The present research work highlights that plant nutrients, like phosphorus and zinc play important roles in the production of barley. The research work done by different scientists on the related investigations has been reviewed and presented here in the chapter under the following categories:

1. Effect of phosphorus on growth and yield of barley crop.
2. Effect of zinc on growth and yield of barley crop.

2.1 Effect of phosphorus on growth and yield

Phosphorus plays a vital role not only in the transformation of ammonium ions into nitrate in protein molecules, but the availability of phosphorus also important under salt stress condition. Therefore, it is necessary to find out the appropriate levels of phosphorus for higher production of barley crop.
Agrawal and De (1979) conducted an experiment to study the effect of different levels of phosphorus on barley varieties and they reported that increasing levels of phosphorus increased the growth and grain yield. Tiwari et al. (1978) reported that application of 40 kg phosphorus per hectare increased the growth and yield attributing characters. Singh et al. (1971), Chaudhary et al. (1971), Singh and Prasad (1972) and Sharma and Sharma (1976) conducted experiments to study the effect of different levels of phosphorus on barley and reported that the increasing level of phosphorus increased the number of fertile tiller per plant, number of grains per ear and grain and straw yield. Similar finding were reported by Warsi et al. (1976).

Turk (1988) recorded that grain and straw yield, total N and P uptake and rainfall use efficiency (RUE) were higher with increasing N and P levels for almost all cultivars. RUE gave the highest grain and straw yield and had the highest RUE at the 10 kg N and 20 kg P/ha level. The cultivar x fertility level (NP) interaction was not significant for grain and straw yields and for total N and P uptake.

Panda et al. (2003) showed that the highest wheat grain yield was recorded with application of phosphorus upto 40 kg P$_2$O$_5$ and inoculation with $P. striata$ or $G. fasciculate$. Nataraja et al. (2005) studied the
relationship between dry matter production and its partitioning in wheat due to the application of phosphorus levels and micronutrients under irrigation. At harvest, the application of 100 per cent $P_2O_5$ of recommended dose resulted in significantly higher dry matter production and its partitioning into leaves, stems and spikes, but it did not differ significantly from 150 per cent $P_2O_5$ of recommended dose but in turn these were significantly superior over 50 per cent $P_2O_5$ of recommended dose and control.

Chaturvedi (2006) observed that growth and yield parameters significantly affected by the rate of phosphorus. During 2003 and 2004, the application of 28.5 kg P/ha was optimum, as it resulted in the greatest plant height (90.1 and 91.9 cm, respectively), total number of tillers/m$^2$ (1423 and 1445), number of grains per spike (45 and 47), and 1000 grain-weight (41.1 and 42.7 g). This treatment also gave the highest average yield, straw yield, and uptake of N and P (4559, 5931, 109.4 and 33.5 kg/ha).

Nataraja et al. (2006) noted that the application of 100% of the recommended rate of phosphorus fertilizer gave the highest values for the different physiological and yield parameters studied. Soil application of $P_2O_5$ at 75 kg/ha was found superior to other micronutrient treatments. Kumar et al. (2007) indicated that the P levels and the methods of
application of phosphorus solubilising bacteria had no influence on the rice-root nematode populations. The nematode build up was higher in the rice-rice system and the population decreased in black gram that followed rice (rice-black gram system). Phosphorus solubilising bacteria application contributed to increased productivity in both rice-rice and rice-black gram rotations.

Panda and Rai (2008) reported that application of phosphorus significantly increased the number of effective tillers/m², number of grains/ear, test weight, grain and straw yield, P content and uptake by wheat. Inoculation with \textit{Pseudomonas striata} or \textit{Glomus fasciculatum} significantly increased the P content, uptake of phosphorus and yield of wheat. The highest grain yield of 57.35 q/ha was obtained due to inoculation with \textit{Pseudomonas striata} followed by \textit{Glomus fasciculatum}.

2.2 Effect of zinc on growth and yield

Zinc is an essential trace element and found nearly in 100 specific enzymes. It has been found essential for carbohydrates and phosphorus metabolism and synthesis of DNA and Auxins.

Kuduk (1987) investigated the effect of Zn applied at various rates on early growth of oats, wheat, barley and peas, on plant uptake of Zn and
on soil properties. Growth of plants was enhanced by low Zn doses. Zinc content in leaves and roots was dependent on Zn application rate. Zinc application led to an increase of soluble Zn in soil, a decrease in soil acidity, and a decrease in cellulolytic microorganism activity.

