CHAPTER - II
REVIEW OF LITERATURE

The adequate phosphorus and sulphur nutrition is necessary for satisfactory yield of pulse crop. Their deficiency can limit the growth and yield. The requirement of both P and S has been found to vary with kind of pulse crop and also type of soil. An attempt has been made in this chapter to review the available literature on P and S nutrition of chickpea and other legume crops, which presented under different headings as mentioned below:

2.1 EFFECT OF PHOSPHORUS
2.1.1 Plant growth and yield attributes
2.1.2 Quality, Content and uptake of nutrients
2.1.3 Available soil nutrients after harvest of crop

2.2 EFFECT OF SULPHUR
2.2.1 Plant growth and yield attributes
2.2.2 Quality, Content and uptake of nutrients
2.2.3 Available soil nutrients after harvest of crop

2.3 COMBINED EFFECT OF PHOSPHORUS AND SULPHUR

2.4 ECONOMICS

2.1 EFFECT OF PHOSPHORUS
2.1.1 Plant growth and yield attributes:

Thiyageshwari and Perumal (2000) concluded that the significant results of phosphorus on yield of blackgram are due to the stimulatory effect of phosphorus on growth, flowering and grain formation. The increase in grain yield due to P application is a consequence of increased number of pods/plant and test grain weight by these treatments. Sole application of tunisia rock phosphate recorded significantly lower yield compared to SSP applied alone and with vermicompost and phosphobacteria.

Shivakumar et al. (2001) reported that application of 30 and 60 kg P₂O₅ ha⁻¹ showed significant increase in growth attributes, nodulation, yield attributes and yield as compared to no phosphorus application. The moisture status in the soil determined the optimum dose of phosphorus needed for greengram. The combination of BBF sowing and application of 60 kg P₂O₅ ha⁻¹ recorded the highest grain yield among all
the combinations of land configuration and phosphorus levels.

Higher dry matter production and higher grain yield were obtained from greengram when greengram was grown after the harvest of hybrid cotton (TCHB 213) when cotton was applied with mussoorie rock phosphate (MRP @ 100 % PP) requirement enriched with FYM + phosphobacteria application + application of 100 per cent recommended phosphorus to greengram as single superphosphate (SSP). However, higher benefit : cost ratio was observed when greengram was grown after the harvest of hybrid cotton, when cotton was manured with 100 percent P$_2$O$_5$ requirement through MRP enriched with FYM + phosphobacteria + 50 per cent P$_2$O$_5$ requirement through SSP to greengram. (Jayaramasoundari et al., 2003).

The highest grain yield (12.49 q/ha), grains pod$^{-1}$ (13), test weight (42 g) and maximum number of nodules (36) of greengram were recorded with the application of *Rhizobium* and PSB + P$_2$O$_5$ @ 75 kg/ha + poultry manure at 5 t/ha. (Yadav et al., 2007).

Singh et al. (2008) showed that Significantly highest seed yield of 651 kg ha$^{-1}$ was recorded due to application of 40 Kg P$_2$O$_5$ ha$^{-1}$ through DAP with PSB in black gram. The increase in seed yield was attributed mainly due to increase in nodulation, plant height, branches per plant, leaves per plant and pods plant$^{-1}$.

Basir et al. (2008) reported that the application of P at 60 P$_2$O$_5$ kg ha$^{-1}$ resulted in maximum grain yield of chickpea and that application of P beyond 60 kg was unnecessary.

Ali et al. (2010) revealed that Chickpea genotypes 97086 and 98004 remained at par giving higher seed yield than other genotypes. Fertilizer dose of N: P$_2$O$_5$ @ 24:60 kg ha$^{-1}$ proved to be the best for increasing chickpea yield under Faisalabad conditions.

Phosphorus had significant influence on growth characters, yield attributing traits, seed and stalk yield in chickpea. The grain and straw yield increased with increasing dose of P$_2$O$_5$ up to 60 kg ha$^{-1}$. 60 kg P$_2$O$_5$ ha$^{-1}$ produced significantly higher seed yield (1761 kg ha$^{-1}$) and stalk yield (2754 Kg ha$^{-1}$) as compared to control and other treatments (Nawange et al., 2011).

Sheikh et al. (2012) observed that all the attributes under study were highly influenced by the *Rizobium* and Phosphate Solublizing Bacteria (PSB) along with nitrogen and phosphorus applied @ 10 kg ha$^{-1}$ and 25 kg ha$^{-1}$, respectively; implying the application of dual doses of biofertilizers helpful in combination with inorganic
nutrient application in overall enhancement of yield of blackgram.

Kumar et al. (2013) reported that significantly maximum plant height, no. of leaves per plant, no. of branches per plant, no. of nodules per plant, no. of flowers per plant and dry weight per plant in greengram were obtained from RDF 85 %, DAP 2 % foliar spray and combination of RDF 85 % with DAP 2 % foliar spray.

Karaman et al. (2013) showed that evaluation of phosphorus (P) efficient chickpea cultivars with and without Rhizobium inoculation will provide considerable genetic resources for sustaining the yields and quality with reduced P application under the P deficient conditions on agricultural fields and results that P treatments with and without Rhizobium inoculation greatly affected the P Efficiency Index (EI) and P utilization performance of chickpea cultivars.

Moinuddin et al. (2014) showed that in chickpea phosphorus application improved all the growth and physiological attributes studied compared to no P application (P0), with P30 and P60 being statistically equal in most cases. Application of N and P biofertilizers increased the values of most of the parameters studied significantly compared to no biofertilizer application (BF0).

