-75 also did well in most of the area where lentil and such other pulses were cultivated. Shsrma et al., (1985) suggested to grow Type 36, Pant L-209, Pant L-406, Pant L-639, etc. for increasing the lentil production in northern India.

Legumes differ in productivity and also in terms of quality due to their genotypic variations. Every genotype has its own characteristics of assimilating the agronomic inputs applied to them. Among the rabi pulses those of prime importance are Bengal gram, lentil and peas. These differ very well in quality aspects particularly in terms of protein, because of their differences in morphological and physiological needs. While studying with 10 soybean cultivars, Kleese et al. (1968) reported that varieties differed significantly in the accumulation of nitrogen and phosphorus contents. Studies conducted at IARI, New Delhi revealed that the
protein content of lentil varieties was variable and it was
30.90, 30.40, 29.0 and 26.30 per cent in Pusa 1-l, L 9-12, T-36
landing B-35, respectively (IARI, 1971). Findings of Razhiera
and Genera (1971) indicated that samples of indigenawa, small
seeded lentils from various sites in Bulgaria had low seed
protein content (22.6 to 28.3 per cent). Samples of small
seeded varieties viz. Laryssa, Slovenssea, Moderia and
Tadizikakya-95 had high seed protein content (30.2 to 31.8%),
while the samples of large seeded improved varieties had
intermediate protein content (28.0 to 29.9 per cent).

Pulses are a rich source of protein. The average
protein content of pulses ranges from 20 to 30 per cent as
compared to about 10-14 per cent in cereals. Pulses also
contain more calcium and phosphorus than cereals and are
good source of vitamin 'B' (Thakur, 1975). The role of legumes
in the nutrition of human and other monogastric animals is
largely that of supplying protein. Thus, grain quality of
legumes may be regarded mainly a matter of protein quality
and quantity (Hulse, 1975).

Amongst the lentil cultivars, the differences in
the protein content are far and wide. Lentil is the most
nutritious among all the pulses due to high protein content.
Abrams (1975) analysed samples of over 200 varieties, and
lines for protein content and reported the range of
variability from 16.0 to over 30.0 per cent. Dimitrov (1974)
indicated that seed protein content of 34 introduced and
local cultivars of lentil grown in 11 locations in Bulgaria ranged from 21.75 to 32.48 per cent depending upon the cultivar and locality.

While studying the comparative protein quality of new high yielding varieties of lentil, Verma et al. (1977) indicated that seeds of 7 lentil cultivars contained 20.2 to 22.9 per cent protein. Pandey and Vaidya (1979) indicated that lentil is the most nutritious among all the pulses due to protein content to the extent of 29.0 per cent. El-Nahry et al. (1980) worked on chemical, composition and protein quality of 3 local lentils and one Pakistan cv. grown and consumed to Egypt. The local cultivar Giza-9 had the highest protein content to the tune of 25.2 per cent. Due to agronomic variables, the increase in the protein content of Giza-9 was to the tune of 25.2 to 26.3 per cent.

