5. DISCUSSION

In the course of presenting results of the experiment on **“Effect of Phosphorus, Sulphur and Seaweed Sap on Productivity of Chickpea (*Cicer arietinum* L.)”** significant variations in the criteria used for evaluating treatments were observed. The variations found significant or assuming trends are discussed to establish the cause and effect relationship vis-à-vis existing evidence and literature.

5.1 CROP SEASON

The results indicated that between the years of study i.e. 2012-13 and 2013-14, the yield levels were almost similar as both the years crops were grown under identical management conditions and input levels. However, the grain yield of first year was lower by 1.20 per cent over its later year mean production (1439 kg ha^{-1}). The observed variation in yield seems to be due to slight variation in climatic conditions which prevailed during various stages of crop growth. The chickpea crop growth period experienced slight variation in amount of rainfall and minimum temperature but other crop weather parameters were almost of same trends in two crop seasons (Table 3.1 and Fig 3.1a and 3.1b). These observations reveal that minimum temperatures ranged between 1.3 to 14.0 ºC during 2012-13 and 3.7 to 16.2 ºC during 2013-14, respectively. The total rainfall received during the chickpea crop season of the 2012-13 was 1.4 mm, while 17.1 mm rains were received during 2013-14. The low temperature of 1.3 ºC and only 1.4 mm *rabi* season rains might be the reasons of lower yield, however, these climatic variation during 2012-13 was taken care to some extent by scheduling of irrigation i.e., on 20.01.13 that has taken care of low temperature injury as well as provide sufficient moisture during flowering and pod filling stage. Weather is a principle parameter which brings year to year variation in crop productivity, despite consistency of input parameters and practices of crop husbandry (Mistry and Patel, 1977).

5.2 EFFECT OF PHOSPHORUS LEVELS

5.2.1 Growth parameters

It is evident from results that phosphorus application most effectively enhanced various morphological and biometric parameters of growth *viz*., plant height, DMA by plant parts at various stages, CGR, RGR, AGR, BMD, chlorophyll content and branches plant^{-1}. The concomitant effect of these improvements ultimately led to production of higher biomass by plant at successive stages and at harvest (Table 4.1-4.8 and 4.17). These increases ultimately positively affected the overall improvement in growth of the crop.

The plant height of chickpea at 30, 60 DAS and at harvest was significantly increased by 17.67, 9.11 and 8.26 per cent when crop was fertilized with 60 kg P_2O_5 ha^{-1} and 15.34, 8.08 and 5.33 per cent with 40 kg P_2O_5 ha^{-1} over 20 kg P_2O_5 ha^{-1} (12.45, 34.92 and 52.89 cm), respectively. However the crop fertilized with 60 kg P_2O_5 ha^{-1} failed to exhibit significant increase in plant height over 40 kg P_2O_5 ha^{-1}. The magnitude of increase in primary branches plant^{-1} at 60 DAS and at harvest with 40 kg P_2O_5 ha^{-1} was 8.04 and 8.60 per cent, respectively over 20 kg P_2O_5 ha^{-1} (3.36 and 314 at 60 DAS and at harvest, respectively), whereas phosphorus fertilization at 60 kg ha^{-1} failed to bring about perceptible variation in number of primary branches. The DMA at 30 DAS by plant parts *viz.*, leaves, stem and total were significantly improved with 40 kg P_2O_5 ha^{-1} by 7.86, 5.61 and 7.09 per cent over 20 kg P_2O_5 ha^{-1}. Whereas, DMA at 60 DAS, 90 DAS and at harvest of chickpea leaves, stem, reproductive parts and total were significantly improved by 40 kg P_2O_5 ha^{-1} and 60 kg P_2O_5 ha^{-1} over 20 kg P_2O_5 ha^{-1} and 40 kg P_2O_5 ha^{-1} except reproductive parts at harvest where 60 kg P_2O_5 ha^{-1} recorded at par results to 40 kg P_2O_5 ha^{-1}. The magnitude of increase in CGR, AGR and BMD at 30-60 DAS with 40 and 60 kg P_2O_5 ha^{-1} were 6.50 and 12.37 per cent, 6.74 and 12.44 per cent and 6.61 and 11.57 per cent whereas the magnitude of increase at 60-90 DAS were 15.30 and 24.48, 15.15 and 24.24 and 9.62 and 16.03 per cent, respectively over 20 kg P_2O_5 ha^{-1}.

In general the overall increase in growth of chickpea with increase phosphorus can be ascribed to its pivotal role in several physiological and biochemical processes which are of vital importance for growth and development of the plant. It is an established fact that among nutrients phosphorus is most important for exploiting genetic potentials for the crop for its growth and development (Tisdale *et al.*, 2003). In addition to its structural role in nucleic acid, nucleotide and phospholipids, phosphorus has essential regulatory functions in photosynthesis and carbohydrate metabolism in its formation of pyrophosphate bonds which allows energy transfer and is required for all biochemical processes which require energy. In fact, it is considered to be energy currency within the plant system (Kanwar, 1976) and Tisdale *et al.*

(2003). An adequate supply of easily available phosphorus is required by plants at early growth stages. Firstly, because the rate of metabolism is high and cell division is rapid. Secondly, the limited root system developed is not capable of drawing sufficiently from phosphorus reserves of the soil.