Kadam et al. (2014) revealed that yield attributes viz., dry matter plant⁻¹, no. of pods plant⁻¹, pod yield (g) plant⁻¹, seed yield (g) plant⁻¹, and test weight (g) of blackgram were significantly influenced by the different levels of phosphorus. Maximum dry matter production plant⁻¹, no. of pods plant⁻¹, pod yield (g) plant⁻¹, seed yield (g) plant⁻¹, and test weight (g) were observed with the application of 75 kg P2O5 ha⁻¹ but was found to be at par with 50 kg P2O5 ha⁻¹.

Dhage et al. (2014) concluded that the application of 60 and 90 kg P2O5 ha⁻¹ increased the seed yield by 22.15 and 28.54 per cent over control. Whereas, application of 90 kg P2O5 ha⁻¹ significantly increased the straw yield of 4909.8 kg ha⁻¹ over rest of the treatments in soybean crop. The significant increased in seed and straw yield might be due to increased supply of phosphorus to plant in P deficient soil.

Neenu et al. (2014) concluded that for production of optimum chickpea seed yield, phosphorus application of 60 P2O5 kg ha⁻¹ is sufficient. Phosphorus application above 60 kg ha⁻¹ increased the in phosphorus content.

In kharif greengram application of phosphorus @ 40 kg ha⁻¹ recorded significantly higher plant height, number of branches plant⁻¹, number of root nodules plant⁻¹, number of pods plant⁻¹, pod length, number of seeds pod⁻¹, seed yield plant⁻¹, seed yield, stover yield and maximum harvest index, over the application of 20 and 0
kg ha\(^{-1}\) phosphorus. (Parmar et al., 2014).

The application of 40 kg ha\(^{-1}\) P\(_2\)O\(_5\) produced significantly highest grain (7.07 q ha\(^{-1}\)), straw yield (13.49 q ha\(^{-1}\)) and dry matter yield (20.56 q ha\(^{-1}\)) over other levels of phosphorus. Further application of phosphorus upto 60 kg ha\(^{-1}\) showed declining effect on grain, straw and dry matter yield of summer green gram. (Kadam and Khanvilkar, 2015).

On the basis of seed yield ha\(^{-1}\), the phosphorus application at the rate of 55 kg ha\(^{-1}\) ranked first with 72.98 % germination, taking 75.50 days to flowering, 44.50 pods plant\(^{-1}\), 49.33 seeds plant\(^{-1}\), 1.38 cm pod length, 415.80 g seed index and 1691.21 kg ha\(^{-1}\) seed yield of chickpea. Phosphorus level of 45 kg, 35 kg, 25 kg and 15 kg ha\(^{-1}\) categorically ranked 2nd, 3rd, 4th and 5th in almost all the studied traits. However, least performance was resulted by the crop receiving no phosphorus (Shabeer, 2015).

Hussena et al. (2015) revealed that phosphorus levels significantly affected plant height, number of branches per plant and number of pods per plant in chickpea. The maximum plant height (39.25 cm) was recorded from plots received 60 kg P\(_2\)O\(_5\) ha\(^{-1}\), while the minimum plant height (32.5 cm) was recorded from the control. Similarly higher number of branches per plant was recorded from the same treatment. The maximum number of pods per plant (49) was observed from the application of 60 kg P\(_2\)O\(_5\) ha\(^{-1}\). Generally the results revealed that the application of 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) better performance in all of the parameters studied.

Hussena et al. (2015) indicated that the application of phosphorus fertilizer had significantly affected all of the parameters; plant height, number of branches per plant and number of pods per plant of chickpea. The application of P\(_2\)O\(_5\) @ 60 kg ha\(^{-1}\) had result better performance in all of the parameters studied.

Kadam and Khanvilkar (2015) revealed sowing of green gram at medium row spacing of 30 x 15 cm produced significantly highest grain, straw and dry matter yield. Application of phosphorus at 40 kg per hectare affected significantly all yield attributes and produced significantly more grain, straw and total dry matter yield of greengram.

The highest seed and straw yields of chickpea were recorded with 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) from SSP with VAM (T\(_8\)) and was at par with 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) from SSP alone (T\(_4\)), 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) from rock phosphate (RP) alone (T\(_3\)) and 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) from RP + VAM (T\(_9\)). The increase in chickpea yields were the results of increased growth and yield attributes viz., plant height, number of branches per plant, dry matter
accumulation, number of pods per plant, pod weight per plant, number of grains per plant and 100 seed weight also these all growth and yield attributes were found in accordance with the trend of chickpea yield. (Chaudhary et al., 2016)

P fertilization at 40 and 60 kg ha$^{-1}$ significantly increased the yield components viz., pods plant$^{-1}$, grains pod$^{-1}$, grains plant$^{-1}$, grain yield plant$^{-1}$, 100 grain weight, grain yield, haulm yield and biological yield. The application of sulphur at 20 and 40 kg ha$^{-1}$ significantly influenced the yield parameters. Seaweed sap sprays at 10% significantly enhanced the yield attributes and yield of chickpea. (Yadav et al., 2016).

2.1.2 Quality, Content and uptake of nutrients:

Prasad and Sonaria (1984) found that P content of Bengal garam seed and straw increased with P application.

Mahajan et al. (1985) reported that in gram, the P uptake significantly increased with increasing soil and fertilizer P$_2$O$_5$ rates from 0 to 90 kg ha$^{-1}$. It was also revealed that the percent utilization of fertilizer P decreased significantly with increasing P levels and fertilizer status of soil.

Kothari and Saraf (1987) reported that the P application markedly increased the uptake of P and K in green gram and sorghum grown in sequence.