Sen (1981) studied the performance in terms of 1000 grains weight of three new lentil lines, viz. S-226, S-235, and the standard cv. B-77 and found 15.4, 15.2 and 14.6 g weight, respectively. Nadeem and Muhammad (1982), while working on the effect of salts on germination, yield and protein percentage and total uptake of nitrogen by three varieties of lentil (Lens esculenta) grown in Pakistan indicated that protein percentage in grain and straw increased with increasing salinity, but the total uptake of nitrogen decreased at higher salinity levels.
Singh and Ram (1986) observed that Pant L-406 and Pant L-639 gave significantly more yield than L9-12 and LG-60. Tripathi and Singh (1987) also reported comparative performance of same varieties of lentil. In this trial, lentil cvs. Pant L-639, Pant L-406, Pant L-234 and L-9L9-12 gave average seed yield of 2.50, 2.48, 2.30 and 2.34 t/ha, respectively. Singh and Singh (1991) noted that variety Pant L-406 produced the highest grain yield, which was significantly higher over PL-639 and HUL-9. Here, the straw yield also exhibited the same trend. Singh and Singh (1991) conducted a field experiment on lentil during 1988-89 at the NDUAT, crop Research Station, Ghaigharaghat, testing the relative performance of three varieties, of which Pant L-406 produced the highest grain yield, straw yield, branches per plant, pods per plant and 1000 grain weight. Gopalrao et al. (1993) reported that 'Pusa Baisakhi' proved superior to the other 3 varieties in respect of all growth parameters, yield components and yield. Phosphorus application increased the grain yield by 18 and 51.2 per cent at 25 and 50 kg P₂O₅/ha over no P. The maximum uptake of P was recorded with 'Pusa Baisakhi' followed by 'LGG 407', 'ML 267' and 'LGG 410' genotypes of greengram. Jadhao (1993) reported that frenchbean variety 'VL 63' gave the highest grain yield, being significantly higher 'HUR 15' and 'HUR 87'. Straw yield also showed the same trend. Negi and Shekhar (1993) reported that all the French bean genotype differed significantly for grain yield and yield attributes. 'B 6' showed
significantly higher yield and yield attributes. Nitrogen application exerted significant beneficial effect on yield of French bean genotypes. **Sharma and Sharma (1993)** reported that genotype 'JS 81-335' gave significantly higher yield than the other varieties except 'JS 81-1619'. 'JS 81-335' gave the highest net return of Rs. 12,618/ha with net return/rupee invested of Rs. 4.2/ha. The highest oil and protein content were observed in seeds of varieties 'JS 81-220' and 'JS 81-1619' of soybean. **Singh et al. (1993)** carried out a field study at Hisar during the winter seasons of 1989-90 and 1990-91 and showed that 'Aparna' and 'HFP 8712' being at par with 'DMR 4' and 'KPPD 1' field pea (*Pisum sativum* L.), gave significantly more yield than 'HFP 8710' and 'Pant P9'. The 'Pant P9' was found significantly poor yielder. Genotypes also varied significantly in yield attributes i.e. pods/plant, 100-seed weight and plant height. 'HFP 8712' performed better (31.77 q/ha) with 500,000 plants/ha in 20 cm x 10 cm plant geometry and 'DMR 4' responded 330,000 plants/ha only with 30 cm x 10 cm geometry.

**Patel (1994)** reported that 'JG 315' cultivar of gram gave significantly higher grain yield than the other cultivars in both the years. **Ahlawat (1995)** reported that genotype 'PDR 14' showed highest seed yield of 11.60 q/ha. Genotypes 'VL 63' and 'HUR 15' being at par with 'HUR 137' recorded markedly higher yield than 'HUR 87'. The French bean genotypes showed differential response to sowing dates.
Siag (1995) conducted a field experiment during the winter season of 1989-90 to 1991-92 to find out response of Kabuli chickpea (Cicer arietinum L.) genotypes under graded levels of phosphorus. The pooled data revealed that the maximum grain yield of 27.45 g/ha was recorded with 'ICCC 32' which was 10.46, 7.78 and 39.55% higher than the grain yield of 'L 550', 'Gora Hissari' and 'L 144', respectively. 'ICCC 32' also produced maximum number of pods/plant (57.5). The maximum number of seeds/pod (1.33) and 100-seed weight (32.7 g) were recorded with 'L 550' and 'L 144', respectively.

The above information on varietal aspect conclusively indicates that lentil cultivars vary significantly in their yield potential as well as in protein content both of which are further influenced with growing conditions. Thus, variety plays an important role in regulating the yield of lentil crop.

**EFFECT OF SULPHUR (LEVELS AND SOURCES) ON CROPS**

The work with sulphur problem in Indian soils could be seen from a few reports of sulphur deficiency in West Bengal (Dutt, 1962) and its deficiency and distribution in the Punjab soils (Kanwar, 1963). However, a wider picture of S requirement of crop unlike that for other major nutrients for the country is not available. Dalal et al. (1963) observed that the yield of groundnut increased by
per cent by the application of ammonium sulphate, 46 per cent by superphosphate and 41 per cent by gypsum over the control. Chopra and Kanwar (1966) observed that the application of NPK containing 200 lb sulphur resulted in 20 per cent increase in the yield of groundnut over NPK alone. The soil content of groundnut kernels was increased to 49.6 per cent from 46.2 per cent.