In the present investigation, growth parameters improvement under increased P application might have increased metabolic processes in plant resulting in greater meristematic activities and apical growth, thereby improving plant height, branches plant^{-1} and also formation of higher number of leaves plant^{-1} ultimately resulting in improved photosynthetic surface of the plant. The larger canopy development under the influence of increased P levels seems to have increased absorption and utilization of radiant energy, resulting in higher dry matter accumulation (Table 4.3, 4.4, 4.5 and 4.6). Utilization efficiency of intercepted radiation is influenced by photosynthetic rate, which is shown to be influenced by P supply (Clarkson *et al.,* 1983). The rate of P absorption and translocation to the leaves is an important factor to increase dry matter accumulation. When P supply is limited, the availability of P and N to chloroplast become limited which ultimately affecting the photosynthetic process as well as photosynthate supply to nodules. Thus, interdependence of these processes in plant on P supply show effect of P on plant growth processes resulted in greater accumulation of biomass.

The results of overall improvement in growth of chickpea with application of P in present investigation are in cognizance with that of Deo and Khandelwal (2009), Kumar *et al.* (2009), Singh *et al.* (2010), Nawange *et al.* (2011) and Shivran and Prakash, (2012).

5.2.2 Yield attributes and yield

The results reveal that P fertilization at 40 and 60 kg P_2O_5 ha^{-1} significantly increased the yield components *viz.* pods plant^{-1}, grains pod^{-1}, grains plant^{-1}, grain yield plant^{-1} and 100-grain weight by 8.37 and 13.15, 6.82 and 8.33, 17.97 and 20.98, 21.60 and 25.70 and 4.38 and 6.35 per cent, respectively over 20 kg P_2O_5 ha^{-1} (Table 4.9), consequently the crop fertilized with aforesaid rates of P produced significantly higher grain, haulm and biological yield to the extent of 10.76 and 14.39, 10.93 and 14.58 and 10.87 and 14.52 per cent over 20 kg P_2O_5 ha^{-1}, respectively (Table 4.12).

The crop efficiency estimated in terms of harvest index did not alter significantly with the application of P levels (Table 4.12).

It is an established fact that photosynthesis together with availability of assimilates (source) and storage organs (sink) exert an important regulatory effect on the complex processes of yield formation. The regulatory functions of phosphorus in photosynthesis and carbohydrate metabolism of leaves can be considered to be one of the major factors limiting plant growth particularly during reproductive phase. The level of phosphorus during this period regulates starch/sucrose ratio in the source leaves and reproductive organs (Gianquinta and Quebedeaux, 1980).

In many legumes (chickpea being not exception to it) poor sink capacity is attributed to low retention of flower to form pods. Three possible explanations have been postulated, first being traditional favourite hormones, the second assumes that other organs compete with flower for want of metabolites, nutrients and last being modification of third refer to limitation of vascular system for rapid supply of growth inputs (metabolites and nutrients) from source to sink (Jeswani, 1986). The later assumptions clearly suggest that plant can't be considered as a pool of carbon from which all sink can draw it equally. This emphasizes need for higher production of metabolites during reproductive phase. Hence, the increased pods plant^{-1} and grains plant^{-1} with the addition of P suggest greater formation of flowers and their retention due to adequate supply of nutrients/metabolites and later on transformation of flowers into pods. Besides higher biomass per plant and involvement of P in root development seems to have induced better hormonal balance in the plant and root are considered primary sites for formation of hormones "cytokinin". These positive influences might have led to better development of individual grain as evidence from grains plant^{-1} and 100-grain weight (Table 4.9) with concomitant increase in productivity of individual plant expressed as grain yield per hectare. Improvement in yield components of chickpea due to P fertilization was also observed by Deo and Khandelwal (2009), Kumar *et al.* (2009), Singh *et al.* (2010), Nawange *et al.* (2011) and Shivran and Prakash, (2012).

The significant increase in grain yield as a result of P application could be ascribed to the fact that yield of crop is artifact of several component characters which are interrelated. The positive and significant relationship was observed between grain yield and primary branches plant^{-1} at 60 DAS (r=0.589**), pods plant^{-1} (r=0.452*), grains plant^{-1} (r=0.533**, grains yield plant^{-1} (r=0.569**) and 100-grain weight (r=0.725**) (Table 5.1). The increased productivity of chickpea crop due to P fertilization corroborates findings of several researchers Deo and Khandelwal (2009), Kumar *et al.* (2009), Singh *et al.* (2010), Nawange *et al.* (2011) and Shivran and Prakash, (2012).

5.2.3 Quality parameters

Quality of chickpea crop is decided by the proportion of various nutrients accumulated and/or development into an essential molecule. This property once again is a function of various complex bio-physico-chemical properties of soil-plant-environment continuum.

The results indicate that P fertilization at 40 and 60 kg P_2O_5 ha^{-1} improved protein content by 3.97 and 4.21 per cent over 20 kg P_2O_5 ha^{-1} (Table 4.16). The improvement in protein content of grain with application of fertilizer (phosphorus) was expected of the nutrient especially N is considered to be an essential constituent and actively involved in synthesis of protein (Tisdale *et al.,* 2003). Similarly, phosphorus increased protein content due to its role in the improvement in nitrogen use efficiency, biological nitrogen fixation by supplying needed energy. Because nitrogen is a basic constituent of protein and with increase in the rate of phosphorus application, nitrogen availability increased which resulted in increased protein content in grain. Significant increase in protein content in grain with increasing P was also estimated by Meena *et al.* (2004) and Kahlon *et al.* (2006).