In blackgram phosphorus uptake at each growth stage indicated that the uptake in control treatment was least and it was maximum when TRP (tunisia rock phosphate) was applied with V (Vermicompost) and PB (phosphobacteria). TRP at different levels when applied alone did not influence P uptake markedly when compared to SSP. TRP (100 %) with V and PB increased P uptake from 5.49 vegetative stage to 18.59 mg plant$^{-1}$ at post harvest stage and this was on par when TRP at 75 per cent levels were applied in combination with V and PB. The lower uptake in rock phosphate treatments may be due to relatively low P content. However, rock phosphate performed better when applied with PB, indicating the beneficial effect of PB. (Thiyageshwari and Perumal., 2000).

Basavaraj and Manjunathaiah (2003) resulted that residual application of P enriched poultry manure with P levels significantly increased the yield of bengal gram. The increase in yield over no organic manures was 118.92 per cent. Residual application of P enriched poultry manure along with HRDF-P has produced yield equivalent to that of RDF-P alone. Higher uptake of phosphorus by bengal gram was registered due to increased availability of phosphorus.
Yaka et al. (2004) reported that 20 kg N + 60 kg P$_2$O$_5$ ha$^{-1}$ recorded maximum dry matter production, N and P uptake. Higher seed and haulm yield. Increasing the levels of nitrogen from 20 to 60 kg/ha did not show any benefit. In general, seeds removed more nitrogen and phosphorus than haulms in greengram during two years.

With increasing in level of S from 0 to 10 and 10 to 20 kg ha$^{-1}$, P and S content in grain and straw were increased significantly. Similarly P and S contents were increased significantly with increasing levels of phosphorus from 0 to 20 and 20 to 40 kg P$_2$O$_5$ ha$^{-1}$. The combined application of 40 kg P$_2$O$_5$ ha$^{-1}$ and 20 kg S ha$^{-1}$ significantly increased P and S content in grain and straw in clusterbean (Yadav, 2011).

Bhatt et al. (2013) concluded that levels of phosphorus @ 40 kg P$_2$O$_5$ ha$^{-1}$ + PSB standing statistically at par with 40 kg P$_2$O$_5$ ha$^{-1}$ recorded significantly higher seed (1099 kg ha$^{-1}$) and stover yield (2301 kg ha$^{-1}$) over PSB only and 20 kg P$_2$O$_5$ with and without PSB. Phosphorus application @ 40 kg ha$^{-1}$ + PSB performed equally as that of P$_2$O$_5$ 40 kg ha$^{-1}$ without PSB, significantly improved the protein content, nutrients content and uptake as well as soil fertility status after harvest the summer greengram crop.

Uddin et al. (2014) reported that phosphorus levels affected the N and P uptake and quality parameters significantly, as indicated by the means across biofertilizer treatments. P$_{30}$ as well as P$_{60}$ resulted in the highest values for N and P uptake as well as for seed protein content. However, P$_{30}$ gave the greatest value for seed carbohydrate content. Thus, P$_{30}$ proved to be the optimum P level, surpassing the P$_0$ (control) by 18.5% in N uptake, by 30.2% in P uptake, by 1.7% in seed protein content, and by 3.4% in and seed carbohydrate content in chickpea.

With increase in P rates from 0 to 30, 30 to 60 and 60 to 90 kg P$_2$O$_5$ ha$^{-1}$, P and S content in grain and straw increased. Similarly P and S content influenced with increasing levels of sulphur from 0 to 20, 20 to 40 and 40 to 60 kg S ha$^{-1}$. The phosphorus content in soybean ranged from 0.39 to 0.575 % in grain and 0.108 to 0.234 % in straw by phosphorus levels and 0.395 to 0.495% in grain and 0.150 to 0.1875 in straw by sulphur levels. While, sulphur content ranged from 0.241 to 0.358% in grain and 0.186 to 0.23% in straw by phosphorus levels and 0.227 to 0.346% in grain and 0.181 to 0.237% by varied levels of sulphur.(Dhage et al., 2014).

Neenu et al. (2014) reported that application of 60 kg P$_2$O$_5$ ha$^{-1}$ is sufficient for production of optimum chickpea seed yield. Phosphorus application above 60 kg ha$^{-1}$
increased the in phosphorus content.

Bicer (2014) reported that chickpea cultivars showed low response to phosphorus application, since the chickpea experiment exposed to drought stress due to late sown. Also, phosphorus fertilization completely could not be effective since late sown caused short growing season. Early sown and supply irrigation can be advisable for more effectiveness phosphorus intake in rainfed conditions.

Pingoliya, (2015) reported that increasing P levels increased protein content in grain up to 23.99% in 40 kg P$_2$O$_5$ ha$^{-1}$ over control (19.09%) in chickpea. But in chlorophyll content at par higher in 40 (2.50 mg g$^{-1}$) and 60 kg P$_2$O$_5$ ha$^{-1}$ (2.52 mg g$^{-1}$) over control (2.30 mg g$^{-1}$) and 20 kg P$_2$O$_5$ ha$^{-1}$ (2.38 mg g$^{-1}$).

The application of 100% recommended P along with recommended N and K significantly enhanced the yield of greengram and safflower. However, these results were comparable with application of 50 % P (20 kg/ha to greengram and 12.5 kg ha$^{-1}$ to safflower) + PSB along with recommended dose of N (20 kg ha$^{-1}$ to greengram and 25 kg ha$^{-1}$ to safflower) and K (20 kg ha$^{-1}$ to greengram and 25 kg ha$^{-1}$ to safflower) to greengram and safflower in crop productivity with higher nutrient uptake and apparent nutrient balance. The higher P use efficiency was observed with the application of 50% recommended P to both the crops along with PSB. (Gabhane et al., 2016).

2.1.3 Available soil nutrients after harvest of crop

Akabari et al. (1983) from their incubation study in greengram showed that the availability of olsen`s extractable-P increased with increasing levels of P and moisture in a calcareous soil. The presence of 20 percent of lime decreased the P availability to the extent of 11.3 percent.

