2. REVIEW OF LITERATURE

A brief review related to the research work done on "**Effect of Phosphorus, Sulphur and Seaweed Sap on Productivity of Chickpea (*Cicer arietinum* L.)**'' is presented in this chapter. An attempt has been made to cite all available literature of chickpea but due to paucity of adequate published information on this particular topic, research work on other crops has also been reviewed.

2.1 EFFECT OF PHOSPHORUS

2.1.1 Growth characters

Meena *et al*. (2001a) reported that increasing levels of phosphorus up to 60 kg P_2O_5 ha^{-1} resulted in significant increase in dry matter accumulation in chickpea over 0 and 30 kg P_2O_5 ha^{-1}. Arya *et al.* (2002) observed that growth attributes like plant height and dry matter accumulation per plant were significantly higher with 60 kg P_2O_5 ha^{-1} than 30 and 0 kg P_2O_5 ha^{-1} in chickpea. In an experiment conducted at Jobner on chickpea reported that the fertility level (20 kg N + 20 kg P_2O_5 ha^{-1}) significantly increased the plant height over control and 10 kg N + 20 kg P_2O_5 ha^{-1} whereas, number of branches per plant and dry matter accumulation per plant increased significantly due to 10 kg N + 20 kg P_2O_5 ha^{-1} over control (Khoja *et al*., 2002).

At SKN College of Agriculture, Jobner experiment conducted on sandy loam soils show that the growth attributes of cowpea like plant height, pods per plant, length of pods etc. were greatly improved by the application of phosphorus at 40 kg P_2O_5 ha^{-1} over control (Sharma and Jat, 2003). Singh *et al.* (2003) reported that the application of phosphorus at 40 kg P_2O_5 ha^{-1} significantly increased all growth attributes i.e., plant height, number of branches per plant, dry matter accumulation, dry weight and number of nodules per plant in lentil over 0 and 20 kg P_2O_5 ha^{-1}. Sunder *et al.* (2003) observed that the application of phosphorus at 40 kg P_20_5 ha^{-1} significantly increased the dry matter accumulation per meter row length by 20.57 and 7.81 per cent over control and 20 kg P_2O_5 ha^{-1} respectively in clusterbean.

At Fatehpur-Shekhawati (Sikar), an application of 80 kg P_2O_5 ha^{-1} increased dry matter accumulation of fenugreek at 30, 60 and 90 DAS and at harvest by 22.38, 20.09, 27.74 and 22.72 per cent over the control, respectively and increased plant height at 60 and 90 DAS and at harvest by 19.06, 17.20 and 15.74 per cent over the control, respectively (Jat, 2004).

Jat and Ahalawat (2004) reported that dry matter accumulation per plant and LAI increased significantly with the application of 26.4 kg P ha^{-1} over 0 and 13.4 kg P ha^{-1} in gram. Meena *et al*. (2004) reported that all growth characters of chickpea *viz*., plant height, number of nodules per plant and dry matter accumulation were significantly increased up to 30 kg P_2O_5 ha^{-1}. However, the plant growth at 0-30 kg P_2O_5 ha^{-1} application was considerably higher as compared to 30-60 kg P_2O_5 ha^{-1}.

A field experiment was conducted at IARI, New Delhi by Shivkumar *et al*. (2004) and they reported that the growth attributes *viz*., plant height, branches per plant and dry matter accumulation were increased with increasing level of P_2O_5 up to 80 kg ha^{-1} over control in chickpea. Tripathy *et al*. (2004) reported that the application of nitrogen at 20 kg ha^{-1} and phosphorus 25 kg P_2O_5 ha^{-1} significantly increased primary, secondary and tertiary branches of chickpea at successive growth stage of 40, 85 days after sowing and harvest over control. An application of 60 kg P_20_5 ha^{-1} significantly increased the growth attributes like plant height, dry matter accumulation and pods per plant over control in chickpea (Choudhary and Goswami, 2005).

Dass *et al*. (2005) also reported that the application of phosphorus 75 kg P_2O_5 ha^{-1} significantly increased growth attributes like plant height and dry root weight over control in vegetable pea (*Pisum sativum*). Jat and Ahalawat (2006) carried out a field experiment at Indian Agricultural Research Institute, New Delhi, India. They reported that the application of phosphorus up to 26 kg ha^{-1} to chickpea improved the dry matter accumulation at 30, 60 and 90 DAS and at harvest.

A field experiment conducted at College of Agriculture, Nagpur on linseed reported that the three levels of phosphorus in incremental dose increased the plant height, number of branches per plant and dry matter accumulation and 45 kg P_2O_5 ha^{-1} was the best and superior over 30 and 20 kg P_2O_5 ha^{-1} (Sune *et al.* 2006). Kumar and Singh (2007) conducted an experiment at New Delhi during winter season of 2003-05 and reported that the application of 50 kg P_2O_5 ha^{-1} increased the plant height, number of branches $plant^{-1}$, number of green leaves, nodules $plant^{-1}$ and dry matter accumulation of fenugreek over control.

Experiment on sandy loam soil at Chitrakoot and observed that application of nitrogen at 15 kg ha^{-1} + phosphorus at 30 kg P_2O_5 ha^{-1} significantly increased the growth parameters, *viz*., plant height, dry matter accumulation, branches per plant and seeds per pod over control in chickpea (Kushwaha, 2007). Singh and Prasad (2008) reported that dry matter accumulation and dry weight of nodules in chickpea increased by levels of phosphorus up to 55 kg P_2O_5 ha^{-1}, thereafter increase was not significant.

Singh and Yadav (2008) concluded that the application of 60 kg P_2O_5 ha^{-1} being at par with 45 kg P_2O_5 ha^{-1} recorded maximum plant height, number of primary branches, dry matter per plant, grain yield, stalk yield and uptake of P in pigeonpea over control. At Turkey, application of 80 kg P ha^{-1} to chickpea crop produced highest values of plant height (36.9 and 37.9 cm), number of branches $plant^{-1}$ (2.6 branches $plant^{-1}$ in both years), number of pods $plant^{-1}$ (13.8 and 13.9 pods $plant^{-1}$) and number of seeds $plant^{-1}$ (13.8 and 14.6 seeds $plant^{-1}$) in 2004 and 2005, respectively (Togay *et al*., 2008).

From the results of a field experiment, Ahmed and Badr (2009) concluded that the application of mineral P fertilizer at 46.5 kg P_2O_5 ha^{-1} resulted in significant increase in growth characters in chickpea over control. Kumar *et al*. (2009) reported that application of phosphorus at 50 kg P_2O_5 ha^{-1} significantly increased the branches per plant, number of pods per plant, number of grains per pod, test weight, grain and straw yield in chickpea over control.

Meena *et al.* (2010) observed that the increasing levels of phosphorus up to 30 kg P_2O_5 ha^{-1} significantly increased the growth attributes, *viz.*, plant height, branches per plant, dry matter accumulation and chlorophyll content as compared to preceding levels in mothbean. Singh *et al.* (2010) observed that the application of 20 and 40 kg P_2O_5 ha^{-1} enhanced dry weight of root and shoot over no application of phosphorus in chickpea. Similarly, Thenua *et al.* (2010) reported that application of P as SSP recorded significantly higher plant height, branches per plant and dry matter accumulation in chickpea. Nawange *et al*. (2011) conducted a field experiment during *rabi* 2009-10 to find out the optimum dose of P and S on growth, yield attributes and yield of chickpea. They observed that the application of P_2O_5 up to 60 kg ha^{-1} linearly increased the growth, yield attributes, seed and stalk yields of chickpea. A field experiment was conducted at Ummedganj, Kota (Rajasthan) during the winter seasons of 2008 and 2009 to evolve an effective nutrient management strategy for chickpea and reported that application of P_2O_5 at 40 kg ha^{-1} resulted significantly higher plant height, branches $plant^{-1}$, number of nodules and dry weight of nodules over control (Shivran and Prakash, 2012).

A field experiment was carried out to study the effect of varying levels of phosphorus (T_1=0 kg ha^{-1}, T_2=30 kg ha^{-1}, T_3=60 kg ha^{-1}, T_4=90 kg ha^{-1} and T_5=120 kg ha^{-1}) on growth performance and yield of chickpea (*Cicer arietinum*) variety "Aratiy" at the experimental field of Wollo university, Kelem meda (Ethiopia) during winter season in 2013. The results revealed that phosphorus levels significantly affected plant height, number of branches per plant and number of pods per plant. The maximum plant height (39.25 cm) was recorded from plots that received 60 kg P_2O_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_2O_5 ha^{-1} (Hussen *et al*., 2013). Yadav *et al*. (2013) from Hamirpur, U.P. reported that increasing levels of phosphorus increased plant height, number of branches per plant and dry matter per plant and dry weight of roots of chickpea significantly up to 60 kg P_2O_5 ha^{-1}.

2.1.2 Yield and yield attributes

Chavan and Patil (1998) reported that phosphorus application increased the yield of gram significantly up to 22 kg ha^{-1}. Beyond this the response was not significant in individual years as well as on pooled basis. The maximum seed yield was recorded with the application of 33 kg P ha^{-1}. Choudhary (1999) reported that application of phosphorus to chickpea at 40 kg P_2O_5 ha^{-1} produced significantly higher number of pods $plant^{-1}$, test weight, straw and seed yield (18.86 q ha^{-1}) than 20 kg P_2O_5 ha^{-1}. Kumar *et al.* (2000) reported that increasing rate of phosphorus application (up to 40 kg P_2O_5 ha^{-1}) produced a maximum net income of ₹ 6050 ha^{-1} and benefit cost ratio of 2.24. On loamy sand soils of Jobner, Meena *et al.* (2001a) observed that the application of 40 kg P_2O_5 ha^{-1} significantly increased pods per plant, seeds per pod, test weight, seed and straw yield of chickpea over control.