5.2.4 Nutrient content and uptake

The concentration and accumulation of nutrients *viz*., N, P, K and S in leaves at 60 DAS and grain and haulm of chickpea at harvest registered marked improvement with application of phosphorus. The P content of leaves at 60 DAS and grain and haulm at harvest of crop was significantly increased with graded levels of phosphorus upto 60 kg ha^{-1}. Whereas N, K and S content in leaves at 60 DAS and grain and haulm at harvest of crop was significantly increased upto 40 kg ha^{-1} over 20 kg ha^{-1}. (Table 4.18 to 4.34). The magnitude of increase in total uptake of N, P, K and S by application of 40 kg P_2O_5 ha^{-1} was 16.09, 15.93, 16.02 and 19.86 per cent and by 60 kg P_2O_5 ha^{-1} was 20.01, 23.02, 21.17 and 24.88 per cent, respectively over 20 kg P_2O_5 ha^{-1}.

In general, improvement in nutritional status of plant under P fertilization might be primarily on account of better growth of roots, which might have increased the absorption and efficient translocation of these towards plant parts. Secondly, the possible increased nodules with addition of P might have resulted in higher biological nitrogen fixation. Dart (1977) also reported that in many leguminous crops, P application enhances root formation and increase the capacity of nodules for fixation of higher atmospheric nitrogen thereby improves nutritional status of the plant. The increased concentration of these nutrients in grain as well as in haulm at harvest was expected as much of the nutrients present in these storage organs during their growth and development are reallocated from the nutrients present in the vegetative plant parts.

The data on uptake of nutrients under the influence of P fertilization show that application of 40 and 60 kg P_2O_5 ha^{-1} caused significant increase in uptake of NPK and S by grain and haulm as well as total uptake of NPK and S by chickpea crop (Table 4.22 to 4.34). The nutrient accumulation is dependent on concentration at cellular level and dry matter accumulation. Hence improvement in both these components under P application reflected in higher uptake of nutrients by the crop. The increased NPK and S content and uptake of chickpea crop due to P application corroborates findings of several researchers Meena *et al.* (2001a), Jat and Ahalawat (2004), Togay *et al.* (2008), Deo and Khandelwal (2009) and Islam *et al.* (2011).

5.2.5 Nutrient status after crop harvest

The soil analysis at the termination of the experiment revealed that graded levels of phosphorus caused significant changes in available N and P status in soil but available K and S status in soil was not affected significantly (Table 4.38).

There seems a synergistic effect of the P application on available N status of soil which may be due to positive influence of applied phosphorus on nodulation and symbiotic nitrogen fixation. Nodules after degradation may also release nitrogen in soil, possibly due to this fact increase in soil nitrogen was recorded. Israel (1985) also reported a specific role of phosphorus in the symbiotic nitrogen fixation and apart from its influence on overall growth. Significant build up of the soil available N could be attributed to increased activity of nitrogen fixing *Rhizobia* thereby resulting in higher accumulation of N in the soil (Parmar *et al.,* 1998). Kundu *et al.* (1998) and

Sharma *et al.* (2000) also reported a positive N balance in soil is due to biological fixation of N_2 consequent to the inclusion of a legume in the crop sequence. Dubey (2000) also observed increased available N in soil after black gram harvest due to application of P which facilitates enhanced nodulation and N_2 fixing activity by *Rhizobium*. It is an accepted fact that 25 to 35 per cent of applied phosphorus is used by the crop and rest remain in soil in different form. Alike findings were also reported by Cahal *et al.* (1984) who estimated increase in available P content from 17.0 to 28.6 kg ha^{-1} (at harvest) with the application of 60 kg P_2O_5 ha^{-1}. Prasad (1983) also observed increased available phosphorus status in soil after harvest of the crop due to phosphorus application. The results are in close accordance with findings of Akbari *et al.* (2002) who also reported that phosphatic fertilizer was found beneficial for increasing available N and P content in medium black soil.

5.3 EFFECT OF SULPHUR LEVELS

5.3.1 Growth parameters

It is evident from results that application of sulphur at 20 and 40 kg ha^{-1} significantly improved various morphological and biochemical parameters of growth over control (Table 4.1-4.8). These increases ultimately resulted in overall improvement in growth of the crop.

The plant height (cm) of chickpea at 30, 60 and at harvest were significantly increased by 13.19, 12.58 and 7.66 per cent when crop fertilized with 40 kg S ha^{-1} and 10.46, 8.52 and 6.92 per cent with 20 kg S ha^{-1} over control (12.81, 34.49 and 52.72 cm). However the crop fertilized with 40 S ha^{-1} failed to exhibit significant increase in plant height over 20 kg S ha^{-1} at 30 DAS and at harvest. The magnitude on increase in primary branches $plant^{-1}$ at 60 DAS and at harvest with 40 kg S ha^{-1} were 17.70 and 11.94 per cent, respectively over control (3.22 and 3.10 at 60 DAS and at harvest, respectively), however, sulphur fertilization at 40 kg ha^{-1} failed to bring about perceptible variation in number of primary branches at harvest over 20 kg S ha^{-1}. The DMA (g $plant^{-1}$) at 30 DAS by plant parts *viz*., leaves, stem and total were significantly improved with 20 kg S ha^{-1} by 10.03, 12.27 and 10.88 per cent over control. Whereas, DMA (g $plant^{-1}$) at 60 DAS of chickpea leaves, stem, reproductive parts and total were significantly improved by 5.20, 27.23, 11.36 and 11.85 per cent with 20 kg S ha^{-1} and 6.98, 29.77, 12.95 and 13.80 per cent with 40 kg S ha^{-1}, respectively over control. The total DMA at 90 DAS was increased significantly by 12.13 and 17.19 per cent, respectively due to 20 and 40 kg S ha^{-1}. The DMA at harvest was significantly improved due to 40 kg S ha^{-1} over control and 20 kg S ha^{-1}. The magnitude of increase in CGR, AGR and BMD at 30-60 kg ha^{-1} with 20 and 40 kg S ha^{-1} was 12.05 and 14.16 per cent, 12.17 and 14.29 per cent and 11.86 and 13.56 per cent whereas the magnitude of increase at 60-90 DAS were 12.40 and 20.45, 12.29 and 20.34 and 11.94 and 15.81 per cent, respectively over control (Table 4.1 to 4.8).