According to Singh et al. (1970), the dry matter yield of soybean increased by 10 per cent when the dose of sulphur applied was 150 kg per hectare. Application of 40 kg/ha sulphur as gypsum increased the protein content of groundnut by 8.4 per cent. In case of mustard, the protein content was found to be increased by 6.3 per cent, when the dose of sulphur applied was 100 kg/ha through gypsum. According to Virmani and Gulati (1971), sulphur had a significant direct effect on the uptake and utilization of soil and fertilizer phosphorus by the crop, but, had little residual effect. Frequent applications of sulphur were generally useful.

Verma et al. (1973) reported that the application of sulphur (irrespective of source) in combination with NPK markedly increased the shelling per cent and the oil and protein content of the kernels of groundnut. Amongst the sulphur sources, gypsum was most effective source in improving oil and protein contents of kernels. There was no difference amongst other sources. In improving shelling
percentage, however, all sulphur sources including gypsum were equally good.

A radio-tracer study showed that different varieties of soybean responded differently to application of sulphur. In a study of 12 varieties the S content in plants ranged from 0.205 to 0.325 per cent with out S and 0.308 to 0.370 per cent with S treatment at the flowering stage, and 0.102 to 0.128 per cent with out and 0.142 to 0.215 per cent with S treatment at the pod formation stage. 'Semmes', 'Bill' and 'Davis' removed the lowest amount of sulphur and exhausted the soil least. The plant removed higher fraction of S from the soil source than from applied fertilizer source. 'Hampton' and 'Dabe' removed more fertilizer before the flowering stage (Sagar and Dev 1974).

The significance of sulphur deficiency as a factor in limiting the yield and quality of grain legumes has been recognised some what late (Kanwar and Randhawa, 1974). According to Pasricha and Randhawa (1975), sulphur deficiency caused an accumulation of soluble N (amide and amino) and a decrease of protein N in plant tissues. Sulphur applied through superphosphate and gypsum significantly increased the protein N irrespective of its effect on the total N content of the plant tissue.

Aulakh et al. (1977) reviewed the deficiency of S in soils of Punjab and the extent of responses obtained to
applied S in different crops. In the groundnut, 32.1 kg sulphur per ha as ammonium sulphate, single superphosphate and gypsum gave additional pod yields of 13.14 and 15 per cent, respectively. The application of 20 kg sulphur per ha in raya gave 155, 167 and 180 per cent response in RL-18, RLM-29/25 and RLM-234 varieties, respectively. Similarly, in brown sarson application of 60 kg S/ha produced an additional yield of 845 kg per ha. The studies revealed that sulphur application in addition to increasing yields of crops, improved the quality of the produce in respect of protein content. Pareek et al. (1978) showed that soil application of 250 kg per ha of elemental sulphur increased the grain production of black gram by 41.5 per cent over control. Increased grain yield was also associated with similar increase in number of pods per plant and the test weight. Application of sulphur increased its content of the plants. Increase in sulphur content was also associated with increase in N and K contents and decrease in Fe content of leaf.

Aulakh and Pasricha (1979) noted that in a soil containing 16.8 kg per ha available sulphur, sulphur application did not increase the yield of chickpea and lentil. Mehta and Singh (1979) showed that chlorosis in green gram was owing to an inactivation of Fe inside the leaves on account of low physiological availability of sulphur. Application of 250 kg per hectare of elemental sulphur, which significantly increased the leaf chlorophyll content by 54.8 per cent and
more than doubled the activity of haemo-enzyme catalase and peroxidase brought about 95 per cent increase in grain production. Sulphur application also significantly increased the N, S and K contents by 44.7, 62.5 and 29.7 per cent, but, significantly reduced iron and Ca+Mg contents by 53.5 and 46.6 per cent, respectively.

Rawat and Sriniwas (1979) reported that the yield of dry matter of linseed showed significant increase by the application of sulphur. Sulphur application also significantly increased its uptake. The plant S content varied from soil to soil as also with levels. However, the maximum dry matter production occurred when the plants contained around 0.38 per cent sulphur. Pathak and Tripathi (1979) reported that the seed yield and protein content of B. juncea were the highest with the application of 80 kg sulphur per hectare. The seed oil content increased with increasing sulphur rates. Methionine content was also increased by the applied sulphur.