Meena *et al.* (2001b) in a field experiment on chickpea reported that application of 40 kg P_2O_5 ha^{-1} significantly increased number of pods per plant, number of seeds per pod, test weight, grain and straw yield over control and 20 kg

P_2O_5 ha^{-1}. However, application of 60 kg P_2O_5 ha^{-1} remained at par with 40 kg P_2O_5 ha^{-1}. Singh and Vaishya (2001) reported that the grain yield increased significantly with increasing phosphorus dose and recorded maximum at 60 kg P_2O_5 ha^{-1} over control in chickpea. Tiwari *et al.* (2001) reported that the grain production of chickpea increased with increasing levels of phosphorus *viz.,* 0, 40, 60 kg P_2O_5 ha^{-1} and maximum yield was observed at 60 kg P_2O_5 ha^{-1} which was 23.1 per cent higher over no P application. Arya *et al.* (2002) in a field experiment on chickpea found that application of 60 kg P_2O_5 ha^{-1} significantly increased number of pods per plant, number of seeds per pod, test weight, grain and straw yields over control and 30 kg P_2O_5 ha^{-1}. On sandy loam soils of IARI, New Delhi, Meena *et al.* (2002) found that application of 60 kg P_2O_5 ha^{-1} significantly increased the seed as well as straw yield of chickpea over control (14.49 and 28.19 q ha^{-1}, respectively). The yield also increased with increasing levels of P_2O_5 from 0 to 60 kg ha^{-1}. The maximum seed (20.41 q ha^{-1}) and straw yield (36.61 q ha^{-1}) were recorded with the application of 60 kg P_2O_5 ha^{-1}.

Lakpale *et al.* (2003) reported that application of 25.8 kg P_2O_5 ha^{-1} significantly increased number of pods per plant and higher seeds of gram over control. Application of 25.8 kg P_2O_5 ha^{-1} significantly increased the seed yield over control but remained at par with 12.9 kg P_2O_5 ha^{-1}. Pramanik and Singh (2003) reported that the application of P_2O_5 at 60 kg ha^{-1} significantly increased yield attributes and yield over control in chickpea. Results of field experiment conducted at Mondouri (West Bengal), revealed that the highest seed yield (10.20 q ha^{-1}) and 1000-seed weight (14.44 g) of fenugreek were obtained with application of 60 kg P_2O_5 ha^{-1} with nitrogen over control (Thapa and Maity, 2003).

Ali *et al.* (2004) in a field experiment on chickpea conducted at Agronomic Research Area, University of Agriculture, Faisalabad (Pakistan) during 1999-2000, observed significantly higher 1000-seed weight, seed yield and biological yield (256.10 g, 3088.21 and 7496.99 kg ha^{-1}, respectively) with application of 90 kg P_2O_5 ha^{-1} over control. Jat and Ahalawat (2004) reported that the pods per plant, seed and straw yields of chickpea significantly increased with the application of 26.4 kg P_2O_5 ha^{-1} over 0 and 13.2 kg P_2O_5 ha^{-1}. Meena *et al.* (2004) reported that number of grains per pod, grain weight per plant, test weight and straw yield of chickpea increased significantly up to 60 kg P_2O_5 ha^{-1} over control and 30 kg P_2O_5 ha^{-1}. However, application of 60 kg P_2O_5 ha^{-1} significantly increased the seed yield over control, but remained at par with 30 kg P_2O_5 ha^{-1}. Similarly, Shivkumar *et al.* (2004) also observed that number of grains per pod, grain weight per plant, test weight, grain and straw yield of chickpea significantly increased with each level of phosphorus up to 80 kg P_2O_5 ha^{-1}.

Choudhary and Goswami (2005) reported that the application of phosphorus at 60 and 90 kg P_2O_5 ha^{-1} significantly increased the grain yield of chickpea over control. However, Kumar and Sharma (2005) found that each successive increase in levels of P up to 40 kg P_2O_5 ha^{-1} significantly increased the number of pods per plant, number of seeds per pod, test weight, seed and straw yield of chickpea but found statistically at par with 60 kg P_2O_5 ha^{-1}. Tiwari *et al.* (2005) reported that yield attributes of chickpea like number of pods per plant, test weight, grain and straw yield and harvest index improved significantly with application of phosphorus up to 50 kg P_2O_5 ha^{-1} over 0 and 25 kg P_2O_5 ha^{-1}. Jain *et al.* (2006) in a field experiment on chickpea at Instructional Farm, Rajasthan College of Agriculture, Udaipur found that application of 50 kg P_2O_5 ha^{-1} gave significantly higher seed yield over control.

At Bundelkhand (U.P.) application of 60 kg P_2O_5 ha^{-1} to chickpea produced better yield attributes by a margin of 26.5 and 14.65 grains per plant and 0.64 and 0.32 grains per pod compared to control and 30 kg P_2O_5 ha^{-1}, respectively. The maximum grain yield of chickpea was recorded under the treatment 60 kg P_2O_5 ha^{-1}. The use of 60 kg P_2O_5 ha^{-1} enhanced the grain yield by 3.0 (19.55 per cent) and 1.27 q ha^{-1} (7.26 per cent) compared to the control and the 30 kg P_2O_5 ha^{-1}, respectively (Ram *et al*., 2007).

An investigation was carried out by Singh and Prasad (2008) at Kanpur and they reported that the application of DAP up to 180 kg ha^{-1} increased the grain yield (20.29 q ha^{-1}) and straw (24.69 q ha^{-1}) over control in chickpea. At Turkey, Togay *et al*. (2008) observed that the highest grain yield of chickpea (8.19 q ha^{-1} in 2004 and 8.79 q ha^{-1} in 2005) from application of phosphorus at 80 kg ha^{-1}. Similarly, maximum biological yield was obtained when crop was fertilized with 80 kg P ha^{-1}.

Verma and Singh (2008) observed that grain and straw yield of mungbean significantly increased with the application of phosphorus (0-75 kg P_2O_5 ha^{-1}) along with *Rhizobium* inoculation.

A field experiment was conducted at ARS, Durgapura, Jaipur on chickpea and it was observed that grain and straw yields increased significantly with increasing levels of phosphorus from 20 to 60 kg P_2O_5 ha^{-1}. The per cent increase in grain yield due to phosphorus application varied from 6.5 to 42.9 per cent, whereas the straw yield increased from 12.1 to 34.1 per cent over control. The highest grain (2.34 t ha^{-1}) and straw yield (3.31 t ha^{-1}) was recorded under 60 kg P_2O_5 ha^{-1} (Deo and Khandelwal, 2009).

Dutta and Bandyopadhyay (2009) conducted a field experiment at Sekhampur, West Bengal on *Cicer arietinum* and recorded the highest seed yield (1085 kg ha^{-1}) with 39.3 kg P ha^{-1}. Islam *et al.,* (2009) reported that application of P (40 & 80 kg P_2O_5 ha^{-1}) resulted in significant increase in grain (22 to 35 per cent) over control. A field experiment was conducted by Kumar *et al.* (2009) at Kanpur and they concluded that the application of 50 kg P_2O_5 ha^{-1} significantly increased average grain yield of chickpea over control.

Meena *et al.* (2010) reported that the application of phosphorus at 30 kg P_2O_5 ha^{-1} being at par with 45 kg P_2O_5 ha^{-1} significantly increased the seed yield of mothbean by 57.54 and 15.56 per cent over control and 15 kg P_2O_5 ha^{-1}, respectively. Singh *et al.* (2010) observed that the application of 20 kg P_2O_5 ha^{-1} increased the grain yield in chickpea over no phosphorus application. A field experiment conducted in Punjab, Pakistan revealed that application of phosphorus resulted in significant increase in seed yield at both the locations. Seed and straw yield increased from 0.70 to 0.85 Mg ha^{-1} and from 1.42 to 1.58 Mg ha^{-1}, respectively, as phosphorus rate was increased from 0 to 80 kg P_2O_5 ha^{-1} (Islam *et al.,* 2011). At Phanda Agriculture farm, Bhopal (M.P.), Nawange *et al.* (2011) observed that increased application of phosphorus from 0 to 60 kg P_2O_5 ha^{-1} resulted in linear increase in various yield attributing traits, seed and stalk yield of chickpea. The application of 60 kg P_2O_5 ha^{-1} produced the highest mean seed yield of 1761 (kg ha^{-1}) and stalk yield of 2754 (kg ha^{-1}). Islam *et al.,* 2012b noted that application of phosphorus resulted in significant increase in seed yield of chickpea by 29 per cent over control. The economic optimum dose of phosphorus, as calculated from quadratic response equations ranged from 56 to 58 kg ha^{-1}.

An experiment was conducted at Agricultural Research Station, Kota to evolve a nutrient management strategy for chickpea and it was found that application of P_2O_5 at 40 kg ha^{-1} resulted in significantly higher number of pods $plant^{-1}$, number of seeds pod^{-1} and hence higher seed and straw yield over control. There were non-significant responses in these parameters when phosphorus level further increased from 40 to 60 kg P_2O_5 ha^{-1} (Shivran and Prakash, 2012).

A field experiment conducted on chickpea at Agronomy farm, College of Agriculture, Bikaner revealed that application of 30 kg P_2O_5 ha^{-1} significantly enhanced pods per plant, seeds per pod, test weight, seed yield (1263 kg ha^{-1}) straw yield (3336 kg ha^{-1}), biological yield (4734 kg ha^{-1}) and harvest index over control and 15 kg P_2O_5 ha^{-1}, respectively (Das *et al*., 2013). A field experiment was conducted to find out the effect of bio-fertilizers and phosphorus levels on growth and yield of chickpea and found that significantly higher number of nodules per plant, pods per plant, seeds per pod, test weight, seed yield and straw yield and dry matter accumulation was recorded with the application of 60 kg/ha phosphorus (Meena *et al*., 2013). Yadav *et al*. (2013) at Hamirpur, U.P. reported that increasing levels of phosphorus increased the yield attributes of chickpea (Pods $plant^{-1}$, seeds $plant^{-1}$ and seed weight $plant^{-1}$) and yield (seed and stover) significantly up to 60 kg P_2O_5 ha^{-1}.

2.1.3 Nutrient uptake and quality

Raju *et al.* (1991) reported that increasing levels of phosphorus from 20 to 40 kg P_2O_5 ha^{-1} brought about corresponding significant increase in uptake of N, P and K. Singh and Ram (1992) conducted a field experiment for two years (1981-82 and 1982-83) with chickpea crop and concluded that application of P up to 60 kg P_2O_5 ha^{-1} significantly increased Mn and Fe contents and their uptake in grain and straw, but decreased with further addition of P i.e. 90 kg P_2O_5 ha^{-1}. Contents of zinc and copper decreased linearly with increasing levels of P. However, uptake of zinc and copper by grain and straw increased up to 60 kg P_2O_5 ha^{-1} and with further increase in the level of P, there was an appreciable reduction.