The role of S can be viewed from its participation in the primary and secondary metabolism as constituent of various organic compounds that are vital for functioning of plant processes. Sulphur in the form of sulphate, is best known for its role in synthesis of S containing amino acids, namely methionine, cysteine and cystine (Lakkaneni and Abrol, 1994). It is also involved in chlorophyll formation, being a constituent of succinyl coenzyme A synthetase (Pirson, 1955). It is also a constituent of glutathione, a compound supposed to play vital role in plant respiration and synthesis of oil (Jordan and Reisenaur, 1957).

Glutathione (γ-glutanyl cysteinyl glycine) is the most abundant low molecular weight thiol in plant cells. Though not a primary product of cellular metabolism essential for life, glutathion plays an important role in detoxification of compounds that are favourable for growth (Rennenberg and Larmoureux, 1990). Sulphur deficiency also leads to an impaired synthesis of several coenzymes and prosthetic groups such as ferredoxin, biotin and thiamine, wherein S forms a structural constituent (Tandon, 1991). Reduced ferredoxin, a protein with iron-sulphur complex act as transmitter of electron generating energy rich compound, NADPH in light reaction of photosynthesis (Marschner, 1986).

It was observed that S fertilization significantly improved chlorophyll content of leaves at flower initiation stage of chickpea. Dube and Mishra (1970) ascribed higher formation of chlorophyll in leaves on account of reduction in nitrates and amides under the presence of S fertilization. Eaton (1942) has also emphasized the importance of S in chlorophyll formation as it is a constituent of succinyl co-enzyme which is a precursor in biosynthesis of chlorophyll. Shibuya *et al.* (1965) found that leaf sulphur proteins are concentrated in chloroplast where chlorophyll molecules comprise prosthetic groups of the chromoproteid complex. Thus, in S deficit plants chlorophyll content declines. It is possible that increased sulphur supply had made up the deficiency and made available the element in sufficient quantities for chloroplast development and chlorophyll formation. Potty (1980) has shown inverse relationship between sulphur and cell sap pH of sunflower and positive relationship between sulphur and chlorophyll. He inferred that in addition to its direct nutritional role, S increases the chlorophyll content through its acidifying effect and amended physiological system. Sulphur also generates a balanced nutritional environmental by restricting accumulation of excess bases (Singh, 1970). Sulphur fertilization has been reported to increase the physiological availability of iron (Potty, 1980). Physiological role of iron as a constituent of electron transport chains in both mitochondria's and chloroplasts is widely documented (Fodor *et al.*, 1955). Therefore, the role of S in chlorophyll synthesis can also be interpreted from this angle. The results of the present investigation on chlorophyll content of chickpea leaves increase due to S application are in accordance with the findings of Nagar and Meena (2004) and Anjum *et al*. (2009).

In the present investigation, growth parameters like plant height, dry matter accumulation, CGR, AGR, RGR and BMD also increased significantly with increasing S levels over a range of control to 40 kg ha^{-1} (Table 4.1 to 4.8). The profound influence of S fertilization on plant height could be attributed to increased metabolic processes in plants which seems to have promoted meristematic activities causing higher apical growth and expansion of photosynthetic surface (leaf area). Furthermore, the improved nutritional environment at cellular level and leaf chlorophyll content appear to have increased photosynthetic rate. Thus, it is obvious that improved growth and development of the crop plants in present study might be due to enhanced metabolic activities. Significant improvement in N content could be ascribed to better metabolism of N under the presence of higher S status of plants. It is also possible that a part of the beneficial effect of S nutrition to the crop might have arisen from the improved water balance. In a solution culture trial with pea and wheat, S deficiency in the nutrient solution increased free water content in the tissues and decreased their water holding capacity, 10-20 per cent dehydration of tissue resulting from S deficiency markedly decreased photosynthesis. It was suggested that water deficit in the plants could be overcome by supplying S to them (Bugakova *et al*., 1975).

Improved growth and development of crop plants in the present investigation might be due to enhanced metabolic activity and photosynthetic rates, resulting in improved RGR and ultimately assimilation of dry matter at successive growth stages. The total shoot dry weight is an integrated measure of photosynthesis and respiration during growth period. Photosynthesis is in-turn dependent to a great extent on area of green leaf surface (Baker and Gabeyehou, 1982).

The results on overall improvement of growth of chickpea with the application of sulphur in the present investigation are in cognizance to that of Kumawat and Khangarot (2002), Sharma and Jat (2003), Choudhary and Goswami (2005), Khatkar *et al.* (2007), Singh *et al.* (2008) and Nawange *et al.* (2011).

5.3.2 Yield attributes and yield

The results show that S application improved various yield components with concomitant significant increase in crop productivity (Table 4.9 and 4.12). The results reveal that S fertilization at 20 and 40 kg ha^{-1} significantly increased the yield components *viz.*, pods $plant^{-1}$, grains pod^{-1}, grains $plant^{-1}$, grain yield $plant^{-1}$ and 100-grain weight by 5.97 and 9.44, 6.02 and 6.77, 14.41 and 17.53, 14.11 and 18.75 and 3.55 and 4.70 per cent, respectively over control (Table 4.9), consequently the crop fertilized with 20 and 40 kg S ha^{-1} produced significantly higher grain, haulm and biological yield to the extent of 18.46 and 22.99, 18.69 and 23.21 and 18.64 and 23.24 per cent over control, respectively (Table 4.12). The crop efficiency estimated in terms of harvest index did not alter significantly with the application of S levels (Table 4.12).