Mohmoud et al. (1991) did experiment on barley and sunflower in alluvial (pH 7-9) and calcareous (pH 8-5) soils and applied 0, 50, 100, 150, 200 or 300 ppm P/pot as mono calcium phosphate where 150 ppm P/pot gave the highest dry matter yield. Zinc content and zinc uptake in both species on both soils were found increases with highest values on alluvial soil. Plot P content was highest with application of 200-300 ppm phosphorus.

Singh et al. (1995) noted that the application of phosphorus decreased the concentration of Zn, Cu and Fe, although the uptake of these nutrients increased dramatically up to an application rate of 60 mg/kg soil. Zn application increased both the concentration and uptake of Zn in barley, while effects on the concentration of Fe and Cu were variable.

Singh et al. (1997) reported that the application of P, S and Zn significantly increased the dry matter yield of barley up to 60, 40 and 50 mg/kg soil application, respectively. P x S, P x Zn and S x Zn interactions were significant for dry matter yield. The application of P and S
significantly increased P concentration in barley, however, the application of Zn significantly decreased the P concentration at all rates. The application of S up to 40 mg/kg soil and Zn up to 5 mg/kg soil also significantly increased the uptake of P. However, higher rates of S and Zn decreased P uptake.

Ekiz et al. (1998) observed significant reduction in plant growth and grain yield due to Zn deficiency in T. durum, followed by oats, barley, bread wheat and triticale. Decrease in yield became more pronounced under rainfed conditions. Although highly significant differences in grain yield were observed between treatments with and without Zn, no significant differences were observed between the Zn fertilizer treatments, indicating that 7 kg Zn/ha may be sufficient to overcome Zn deficiency. Increasing doses of Zn application resulted in significant increase in the concentration and content of Zn in shoots and grain. The sensitivity of various cereals to Zn deficiency was different and closely related to Zn content in the shoot but not to Zn amount per unit dry weight. Irrigation was effective in increasing both shoot Zn content and the Zn efficiency of cultivars. A significant genotypic variation in Zn efficiency existed among and within cereals and it is suggested that plants may become more sensitive to Zn deficiency under rainfed compared with irrigated conditions.
Morsy and Moussa (1998) reported that grain and straw yield increased with increasing rates of Zn up to 1200 mg/litre and recorded the highest straw yield when sprayed with 1200 mg Zn/litre. Application of Zn increased the values for spike length, number of spikes, number of spikelets/spike, number of kernels/spike and grain weight per plant during one season only. The 1000-grain weight decreased with increasing rates of Zn. Zn uptake increased with increasing rates of Zn. Protein content was highest with the application of 2800 mg Zn/litre.

Gupta and Dev (1999) recorded the highest increase in grain yield (35%) in barley followed by oats (31%) and wheat (23%) with the application of Zn (5 mg/kg of soil in the form of zinc sulphate). The Zn concentration of seeds/grains increased significantly over controls in all the crops. The highest Zn concentration after Zn application was recorded in peas, followed by linseed, and the lowest was in oats. The highest increase in Zn concentration due to Zn application was recorded in peas followed by methi and barley. Channabasavanna et al. (2001) resulted in the highest seed yield and panicles per hill with the application of 25 kg ZnSO₄/ha.

Vasudeva and Ananthanarayana (2001) showed that the paddy rice responded well to zinc application at 20 kg ZnSO₄/ha in acid soils which gave a maximum grain yield of 7002 kg/ha. With regards to zinc source,
the plants which received zinc as ZnO showed lower yield compared to zinc as ZnSO₄. This could be attributed to the lower solubility of zinc oxide. Antagonistic effect on the availability and uptake of zinc were observed due to increased solubility of iron and magnese upon submergence. Zinc concentration in soil after harvest ranged from 1.96 to 18.52 µg/g. It was suggested that ZnSO₄ at 20 kg/ha can be used to produce maximum grain yield and nutrient dynamics of wetland rice.