Singh *et al.* (1993) conducted a field experiment and concluded that iron content in grain and straw increased consistently by application of Fe but decreased on P addition (0-100 mg kg^{-1}) in chickpea crop. Enania and Vyas (1994) conducted a field experiment at Udaipur on clay loam soil and revealed that uptake of phosphorus increased significantly up to 50 kg P_2O_5 ha^{-1} and zinc up to 25 kg ha^{-1} in chickpea.

Krishna and Yadav (1997) conducted a field experiment with chickpea and concluded that copper content decreased progressively with increasing doses of phosphorus and accordingly minimum Cu content was obtained at 90 kg P_2O_5 ha^{-1} in both grain and straw. Mn and Fe uptake in both seed and straw increased significantly up to 60 kg P_2O_5 ha^{-1} and thereafter decreased.

Reddy and Ahalawat (1998) reported that the application of 40 kg P_2O_5 ha^{-1} increased N, P, Zn uptake and protein content in chickpea crop. Application of P at 60 kg ha^{-1} significantly increased the N and P content in grain and straw, N and P uptake by grain and straw and protein content in grain over their lower doses in black gram crop (Dadheech, 2001). Meena *et al*. (2001a) reported that the protein content in seeds was significantly higher with the application of 60 kg P_2O_5 ha^{-1} over control in chickpea. Similarly, Patel *et al.* (2001) observed that the application of 40 kg P_2O_5 ha^{-1} gave the maximum grains protein and nutrient uptake was also enhanced significantly due to P levels up to 60 kg P_2O_5 ha^{-1} in black gram. Ram and Dixit (2001) conducted a field experiment at Faizabad, and results showed that the application of phosphorus at 60 kg P_2O_5 ha^{-1} gave significantly higher value of protein content over control in green gram. Tiwari *et al.* (2001) reported increased P uptake due to 40 and 60 kg P_2O_5 ha^{-1} over no P application in chickpea.

Yadav *et al.* (2002) conducted a field experiment during *kharif* season of 1997 with mung bean crop and they concluded that P content and uptake by seed and straw and uptake of micronutrients (Fe, Mn, Cu & Zn) in seed increased significantly with increasing levels of P but decreased the content of Cu and Zn in seed and straw. Mishra (2003) conducted a field experiment at Bulandshahar (U.P.) and concluded that phosphorus markedly improved the quality of cowpea in terms of protein yield in seeds with increasing levels of phosphorus from 0, 30, 60, and 90 kg ha^{-1}. A similar trend was notified for protein yield in stover and total production. A field experiment was conducted by Pramanik and Singh (2003) at IARI, New Delhi and they reported that the application of phosphorus significantly increased the P uptake up to 60 kg P_2O_5 ha^{-1} in the first year and up to 30 kg ha^{-1} in the second year in chickpea. Singh *et al.* (2003) found that the application of P up to 40 kg P_2O_5 ha^{-1} significantly increased the uptake of N and P in grain and straw of chickpea over control and 20 kg P_2O_5 ha^{-1}.

Sunder *et al.* (2003) observed that the application of 40 kg P_2O_5 ha^{-1} significantly increased the protein content in seed over control and 20 kg P_2O_5 ha^{-1} in clusterbean. Jat and Ahalawat (2004) reported that application of P up to 26.4 kg ha^{-1} significantly increased the total uptake of N and P by chickpea over control. Whereas Meena *et al.* (2004) in a field experiment on chickpea crop found that the application of P up to 60 kg P_2O_5 ha^{-1} significantly increased the uptake of N, P and K and protein content in chickpea over control and 30 kg P_2O_5 ha^{-1}. Shivkumar *et al*. (2004) conducted a field experiment at IARI, New Delhi and they concluded that the increasing levels of phosphorus up to 80 kg P_2O_5 ha^{-1} recorded significantly higher uptake of phosphorus with each successive levels in chickpea.

Tiwari *et al.* (2005) reported that application of P up to 26.4 kg P_2O_5 ha^{-1} significantly increased the uptake of N, P and K in grain and straw by chickpea over control and 25 kg P_2O_5 ha^{-1}. Singh and Chauhan (2005) reported that the application of phosphorus up to 25.8 kg ha^{-1} significantly increased Mn and Fe contents in grain and straw, but decreased with further increase of P *i.e.*, 38.7 kg P_2O_5 ha^{-1}. Zn and Cu content in grain and straw of lentil decreased linearly with increasing levels of P. Gupta *et al*. (2006) reported that the response of urdbean to phosphorus fertilization was significant up to 60 kg P_2O_5 ha^{-1} for seed and straw yield over control. Phosphorus application also increased the seed protein content, N & P uptake in seed and straw.

At Udaipur, Jain *et al*. (2006) found that application of 50 kg P_2O_5 ha^{-1} resulted in enhanced uptake of N and P (141.65 and 27.88 kg ha^{-1}, respectively) by the chickpea over control. Kahlon *et al.* (2006) reported that the application of 50 kg P_2O_5 ha^{-1} resulted in a better uptake of N, P, K, S, Zn, Fe and Cu as compared to other treatments in cowpea.

Kharche *et al.* (2006) carried out study at Akola, Maharashtra and reported that the application of 60 kg P_2O_5 ha^{-1} was beneficial for enhancing the protein content and total uptake of nitrogen, phosphorus and sulphur by plant, followed by 30 kg P_2O_5 ha^{-1} and the control. Kumar and Kushwaha (2006) conducted a field experiment at Chitrakoot, M.P. during rainy season in 1999-2000 and they concluded that the application of phosphorus up to 80 kg P_2O_5 ha^{-1} significantly increased the total P uptake over control in pigeonpea. A pot experiment was conducted by Srinivasarao *et al.* (2007) and they concluded that the application of P up to 27.0 mg kg^{-1}, significantly reduced the Fe concentration in plant. Up to 13.5 mg kg^{-1} P application, Cu concentration increased and thereafter it decreased, while the concentration gradually increased with increasing P levels. Sharma and Abrol (2007) conducted a field experiment at Jammu and concluded that the uptake of P by chickpea significantly increased by increasing levels of phosphorus up to 60 kg P_2O_5 ha^{-1} over control.

A field experiment conducted at Institute of Agricultural Sciences, BHU, Varanasi by Singh and Yadav (2008) revealed the maximum N and P uptake with 60 kg P_2O_5 ha^{-1}, which was significantly superior to the remaining levels except 45 and 30 kg P_2O_5 ha^{-1} in pigeonpea. In an experiment conducted at Turkey, Togay *et al*. (2008) found maximum uptake of nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn) by grain and shoot of chickpea plants under application of 80 kg P ha^{-1}. The total uptake by crop increased with increasing doses of P. In a field experiment at ARS, Durgapura, Jaipur on chickpea, it was found that the uptake of P, S and protein and N content by crop was significantly increased with increasing levels of Phosphorus from 0 to 60 kg P ha^{-1}. The maximum uptake of P (21.6 kg ha^{-1}), S (14.9 kg ha^{-1}) and protein (23.9%) and N (3.68%), content was recorded under application of 60 kg P ha^{-1} (Deo and Khandelwal, 2009). Kumar *et al*. (2009) reported that the application of 50 kg P_2O_5 ha^{-1} significantly increased P uptake by grain and straw in chickpea over control.

Meena *et al*. (2010) observed that the nitrogen content in seed and straw, phosphorus content in straw as well as protein content in seed were significantly higher with 30 kg P_2O_5 ha^{-1} as compared with preceding levels in mothbean. Islam *et al*. (2011) conducted a field experiment at Barani Agriculture Research Institute Chakwal, Punjab, Pakistan to conclude that significant increase in P uptake due to P and S application. Phosphorus uptake increased from 3.77 to 4.68 kg $ha^{-1}$and from 3.89 to 4.51 kg ha^{-1}as P rate was increased from 0 to 80 kg P_2O_5 ha^{-1} and S from 0 to 30 kg ha^{-1}, respectively.

In a field experiment conducted at Punjab, Pakistan, to assess the amount of nitrogen fixation and nitrogen uptake by chickpea during crop growing seasons 2006-2007 and 2007-2008 and observed that application of phosphorus at 80 kg P_2O_5 ha^{-1} resulted in statistically increased values of nitrogen fixed and uptake by 33 and 31 per cent over control (Islam *et al.*, 2012a). At ARS, Kota (Rajasthan), protein content of chickpea was significantly higher if crop fertilized with P_2O_5 at 40 kg ha^{-1} over control (Shivran and Prakash, 2012).

In a field experiment at COA, Bikaner Das *et al*. (2013) reported that application of 30 kg P_2O_5 ha^{-1} significantly increased the N and P content in seed and straw and uptake and total uptake of N and protein content in seed over control and 15 kg P_2O_5 ha^{-1}, respectively. The field experiment was conducted during *rabi* season of 2011-12 at the Instructional Farm of Rajasthan College of Agriculture, Udaipur with chickpea (*Cicer arietinum* L.) on a sandy loam soil (Typic Haplustept) with four levels of phosphorus (0, 20, 40 and 60 kg P_2O_5/ha) and sulphur (0, 15, 30 and 45 kg S/ha). Application of P up to 60 kg/ha, progressively increased the Mn contents and their uptake in grain and haulm. Content of Fe, Cu and Zn decreased linearly with increasing levels of P. However, uptake of Fe, Cu and Zn by grain increased up to 60 kg P_2O_5 (Murari Lal *et al.*, 2014). Protein content in chickpea seed increased with increasing levels of phosphorus significantly up to 60 kg P_2O_5 ha^{-1} (Yadav *et al*., 2013).

2.1.4 Soil nutrient status after harvest of crop

Enania and Vyas (1994) observed in an experiment that the availability of zinc in soil decreased with increasing doses of phosphorus due to the formation of insoluble Zn-phosphate. Choudhary and Das (1996) found that the application of phosphorus at 30 and 60 kg P_2O_5 ha^{-1} significantly increased the available phosphorus content in soil over control. Bahl and Singh (1997) conducted a green house experiment on ten soils to study the effect of added P on Olsens-P and inorganic soil P fractions. The amount of Olsens extractable P decreased during first 40 days but increased thereafter. Jakhar (1997) reported that application of 40 kg P_2O_5 ha^{-1} significantly increased the available nitrogen and phosphorus content in soil after harvest of mungbean crop. Panwar (1997) also showed that additions of P increased Olsens-P significantly in the soil. The mean values were 3.1, 9.1 and 17.7 mg P kg^{-1} soil at 0, 20 and 40 mg kg^{-1} soil P, respectively at the end.