In general, increase in yield parameters of chickpea with S application could be ascribed to its role in improving mineral nutrition of the crop. In preceding section it was emphasized that S fertilization play an important role to alter physico-chemical properties of soil conducive for growth and development of the crop. Reviewing the work done on effect of gypsum (S source) application to a variety of crops, it was inferred that its application promoted root growth and yield of crops (Shainberg *et al.*, 1989). This eventually suggests better availability of nutrients. These nutrients upon translocation towards reproductive structures and also higher photosynthetic activity might have resulted in significant increase in yield attributes.

Photosynthesis is a direct function of leaf area and chlorophyll content of leaves. Higher rate of photosynthesis may have resulted in greater accumulation of dry matter, which in turn is positively correlated to grain yield. Campbell and Kondra

(1978), while studying single plant of *Brassica napus* cultivars found that grain yield was significantly correlated with total dry matter production plant^{-1}. The data presented in Table 4.9 indicate that all the yield attributes were significantly influenced by S fertilization. This marked improvement in yield attributes seems to be due to balanced nutritional environment.

Another possible reason could be efficient and greater partitioning of metabolites and adequate translocation of nutrients towards reproductive site. Wareing and Patrick (1975) reported that improvement in yield parameters was attributed to diversion of greater proportion of assimilates to the developing pods of groundnut due to increased sink strength reflected through its larger demand for photosynthesis.

The net result of increased yield attributes was reflected in increased grain yield of chickpea with S fertilization. In examining yield and yield component of ten European winter rape cultivars over a period of three years, Grosse *et al.* (1992) concluded that high yields could be attained from different combinations of three yield components *viz*., Pods plant^{-1}, grains pod^{-1} and individual grain weight. Positive and significant interrelationship were observed between grain yield and pods plant^{-1} (r = 0.452*), grains plant^{-1} (r = 0.533**) and 100-grain weight (r = 0.725**) (Table 5.1).

In the later section (protein content) N S ratio is discussed. The relative amount of available S and N has an important influence on grain yield. Being a legume crop most of N demand is meet out from biological nitrogen fixation process. Therefore, the marked increase in various yield attributes and yield with sulphur application might have balanced S supplies to the plants. Sunflower was shown to have similar effect to N stress on a number of agronomically important plant characters including leaf area, florate number and grain size (Hocking *et al.,* 1987). Also at higher N supply, increasing S supply from deficient to adequate resulted in 2.4 fold increase in grains plant^{-1} and 2 fold increase in single grain weight, so that grain yield plant^{-1} increased 5 fold. Therefore, maximum yields were obtained only when N and S application were balanced. It was concluded that application of 40 kg S ha^{-1} to chickpea receiving basal dose of N are likely to improve their yield. Finding of Shrikrishna *et al.* (2004), Choudhary and Goswami (2005), Deo and Khandelwal

(2009) and Nawange *et al.* (2011) provide support to the findings of the present investigation.

The increase in haulm yield due to sulphur application might be due to the cumulative effect of increased plant height, dry matter production and chlorophyll content i.e. increase growth parameters. Strong positive and significant correlation existed between haulm yield and plant height at 60 DAS (r = 0.780*) (Table 5.1). Biological yield is the function of grain (r = 1.000**) and haulm yield (r = 1.000**).

Grain and haulm yields combined together significant increase in biological yield of chickpea (Table 4.12). These results are in conformity with the findings of Deo and Khandelwal (2009) and Nawange *et al.* (2011).

5.3.3 Quality parameters

It is evident from results that application of S upto 40 kg ha^{-1} improved the protein content in grain and S containing amino acids, namely methionine, cysteine and cystine. The magnitude of increase in methionine, cysteine and cystine due to 20 kg S ha^{-1} was 4.27, 7.00, 6.73 and 7.14 and due to 40 kg S ha^{-1} was 5.22, 15.00, 15.38 and 11.22 per cent, respectively over control (Table 4.16).

The role of S can be viewed from its participation in the several biochemical processes for the metabolism of carbohydrates, fat and protein in plant system. Sulphur in the form of sulphate, is best known for its role in synthesis of S containing amino acids, namely methionine, cysteine and cystine (Lakkaneni and Abrol, 1994).

The improvement in protein content in grain with the S fertilization seems to be on account of increased S and N content of chickpea grain. It has also been empirically established that for every 15 part of N in proteins, there is 1 part of S which implies that N:S ratio is fixed within a narrow range of 15:1. Therefore, lack of S would reduce the amount of protein synthesized even if there were plenty of N available to plants (Dev and Sharma, 1988). Sulphur is known to increase the metabolic utilization of nitrogen by keeping N:S ratio within optimum range (Dijkshoorn and Van Wijk, 1967). Therefore, increasing S levels could be expected to have worked a favouable N: S ratio for better synthesis of protein in plant system.

5.3.4 Nutrient content and uptake

The concentration and accumulation of nutrients *viz*., N, P, K and S in leaves at 60 DAS and grain and haulm of chickpea at harvest observed marked improvement with application of sulphur. The S content of leaves at 60 DAS and grain and haulm at harvest of crop significantly increased with graded levels of sulphur upto 40 kg ha^{-1}. Whereas N, P and K content in leaves at 60 DAS and grain and haulm at harvest of crop was significantly increased upto 20 kg ha^{-1} over control (Table 4.18 to 4.34). The magnitude of increase in total uptake of N, P, K and S by application of 20 kg S ha^{-1} was 23.07, 23.42, 34.19 and 29.49 per cent and by 40 kg S ha^{-1} was 28.59, 29.30, 40.85 and 39.74 per cent, respectively over control. (Table 4.18-4.34).