Genc et al. (2000) noted that plants grown from seed with low Zn content developed symptoms of Zn deficiency by the 2-leaf stage in soil with no soil-allied Zn. Symptoms were reduced markedly as seed Zn content increased. Shoot and root growth increased as the amount of Zn in seed increased, but the effect was most evident when soil Zn supply was limiting plant growth (<=0.04 mg Zn/kg soil). For instance, when no Zn was added to the soil, shoot dry weight of plants grown from high-Zn seed was 108% greater than that of plants grown from low-Zn seed; whereas at 0.04 and 0.8 mg Zn/kg soil, the increases were only 52% and 18%, respectively. Soil Zn application significantly increased tissue Zn concentrations. However, the effect of seed Zn content on tissue Zn concentrations was significant only at very high levels of seed Zn. The results presented showed that seed Zn content improves vegetative growth in barley, especially when Zn supply is deficient for plant growth. Seed Zn
content also affected the determination of Zn efficiency of genotypes, and comparisons of dry matter production of seedlings grown from seed with a wide range in Zn content may alter their rankings for Zn efficiency as determined in this pot assay. The results indicate that seed of similar Zn content needs to be used when comparing genotypes for determination of Zn efficiency.

Kenbaev and Sade (2002) reported that relative increase in grain yield as a result of Zn applications over control ranged from 16 to 29% in the 1994-95 and 1995-96 growing season, respectively. However, all Zn rates were placed in the same yield group. In the control plot, Zn concentrations of the leaves and grains were 10.55 and 9295 mg/kg, respectively, as the mean of all varieties. These Zn concentrations were below the critical Zn concentration which was reported as 10-15 mg/kg. Zinc concentrations of the leaves and grains were increased by Zn and 122% (20.00 mg/kg), respectively. The yield components showed marked increases as a result of Zn application. Results showed that Zn concentrations in leaves and grains were below the critical Zn concentration, and significant increases in grain yield, Zn concentration of leaves and grains and some yield components as a result of Zn applications were found.
Shrivastava and Rajput (2003) obtained the highest yield and net returns were with the adoption of improved practices and application of zinc. The yield obtained under farmers practice using the improved cultivar was higher by 12.18% than the yield obtained under farmers practice using the local cultivar. The yield obtained with the application of the recommended fertilizer rate was also higher by 16.65% than the obtained under farmers practice. The application of zinc along with the adoption of improved practices resulted in a higher yield (by 86.8%) than the application of the recommended fertilizer rate along with the adoption of local practices.

Zhi Gang et al. (2003) found largest root: shoot ratio, highest yield of biomass and rice grain regardless of cultivar due to increasing Zn supply. Zinc partitioning into rice grain increased with an increase in Zn supply. Zn content in grain differed greatly among the cultivars and was also remarkably affected by Zn supply. Zn content in both grain hulls and milled rice increased with increasing Zn supply.

Kulandaivel et al. (2004) reported that the application of 30 kg ZnSO$_4$ + 5 kg FeSO$_4$/ha through chelating with FYM found to be the best combination for rice. However, for hybrid rice-wheat cropping system, application of 40 kg ZnSO$_4$ + 10 kg FeSO$_4$ was found to be the most
appropriate combination to maximum the grain yields of this system and improve the zinc and iron status of soil.

Singh and Singh (2004) observed that the increases in growth and yield attributes were dependent on dose of zinc. Soil application of 10 kg Zn/ha was adequate in partially reclaimed alkali soil with initial pH 10.3, exchangeable sodium percentage of 85 and electrical conductivity of soil solution (1:2) 2.1 dS/m. Zinc sulphate was the superior source of zinc compared to zinc frits. Zinc application increased chlorophyll and increased the tissue concentration of Zn, Ca, Mg, K and P, whereas Na content decreased. Zinc modified the elemental composition of plant tissues favourably and thereby accelerated plant growth and yield.

Jana et al. (2005) noted that Zinc sulphate at 30 kg/ha increased plant height by 3.2%, effective tillers by 11.6%, panicle length by 3.8% and grains per panicle by 11.0% over the control. Comparative data on yield response and economic analysis of zinc application to wheat were also tabulated.

Khan et al. (2005) recorded a significant increase in yield and yield components for increasing levels of Zn (P<0.05). The application of 1.0% Zn solution appeared to be an optimum level for rice crops in these soil series. Tikken soil series gave the highest paddy straw yield, while the
Ramak series gave the lowest. The interaction between the soil series and Zn levels was significant for all parameters.

Majcherczak et al. (2006) reported that the application of the microelements in the form of chelated fertilizer and solutions of Cu significantly reduced the K content in the grains by 6.6 and 3.5%, respectively. Foliar application of Zn solution reduced the phosphorus and Mg contents by 8.6 and 10.7%, respectively. The results showed that application of Zn, Mn and B significantly increased the ionic ratio of the sum of univalent and bivalent cations.