Ammal *et al.* (2001) reported significant increase in available phosphorus in soil up to 60 kg P_2O_5 ha^{-1}. Khoja *et al.* (2002) also showed in a field experiment that 40 kg P_2O_5 ha^{-1} + 10 kg N application in soil increased availability of N and P leading to better nutritional environment in the root zone for growth and development.

Singh and Chauhan (2005) observed that the application of P increased the available P status in the soil at highest. Kumar and Kushwaha (2006) reported higher

APUE from soil under 20 kg P_2O_5 ha^{-1} followed by that under 40 kg P_2O_5 ha^{-1} owing the greater grain production per unit of P applied. Srinivasarao *et al*. (2006) reported that the increasing levels of phosphorus up to 27.0 mg kg^{-1} in soil decreased the Fe content whereas Mn content in soil was increased gradually. Deo and Khandelwal (2009) showed that the available P in soil increased with increasing levels of phosphorus up to 60 kg P_2O_5 ha^{-1}. Islam *et al*. (2011) conducted a field experiment at Barani Agriculture Research Institute, Chakwal, Punjab, Pakistan and concluded that Phosphorus application was significantly higher amount of N taken from soil. Amount of N derived from soil increased from 20 to 25 kg ha^{-1}due to application of 80 kg P_2O_5 ha^{-1}. Yadav (2011) observed that the available P increased consistently with increasing level of phosphorus; P content in soil increased from 22.3 kg P_2O_5 ha^{-1} in control to 32.9 kg P_2O_5 $ha^{-1}$with application of 40 kg P_2O_5 ha^{-1}.

2.2 EFFECT OF SULPHUR

2.2.1 Growth characters

Shivran *et al*. (1996) working on clusterbean at Jobner reported that application of 60 kg S ha^{-1} significantly increased the plant height over control only, whereas, dry matter increased with an increase in S up to 60 kg S ha^{-1}. Kumar and Pareek (1997) reported that sulphur fertilization at 80 kg S ha^{-1} in cowpea significantly increased the plant height, dry matter accumulation and branches $plant^{-1}$ over control and 40 kg S ha^{-1}. Shivran *et al*. (2000) while working on pigeonpea found that 30 kg S ha^{-1} was equally effective to that of 60 kg S ha^{-1} in enhancing different growth and yield attributes *viz*; plant height, LAI and number of branches $plant^{-1}$ over control.

Kumawat and Khangarot (2002) conducted a field experiment at S.K.N. college of Agriculture, Jobner (Jaipur) during *kharif* 1996 on loamy soil and they concluded that the application of 80 kg S ha^{-1} significantly increased the plant height, dry matter production, number of pods per plant, number of seeds per pod, seed and haulm yield of chickpea over control.

An investigation was carried out by Sharma and Jat (2003) at S.K.N. College of Agriculture, Jobner, to study the response of cowpea to Phosphorus and Sulphur under rainfed condition during *kharif* 1992. They observed that application of S at 40 kg ha^{-1} significantly increased all the growth parameters in cowpea crop over control. Nagar and Meena (2004) in a study at Jobner found that plant height, dry matter accumulation and chlorophyll content increased significantly with increasing levels of sulphur from 0 to 60 kg ha^{-1} in guar.

Choudhary and Goswami (2005) conducted a field experiment at Bulandshahr, U.P. during *rabi* season of 2002 with chickpea cultivar P.G. 186. They concluded that the growth parameters *viz.*, number of pods per plant and test weight were significantly superior by the application of sulphur at 30 kg ha^{-1} as compared to control. Sharma and Singh (2005) in a study at Fatehpur, Shekhawati found that application of 25 and 50 kg S ha^{-1} in clusterbean significantly increased dry matter accumulation and branches $plant^{-1}$ as compared to control. A field experiment was carried out by Khatkar *et al.* (2007) at Allahabad during *kharif*, 2005 and they reported that the successive increase in S levels up to 20 kg S ha^{-1} significantly increased the plant height, number of leaves $plant^{-1}$ and plant dry weight over control.

Singh *et al*. (2008) conducted a field experiment and concluded that the application of 40 kg S ha^{-1} increased the plant height, number of leaves and number of branches per plant significantly as compared to control at all the growth stages of black gram. Togay *et al*. (2008) in a field experiment on chickpea at Turkey reported that the highest plant height (37.0 and 37.2 cm), number of branches (2.6 branches $plant^{-1}$ in both years), number of pods $plant^{-1}$ (12.6 and 12.7 pods $plant^{-1}$) and number of seeds $plant^{-1}$ (12.7 and 13.1 seeds $plant^{-1}$) were recorded with 100 kg S ha^{-1} in 2004 and 2005, respectively.

Nawange *et al.* (2011) conducted a field experiment during *rabi* season 2009-10 to find out the optimum dose of P and S on growth, yield attributes and yield of chickpea. They observed that the increasing levels of S up to 40 kg ha^{-1} showed a linear increase in the growth, yield attributes, seed and stalk yield of chickpea. A field experiment was conducted at Ummedganj, Kota (Rajasthan) during the winter season of 2008 and 2009 to evolve a nutrient management strategy for chickpea and reported that application of S at 20 kg ha^{-1} resulted significantly higher plant height, branches $plant^{-1}$, number of nodules and dry weight of nodules over control (Shivran and Prakash, 2012). Kharol (2013) conducted a field experiment at Instructional Farm, Rajasthan College of Agriculture, Udaipur during *rabi* season of 2011-2012 and reported that application of 30 kg S ha^{-1} significantly increased the growth characters of the chickpea (plant height and branches per plant) over control and 15 kg S/ha.

2.2.2 Yield and yield attributes

Chaubey *et al.* (2000) in a field experiment on groundnut at Pantnagar observed that application of sulphur through gypsum 45 kg ha^{-1} significantly increased number of primary branches (8.41), pods plant^{-1} (19.57), plant height (36.4 cm), 1000 kernel weight (42.45 g) and pod yield (2,879.18 kg ha^{-1}). A field experiment was conducted by Ghosh and Sarkar (2000) at Birsa Agricultural University, Ranchi, Bihar during winter season (*rabi*) of 1995 with chickpea crop. Sulphur applied as phosphogypsum in 5 doses i.e. 0, 10, 20, 30 and 40 kg S ha^{-1} as basal dressing. Results indicated significant increase in the straw, grain and total dry matter yield over control.

Shivkumar (2001) noted significantly higher pod weight plant^{-1}, number of pods plant^{-1}, number of seeds pod^{-1}, seed yield, net returns and benefit cost ratio in chickpea due to application of S up to 80 kg ha^{-1} than that recorded with no S application. Singh *et al.* (2001) in a field experiment at Udaipur found that application of 60 kg ha^{-1} sulphur to soybean crop significantly increased grain yield (19.06 q ha^{-1}), haulm yield (43.40 q ha^{-1}), oil yield (378.80 kg ha^{-1}) and protein yield (736.37 kg ha^{-1}) over control. Kumawat and Khangarot (2002) conducted a field experiment at S.K.N. college of Agriculture, Jobner (Jaipur) during *kharif* 1996 on loamy sand soil. They observed that the grain yield of chickpea crop was significantly increased with the application of 40 kg S ha^{-1} as compared with control.

A field experiment was conducted by Kaprekar *et al.* (2003) during *rabi* season of 1992-93 and 1993-94 to study the effect of P and S with and without inoculation of PSB on yield, test weight, nutrient uptake by gram and production under irrigated condition. They reported that the application of 60 kg S ha^{-1}, P and PSB inoculation gave significantly higher grain and stover yield. Shrikrishna *et al*. (2004) conducted a field experiment at C.S.A.U.A.T., Kanpur to study the interactive effects of N and S on yield, harvest index, total N and S uptake and protein content of chickpea. The results revealed that application of 40 kg S ha^{-1} significantly increased seed yield over control. A field experiment was conducted by Singh and Singh (2004) on a sandy loam soil. The treatments consisted of three levels of Sulphur (0, 30 and 60 kg ha^{-1}) and four levels of Phosphorus (0, 30, 60 and 90 kg ha^{-1}) applied through gypsum and Triple Super Phosphate, respectively. They reported that increasing dose of S significantly increased the grain, straw and total produce of black gram.

Choudhary and Goswami (2005) conducted a field experiment during *rabi* season of 2002 with chickpea cultivar PG 186 with three levels of P (0, 60 and 90 kg P ha^{-1}) and three levels of sulphur (0, 30 and 45 kg S ha^{-1}). It was found that application of 30 kg S ha^{-1} produced significantly higher grain yield as compared to control. Singh and Chauhan (2005) observed that the application of S up to 60 kg S ha^{-1} significantly increased the yield and Fe content of lentil, whereas Zn, Cu and Mn contents increased with increasing level of S. Ram *et al*. (2007) in a field experiment at Bundelkhand, India found that application of 20 kg S ha^{-1} produced significantly better growth and yield attributes by a margin of 11.00 and 5.85 grains per plant compared to the control and the 10 kg S ha^{-1}, respectively. The use of 20 kg S ha^{-1} enhanced the grain yield with percentage increment of 16.87 and 6.13 compared to the control and the 10 kg S ha^{-1}, respectively. An experiment, carried out at Turkey during 2004-05 revealed that application of 100 kg S ha^{-1} significantly increased the seed yield with 758 kg ha^{-1} in 2004 and 818 kg ha^{-1} in 2005 of chickpea. The highest biological yield was obtained with application of 100 kg S ha^{-1} (2010 and 2137 kg ha^{-1} in 2004 and 2005) (Togay *et al*., 2008).