Improvement in nutritional environment of plants in general seems to be due to greater availability of nutrients from the soil and later on their higher extraction by roots and translocation to plant parts. Reviewing the work done on effect of gypsum application to a variety of crops it was inferred that its application promoted root growth (Shainberg *et al.,* 1989). Better root development can therefore, be reasoned for greater extraction of nutrients. It is generally believed that the extracted nutrients are used to maintain their critical concentration in plants and thereby for the use of developing structures. Thus, higher concentration of nutrients under S fertilization suggests adequate supply of nutrients. Souza and Ritchey (1986) found that improved root development following gypsum use also resulted in enhanced nitrate recovery from soil. Interdependence of N and S on each other has been elaborately discussed in earlier section, which provides ample explanation of higher N concentration in grain and haulm under S fertilization.

Greater K and S concentration can be reasoned to better root development and higher availability in the soils as explained earlier. Burghardt (1962) opined that as a consequence of lower hydration of SO_4^{-2} ions, the cell colloids get swollen and result in reduction of osmotic pressure which increase transpiration and thereby higher uptake of nutrients. Therefore, the efficient uptake of nutrients by plants under the influence of S fertilization could partly be ascribed to the role of SO_4^{-2} ions in maintaining turgor pressure in plant cells.

Nutrient uptake by crop is a function of their concentration and dry matter production of plants. This marked improvement in accumulation of plant nutrients by crop under the influence of S fertilization can be very well explained. The results obtained in the present investigation are in conformity with the findings of Ram and Dwivedi (1992), Kaprekar *et al.* (2003), Singh and Singh (2004), Deo and Khandelwal (2009) and Ruchi *et al* (2012).

5.3.5 Soil nutrient status after crop harvest

Soil analysis at the harvest of the crop revealed that increasing application of sulphur causes significant changes in available S status in soil (Table 4.38). The magnitude of increase due to 20 and 40 kg S ha^{-1} was 10.29 and 33.48 per cent, respectively over control.

The increase in availability of nutrients with S might be due to higher rate of mineralization of nutrients, favourable environment for microbial activity as well as chemical activity, improved physico-chemical properties, ameliorative effect of S and better growth of roots resulting in high organic matter addition. Dose of sulphur fertilization seems to be the reason for relative enhancement in SO_4^{-2}-S content of soil (Tandon, 1991). Nguyen and Goh (1992) reported increase in carbon bonded sulphur fraction with increasing level of sulphur applied. Further similarly positive response of application of S fertilization to available S of soil was also reported by Ram and Dwivedi (1992), Kaprekar *et al.* (2003), Singh and Singh (2004), Deo and Khandelwal (2009) and Ruchi *et al.* (2012).

5.4 INTERACTION EFFECT OF PHOSPHORUS AND SULPHUR

It was observed that combined application of phosphorus and sulphur on chickpea resulted in significant interaction in respect of yield attributes (pods $plant^{-1}$ and grain yield $plant^{-1}$), grain and haulm yield, nutrient uptake by grain and haulm as well as total uptake of NPK and S. Thus, combined application of phosphorus and sulphur improved the nutritional environment of rhizosphere and thereby increase in yield attributes (pods $plant^{-1}$ and grain yield $plant^{-1}$), grain and haulm yield, nutrient uptake by grain and haulm as well as total uptake of NPK and S by chickpea because of their synergistic effect at lower levels resulted favored uptake of nutrient, promoted growth and yield attributes ultimately the grain and haulm yield.

This was partly attributed to increased availability of the nutrients in soil owing to reduction in soil pH increased the availability of other essential nutrients like etc. (Noellemeyer *et al.*, 1981).

Positive interaction effect of phosphorus and sulphur on grain and haulm yields of chickpea seems to be responsible for significant interactive effect of phosphorus and sulphur on NPK and S uptake by grain and haulm as well as total uptake of NPK and S by the crop.

Among all interaction involving S in India, phosphorus sulphur interaction is the most researched one both positive and negative interaction has been reported but recent research shows that the nature of P x S depends on their rate of application. Researchers have reported that the P x S interaction is synergistic at low-medium levels of P and antagonistic only at higher levels, usually at 60 kg P_2O_5 ha^{-1} or more for field crops (Tandon, 1991). In the present study phosphorus over a range of 20 to 60 kg P_2O_5 ha^{-1} was given. Hence, experimental field are medium in available phosphorus and low in available S status (Table 3.2). Therefore, a synergistic relationship between P and S in respect to crop growth, yield attributes, nutrient content as well as uptake by the chickpea was perfectly in line with referred statement. This positive interaction may be attributed to the promotion of root development and proliferation. These results are in agreement with those of Aulakh *et al.* (1990) and Sharma and Singh (1997).