Singh and Yadav (2006) reported that increasing dose of ZnSO₄ improved growth and yield parameters of wheat. Maximum values were recorded with the application of 40 kg ZnSO₄/ha. However, it was statistically at par with 30 kg/ha.

Abdul-Hady (2007) reported that salinity decreased the fresh and dry weights of the barley plant (Hordeum vulgare L.), while this effect diminished with increasing Zn levels. The maximum dry weights were obtained from the treatment of 3000 ppm salinity level, for different Zn treatments (1.69, 1.84 and 2.05 g/pot) as compared with the control (1.40, 1.52 and 1.62 g/pot), respectively. Nitrogen, P and K concentrations and their uptake of barley plants were increased by increasing Zn application.
Sodium concentration of tissues decreased with increasing Zn rate and its uptake. Zn content of the fresh and dry weight was increased with increasing Zn rate at different salinity levels as compared with control.

Khan et al. (2007) studied that Zn application significantly increased wheat grain yield, ranged from 2.7 to 3.5 t/ha, giving highest increase of 31.6% over control from 5 kg Zn/ha. The number of tillers, number of spike/m², spike length, plant height and 1000-grain weight of wheat were also significantly affected over control with the same treatment. Paddy yield was also significantly affected by Zn levels ranged from 3.9 to 5.9 t/ha. The highest yield was obtained from 10 kg Zn/ha each applied to both crops. Similarly Zn application also affected significantly to the yield parameters of rice like the number of spike/m², number of spike/plant, spike length, plant height and 1000-grain weight over control from the above said treatment of 10 kg Zn/ha. The residual application of 10 kg Zn/ha can be recommended for economical production in wheat rice system.

Misra and Abidi (2007) recorded maximum broken rice recovery with application of 30 kg ZnSO₄/ha (21.45 and 21.44%). The maximum milling percentage was obtained with Proagro-6444 supplemented with 30 kg ZnSO₄/ha. Sudhalakshmi (2008) conducted experiment to determine the
influence of Zn stress on root dry weight of rice genotypes and classified as Zn efficient, moderately efficient and Zn inefficient based on the relative depression in root dry weight.

Shivay et al. (2008) revealed that the zinc-enriched urea (ZEU) had a significant effect on growth, yield attributes and yields of aromatic rice. Highest values for all these attributes and yields were recorded at the highest enrichment (3.5%) of the PU with zinc. The highest zinc concentration and uptake in rice grain and straw were also significantly higher with the highest level (3.5%) of zinc enrichment. The residual effect of zinc-enriched urea on succeeding wheat yield and zinc uptake was significant only at a higher level of zinc-enriched urea and only in the second year of study. Considering all the economic parameters (benefit, benefit: cost ratio, IR-1 invested in zinc), 1-1% ZEU proved the most economic source for aromatic rice-wheat cropping system and therefore is recommended for rice-wheat cropping system in Delhi and adjoining areas of north India.

Singh and Yadav (2008) reported that increasing dose of ZnSO$_4$ increased the wheat yield significantly. Maximum values were recorded with the application of 40 kg ZnSO$_4$/ha. However, it was statistically at par
with 30 kg ZnSO$_4$/ha and optimum dose of zinc was found 38 kg/ha for maximum yield potential of wheat under high RSC irrigation water.

Doran et al. (2009) reported that grain yield of wheat at third and fourth doses increased 15.0 and 17.4\%, over all application methods, respectively. Yield components, i.e. spike length, spikelet number, grain number per spike and thousand grain weight were increased approximately 10\% upon the addition of third and fourth doses. Application methods significantly affected to grain yield, zinc concentration, protein content of grain and plant height. The highest doses of soil, leaf and seed application increased grain yield up to 26.9, 12.5 and 12.2\%, respectively. The application of 6.9 kg zinc/ha to soil or 5400 g zinc/ton seed to seed or 550 g zinc/ha solution to the plants may be more efficient in terms of their economical feasibility and yield increases.

2.3 Effect of Phosphorus and zinc on growth and yield

Choudhary and Mali (1988) recorded barley grain yields of 3.55, 3.95 and 4.30 tonnes/ha with the application of 0, 20 or 40 kg P$_2$O$_5$/ha. Applying 0, 2 and 4 kg Zn/ha gave yields of 3.77, 3.93 and 4.11 tonnes/ha respectively, but the differences were not significant. Ghose et al. (1999) reported that grain yield increased with up to 60 kg P$_2$O$_5$. Available Zn in
soil decreased over time, while P content increased over time and with increasing P application.