Kumar and Singh (1980) reported that sulphur application up to 160 kg per ha increased the dry matter and grain yield significantly. Kumar and Singh (1980) reported that the addition of S to soil up to 160 kg per ha increased growth and grain yield of soybean, while the higher dose of S (240 kg per ha) significantly decreased the yield. Singh and Singh (1980) reported that the nitrogen concentration increased significantly by applicatio
of 60 and 120 kg per hectare sulphur whereas phosphorus concentration increased only with 60 kg per ha of sulphur.

Nad and Goswami (1983) reported that cowpea responded to direct application of sulphur by increasing dry matter yield and sulphur uptake, irrespective of the sulphur status of soils. Residual effect was similarly beneficial to mustard as second crop in the sequence in soils comparatively richer in available sulphur. Moong or green gram (*Phaseolus aureus* Roxb) raised as the third crop showed greater uptake of sulphur particularly from calcium sulphate. In general, ammonium sulphate proved to be a better source of sulphur closely followed by potassium schoenite.

Agrawal and Gupta (1982) reported that the dry matter of mustard crop was increased by 13.18-25 per cent and 16.79-20.94 per cent at 40 days and maturity, respectively over control. Crain yield and oil contents were also increased from 18.05-30.09 per cent and 9.91-11.89 per cent over control. De et al. (1982) conducted a trial on an alfisol (red sandy loam soil) at Hyderabad during the winters of 1979 and 1980 to evaluate the response of TMV-2 groundnut (*Arachis hypogea* Linn.) to the application of gypsum and zinc sulphate. The highest pod yield (28.5 q/ha in 1979 and 33.7 q/ha in 1980) was obtained when 1000 kg per hectare of gypsum was applied at the time of earthing up along with 25 kg zinc sulphate applied at sowing. This treatment was on
a par with that of 100 kg per ha gypsum application at earthing up alone. The pod yield with 1000 kg per ha gypsum was significantly higher than with 500 kg per ha gypsum application. Zinc application was also significant in 1980 and in pooled analysis. The rate of return per rupee investment on any treatment was the highest (Rs. 7.21) when zinc sulphate was used alone. The return was Rs.3.81, when 1000 kg gypsum was incorporated at earthing up.

Singh (1983) reported that the application of 90 kg sulphur per ha resulted in maximum seed yield (87.8 per cent more than the control) and influenced the number of primary branches and siliquae on main shoot and water use efficiency of the rainfed crop. While in the irrigated crop, 30 kg S per ha seemed to be adequate. Application of 90 kg S per ha to the rainfed crop and 150 kg S per ha to irrigated crop gave the highest monitory returns of Rs. 867/- and Rs. 1897/- per hectare, respectively.

Raikhy et al. (1985) reported that sulphur fertilization of desertic sandy soil has a beneficial effect on cowpea. It increased the uptake of S and other nutrients especially P and N by the plants. The enhanced availability of nutrients reflected in an improvement in the dry matter yield. While gypsum produced higher dry matter them pyrite, the latter was more effective in increasing the available P in soil. Patel and Patel (1985) reported that sulphur application favourably affected the dry matter yield of
root and pod yield of groundnut.

Thirumalaisamy et al. (1986) reported that basal application of sulphur in the form of sulphur dust (22 kg per hectare) increased the dry matter and pod yield of groundnut significantly. Sulphur application had increased the carbohydrate, protein and oil contents in kernel. The 100 kernel weight and shelling percentage were also high in sulphur applied plots.

Bahal et al. (1986) reported that the yield of groundnut increased with the application of sulphur upto 15 kg per hectare. The sulphur contents of pods and its uptake by plants increased with the application of sulphur. Singh et al. (1986) reported that the linseed crop exhibited significant response to sulphur application. Sulphur application also increased the contents and uptake of NPK and S by linseed. Additionally Singh et al. (1986) found that the dry matter yield of mustard increased significantly with the application of sulphur.

According to Bhardwaj and Pathak (1987) there was continuous increase in number of pegs and pods per plant, weight of 100 pods. Kernel shell ratio and yield in all treatments increased with the advancement of age of the crop. The number of pegs, pods and yield at all stages of growth in different concentrations of sulphur were in the order of S 162, S 54, S 18, S 6. So thus, the doses 0, 6 and 18 kg
per ha sulphur were found to be deficient and 54 kg per ha as the optimum concentration of sulphur. While 162 kg/ha sulphur showed reduction in plant growth.