Deo and Khandelwal (2009) noted in a field experiment at Agricultural Research Station, Durgapura, that grain and straw yield increased significantly with increasing levels of sulphur from 0 to 30 kg ha^{-1}. The per cent increase in grain yield due to sulphur application varied from 8.2 to 20.5 per cent over control (1.82 t ha^{-1}), whereas the straw yield increased from 5.0 to 15.9 per cent over control (2.63 t ha^{-1}). The highest grain (2.19 t ha^{-1}) and straw yield (3.05 t ha^{-1}) was recorded under 30 kg S ha^{-1}. A field experiment conducted at BARI Chakwal, Pakisthan to study the effect of S application on chickpea and found that highest seed yield (1422 kg ha^{-1}) was recorded under treatment having 30 kg S ha^{-1} followed by 15 kg S ha^{-1} (Islam *et al*., 2009). Islam *et al.* (2011) from a field experiment on chickpea reported that application of phosphorus and sulphur resulted in significant increase in seed yield by 21 and 12 per cent over control, respectively. Effect of combined application of P and S was synergistic at nutrient application rate of $P_{40}S_{15}$, while antagonistic at $P_{80}S_{30}$. There was significant increase in seed and straw yield of chickpea with S application. Further, results also revealed that seed and straw yield increased from 0.70 to 0.85 Mg ha^{-1} and from 1.42 to 1.58 Mg ha^{-1}, respectively, as S rate was increased from 0 to 30 kg S ha^{-1}.

Nawange *et al.* (2011) at Bhopal found that the levels of sulphur up to 40 kg ha^{-1} showed linear increase in the growth, yield attributes, seed and stalk yield of chickpea. The application of 40 kg S ha^{-1} produced the highest mean seed yield of 1665 kg ha^{-1} and stalk yield of 2665 kg ha^{-1}. A pot experiment was conducted at Rajasthan College of Agriculture, MPUAT, Udaipur by Yadav (2011) and he reported that the increasing level of phosphorus and sulphur increased grain and straw yield of clusterbean. An experiment conducted at ARS, Kota (Rajasthan) on chickpea revealed that application of S at 20 kg ha^{-1} resulted significantly higher number of pods $plant^{-1}$, number of seeds pod^{-1} and hence higher seed and straw yield. There were no significant differences observed within 40 and 60 kg P_2O_5 ha^{-1} over control (Shivran and Prakash, 2012). Kharol (2013) in a field experiment at RCA, Udaipur observed that application of 30 kg S ha^{-1} significantly increased the pods per plant, grain, haulm and biological yield of chickpea over control and 15 kg S/ha.

2.2.3 Nutrient uptake and quality

Ram and Dwivedi (1992) recorded the maximum uptake of nitrogen (174.7 kg ha^{-1}) P (19.6 kg ha^{-1}) and S (14.2 kg ha^{-1}) in chickpea due to application of 40 kg S ha^{-1} through gypsum. Kumar and Pareek (1997) reported that sulphur fertilization at 80 kg S ha^{-1} in cowpea significantly increased the nitrogen, phosphorus and sulphur contents in seed and straw and their uptake over control. A field experiment was conducted by Ghosh and Sarkar (2000) at Birsa Agricultural University, Ranchi, Bihar during winter season (*rabi*) of 1995 with chickpea crop. Sulphur was applied as phosphogypsum in 5 doses *i.e*. 0, 10, 20, 30 and 40 kg S ha^{-1} as basal dressing. Results indicated an increase in the concentration and uptake of sulphur in straw and grain over control with increase in levels of S application.

Singh *et al.* (2001) reported that increasing level of sulphur (0, 10, 20 and 30 mg S kg^{-1} soil) significantly increased the Ca, Mg and Fe content of soybean seed up to 20 mg kg^{-1} soil over control. A field experiment was conducted by Kaprekar *et al.* (2003) during *rabi* season of 1992-93 and 1993-94 to study the effect of phosphorus and sulphur with and without inoculation of PSB on yield, test weight, nutrient uptake and economics of gram production under irrigated condition. Higher total uptake of nutrients along with maximum gross income, net income and net return were also recorded with application of 60 kg ha^{-1} P_2O_5 and S and PSB inoculation.

Nagar and Meena (2004) in a study at Jobner found that chlorophyll content increased significantly with increasing levels of sulphur from 0 to 60 kg ha^{-1} in *guar* and also significantly increased protein content and total uptake of N, P and S up to 60 kg ha^{-1}. Sangale and Sonar (2004) in a study at Maharashtra observed that application of sulphur in soybean at increasing level from 0 to 30 kg ha^{-1} significantly increased seed yield and nutrient uptake. Shrikrishna *et al*. (2004) conducted a field experiment for two years to study the interactive effects of N and S application on uptake of nutrients and protein content over control during both years and observed that 15 kg N ha^{-1} with 20 kg S ha^{-1} proved the best combination with respect to various parameters of chickpea taken into consideration. Singh and Singh (2004) conducted a field experiment on a sandy loam soils and reported that application of sulphur significantly increased the uptake of P, the increase of P uptake was 0.31 kg ha^{-1} with application of 60 kg over 30 kg S ha^{-1} (1.40 kg ha^{-1}) in black gram.

At Akola, Maharashtra, Kharche *et al.* (2006) observed that protein content of grain and total uptake of nitrogen, phosphorus and sulphur in chickpea plant was significantly increased when crop fertilized with sulphur at 40 kg ha^{-1} in comparison to unfertilized control. In an experiment conducted at Turkey, Togay *et al*. (2008) reported that the magnitude of uptake of nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn) increased with increasing doses of S and maximum accumulation of nutrients by grain and shoot of chickpea plants were recorded under application of 100 kg S ha^{-1}. The uptake of N, P, S and protein content in chickpea crop was significantly increased with increasing levels of sulphur. The maximum uptake of N, P, S and protein content was recorded under 30 kg S ha^{-1} (Deo and Khandelwal, 2009). Islam *et al*. (2009) conducted a field experiment at Arid Agricultural University, Rawalpindi, Pakistan and they concluded that increasing level of sulphur up to 30 kg ha^{-1} recorded increased N, P, K, S, Fe, Mn, Cu and Zn uptake by grain and straw in chickpea.

Islam *et al*. (2011) conducted a field experiment at Barani Agriculture Research Institute, Chakwal, Punjab, Pakistan. They studied variation in the seed yield, nitrogen fixation and nutrient uptake by chickpea (*Cicer arietinum* L.) in response to application of different levels of phosphorus (P) and sulphur (S). The treatments comprised three levels (0, 40 & 80 kg P_2O_5 ha^{-1}) of P and three levels (0, 15 &30 kg S ha^{-1}) of S. They observed that increasing levels of P and S significantly increased nitrogen (N) fixation and nutrients uptake. A pot experiment was conducted at Rajasthan College of Agriculture, MPUAT, Udaipur by Yadav (2011) and he observed that N, P and S contents in grain and straw were significantly increased with increase in level of sulphur. Islam *et al.* (2012a) in a field study on chickpea in Punjab, Pakistan recorded that application of sulphur at 30 kg S ha^{-1} increased amount of nitrogen fixed and nitrogen uptake by 6, 25 and 17 per cent over control at harvest. Ruchi *et al.* (2012) conducted a field experiment at Rath, Hamirpur (U.P.) and observed that the sulphur application increased the content and uptake of N, P, K and S by grain and straw in chickpea crop significantly up to 60 kg S/ha. At Agricultural Research Station, Kota (Rajasthan) Shivran and Prakash (2012) found that application of S at 20 kg ha^{-1} to chickpea resulted in significantly higher protein content over control.

Kharol (2013) conducted a field experiment at Udaipur and reported that increasing levels of sulphur increased the protein content, nutrient content (N, P, K, Fe, Cu and Zn) and nutrient uptake by chickpea significantly up to 30 kg S ha^{-1}. While, significant increase in sulphur uptake was found at 45 kg S ha^{-1}. In an experiment on chickpea at Udaipur Murari Lal *et al.* (2014) observed that application of S (0 to 45 kg ha^{-1}) progressively increased the content and uptake of Fe, Mn, Cu and Zn in grain and haulm.

2.2.4 Soil nutrient status after harvest of crop

Ghosh and Sarkar (2000) conducted a field experiment at farmer’s field near Birsa Agricultural University and found that the recovery was more at lower levels of S application and it decreased with increasing S levels in chickpea. Togay *et al*. (2008) conducted a field experiment at Van, Turkey (2004 and 2005) and they observed that the application of sulphur significantly increased availability of these micronutrients (Fe, Mn, Zn and Cu), owing to a decline in soil pH caused by the applied S, this seems to be responsible for increased uptake in the lentil plants.

Deo and Khandelwal (2009) conducted a field experiment at Agricultural Research Station, Durgapura; Jaipur and found that available S in the soil increased with increasing levels of sulphur. Islam *et al*. (2009) conducted a field experiment at Arid Agricultural University, Rawalpindi, Pakistan and they concluded that application of phosphorus and sulphur increased uptake of these nutrients by plant, which may be due to their increased availability in soil. Sheikh *et al.* (2009) found that mungbean included under cropping system improve the soil health through increase in organic matter, total N, available P and S.

Shamshuddoha *et al.* (2011) conducted an experiment on silty clay loam at Dhaka (Bangladesh) and reported that application of sulphur at 8 kg ha^{-1} to mungbean significantly increased the total available P, exchangeable K and available S in the soil after harvest the crop. Yadav (2011) found that application of S significantly increased the available S content in the soil. The increase was 56 and 24% with the application of 20 kg and 10 kg S ha^{-1} over control.

Ruchi *et al*. (2012) conducted a field experiment at Rath, Hamirpur (U.P.) and concluded that the increasing levels of sulphur application increased the N availability in soil which was utilized by plants and thereby more N-content in grain of chickpea. Kharol (2013) at Udaipur found that available N, P, S Fe, Mn and Cu in soil after harvest of chickpea increased significantly with increasing levels of sulphur up to 45 kg S ha^{-1}. However, available zinc was adversely affected by increasing levels of sulphur.

2.3 EFFECT OF SEAWEED SAP

2.3.1 Growth characters

Verkleij (1992) reported the benefits of diluted seaweed extracts when applied with the aim of promoting growth, preventing pests and diseases and improving the quality of the products of biological agriculture and horticulture. Benefits are thought to be due to plant hormones (mainly cytokinins) and trace elements. The significant growth of the seedlings of black gram and green gram have been reported when the seeds were soaked in 0.1 per cent and 0.05 per cent solutions of seaweed extract, Algifert over control (Mohan and Venkataraman, 1993). The seaweeds and various seaweed products have been utilized in agricultural practices for many years, the precise mechanism by which they elicit their beneficial growth responses is still not fully understood (Crouch and Van Staden, 1993).