Raju and Verma (1984) reported that available N and P in soil improved due to their application as compared to their initial level in bengalgram experiment.

Ghosh (1985) observed that applied P improve fertility status of soil in terms of available sulphur and phosphorus status of soil and also increased uptake of K and Fe by chickpea.

Narwal and Malik (1987) indicated in chickpea experiment that application of nitrogen and phosphorus improved the organic carbon and available P, but deceased the available K status of soil.

The result of Aulakh et al. (1990) revealed that P fertilizer application promoted the availability of native soil P. The deficiency of native S was almost
double that of native P in the soil during soybean experiment.

Maximum available P at all stages of blackgram was recorded by the combination of TRP (tunisia rock phosphate 100%) with V (Vermicompost) and PB (phosphobacteria) (19.82, 19.65 and 15.01 kg ha\(^{-1}\) at vegetative, flowering and post harvest stages, respectively). Application of V and PB had an impressive effect on available P when compared to TRP alone, trio combination of SSP, V and PB and SSP alone. (Thiyageshwari and Perumal., 2000).

The available P was increased consistently with increasing in level of phosphorus; P content in soil increased from 22.3 kg ha\(^{-1}\) in control to 32.9 kg P\(_2\)O\(_5\) ha\(^{-1}\) with application of 40 kg P\(_2\)O\(_5\) ha\(^{-1}\). Application of S did not affect the available P significantly in the soil but it tends to increase with increasing level of sulphur. Application of S significantly increased the available S content in the soil and increase was 56 and 24 % with the application of 20 kg and 10 kg S ha\(^{-1}\) over control. (Yadav, 2011).

Islam et al. (2013) studied about phosphorus effect on chickpea at two location in Pakistan. Phosphorus application resulted in decline in soil N balance from 4 to -10 kg ha\(^{-1}\) at Chakwal and from -6 to -26 kg ha\(^{-1}\) at Talagang. This was mainly due to increase in N removal by plants as a result of increase in dry matter yield. Although there was increase in amount of N fixed, yet it could not match plant N uptake, resulting in increase in N deficit in soil with P application.

Dhage et al. (2014) showed that the available nitrogen numerically increased with increase in rates of P, S application in the soil up to 60 kg P\(_2\)O\(_5\) and 60 kg S ha\(^{-1}\), N content increased from 102.28 in control to 108.99 kg ha\(^{-1}\) and from 92.48 in control to 106.08 kg ha\(^{-1}\) with application of 60 kg P\(_2\)O\(_5\) and 60 kg S ha\(^{-1}\), respectively in soybean.

2.2 EFFECT OF SULPHUR

2.2.1 Plant growth and yield attributes:

Shinde (1983) observed 15 percent increase in blackgram yield with 25 ppm S in a pot culture trial conducted on black cotton soil. Upadhyay and Singh (1991) also found that S application significantly increased the grain yield of blackgram grown in inceptisol.

Tiwari et al. (1985) found that the grain yield of chickpea, lentil and pea significantly increased with the application of 60 and 120 kg S ha\(^{-1}\) as pyrites.

Chu et al. (1989) reported that the application of 0.67 g ammonium sulphate +
0.17 g potassium chloride/kg soil significantly increased yields of soybean.

Rehm (1990) reported that the application of 10 lb S was adequate for optimum seed yield at 3 of 4 sites, had no significant effect on DM (dry matter) yield at any site.

Hari and Dwivedi (1992) observed that seed yield of chickpea was improved by application of 40 kg S ha\(^{-1}\) through gypsum as a source of sulphur.

An Experiment conducted at Coimbatore, Tamilnud and concluded that the application of 43 kg S ha\(^{-1}\) increased the seed yield of blackgram (Kasturi et al., 1992).

The results of experiment conducted by Sharma et al. (1993) at Faizabad (Uttar Pradesh) on silty loam soil during the summer season of 1989-90 and observed the highest seed yield of 1.28 t ha\(^{-1}\) of chickpea with application of 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) + 40 kg S ha\(^{-1}\).

Joseph and Verma (1994) conducted an experiment on chickpea at Banaras (UP). They found that application of S at 40 kg ha\(^{-1}\) significantly increased pods per plant (48.98), seed weight per plant (15.41g), stover yield (34.98 q ha\(^{-1}\)) and finally seed yield (22.47 q ha\(^{-1}\)) over 20 kg S ha\(^{-1}\).

Naidu and Ram (1996) observed that dry weight of nodule was highest with 60 kg S + inoculation with USDA-346, but seed yield was highest with 40 kg S + seed inoculation with USDA-346 in greengram.

Saraf et al. (1997) conducted an experiment on chickpea at I.A.R.I. New Delhi. They found that significantly higher seed yield (9.7 q ha\(^{-1}\)) was noted due to 40 kg S ha\(^{-1}\).

Teotia et al. (2000) reported that highest seed and straw yield of moongbean were recorded in the treatment receiving 80 kg S ha\(^{-1}\).

An experiment conducted at Panthnagar, India, by Teotia et al. (2001) and revealed that application 40 kg S ha\(^{-1}\) of soil increases seed in moongbean.

Pandey et al. (2002) found that an application of sulphur up to 20 mg kg\(^{-1}\) in pot experiment significantly increased yield of chickpea.

An experiment carried out by Singh et al. (2003) at Sehore (Madya Pradesh) on chickpea. They reported that application of 40 kg S ha\(^{-1}\) significantly increased plant height.

Maurya et al. (2004) reported that plant height and number of branches increased with increasing rates (40 to 60 kg ha\(^{-1}\)) of S in chickpea and also increased
leaf area index, dry weight per plant, seed yield, stover yield, harvest index of chickpea with increasing rates of S.