5.5 EFFECT OF SEAWEED SAP SPRAY

5.5.1 Growth parameters

The result show that foliar spray of 10 per cent *Kappaphycus* and *Gracilaria* saps recorded over all better growth, estimated in terms of plant height, dry matter accumulation at 60, 90 DAS and at harvest, dry matter accumulation by leaf, stem and reproductive parts at corresponding stage, chlorophyll content, CGR, RGR, AGR and BMD of chickpea (Table 4.1 to 4.8). The magnitude of increase in plant height (cm) of chickpea at 60 DAS and at harvest were by 14.00 and 6.42 per cent with application of 10 % *Kappaphycus* sap and 13.76 and 5.09 per cent with *Gracilaria* sap over control (33.79 and 53.24 cm). However, the *Kappaphycus* and *Gracilaria* saps recorded at par effects. The magnitude of increase in primary branches $plant^{-1}$ at 60 DAS and at harvest with *Kappaphycus* and *Gracilaria* saps were 26.43 and 13.38 and 11.90 and 9.65 per cent, respectively over control (3.14 and 3.11 at 60 DAS and at harvest, respectively). The DMA (g $plant^{-1}$) at 60 DAS of chickpea leaves, stem, reproductive parts and total were significantly improved by 10.47, 25.78, 16.19 and

15.41 per cent with *Kappaphycus* sap spray and 4.92, 24.14, 10.64 and 10.89 per cent with *Gracilaria* sap, respectively over control. The total DMA at 90 DAS and at harvest was increased significantly due to foliar application of *Kappaphycus* and *Gracilaria* saps over control. (Table 4.1 to 4.8).

It is an established fact that India has vast sea coast having abundance of marine seaweeds. Seaweeds are good source of nutrient and plant growth promoting substances (Norrie and Hiltz, 1999). *Kappaphycus* and *Gracilaria* seaweed extracts has growth substance like indole acetic acid, riboflavin and auxins which may have increased cell division, cell development and caused beneficial effect on the growth and development of root and shoot of the plant. It also enhanced the nutrient supply, absorption, translocation and their metabolism and also the growth promoting substances present in extract resulted in enhanced plant height, dry matter accumulation. Increase growth may probably due to the availability of auxin, cytokinin and other micro elements present in the seaweed sap (Selvakumari *et al*. 2013).

These results are in conformity with earlier observation, *viz.*, Mohan and Venkataraman (1993), Mohan *et al*. (1994), Thangam *et al*. (2003), Sridhar and Rengasamy (2002), Singh (2010), Zodape *et al.* (2011), Dogra and Mandradia (2012), Abou El-Yazied *et al.* (2012) and Taresh Kumar (2013).

5.5.2 Yield and yield attributes

Spray of 10% *Kappaphycus* and *Gracilaria* saps improved yield components *viz,* pods plant^{-1}, grains pod^{-1}, grain plant^{-1}, grain yield plant^{-1}, 100-grain weight, grain and haulm yield over water spray (Table 4.9 to 4.12). There may be many criteria for effectiveness of the treatment but the yield and yield attributing components are most common. Data (Table 4.9 to 4.12) show that three sprays of *Kappaphycus* 10 per cent significantly increased the yield and yield attributing characters over water spray. However, it remained at par with *Gracilaria* 10 per cent. Yield is result of many yield attributing characters mainly pods plant^{-1}, grain pod^{-1}, grain plant^{-1}, grain yield plant^{-1} and 100 grain weight. The results reveal that 10% *Kappaphycus* and *Gracilaria* saps significantly increased the yield components *viz.* pods plant^{-1}, grains pod^{-1}, grains plant^{-1}, grain yield plant^{-1} and 100-grain weight by 9.38 and 7.41, 7.52 and 5.26, 16.08 and 14.10, 17.56 and 16.49 and 7.29 and 3.13 per cent, respectively over control

(Table 4.9), consequently the crop sprayed with aforesaid seaweed saps produced significantly higher grain, haulm and biological yield to the extent of 15.96 and 13.43, 16.25 and 13.64 and 16.15 and 13.57 per cent over control, respectively (Table 4.12). The crop efficiency estimated in terms of harvest index did not alter significantly with the seaweed saps spray (Table 4.12).

Seaweed extracts are rich source of several primary nutrients like K, P; secondary nutrients like Ca, Mg; trace elements like zinc (Zn), copper (Cu), iron (Fe), manganese (Mn) and beneficial elements like nickel (Ni), sodium (Na) *etc*. Sea weed extracts stimulate various aspects of growth and development resulting in around good health of the plants, while deliberating the effect of seaweed extracts on crops the aspects of root development and mineral absorption, shoot growth and photosynthesis and ultimately crop yield, even vegetative propagation can also be taken into consideration. Due to the presence of good amount of P in it, the liquid seaweed fertilizers proliferate root development, enhance root to shoot ratio, thereby, making the plants more able to mine adequate nutrients from the deeper layer of soil and influence crop maturity as a whole. As P is the important constituent of Nitrate reductase (NADP), the niacin component of Vitamin-B complex, helps in photosystem-I to produce NADPH. As liquid seaweed fertilizers is a very good source of K, it helps in regulating the water status of the plants, controls the opening and closing of stomata and thereby the photosynthesis to a large extent. The meristematic growth, translocation of photosynthates and disease resistance are also influenced by it due to the manifestation of good impact of K. Ca being present in seaweed extracts helps in enzyme activation, cell elongation and cell stability. Liquid seaweed fertilizers is the opulent source of secondary nutrients like Mg; hence, it helps in photosynthesis, phloem export, root growth and nitrogen metabolism. It also influences the N-fixation in legumes as it contains Mn. Mn is a constituent of several cation activated enzymes like decarboxylase, kinase, oxidase etc., and hence, essential for the formation of chlorophyll, reduction of nitrates and for respiration. The trace elements like Fe, Cu and Zn being present in considerable amount in seaweed extracts inspire redox reaction of respiration and photosynthesis, promote reduction of nitrates and sulphates and stimulate the cation activated enzymes. The organic constituents of seaweed extract include plant hormones which elicit strong physiological responses in low doses. A panorama of phytohormones and plant growth regulators are found in different seaweed concentrates and marine macroalgal extracts *viz.* Auxins, Gibberellins, Cytokinins etc. which simulate rooting, growth, flower initiation, fruit set, fruit growth, fruit ripening, abscission and senescence when applied exogenously. Seaweeds also contain a diverse range of organic compounds which include several common amino acids inter alia aspartic acid, glutamic acid and alanine in commercially important species. Alginic acid, laminarin and mannitol represent nearly half of the total carbohydrate content of commercial seaweed preparations. Seaweeds also contain a wide range of vitamins which might be utilized by the crops. Vitamins C, B, (thiamine), B_2 (riboflavin), B_{12}, D_3, E, K, niacin, pantothenic, folic and folinic acids occur in algae. Although vitamin A is not present, the presences of its precursor carotene and another possible precursor fucoxanthin have been found. Apart from the above organic and inorganic constituents, there is an evidence of existence of different other stimulatory and antibiotic substances. These findings are in agreement with Jeannin *et al.* (1991), Vernieri *et al.* (2005), Kowalski *et al.* (1999), Zhang and Ervin (2008), Mancuso *et al.* (2006), Norrie and Keathley (2006) and Rayorath *et al.* (2008). Thus, being a wealthy source of versatile plant nutrients, phytohormones, amino acids, vitamins, stimulatory and antibiotic substances, the liquid sea weed extract enhances root volume and proliferation, bio-mass accumulation, plant growth, flowering, distribution of photosynthates from vegetative parts to the developing fruits and promotes fruit development, reduces chlorophyll degradation, disease occurrence etc. resulting in improved nutrient uptake, water and nutrient use efficiency causing sound general plant growth and vigor ultimately reflecting higher yield and superior quality of agricultural products.