Mohan *et al.* (1994) prepared extracts from five seaweeds namely *Padina, Sargassum, Turbinaria, Champia* and *Helminthocladia* and the seeds of *Cajanus cajan* were soaked in it for 24 hrs. They studied the germination and seedling growth and found that crude extract obtained from brown seaweeds especially that of

Sargassum and *Padina* were more effective than others. Tamilselvan and Kannan (1994) reported that application of *Hypnea masciformis* along with NPK gave maximum growth. Venkataraman and Mohan (1997) reported that the seaweeds are effective not only to crop plants but have a beneficial effect on the growth and biochemical constituents of cyanobacterium such as *Scytonema* sp. and *Oscillatoria* spp. Low concentration of seaweed extract was found to be most effective in inducing maximum growth. This finding can help in the large scale production of bio-fertilizers, *Scytonema* with enhanced growth.

The combination of seaweed extract and inorganic fertilizer gave a significant effect on the growth of potato over seaweed extract and inorganic fertilizers individually (Montano *et al.,* 1999). Zahid (1999) reported that *Codium iyengarii,* which grows wild on the coast, is utilized for the preparation of compost. The effect of this compost on the growth of vegetables and flowering plants was investigated. Results showed that seaweed manure significantly increased the rate of growth of plants.

Seaweed extract enhanced seed germination, increased plant nutrient uptake, increased plant resistance against frost and fungal diseases and is effective for ripening of fruits, increased shelf life of produce and are an excellent soil conditioner also (Zodape, 2001). The increase in seedling growth may also be due to presence of Phenyl Acetic Acid (PAA) and other closely related compounds in the seaweed liquid fertilizer. It has been suggested that the growth promoting activity of seaweed extract was due to macro and micro elements as well as growth promoting substances like cytokinin (Sridhar and Rengasamy, 2002).

Thangam *et al.* (2003) reported that the growth of seedling in terms of shoot and root length and fresh weight of vegetable plant *Cyamposis tetragonoloba* increased with the use of optimum concentration of seaweed liquid fertilizer extracted from *Caulerpa scalpeliformis* and *Gracilaria corticata* when the seeds were soaked in it. A pot experiment conducted at Tamil Nadu on clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] revealed that application seaweed sap liquid extracts at 1.5 per cent concentration increased plant height (33%), total fresh weight (155%), dry weight (140%), leaf area (61%) and moisture content (55%) (Ramya *et al.,* 2011). In a field study on tomato at Udaipur, it was recorded that 5.0 per cent spray of *Kappaphycus alvarezii* sap (seaweed) significantly increased height (34.44%), root length (45.05%) and chlorophyll content in leaves (53.85%) over control (Zodape *et al.*, 2011). A study was carried in Egypt on snap bean (*Phaseolus vulgaris* L.). It was found that the foliar application of seaweed extract at 750 ppm concentration increased significantly leaf number, leaf area, leaf fresh weight and stem fresh weight as compared with the other studied levels of the treatments (Abou El-Yazied *et al*., 2012).

Dogra and Mandradia (2012) conducted an experiment at Hamirpur (H.P.) and observed that application of sea weed (*Ascophyllum nodosum*) at 3.5 g m^{-2} recorded significantly higher plant growth of onion over control. A field experiment was conducted during the *pre-kharif* season at Uttar Chandamari village, West Bengal during 2012 to study the effect of seaweed saps on growth, yield and quality improvement of green gram. The foliar spray was applied twice at different concentrations (0, 2.5, 5.0, 7.5, 10.0 and 15.0% v/v) of seaweed extracts (*Kappaphycus* and *Gracilaria*). Foliar applications of seaweed extract enhanced all the growth characters significantly over control. A gradual increase in plant height, dry matter accumulation and LAI was observed with increasing seaweed extract application. Though these parameters are not significantly affected by foliar applications of seaweed extracts up to 5% concentration. Maximum plant height, dry matter accumulation, number of nodules per plant was recorded with 15% *Kappaphycus* sap + RDF and was statistically at par with 15% *Gracilaria* sap + RDF. In case of CGR at 21 to 42 DAS, the best result (7.75 g m^{-2} day^{-1}) was recorded with 15% *Kappaphycus* sap. Highest value of LAI was recorded with 15% *Kappaphycus* sap at 21, 42 and 63 DAS (Pramanick *et al*., 2013).

An experiment was conducted to study the effect of seaweed gel on growth and yield of tomato (*Solanum lycopersicum* L.) hybrid COTH 2 at College Orchard, Department of Vegetable Crops, Horticultural College and Research Institute, Coimbatore during 2008-09. The treatment NPK at 200:300:200 kg ha^{-1} + O6 EM and MA GEL at 12.5 kg $acre^{-1}$ + O6 EM and MA GEL 1% spray recorded highest plant height, number of leaves, number of branches and leaf area index (Selvakumari *et al*., 2013a). Selvam and Sivakumar (2013) conducted a field experiment at botanical garden, Annamalai University, Annamalainagar to identify the effect of seaweed liquid fertilizer of *Ulva reticulate* on *Vigna mungo*. Seaweed extract was applied as a foliar spray, then the maximum growth, biochemical properties like chlorophyll a and b content were recorded at 2 % among various concentrations as well as control. A significant increase in the number of epidermal and stomata cells as observed in 2 % whereas at higher concentrations such as 4, 6 and 8 % the values of all parameters decreased significantly than in the control group.

An experiment conducted on farmer's field near Bhavnagar (Gujarat) and revealed that applications of *Kappaphycus alvarezii* and *Gracilaria edulis* sap significantly increased the growth characters like number of spike, spike weight, spike length and 100 seed weight. The maximum values were reported under *K. alvarezii* sap at 7.5% in wheat (Shah *et al.,* 2013).

2.3.2 Yield and yield attributes

An increase in the yield of marketable bean by 24 per cent has been reported when the plants in the field trials were given the foliar spray of different concentrations of seaweed (Temple and Bomke, 1989). Kelpak (seaweed extract) recorded significantly higher yield of *Phaseolus acutifolius* growing at all concentrations of nutrient supply by increasing bean weight rather than bean number. Kelpak treated plants produced more grains in number of bigger size (Beckett and Van Staden, 1990).

The seaweed concentrate made from *Ecklonia maxima* when applied as a foliar spray on marigold increased the vegetative growth as well as yield contributing parameters such as number of seeds/flower head, number of flower buds and flowers and number of seeds per plant. In some instances seed production was increased by as much as 50 per cent (Van Staden *et al.,* 1994). Csizinszky (1995) reported the effects of two foliar seaweed spray application, 2 micro nutrient application and two N and K rates on Agriset 761 tomato yield. Plants treated with 112 fl oz seaweed concentrate/acre at the higher N + K rates had a higher marketable yield than plants sprayed with seaweed concentrate or water at the lower N + K rate.

Application of an aqueous alkaline extract of *Ascophyllum nodosum* to the soil resulted in higher concentration of chlorophyll in the leaves of treated plant in comparison to control plants. Positive results were obtained with all species tested (tomato dwarf French bean, wheat, barley, maize). Similar effects on leaf chlorophyll content was observed and enhanced leaf chlorophyll content of plant treated with seaweed extract is dependent on the betane present in it . Earlier studies had shown that the betane present in the extract of *Ascophyllum nodosum* when used in cucumber cotyledon bioassay devised for cytokinin resulted in enhanced chlorophyll levels in comparison to control (Blunden *et al.,* 1997).

The significant promoting effects were observed in black gram with seaweed liquid fertilizer which ranged from 65 per cent to 69 per cent as compared to 61 per cent in control. It has been reported that the yield of black gram was increased due to increase in length of pod (11.87 per cent to 19.70 per cent), weight of pod (11.28 to 38.99 per cent), seed weight pod^{-1} (21.8 to 67.25) and the 100 seed weight (2.19 to 10.40 per cent) over the control plants (Venkataraman and Mohan, 1997). Canales (1999) reported that the use of seaweed in agronomy along with seaweed products enhance quality and yield of crop. In addition to it, they improved the condition of the soil by the incorporation of the organic matter.

Bhowmick *et al.* (2000) conducted a field experiment to study the effect of kri-kelp powder, a sea weed *(Ascophyllum nodosum)* based bio-organic material on groundnut. Pod yield was 2.64 t ha^{-1} with 100 per cent of recommended NPK (20:40:40 kg N:P_2O_5:K_2O ha^{-1}) and highest (2.99 t ha^{-1}) with 78 per cent NPK plus basal application of 12.8 kg kri-kelp powder ha^{-1}. Sankar *et al.* (2001) studied the effect of organic seaweed extract on growth, yield and quality of onion cv. N-2-4-1 in a field experiment. Application of organic seaweed extract at 30, 45 and 60 DAT significantly increased the yield and yield attributes.

Application of seaweed extracts (brown algae) based leaf sprays (by a commercial product) including mineral nutrient at the rate of 3.8, 3.5, 5.9 kg ha^{-1} year^{-1} of N, P_2O_5, K_20, respectively resulted improved red colour intensity and distribution in cultivar mondial Gala but not in Fugi cultivar (Malaguti *et al*., 2002). Norrie and Keathley (2006) reported that effect of *Ascophyllum nosodum* marine plant extract on yield and cluster quality of Thompson seedless grapes. Results indicated a consistent increase in berry size (from 6.1 to 8.6 per cent), weight (from 3.2 to 29 per cent) and firmness (from 8.6 to 27.1 per cent) for several varieties and location.

A field experiment was conducted on Inceptisol at ICAR Research Complex, N.E.H. region, Jharnapani Centre, Nagaland, India during rainy (*kharif*) season 2006 to study the effects of foliar applications of different concentrations of seaweed extract (prepared from *Kappaphycus alvarezii*) on nutrient uptake, growth and yield of soybean [*Glycine max* (L.) Merr.] grown under rainfed conditions without the application of chemical fertilizers. The foliar spray was applied twice at seven concentrations (0, 2.5, 5, 7.5, 10, 12.5 and 15% v/v) of seaweed extract. Foliar applications of seaweed extract significantly enhanced yield parameters. The highest grain yield was recorded with applications of 15% seaweed extract, followed by 12.5% seaweed extract that resulted in 57% and 46% increases, respectively compared to the control (Rathore *et al*., 2009).