Singh and Yadav (2004) concluded that the yield and yield components except pod length and seed per pod increased with increasing S rates up to 30 kg ha$^{-1}$ in green gram.

Mondal et al. (2005) reported that dry matter accumulation at harvest, number of pods per plant, test weight and seed yield of chickpea increased significantly with the application of higher doses of both potassium (60 kg ha$^{-1}$) and sulphur (40 kg ha$^{-1}$) as compared to without potassium and sulphur applications. The highest seed yields of 1.163 t ha$^{-1}$ and 1.252 t ha$^{-1}$ were obtained during 1998 and 1999 respectively with 60 kg K ha$^{-1}$, which were significantly higher than without potassium.

It was noticed from a field experiment conducted at Kanpur (Uttar Pradesh), that successive higher fertilizer application levels (26.2 kg P and 40 kg S ha$^{-1}$) were effective in increasing nodulation and yield of green gram. (Ganeshamurthy et al., 2005).

Srivastava et al. (2006) reported that the combined application of Rhizobium inoculation along with 30 kg S ha$^{-1}$ and 5 kg Zn ha$^{-1}$ produced significant influence in respect of plant height, number of nodules per plant, number of pods per plant and number of grains per pod of greengram.

At Haryana, Karwasra et al. (2006) carried out field trial during kharif season of 2000 and 2001; the results revealed that the application of 50 kg P$_2$O$_5$ and 40 kg S ha$^{-1}$ significantly influenced the plant height, number of branches plant$^{-1}$ and pods per plant of greengram.

An investigation was carried out at West Bengal by Mitra et al. (2006) and found that the application of 60 kg P$_2$O$_5$ and 40 kg S ha$^{-1}$ fertilizers produced significantly higher yield, number of pods per plant and number of seeds per pod of greengram.

Bharathi and Poongothai (2008) found that 35 kg S ha$^{-1}$ application increased yield attributes and seed yield in chickpea.

Goyal et al. (2010) reported that application of higher fertilizer dose 30 kg N ha$^{-1}$ + 60 kg P$_2$O$_5$ ha$^{-1}$ + 60 kg K$_2$O ha$^{-1}$ + 40 kg S ha$^{-1}$ was recorded significantly higher growth and yield attributes, seed and stover yield of chickpea compared to lower fertility level 20 kg N ha$^{-1}$ + 40 kg P$_2$O$_5$ ha$^{-1}$ + 20 kg K$_2$O ha$^{-1}$ + 20 kg S ha$^{-1}$.
Higher grain yield with higher fertilizer dose must be the contribution of higher pods plant$^{-1}$ and seed yield plant$^{-1}$.

Srinivasa et al. (2010) conducted field investigation on Typicustochrept soil during rabi season of 2000-04 at Indian Institute of Pulse Research, Kanpur and the reported that significant increase in seed and stover yield as well as harvest index in chickpea by application of sulphur.

Field investigation carried during rabi seasons of 2000-04 at Indian Institute of Pulse Research, Kanpur. Srivasa et al. (2010) and found that application of 40 kg S ha$^{-1}$ significantly increased the number of nodules per plant and nodules dry weight in chickpea.

Surendra and Katiyar (2010) reported that the application of 40 kg S ha$^{-1}$ significantly increased the plant height, number of branches, number of nodules per plant, number of pods per plant of chickpea.

Rahman et al. (2011) reported that addition of S at the rate of 5 t ha$^{-1}$ recorded superior total dry matter (TDM) and growth of chickpea in Al Zaid than Al Semaih soils.

An experiment was conducted at Lakhati by Kumar et al. (2012) and result found that the application of 56 kg S ha$^{-1}$ increase the seed yield and productivity in blackgram.

Bhatt and Jain (2012) reported that graded levels of sulphur up to 45 kg S ha$^{-1}$ had significant effect on chickpea plant height. However, growth rate during 30-40 DAS responded significantly up to application of 15 kg S ha$^{-1}$ only, and during 40-60 DAS stage, application of 45 and 60 kg S ha$^{-1}$ significantly improved.

Patel et al. (2013) found that application of 40 kg S ha$^{-1}$ recorded significantly maximum seed (1486.08 kg ha$^{-1}$) and stover yield (2161.79 kg ha$^{-1}$) of greengram.

Kim et al. (2013) found that when 40 kg S ha$^{-1}$ is applied, it can be taken up by chickpea in greater quantities that are needed for increasing or maintaining seed yield.

Muhammad et al. (2013) found that seed yield of chickpea in response to application of different levels of sulphur (0, 15 & 30 kg S ha$^{-1}$) from two sulphur sources (gypsum & ammonium sulphate) in different combinations. Application of 30 kg S ha$^{-1}$ should be applied in order to maximize yield and profit from chickpea crop under rainfed conditions.
Bohra (2014) reported that increasing level of sulphur application up to 50 kg S ha\(^{-1}\) had a marked effect on all the yield attributes and yield of chickpea.

Patel et al. (2014) studied application of sulphur with rate of 20 kg S ha\(^{-1}\) gave maximum grain (807 kg ha\(^{-1}\)) and stover yields (1996 kg ha\(^{-1}\)). Sulphur besides improving vegetative growth it activates certain photolytic enzymes and co-enzymes. Thus, these bio-activities of sulphur might have played important role in improving yield attributing characters and total yield of chickpea.

Kumar et al. (2014) found that fertilizer dose at 50 kg S ha\(^{-1}\) gave significantly higher plant height of chickpea.

2.2.2 Quality, Content and uptake of nutrients:

Singh and Ram (1992) carried out an experiment at Varanasi (U. P.) on chickpea. They recorded the content and uptake of Mn in seed and stover whereas, maximum crop yield as well as content and uptake of Cu, Zn, and Fe in seed and stover were observed at 60 kg applied S ha\(^{-1}\), and thereafter at 120 kg S ha\(^{-1}\), they were decreased.