The positive regression between grain yield (kg ha^{-1}) and different parameters *viz.*, pods $plant^{-1}$ ($r = 0.452^*$), grains $plant^{-1}$ ($r = 0.533^{**}$) and 100-grain weight ($r = 0.725^{**}$) also indicated substantiated dependence of grain yield on these components (Table 5.1).

Significant improvement in grain yield with spray could be ascribed to the fact that yield of crop is a function of several yield components which are dependent on complementary interaction between vegetative and reproductive growth of crop. As seaweed saps contain cytokinins, auxins, and also hydrolyzed proteins which may have improved chickpea productivity and its quality. Several researchers *viz*, Gupta

(2007) Zodape *et al.* (2009), Singh (2010), Zodape *et al.* (2011), Dogra and Mandradia (2012) and Abou El-Yazied *et al.* (2012) also observed similar findings.

5.5.3 Quality parameters

It was observed that 10 % spray of *Kappaphycus* and *Gracilaria* saps improved protein and methionine, cysteine and cystine content in chickpea grains. The magnitude of increase was 4.29, 13.00, 9.43 and 9.09 per cent with spray of 10 % *Kappaphycus* sap and 3.69, 8.00, 6.60 and 6.06 per cent with spray of 10 % *Gracilaria* sap over control in protein and methionine, cysteine and cystine content, respectively (Table 4.16). Which might be because of promotive effects on root proliferation, thus higher uptake of nutrients particularly those needed as constituents in protein synthesis (nitrogen, phosphorus, and sulphur) resulting in higher protein synthesis This may be due to the presence of micro elements and plant growth regulators especially cytokinin present in the cell sap. The results are in line with the findings of Zodape *et al.,* 2008.

5.5.4 Nutrient content and uptake

It was observed that spray of 10 % *Kappaphycus* and *Gracilaria* saps improved NPK and S content in leaf at 60 DAS, grain and haulm and their uptake by grain, haulm and total uptake over water spray. The magnitude of increase in total uptake of N, P, K and S by application of 10 % *Kappaphycus* sap were 23.49, 25.26, 28.64 and 25.54 per cent and by *Gracilaria* sap were 18.83, 21.89, 24.00 and 21.45 per cent, respectively over control (Table 4.18-4.34).

As a biostimulant, seaweed sap may contain chelating compounds (i.e., mannitol) that can increase nutrient availability, a better absorption of the chelated compounds at leaf level has been suggested (Salat, 2004). In addition, concentrates can increase root size, thus increasing the volume of soil sampled by a plant (Nelson and Van Staden, 1984), which indeed helps in uptake of nutrients by plant. Increasing evidence exist that nutrient uptake and movement within plants is under hormonal control (Glass, 1989).

The significant improvement in nutritional status of grain and haulm due to these sprays could be ascribed to greater availability of nutrients, and their transportation towards the site of their utilization. Higher plant biomass and grain yield with higher content of NPKS and uptake, which are evident from the content and uptake data (Table 4.18 to 4.34) for their nutrients. High uptake further indicated that the physico-chemical environment of rhizosphere was congenial for transformation and maintaining the availability of nutrient of plant, Backett and Van Staden (1990) has also reported higher uptake commensurate with similar treatment to different test crops. Higher the Chlorophyll content more efficiency is of the photosynthesis, resulting in greater CO_2 fixation and plant dry matter production.

Data presented in Table 4.17 clearly show the benefit of seaweed saps which enhanced the chlorophyll content. Also its mineral composition determines the nutritional value and suitability for industrial use. 10 % seaweeds saps spray treated plants have higher content of nitrogen, S containing amino acids as well as protein. Higher nitrogen content has contributed towards the synthesis of balanced amino acid and finally to higher crude protein. Singh (2010), Zodape *et al.* (2011), Dogra and Mandradia (2012) and Abou El-Yazied *et al.* (2012) also conforms the findings.