A pot experiment was conducted at CSMCRI, Bhavnagar to study the effect of *Kappaphycus alvarezii* spray on wheat and found that by spray of 1.0% *K. alvarezii* yield of grain increased by 80.44% compared to control (Zodape *et al.,* 2009). Singh (2010) at Udaipur (Raj.) observed that application of 1000 ppm zymegold recorded significantly higher leaf area index, cob weight, grain weight cob^{-1}, shelling %, 1000-grain weight, grain yield, stover yield and biological yield, net returns and B/C ratio of maize crop over water spray.

Experiment conducted by Ramya *et al*. (2011) and observed that seaweed liquid extracts of marine algae *Stoechospermum marginatum* (as soil drench) significantly increased the number of clusters/plant, number of flowers/clusters, pod weight, pod length and number of seeds per pod with 1.5%. Higher concentrations (above 1.5%) were found to show inhibitive effect. Sarhan (2011) conducted a study at College of Agriculture Farms/University of Duhok, Iraq on potato plants CV. Desiree with two factors as humic acid and two seaweeds extract Alga 600 and sea force 2. Seaweed extracts treatments caused a significant increase in all vegetative growth and yield characteristics of potato. An experiment was carried out at Horticulture Farm, Rajasthan College of Agriculture, Udaipur to see the effect of *Kappaphycus alvarezii* sap (seaweed) on growth and yield of tomato. It was observed that 5.0 per cent foliar spray attributed to increase in number of fruits per plant, size of fruit and yield of tomato fruit (60.89%), compared to control plants sprayed with water (Zodape *et al.*, 2011).

The experiments carried out during 2009 and 2010 seasons, on snap bean, (*Phaseolus vulgaris* L.) cultivar “Bronco” fine type at Brnashat village, Giza governorate, Egypt to study the effect of four different seaweed compost levels (0, 1, 2 and 3 m^3 seaweed compost/feddan) and four concentrations of seaweed extract (0, 250, 500, 750 ppm) as a foliar application on yield parameters and yields. Results indicated that spraying the plants with seaweed extract at higher rate (750 ppm) significantly increased percentage of fruit set and pods yield compared to those of untreated check and other treatments (Abou El-Yazied *et al*., 2012).

Dogra and Mandradia (2012) conducted an experiment at Hamirpur (H.P) and observed that application of seaweed (*Ascophyllum nodosum*) resulted significantly higher yield of onion over control. Pramanick *et al*. (2013) conducted a field experiment at Uttar Chandamari village, West Bengal and reported that maximum numbers of branches per plant, pods per plant and seeds per pod were observed under foliar application of 15% *Kappaphycus* sap along with RDF which was closely followed by 15% *Gracilaria* sap + RDF. The 15% *Kappaphycus* sap + RDF showed the maximum seed and straw yield (1265.0 and 5220.3 kg ha^{-1}) increase over control to the extent of 38.97 and 40.60 per cent, respectively.

In an experiment, Selvakumari *et al*. (2013a) at TNAU, Coimbatore (T.N.) reported that NPK at 200:300:200 kg ha^{-1} + O6 EM and MA GEL at 26.60 kg ha^{-1} + O6 EM and MA GEL 1% spray recorded highest individual fruit weight, fruit yield per plant, yield per plot and yield per hectare. Selvam and Sivakumar (2013) in an experiment at Botanical Garden, Annamalai University, Annamalainagar observed higher values of number of pods per plant, length of pods per plant and number of seeds per pod in all the seaweed liquid fertilizer (*Ulva reticulate*) treated plants as compared to control. The maximum values were recorded at 2 % spray of seaweed liquid fertilizer.

The experiment was conducted on a farmer's field near Bhavnagar (Gujarat, India) during the *rabi* season of 2008–2009 to study the effect of foliar applications of *Kappaphycus alvarezii* and *Gracilaria edulis* sap on growth and yield response of wheat var. 'GW 496'. Three foliar sprays of both saps were applied at the rate of 2.5, 5.0, 7.5, and 10.0% (v/v) along with water as a control at different stages of the crop. It was found that grain yield was increased significantly by 19.74% and 13.16% for plants receiving 7.5% and 5.0% concentrations of *K. alvarezii* and *G. edulis* sap, respectively, over control in wheat (Shah *et al*., 2013).

2.3.3 Nutrient uptake and quality

Crouch *et al.* (1990) noted increased uptake of magnesium, potassium and calcium in lettuce with seaweed concentrate application. Application of seaweed extract for 34 days either to the soil or to the foliage of tomato plants produced greener leaves than those of control plants. The seaweed extract treated leaves had 20-80 per cent higher chlorophyll content than the leaves of control plants (Whapham *et al*., 1992). Tamilselvan and Kannan (1994) reported that application of *Hypnea musciformis* along with NPK gave maximum growth, chlorophyll, nutrient content, sugar, protein and yield of black gram.

The results suggested that seaweed concentrates are unlikely to be useful in promoting the uptake of foliar applied trace elements in tomatoes grown under normal commercial conditions. Two foliar seaweed spray application, two micronutrient applications and two N and K rate on agriset 761 tomatoes had no significant effect on nutrient uptake. Residual concentration of K in soil was higher than at the lower K rate (Csizinszky, 1995). Possible explanation for increase in chlorophyll content in seaweed treated seedling may be due to increase in magnesium content which is a constituent of chlorophyll (Mostafa and Alaa Eldin, 1999). Shpigel (1999) reported the nutritional value of *Ulva lactuea.* The seaweed was cultured at two levels of ammonia N enrichment. The nutritional value of *Ulva lactuea* was greatly improved by high protein content, with high supply rates of ammonia.

Yesiloglus (2001) conducted study to determine the effect of gibberellic acid (GA_3), seaweed extract and Fe-chelates application with girdling, on mandarin cv. Clementine fruit yield and mineral composition. P levels in fruits were lowest in treatments with GA_3. Na levels were higher in double girdling + seaweed and seaweed treatments. Zodape (2001) observed that commercially available as maxicrop, seasal, SM_3 kelpak and cytokinin seaweed extracts enhance seed germination, increase plant nutrient uptake, increase plant resistance against frost and fungal diseases. It was also effective for ripening of fruits and increasing shelf life of produce.

Seedling of alfalfa rape, spinach and wheat, potted on sandy soil, when irrigated with an aqueous extract of pea shoot (PE 9.84 g dry weight litre^{-1}) or a solution of Ca, K, Mg, P and NO_3-N salts (SS) in a concentration similar to that in PE in comparison to water irrigated control showed had higher Ca, K, Mg and organic N, but lower, As and Ni content in plant and were thus of higher nutritive value in treated PE (Gramass *et al.*, 2003).

Turan and Kose (2004) reported the effect of seaweed extract on macro and micro nutrient uptake of grapevine *(Vitis vinifera* L. cv. Karaerik). One year old grapevine *(Vitis vinifera* L. Karaerrk) seedlings were planted in perlite with different nutrient element levels under green house condition. Three seaweed extracts maxicrop, proton and Algi powder were sprayed on the foliage at different concentrations (0, 0.5, 1.0 and 2.0 g l^{-1}). Results indicated that foliar application of seaweed extract increased uptake of grape vine in the growth media which had insufficient nutrient element. In contrast seaweed extract was more effective in supporting Cu uptake in vines than nutrient element level of growth media. Kelpak significantly increased the yield and the concentration and amounts of Ca, K, and Mg in the leaves of lettuce.

Mancuso *et al.* (2006) observed increased uptake of N, P, K and Mg in grape with the application of seaweed extract. Rathore *et al*. (2009) conducted a field at Nagaland during *kharif* 2006 and reported that foliar applications of different concentrations of *Kappaphycus alvarezii* significantly improved the nutrient uptake by seed and straw (N, P, K and S) in soybean over control. They reported that under rainfed production, foliar applications of seaweed extracts could be a promising option for yield enhancement. In a pot experiment at Bhavnagar it was found that compared to control, plants sprayed with 1.0 per cent *K. alvarezii* extract showed increase in nutritional quality of wheat as: carbohydrate 39.20%, protein 21.74%, and fat 31.64% compare to control. Similarly, macro and micro nutrients also increased in the range 15.86% - 75.02% and 1.28% - 20.0%, respectively under the influence of *K. alvarezii* extract treatment (Zodape *et al.,* 2009).

A pot experiment was conducted at Tamil Nadu on clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] and reported that seaweed liquid extracts of marine alga *Stoechospermum marginatum* significantly enhanced the growth, biochemical and yield of the clusterbean plant when treated as soil drench. Significantly enhanced biochemical parameters such as photosynthetic pigments, protein content, sugars, ascorbic acid and nitrate reductase activity when treated with 1.5% seaweed liquid extracts compared to untreated seedlings (Ramya *et al*., 2011). In a field experiment at Udaipur, it was found that 5.0 per cent spray of *Kappaphycus alvarezii* sap (seaweed) improved the fruit quality and increased macro (13.24 - 67.50%) and micro (23.84 - 42.61%) elements content significantly of tomato over control. Nutrient uptake by fruit and shoot were also improved with foliar application of *K. alvarezii* sap. Plants receiving foliar applications showed resistance to leaf curl, bacterial wilt and fruit borer (Zodape *et al.*, 2011).

Abou El-Yazied *et al*., (2012) in Egypt found that spraying seaweed extract at 750 ppm on snap bean (*Phaseolus vulgaris* L.) recorded the highest values of photosynthetic pigments, N, P, K and Mg content of leaves. Similarly, maximum values of protein and carbohydrates content in snap bean pods were observed by spraying seaweed extract at 750 ppm. Pramanick *et al*. (2013) reported that the use of the seaweed extracts significantly increased N, P and K uptake by grains at higher concentrations (10% and above) and reached maximum at 15% seaweed extract compared with control. The highest N and K uptake by grain was recorded with 15% *Kappaphycus* sap + RDF which was statistically at par with 15% *Gracilaria* sap + RDF, 10% *Kappaphycus* sap + RDF and 7.5% *Kappaphycus* sap + 50% RDF. 15% *Kappaphycus* sap + RDF showed the maximum uptake of P by grain. In case of nutrient uptake by stover, 15% *Kappaphycus* sap + RDF was observed to be the best and it was closely followed by 15% *Gracilaria* sap + RDF and 10% *Kappaphycus* sap + RDF.