Naidu and Ram (1996) found highest protein content with application of 40 kg S + seed inoculation with *R. Leguminosarum phaseoli*.

Das et al. (1999) study on Sulphur helps towards conversion of nitrogen into protein in pulse crops. Sulphur also improves the S containing amino acid in crop and thus enhances the protein content.

Sakal et al. (2000) reported that by application of 40 kg S ha\(^{-1}\) level the crude protein content was significantly increased to the tune of 23.5 to 24.3% in chickpea seed.

Majumdar et al. (2001) also recorded that application of sulphur up to 60 kg ha\(^{-1}\) significantly increased nitrogen, phosphorus and sulphur uptake by grain and straw of soybean over control.

Monda (2001) reported that the application of potassium @ 60 kg ha\(^{-1}\) along with sulphur @ 40 kg ha\(^{-1}\) significantly increased uptake of potassium by chickpea and he also reported that application of potassium @ 25 kg ha\(^{-1}\) along with sulphur @ 40 kg ha\(^{-1}\) significantly increased protein content in chickpea.

Pandey et al. (2002) showed that by application of sulphur up to 20 mg/kg significantly increased sulphur content, sulphur uptake and the response to applied sulphur was greater in soils with low content of available sulphur (<10 mg kg\(^{-1}\) soil) than in soils with high content of available sulphur (>10 mg kg\(^{-1}\)).
Kalaiyarasan *et al.* (2003) found that application of S significantly increased the nutrient uptake over the control. Application of 45 kg S ha$^{-1}$ registered maximum uptake of N (142 and 144 kg ha$^{-1}$), P (16.0 and 16.5 kg ha$^{-1}$), K (112.6 and 116.9 kg ha$^{-1}$) and S (14.6 and 15.1 kg ha$^{-1}$) during 1999 and 2000, respectively, being at par with sulphur applied by SSP at 30 kg ha$^{-1}$.

XieRui *et al.* (2003) reported that S fertilizer application significantly increased the N, P, K, S and micro-element contents in the seed of chickpea and also reported that 30 kg S ha$^{-1}$ fertilizer application significantly increased the protein, fiber, amino acid, soluble sugar, crude fat, proportion of amylopectin in starch and starch content was increased in chickpea.

An experiment carried out by Singh *et al.* (2003) at Sehore (M. P.) on chickpea. They reported that application of 40 kg S ha$^{-1}$ significantly increased protein content of seed as compared to control and found statistically at par with 20 kg S ha$^{-1}$.

Maurya *et al.* (2004) reported that protein content significantly increased with increasing rates of S in chickpea.

Chiaiese *et al.* (2004) suggested that free methionine and O-acetylserine (OAS) acted as signals that modulated chickpea seed protein composition in response to the variation in sulphur demand, as well as in response to variation in the nitrogen and sulphur status of the plant.

Mondal *et al.* (2005) revealed that maximum protein content in the seeds of chickpea (23.25 %) was obtained with 25 kg K ha$^{-1}$ ($K_2$) with 40 kg S ha$^{-1}$ ($S_2$).

At Haryana, Karwasra *et al.* (2006) carried out field trial in during *rabi* seasons of 2000 and 2001, results revealed that application of 50 kg P$_2$O$_5$ and at 40 kg S ha$^{-1}$ significantly influence the 1000 seed weight. It was highest with the application of 40 kg S ha$^{-1}$ in greengram.

An investigation was carried out at West Bengal, by Mitra *et al.* (2006) and found that the application of P$_2$O$_5$ at 60 kg ha$^{-1}$ and S at 40 kg ha$^{-1}$ produced significantly highest 1000 seed weight of greengram.

The results obtained by Kumar and Rana (2007) on pigeon pea-green gram intercropping system at New Delhi during rainy season of 2004 and 2005, the maximum nutrient uptake by greengram recorded under application of 40 kg P$_2$O$_5$ ha$^{-1}$ + 25 kg S ha$^{-1}$ + phosphate solubilizing bacteria (PSB).

Bharathi and Poongothai (2008) found that 40 kg S ha$^{-1}$ application increased,
nutrient uptake in chickpea.

Kaya et al. (2009) found that applications of elemental 20 kg S ha\(^{-1}\) and S-containing waste resulted in increase nutrient concentrations bean crop. In addition S-containing waste could be used as an alternative to elemental S for improvement of plant nutrition in calcareous soils.

Rahman et al. (2011) reported that addition of S at the rate of 5 t ha\(^{-1}\) (gypsum) recorded superior total dry matter (TDM) and growth of chickpea in Al Zaid than Al Semaih soils. Total dry matter accumulation and nutrient uptake had positive correlation, while soil pH showed negative correlation with TDM.

Bhatt and Jain (2012) reported that sulphur fertilization up to 45 kg ha\(^{-1}\) significantly increase the total nitrogen, sulphur and zinc uptake of chickpea.

Poonia et al. (2013) found that application of sulphur at 40 kg ha\(^{-1}\) through gypsum significantly increased the nitrogen, phosphorus, potash, sulphur and micro-nutrients uptake by chickpea crop over control.

Jawahar et al. (2013) concluded that application of S @ 40 kg ha\(^{-1}\) recorded highest growth (plant height, leaf area index, chlorophyll content, dry matter production and number of branches plant\(^{-1}\)), yield components (number of pods plant\(^{-1}\) and number of seeds pod\(^{-1}\)) and yield (grain and haulm) of blackgram. This study showed that supplementation of sulphur as gypsum significantly increased the growth and yield of blackgram.

Upadhyay (2013) reported that increased doses of sulphur 30 to 50 kg ha\(^{-1}\) significant increase in protein content of lentil.