Choudhary and Majumdar (2002) observed that the zinc application decreased the P-content. The percent decrease in the P concentration was 21.78, 32.85 and 38.66 following 2, 4 and 6 kg Zn/ha application as compared to control. Uptake of P and K increased with Zn application but the reverse was true of P uptake.

Hood (2002) showed that phosphorus improved the seedling vigour and dry matter yield at panicle initiation in all treatments. Tillering and yields were severely reduced where no phosphorus was applied. The highest paddy yields were obtained with Granulock 12Z, where soil zinc levels were very low. The treatment receiving 3.3 kg/ha of zinc blended with incitec super resulted in lower yield than other zinc treatments at all sites except one. The average net return from the application of phosphorus and zinc fertilizers compared with nitrogen alone was $173/ha for Granulock 12Z lite, $187/ha for Granulock 12Z and $161/ha for incitec super blended with zinc. It is suggested that growers should band phosphorus and zinc fertilizers under the soil rather than broadcasting them on top.
Hussien et al. (2002) reported that the application of P fertilizers alone or in combination with Zn, Mn and FYM resulted to a significant increase of barley dry weight. The response of barley plants for added P depended on the P source, P level and other treatments under where the highest response was obtained in plants treated with superphosphate at 90 ppm P$_2$O$_5$ with 4% FYM. The lower response was recorded in the treatment of bone powder at all levels. Nitrogen, P, K concentrations and their uptake (mg/pot) by barley increased by increasing Zn application from 4 to 8 ppm alone or in combination with P fertilizers. The application of either alone (2 and 4%) or in combination with P fertilizers also resulted to a significant increase in N, P and K concentration and uptake. In addition, the application of FYM alone significantly increase the concentration and uptake of both Zn and Mn in barley compared with the untreated plants.

Arora and Singh (2003) found that the P content in barley grain and straw decreased with increasing levels of Zn, although total P uptake increased with Zn application. N enhanced the content and uptake of P. The highest P contents in grain and straw (0.558 and 0.132%, respectively) were recorded in 90 kg N/ha. The total uptake of P in barley increased both with the application of Zn and N. The P and Zn ratio both in grain and straw significantly decreased with increasing levels of Zn.
Arora and Singh (2004) found that the application of zinc and nitrogen enhanced the grain and straw yield of barley (*Hordeum vulgare* cv. RD-2052). Grain and straw yield increased significantly with the application of Zn and N at the rate of 5.0 kg Zn/ha and 60 kg N/ha, respectively. Yield components like effective tillers, ear length, number of grains per ear and test weight increased significantly with the application of 5.0 kg Zn and 60 kg N/ha as compared to lower levels. Higher doses of Zn and N increased yield and yield components non-significantly. The interaction effect of Zn x N on grain yield was found to be significant. The combined application of 7.5 kg Zn along with 90 kg N/ha registered the maximum grain yield of 49.20 q/ha and straw yield of 72.6 q/ha, which was 21.17 and 28.58 q/ha higher over the control.

Dewal and Pareek (2004) observed that growth parameters, yield attributes, yield, net return and benefit: cost ratio increased significantly with application of 40 kg P$_2$O$_5$, 40 kg S and 5 kg Zn/ha. In general, nutrient uptake increased up to highest level of P, S and Zn, except that P uptake was reduced at highest level of zinc and Zn uptake was reduced at highest level of phosphorus.

Patel *et al.* (2004) achieved higher grain yield under 40 kg P$_2$O$_5$/ha over the lower levels. Application of N at 80 kg/ha and P at 40 kg/ha also
recorded significant values for nutrient uptake. Sowing of barley during the second fortnight of November and nourished with 80 kg N/ha and 40 kg P/ha fetched better profit.

Swami and Shekhawat (2009) observed that the grain, straw yield and the uptake of N, P and K by rice increased significantly with increasing levels of zinc up to 30 kg ZnSO₄/ha. The relative uptake at the first level of 15 kg ZnSO₄/ha rather than respective higher doses. A slight increase in the grain and straw yield of rice was observed with higher moisture regimes. The productivity and uptake of various nutrients by rice were highest at 30 kg ZnSO₄/ha and 75 mm of irrigation.