Field experiment was conducted to study the influence of seaweed gel on quality parameters in tomato hybrid COTH 2 at Coimbatore during 2008-09. There were ten treatments including one absolute control. The seaweed gel influence the quality parameters like TSS (o brix), titrable acidity (%), ascorbic acid (mg 100 g^{-1}), total sugar (%), lycopene (mg 100 g^{-1}) content and were found higher in the plants applied with NPK at 200:300:200 kg ha^{-1} + O6 EM and MA GEL at 12.5 kg acre^{-1} + O6 EM and MA GEL 1% spray (Selvakumari *et al*., 2013b).

Selvam and Sivakumar (2013) at Annamalai University, Annamalainagar reported that application of seaweed liquid fertilizer (*Ulva reticulate*) increase the concentration of nutrients in leaves of *Vigna mungo*, among ten elements (N, P, K, Ca, Mg, S, Na, Mn, Zn and Fe), the higher value of N, lower values of P and almost similar value of Ca were reported in 2 per cent spray of seaweed liquid fertilizer than control. The order of chemical elements from epidermal portion of the leaf of *Vigna mungo* seaweed liquid fertilizer treated and control were follows as Ca>P>N>Na>K>Mg>Mn>S>Fe>Zn and Ca>N>P>Na>Mg>Mn>K>Zn>S>Fe, respectively.

Shah *et al*. (2013) conducted an experiment at farmer's field near Bhavnagar, Gujarat reported that foliar applications of *K. alvarezii* sap at 7.5% increased N, P, K, S, Ca, Mg and Na contents in wheat grains by magnitude of 7.91% to 31.82%, whereas *G. edulis* sap increased nutrient content by 5.72% to 37.54% over control. The study revealed that there was an improvement in the uptake of nutrients (N, P, K, S, Ca, Mg and Na) by shoots of wheat under the influence of foliar applications of both the saps and it increased with the increase in the concentration of both saps and was maximum in 7.5% and 5.0% of *K. alvarezii* and *G. edulis* sap, respectively, as compared with the control. Taresh Kumar (2013) reported that protein, gluten, nitrogen, phosphorus and potassium content and uptake of N, P, K and by grain and straw in wheat and chlorophyll (a & b) content of leaves at 55 DAS significantly increased due to foliar spray of Zymegold (Seaweed sap).

2.4 INTERACTION EFFECT

2.4.1 Growth characters

Jat (2004) observed the highest plant height, dry matter accumulation and seed yield of fenugreek with combined application of phosphorus and sulphur (80 kg ha^{-1} and 40 kg ha^{-1} respectively) over control. A pot experiment was carried out to study the phosphorus-sulphur interaction at Department of Agricultural Chemistry and Soil Science, Rajasthan College of Agriculture, Udaipur on a sandy loam soil (Typic Haplustept) medium in P and deficient in S with clusterbean. The treatment consisted of three levels of P (0, 20 and 40 kg P_2O_5 ha^{-1}) and three levels of S (0, 10 and 20 kg ha^{-1}) applied from gypsum and triple superphosphate, respectively. The result showed that the interaction effect of P and S significantly influenced the number of nodules plant-^{1} and weight of nodules $plant^{-1}$. The maximum number of nodules $plant^{-1}$ (27.8) and weight of nodules $plant^{-1}$ (33.39) was reported with the highest level of phosphorus at 40 kg ha^{-1} along with sulphur 20 kg ha^{-1} (Yadav, 2011).

2.4.2 Yield and yield attributes

Soundrajan *et al*. (1984) obtain significantly higher pod and haulm yield and uptake of N, P, K, Ca and S due to combined application of gypsum and NPK fertilizer over NPK alone in groundnut. Sridhar *et al*. (1985) applied 250 kg gypsum ha^{-1} as basal or top dressing at 30 DAS over a basal application of N, P fertilizer which produced significantly higher pod yield of groundnut compared to their individual application. Phosphorus application to the soil in combination with low rate of gypsum increased the peanut yield at Oklahona, USA (Sistani and Morril, 1989). At Junagarh, in a pot trial of groundnut with calcarious soil, applied S and P showed synergistic effect on pod yield, plant concentration and uptake of S and P at lower levels (Singh and Choudhary, 1996).

A field experiment conducted at New Delhi revealed that significant positive interaction of phosphorus and sulphur on pod yield in groundnut was noted with the combined application of 40 kg P_2O_5 and 30 kg S ha^{-1} (Maity and Giri, 2003). Nehra *et al.* (2006) found the synergistic effect of phosphorus and sulphur on yield attributing and seed, straw and biological yield and uptake of phosphorus and sulphur at their lower levels in fenugreek. The synergistic effect of phosphorus and sulphur interaction on grain and straw yield was reported by Deo and Khandelwal (2009) in chickpea. The grain and straw yield was highest at 60 kg P_2O_5 + 30 kg S ha^{-1} followed by 40 kg P_2O_5 + 30 kg S ha^{-1} in grain yield and 60 kg P_2O_5 + 15 kg S ha^{-1} in straw yield. The magnitude of increase in grain and straw yield was 63.44 and 47.19 % due to combined application of phosphorus and sulphur (60 kg P_2O_5 + 30 kg S ha^{-1}) over control, respectively.

Field experiments were conducted at two different locations (Barani Agriculture Research Institute, Chakwal, and farmer's field, Talagang) in northern rainfed Punjab, Pakistan, to assess nodulation, nitrogen fixation and nutrient uptake by chickpea (*Cicer arietinum* L.) in response to application of P (0, 40 and 80 kg ha^{-1}) and of S (0, 15 and 30 kg ha^{-1}) in different combinations. Application of P and S significantly increased seed yield (27 to 41 % and 7 to 11 %) over control (Islam and Ali, 2009).

Jat (2011) in an experiment at Udaipur reported that combined application of phosphorus and sulphur significantly affected the seeds pod^{-1}, pods $plant^{-1}$ and 1000 seeds weight of fenugreek. For the same level of phosphorus, increasing levels of sulphur increased the 1000 seed weight. Similarly, there was also increase in 1000 seed weight with the increasing levels of phosphorus at the same level of sulphur application. Maximum (13.65 g) 1000 seed weight was recorded with the application of 60 kg P_2O_5 ha^{-1} + 45 kg S ha^{-1} followed by 40 kg P_2O_5 + 45 kg S ha^{-1} (13.43 g).

Yadav (2011) conducted a pot experiment at Udaipur and reported that the grain and straw yield of clusterbean increased with increase in level of P and S individually as well as in various combinations. The per cent increase in grain yield due to phosphorus and sulphur varied from 11.8 to 24.2 % and 5.3 to 10.8 %, respectively, whereas the straw yield increased from 9.2 to 17.7 % and 7.5 to 10.5 %. Synergistic effect of phosphorus and sulphur interaction on grain and straw yield was highest at 40 kg P_2O_5 and 20 kg S ha^{-1}. The magnitude of increase in grain and straw yield was 22.8 and 18.6 % due to combined application of phosphorus and sulphur (40 kg P_2O_5 and 20 kg S ha^{-1}) over control, respectively.

2.4.3 Nutrient uptake and quality

Mishra and Singh (1989) obtained highest pod yield and uptake of S and P due to application of 40 kg S + 50 kg P_2O_5 ha^{-1} in groundnut. Dwivedi and Bapat (1998) reported that nitrogen content in soybean increased significantly by S and P application up to 50 kg ha^{-1} of each nutrient. The interaction of S and P was significant and maximum nitrogen content was recorded at 60 kg P_2O_5 + 30 kg S ha^{-1} level. The increase in nitrogen content ranged from 2.77 % without S and P to 3.90 % at 60 kg P_2O_5 + 30 kg S ha^{-1} level. Dayanand *et al.* (1999) found the highest protein content and nutrient uptake with the combined application of 40 kg ha^{-1} P + 50 kg ha^{-1} S over the control in fenugreek.

An experiment was carried out in Turkey and reported that highest phosphorus and sulphur uptake in fenugreek due to combined application of elemental sulphur with NP over NP alone (Togay *et al.*, 2008). Deo and Khandelwal (2009) at ARS, Durgapura, Jaipur reported the synergistic effect of phosphorus and sulphur on protein content, Phosphorus and sulphur content in seed and straw and uptake of sulphur and phosphorus in chickpea. In a pot experiment at Department of Agricultural Chemistry and Soil Science, Rajasthan College of Agriculture, Udaipur, Yadav (2011) reported that applied P and S increased grain nitrogen, phosphorus, sulphur and protein contents in clusterbean. The interaction of P and S was significant and maximum nitrogen, phosphorus, sulphur and protein content was recorded at 40 kg P_2O_5 and 20 kg S ha^{-1}.

A field experiment was conducted at Instructional farm, Rajasthan College of Agriculture, Udaipur during *rabi* season of 2011-2012 which reported that the interaction effect of phosphorus and sulphur was found to be significant on phosphorus and sulphur content in grain. For the same level of phosphorus, increasing levels of sulphur increased the phosphorus content in grain. Similarly, there was also increase in phosphorus content with the increasing levels of phosphorus at the same level of sulphur application. Maximum (0.44 %) and minimum (0.29 %) phosphorus content in seed was recorded with the application of 60 kg P_2O_5 ha^{-1} + 45 kg S ha^{-1} and control, respectively. For the same level of phosphorus, increasing levels of sulphur increased the sulphur content in grain. Similarly, there was also increase in sulphur content with the increasing levels of phosphorus at the same level of sulphur application. Maximum (0.22 %) and minimum (0.17 %) sulphur content in seed was recorded with the application of 60 kg P_2O_5 ha^{-1} + 45 kg S ha^{-1} and control, respectively (Murari Lal, 2012).

2.4.4 Soil nutrient status after harvest of crop

Randhawa and Arora (1997) in an incubation study observed synergistic effect of S and P in increasing extractable amount of S and P from native as well as applied sources. In an experiment on chickpea, Deo and Khandelwal (2009) found that the available P increased consistently with increase in rates of P application in the soil from 24.5 kg ha^{-1} in control to 45.9 kg P_2O_5 ha^{-1} with application of 60 kg P_2O_5 ha^{-1}. Application of sulphur did not affect available phosphorus significantly in the soil after harvest of chickpea but it tended to increase with increasing levels of sulphur

In a pot experiment at Udaipur, Yadav (2011) found that available P in soil was increased with increasing levels of phosphorus. Similarly, available S in soil increased with increasing levels of sulphur after harvest of clusterbean. Phosphorus application had no effect on sulphur content of the soil.