Singh et al. (1988) reported that increasing levels of sulphur increased the grain and stover yield of Indian rapeseed. Oil percentage increased with sulphur addition. Sulphur addition significantly increased the utilization of N, P and S by grain. Singh and Singh (1990) reported that the application of sulphur increased the grain and stover yield, sulphur content and its uptake by linseed. Singh and Malik (1990) reported that dry matter yield and S concentration in berseem increased significantly with S application. Nabi et al. (1990) reported that groundnut responded to sulphur application through three sources viz. sulphate salts of ammonium, potassium and calcium on Gujranwala and Balkasar soils (Udic haplustalf). Sulphur application significantly increased dry shoot weight of eight week old groundnut plants. The sources of sulphur had almost same effect.

According to Sharma et al. (1991), 60 kg S per ha was optimum for obtaining the highest oil content, seed and oil yield and protein content of mustard crop. Amongst different sources of sulphur fertilizers, ammonium sulphate and ammonium sulphate nitrate were most effective as compared with single superphosphate, elemental sulphur and pyrites. Parashar (1991) reported that gypsum proved superior over other sources of sulphur for lentil crop. A significant response to sulphur levels was also observed. Sulphur appli-
cation increased the content and uptake of N, P and S by lentil crop. Protein content was also improved with sulphur addition. Singh and Ram (1991) reported that the effects of phosphorus and sulphur application on the yield, concentration and uptake of phosphorus by chickpea were studied in field experiments conducted on alluvial soil of Varanasi at Banaras Hindu University. Phosphorus was applied at 0, 13, 26 and 39 kg per ha as KH₂PO₄ (Potassium dihydrogen phosphate) and sulphur at 0, 40, 80 and 120 kg per ha as sulphur powder. A maximum yield of chickpea was observed with 26 kg P and 80 S per ha. Further increment of P and S decreased the yield. The application of P upto 26 kg per ha significantly increased the P concentration of nodule, whole plant, grain and straw of chickpea. The application of sulphur had a synergistic effect on the concentration of P to a certain level of applied S upto 80 kg per ha in various plant parts of chickpea. Combined application of 26 kg P and 80 kg S per ha significantly increased the concentration and uptake of P in various plant parts of the test crop. Total uptake of P increased significantly with 40 and 80 kg applied S as well as 13 and 26 kg of applied P per ha, but, thereafter increased dose of phosphorus and sulphur, i.e. 39 kg and 120 kg per ha, respectively, showed decrease in the concentration and uptake of both the elements in chickpea.

Narwal et al. (1991) studied the response of different sources of sulphur applied through superphosphate,
gypsum, pressmud and pyrites, on mustard on an Entisol. Grain/stalk yield, total S uptake and oil yield of mustard increased significantly with increasing levels of sulphur. Amongst the various sources of S tested, gypsum was the best in respect of both grain and oil yield, as well as uptake of S by mustard. Next in order were single superphosphate, pressmud and pyrites. Arora et al. (1991) reported that gypsum and superphosphate generally performed better than sodium sulphate.

A field experiment was conducted by Singh and Ram (1990) on light textured sandy loam soil in 1982 and 1983 on chickpea with three levels of phosphorus (30, 60 and 90 kg P₂O₅ per ha) and three levels of sulphur (40, 80 and 120 kg S per ha) including a separate control. The N, Ca and Mg contents increased significantly in nodules, plants (at flowering) grain and straw (at harvest) upon 60 kg P₂O₅ per ha and 80 kg S per ha, but N, Ca and Mg content decreased at 90 kg P₂O₅ and 120 kg S per ha. Similar trend was found on the uptake of N by grain and straw and Ca, Mg by grain of chickpea also.

Singh et al. (1991) collected one hundred samples from the soils of alluvial plains (ustifluvents) in semiarid region of Rajasthan and analysed for total and available sulphur. Available sulphur and organic carbon (in soil) were significantly correlated. Lentil (Lens esculenta Moanch), responded significantly to sulphur and calcium application.
Sulphur application also enhanced the contents and uptake of sulphur and calcium by lentil grain and straw both. Calcium addition decreased the sulphur content, but enhanced the sulphur uptake by crop.