Patel et al. (2014) revealed that application of sulphur @ 40 kg S ha\(^{-1}\) were gave higher protein content of chickpea.

2.2.3 Available soil nutrients after harvest of crop

Singh and Kumar (1982) noticed that application of elemental sulphur significantly increased availability of S in red sandy loam soil with low in available SO\(_4\)-S at Rajendranagar, Hyderabad.

Reddy and Sreenivasa (1986) reported that the S availability in soil significantly increased up to 30 ppm S applied through elemental S.

Ramkala and Gupta (1999) reported that increasing sulphur levels 20 kg ha\(^{-1}\) to 40 kg ha\(^{-1}\) increased availability of N and S in the soil after harvest of chickpea.

A study was conducted at JNKVV, Jabalpur by Sasode (2002). They found that application of 30 kg S ha\(^{-1}\) through various sources of sulphur could not
significantly influenced the available nitrogen status of soil however, sulphur application through ammonium sulphate fixed 10 kg ha\(^{-1}\) more available N in mungbean.

Sankaran et al. (2002) reported that application of S up to 45 kg ha\(^{-1}\) to groundnut improved available S status of soil as compared to its initial status.

Singh and Mann (2007) found that application of S at 60 kg ha\(^{-1}\) significantly increased the available S status at harvest stage of groundnut in the soil.

Kaya et al. (2009) found that applications of elemental S and S-containing waste in bean increase in residual available nutrient concentration in the experimental soils.

Sakarvadia et al. (2009) found that soil availability of S and K was increased significantly in pigeon pea with increased level of application of 40 kg S & 50 kg K\(_2\)O ha\(^{-1}\) respectively.

Bhatt and Jain (2012) reported that by application of optimum levels of 45 kg S ha\(^{-1}\) the S status after harvest of chickpea significantly increases.

Muhammad et al. (2013) conducted field experiment in which three levels of sulphur (0, 15 and 30 kg ha\(^{-1}\)) from two sulphur sources (gypsum and ammonium sulphate) were taken and reported that higher level of nutrient (30 kg S ha\(^{-1}\)) should be applied to chickpea in order to maintain soil fertility status.

A field experiment was conducted by Meena and Ram (2013), they observed that the application of RDF + 60 kg K ha\(^{-1}\) + 40 kg S ha\(^{-1}\) + 5 kg Zn ha\(^{-1}\) along with seed inoculation with *Rhizobium* + PSB + 2 % urea spray at 70 DAS recorded higher available organic carbon (0.65 %), nitrogen (312 kg ha\(^{-1}\)), phosphorus (12.7 kg ha\(^{-1}\)), potassium (413 kg ha\(^{-1}\)), sulphur (20.2 kg ha\(^{-1}\)) and zinc (1.37 kg ha\(^{-1}\)) contents in the soil over rest of the treatments after harvest of chickpea.

Patel et al. (2014) reported that 40 kg S ha\(^{-1}\) in chickpea, after harvest soil was low in organic matter and available nitrogen, medium in available phosphorus and high in potassium and sulphur.

**2.3 COMBINED EFFECT OF PHOSPHORUS AND SULPHUR**

Patil et al. (2011) concluded that application of phosphorus 50 kg ha\(^{-1}\) was optimum to harvest maximum yield of greengram and sulphur application @ 40 kg ha\(^{-1}\) was beneficial to increase growth and yield of greengram while there was no positive effect of phosphorus and sulphur interaction on growth and yield of greengram.
Yadav (2011) concluded that applied P and S increased in nitrogen and protein contents. Available P in soil was increased with increasing levels of phosphorus. Similarly available S in soil was increased with increasing levels of sulphur. The synergistic effect of phosphorus and sulphur was reported on number and weight of nodules per plant, N, P, S and protein content of clusterbean.

Islam et al. (2012) revealed that application of P and S resulted in significant increase in seed yield of chickpea. Interaction between P and S was positive at both lower and higher rate of nutrient application. They also reported that Sulfur application resulted in a significant increase in micronutrient uptake by plant; however effect of sulfur application on soil pH at the end of experiment was not significant. Availability of soil zinc and copper increased with sulfur application at the end of two year experiment.

Shukla et al. (2013) reported that amongst the foliar spray nutrients, DAP (2%) and N20, P50, K20, S20 as basal, when applied separately or in combination, resulted in highest growth parameters, chlorophyll content, grain yield, grain protein and net income from the rainfed chickpea cv. JG 315. Thus, the combined input of DAP (2%) x N20, P50, K20, S20 gave maximum grain yield of 17.23 q ha\(^{-1}\), grain protein 23.13\% and net income up to Rs. 51,201 ha\(^{-1}\). The net income was higher by Rs. 32457 ha\(^{-1}\) over the absolute control.

Lai et al. (2013) indicated that application of increasing levels of phosphorus and sulfur increased the yield, protein content, nutrient content and nutrient uptake of chickpea. But increase in grain yield, protein content, nutrient content and uptake were found to be significantly up to 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) and 30 kg S ha\(^{-1}\).

Height, number of branches plant\(^{-1}\), number of nodules plant\(^{-1}\), dry weight of nodules plant\(^{-1}\), number of pods plant\(^{-1}\), grain yield plant\(^{-1}\), grain and straw yields. While, maximum improvement in yield attributes was achieved up to application of 20 kg S ha\(^{-1}\). Phosphorus management treatment either through application of 25 kg P\(_2\)O\(_5\) ha\(^{-1}\) or combine application of 25 kg P\(_2\)O\(_5\) ha\(^{-1}\) + PSB gave significant results on growth and yield attributes. Application of 20 kg S ha\(^{-1}\) and 25 kg P\(_2\)O\(_5\) ha\(^{-1}\) + PSB to chickpea recorded maximum grain yield. (Patel et al., 2013.)