Kasthuri et al. (1992) studied the effect of sulphur nutrition on the quality and yield of blackgram (Vigna mungo). Sulphur was applied in the form of elemental sulphur and gypsum at four levels in two stages of plant growth. Application of elemental sulphur showed significant increase in the yield of grains, protein content of the grains and total dry matter production. Singh and Singh (1992) conducted a pot experiment for consecutive years commencing in 1981-82 with the view to evaluate the effect of sulphur fertilization and Rhizobium inoculation on yield and nutrient uptake by a variety T-163 in four different soils of Uttar Pradesh viz. calcareous, mar, red and alluvial, four levels of sulphur (0, 20, 40 and 60 kg per ha) as elemental sulphur were applied as basal dressing. Grain and straw yields increased significantly due to sulphur fertilization and Rhizobium-inoculation. The highest grain and straw yields were obtained at 60 kg per ha of sulphur during both the years. Among soils, higher yields were recorded in red followed by alluvial, calcareous and mar soils. The magnitude of response to inoculation on grain and straw yields was reckoned to be 8.45 and 10.75 per cent and 6.32 and 11.26 per cent in the crop season of 1981-82 and 1982-93, respectively. However, the interactions effect on the yield was nonsignificant. Uptake of N, P, K and S increased with an
increase in sulphur level and was recorded higher in red
followed by alluvial, calcareous and mar soils. Inoculation
increased the uptake of nutrients appreciably.

Ram and Dwivedi (1992) conducted a field experiment
during 1984-85 and 1985-86 on sandy loam soil to study the
effect of source and level of sulphur on grain yield and
quality in chickpea. The application of sulphur sources
(gypsum, pyrite and elemental sulphur) at various levels,
viz. 0, 20, 40 and 60 kg S per ha affected the yield of
chickpea. Maximum increase in grain yield was 26.99 per cent
during 1984-85 and 17.98 per cent during 1985-86, whereas
that in straw was 21.29 and 19.34 per cent compared with the
control in first year and second year, respectively. Sulphur
significantly affected the protein, methionine and tryptophan
(%). Gypsum @ 40 kg S per ha was the best in increasing the
yield and nutritional quality of chickpea. Tiwari et al.
(1992) reported that application of 40 kg S/ha increased the
yield, protein and amino acid content and nutrients(NPK) up-
take in lentil crop.

Srivastava and Srivastava (1993) studied the effects
of levels of sulphur (0, 20, 40 and 60 kg/ha) through pyrite
(22% S) and phosphorus (0, 8.7, 17.5 and 26.2 kg/ha)
through single superphosphate (16% P₂O₅ + 12% S). The
interaction effect between levels of P and S had significant
influence on the grain and stick yields of pigeon pea. The
maximum grain (1590 kg/ha) and stick (7200 kg/ha) yields of
pigeon pea were obtained at 26.2 kg P per ha along with 20 kg S per ha, which were superior to the rest of the P and S combinations. Dimree et al. (1993) reported that application of S and P improved the yield and yield attributes of groundnut. Hadvani et al. (1993) reported that application of S did not show significant effect on growth, yield attributes and yield of groundnut. The effect of sulphur on oil content was significant. Khandpal and Chandel (1993) reported that the application of 30-40 kg S/ha improves nitrogenase activity, N fixation, plant dry matter, grain yield, oil and protein content in grain of soybean in S deficient soils. Sources of S did not show any significant effect on yield and quality of soybean grain. According to Nagar et al. (1993) only the use of P and S in soybean crop not improved the quality of the seed, but also played an important role in increasing the oil and protein yield.

Agrawal and Mishra (1994) reported that applying 40 kg S ha\(^{-1}\) increased soybean grain yield by 360 kg ha\(^{-1}\) protein content by 10.6 per cent and oil content by 1.4 per cent as compared to the control. Ammonium sulphate, single superphosphate and elemental S were found to be equally effective S fertilizer sources in raising soybean yield. Jaggi (1994) reported that the application of 50 kg S ha\(^{-1}\) in a field experiment on an Alfisol increased the seed yield, sulphur uptake and oil content of raya. Gypsum was the best source of sulphur. Sulphur application at optimum rate (49.4 kg ha\(^{-1}\)) gave the highest benefit: cost ratio. Field trials conducted
by Naidu (1993) on green gram (mung bean) indicate that applying 40 kg S ha\(^{-1}\) in the form of elemental sulphur increased grain yield over control by 151 kg ha\(^{-1}\) and protein in grain by 3.5 per cent. Tiwari and Pandey (1993) reported that applying elemental S at the rate of 40 kg S ha\(^{-1}\) increased grain yield by 34.3 per cent, protein content of grain by 6.5 per cent. The concentration of essential amino acids with cysteine and methionine also were increased. Patel and Patel (1994) reported that treatment of 80 kg ha\(^{-1}\) each of P and S had the most favourable effect on DMY and mineral composition for P and S of lucerne. Therefore, it may be recommended that addition of S is necessary along with P for soil deficient in available sulphur. Singh (1984) reported that applying 80 kg S ha\(^{-1}\) increased the grain yield of chickpea by 20.6 per cent and protein content by 2.7 per cent. In nine field experiments with graded rates of 0, 30, 60 and 90 kg P\(_2\)O\(_5\) ha\(^{-1}\) and 0, 20, 40 and 60 kg S ha\(^{-1}\) optimum response of soybean to P was noted at 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) and that of S at 40 kg S ha\(^{-1}\) (Subba Rao and Ganeshamurthy 1994).

Biswas et al. (1995 a) reported that seed and straw yield of gobi sarson (Brassica napus L.) increased significantly due to N application in a greenhouse experiment on sandy loam soil (Typic Ustochept). Application of S also enhanced the seed and straw yield. However, the effect was limited to the application of 50 kg S ha\(^{-1}\) in case of seed and 75 kg S ha\(^{-1}\) in case of straw yield. Combined application of 120 kg N ha\(^{-1}\) along with 50 kg S ha\(^{-1}\) gave the maximum
seed yield (5.60 g/pot). Nitrogen and sulphur application also increased the uptake of nitrogen and sulphur and oil yield significantly. **Biswas et al. (1995 b)** reported that nitrogen and sulphur interacted synergistically on the uptake of P, K, Zn, Cu and Fe by Gobhi sarson.

**Singh (1995)** in his review article stated that crops responded to 20 to 40 kg S ha\(^{-1}\) application and the mean increase in grain yield of cereals was 23.9 per cent, oilseeds 19.57 per cent of pulses 31.1 per cent. **Singh et al. (1995)** reported that bulb yield, content and uptake of N, P and S by garlic increased significantly with increasing levels of sulphur. Amongst the sources of S tested, gypsum and potassium sulphate were the best in respect of both the bulb yield as well as uptake of nutrients by garlic. Next in order were elemental S and sodium sulphate. **Singh et al. (1995)** reported that the mean bulb yield of garlic increased significantly with successive increase in level of S application upto 25 mg kg\(^{-1}\). Among the sources of sulphur, ammonium sulphate exhibited the highest yield and S content and uptake and the lowest yield, S content and uptake was observed with elemental S. **Tripathi and Sharma (1995)** reported that sulphur fertilization @ 40 kg ha\(^{-1}\) is beneficial and effective in increasing seed yield, oil and protein content of mustard. The effect of S sources on these parameters was non-significant. **Tripathi et al. (1995)** reported that sulphur application increased yields of crops in cowpea-sorghum and sorghum-cowpea crop sequences. Among the different sources, ammonium sulphate was superior to others.
(pyrites, gypsum and elemental S). The response was economically viable. Tandon (1995) in his review article stated that the application of 20 to 60 kg S ha\(^{-1}\) on S-deficient soils increased the yields significantly. Mean yield increases due to S application are 638 to 813 kg ha\(^{-1}\) for cereals, 137 to 340 kg ha\(^{-1}\) for pulses, 144 to 566 kg ha\(^{-1}\) for oil seeds and 17.1 t ha\(^{-1}\) for sugarcane. The average yield percentage response to S for crops grown in S-deficient soils is 17.1% for rice, 25.3% for wheat, 30% for rapeseed mustard, 31.7% for groundnut, and 21.5% for sugarcane on alluvial soils. Generally, cereals and oil seeds are equally responsive to S, because cereals have a higher yield with a lower S requirement, whereas, oilseeds have lower yields, but higher S needs per ton for seed production. Up to a 34% increase in protein production due to S application was reported in several crops. Further, S has a profound positive impact on seed yield, increasing oil concentration in seeds by 2% to 3% in safflower and sesame, 9.6% in rapeseed mustard, and 11.3% in groundnut. Each unit of S applied to S-deficient soils augmented the supply of edible oils- an essential part of the daily diet by 3 units to 4 units. Overall, different sulphate (SO\(_4^{2-}\)) sources are equally effective. Ammonium sulphate offers the best opportunity to correct S deficiency in standing crops. Single superphosphate (SSP) and gypsum often are superior to ammonium sulphate for oilseeds, particularly with groundnut. Increasingly, phosphogypsum and sugar factory pressmud discharged in the
sulphitation process are being recognized as useful S sources. Elemental S has been found to be an effective source of plant nutrient S in alkaline and calcareous soils, particularly in Gujarat and Rajasthan. According to Singh et al. (1996), 30 mg S ha\(^{-1}\) soil in mustard, 20 mg kg\(^{-1}\) soil in niger and 10 mg kg\(^{-1}\) soil in lentil and black gram appear to be optimum levels. Application of gypsum significantly increased the pod yield, oil content, oil yield and S uptake by groundnut in limed acid soil. Phosphogypsum (16 per cent S) and low grade pyrites (20-22 per cent S) are also effective indigenous sources of S for crops. In black gram, at all S levels, pyrite was inferior as S-source compared to phosphogypsum. A significant increase in grain yield and protein yield of black gram with S application @ 24 kg\(^{-1}\) as phosphogypsum were recorded.