Islam et al. (2013a) reported that application of P and S resulted in increased dry matter yield of crop, but at the same time, it resulted in considerable improvement in soil fertility status of soil. Therefore, higher level of P (34 kg ha\(^{-1}\)) and S (30 kg ha\(^{-1}\)) should be applied to chickpea grown under rainfed conditions in order to
maintain soil health and sustainable crop yield.

Islam et al. (2013b) reported that Effect of phosphorus application was non significant while that of sulfur was significant on percent nitrogen derived from atmosphere. Both phosphorus and sulfur application resulted in increase in nitrogen fixation up to 38% and 33% over control, respectively. Nutrient uptake (N, P, and S) increased significantly with the application of phosphorus and sulfur and correlated positively with nitrogen fixation.

Patel et al. (2014) revealed that application of sulphur and phosphorus fertilization with PSB inoculation study in chickpea gave significant effect on yield, protein content, nitrogen content, sulphur content and post harvest soil nutrients status.

Sole chickpea gave significantly higher yield however, yield attributes and quality parameters were not influenced by intercropping system. P and S application influenced significantly the growth attributes, nodulation, leghaemoglobin content, nitrogenase activity, yield components and seed yield (Rana et al., 2014.). Interaction effect of phosphorus and sulphur levels in plant height was higher up to 60 kg P₂O₅ ha⁻¹ and up to 20 kg S ha⁻¹. Similarly the number of primary and secondary branches, biological yield, grain yield and straw yield were increased with doses up to 60 kg P₂O₅ ha⁻¹ and up to 20 kg S ha⁻¹. The best quality of grains of chickpea was obtained with the combined application of 60 kg P₂O₅ ha and 20 kg S ha⁻¹ (Pandey et al., 2016).

2.4 ECONOMICS

In blackgram the applications of 40 kg P₂O₅ ha⁻¹ through DAP along with PSB inoculation resulted in highest seed yield as well as net return per hectare. The higher level of phosphorus through DAP with PSB inoculation brought about the highest net return up to Rs. 2624 ha⁻¹.(Singh et al., 2008).

The highest seed yield 11.18 q/ha, protein yield 2.96 q ha⁻¹, protein content 26.29 %, uptake of 47.26 kg ha⁻¹ N, 5.75 kg ha⁻¹ P, 22.19 kg ha⁻¹ K, 2.73 kg ha⁻¹ S and 85.26 g ha⁻¹ Zn were recorded under ammonium sulphate in two years pooled results, whereas, single superphosphate produced one kilogram seed of greengram at a minimum cost of Rs. 6.57 with highest Benefit Cost Ratio 1: 2.82.(Sasode, 2008.)

The economic return from the use of P and FYM was very similar but the cost benefit ratio of P application (0.0625) is much lesser than the application of FYM (0.185). This was due to the high cost of the FYM as compared to the P fertilizer.
Under these cost scenarios, the farmers are advised to apply P @ 60 kg ha\(^{-1}\) to their chickpea crop for maximum return. (Basir et al., 2008).

Application of 40 kg N ha\(^{-1}\) gave 8.23 per cent higher yield over 20 kg N ha\(^{-1}\). Application of 20 kg S ha\(^{-1}\) significantly increased the seed yield of chickpea and recorded 5.5 per cent increase in seed yield over no sulphur. Phosphorus and *Rhizobium* application did not show any significant effect on seed yield of chickpea. The most productive and economical level of fertilization was 40 kg N and 20 kg S ha\(^{-1}\). (Jakasaniya *et al*., 2012).

Rashid *et al*. (2013) found that gram cultivar Paidar-91 gave the highest yield when cultivated with fertilization of N: P\(_2\)O\(_5\): K\(_2\)O @ 25: 50: 0 kg ha\(^{-1}\) and exceeding above this combination was found to be uneconomical.

Shukla *et al*. (2013) reported that amongst the foliar spray nutrients, DAP (2\%) and N\(_{20}\), P\(_{50}\), K\(_{20}\), S\(_{20}\) as basal, when applied separately or in combination, resulted in highest growth parameters, chlorophyll content, grain yield, grain protein and net income from the rainfed chickpea cv. JG 315. Thus, the combined input of DAP (2 \%) x N\(_{20}\), P\(_{50}\), K\(_{20}\), S\(_{20}\) gave maximum grain yield of 17.23q ha\(^{-1}\), grain protein 23.13\% and net income up to Rs. 51,201 ha\(^{-1}\). The net income was higher by Rs. 32,457 ha\(^{-1}\) over the absolute control.

The application of 75 kg P\(_2\)O\(_5\) ha\(^{-1}\) gave highest gross monetary returns (Rs.46165 ha\(^{-1}\)), net monetary returns (Rs.16923 ha\(^{-1}\)) followed by the application of 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) and 25 kg P\(_2\)O\(_5\) ha\(^{-1}\) in blackgram. This may be due higher economic yield and higher gross monetary return received due to application of 75 kg P\(_2\)O\(_5\) ha\(^{-1}\). The data on benefit: cost ratio it was seen that the application of 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) gave higher on benefit: cost ratio (1.58) than application of 75 kg P\(_2\)O\(_5\) ha\(^{-1}\). It may be due to higher GMR and lower cost of cultivation resulted in higher B: C ratio. (Kadam *et al*., 2014).

Srinivasulu *et al*. (2015) observed that application of S @ 40 kg ha\(^{-1}\) also recorded significantly higher seed yield, net return and B: C ratio and remained at par with 20 kg S ha\(^{-1}\). Similarly interaction between sulphur and irrigation levels, 20 kg S ha\(^{-1}\) and 0.7 IW/CPE has reported higher seed yield, net returns and B: C ratio.