DIFFERENTIAL RESPONSE OF CROPS VARIETIES TO SULPHUR APPLICATION.

six varieties of Sesame were screened for relative susceptibility to S deficiency in a field experiment in calcareous soil conditions with available S at 4.17 mg kg\(^{-1}\) (Sakal et al., 1992). The Krishna and AVT-17 varieties produced maximum grain yield response of 40% and 21%, respectively, at 40 kg S ha\(^{-1}\). Other varieties including Red Local, IET-21, AVT-7, and AVT-18 responded at 20 kg S ha\(^{-1}\) level. The relative responses were as follows: Krishna, 40% > Red Local, 20% > AVT-17, 21% > IET-21, 19% AVT-7, 18% > AVT-18, 15%
Hence, Krishna may be regarded as most responsive, and AVT-18 as least responsive to S application.

In a field experiment at the Dholi farm, 20 varieties of rapeseed mustard were tested for their relative responses to S application in S-deficient soil containing 6.7 mg S kg\(^{-1}\). Of these 20 varieties, nine—RAURD-90-501, RAURD-109, RAURD-102, RAURD-106, RAURD-110, RAURD-105, BR-40, RAURD-104 and RAURD-107—responded at the 20 kg S ha\(^{-1}\) level; whereas, the remaining 11 varieties—RAURD-1001, RAURD-90-502, RAURD-101, Varuna, Kranti, Pusa bold, RAURD-1002, RAURD-103, RAURD-108, RAURD-90-503 and NDR-8501—responded at the 40 kg S ha\(^{-1}\) level. The grain-yield response ranged from 17 to 32 per cent (Sakal et al., 1993).

Sreemannarayana and Sreenivasa Raju (1994) studied the pattern of sulphur uptake by three genotypes of sunflower (Helianthus annuus L.) at four growth stages using \(S\) labelled sources under field conditions on sulphur deficient Vertisol and Alfisols with four doses of sulphur. In case of Alfisol, while there was increase in dry matter yield upto 60 kg S ha\(^{-1}\), with respect to Vertisol, the increase in yield was recorded only upto 40 kg S ha\(^{-1}\). Sulphur content of plants increased with S application through different sources viz., gypsum, ammonium sulphate and superphosphate and decreased with progress in plant growth.
Sulphur application increased S uptake by sunflower at star, bud, flowering and maturity stages. The ratio of S uptake from native to applied source indicated preferential absorption of soil sulphur at all levels of applied S. The efficiency of native source of S was high at all the growth stages.