Globally India accounts for 33 per cent area and 22 per cent production of pulses. About 90 per cent of the total global pigeonpea, 65 per cent of chickpea and 37 per cent of lentil area fall in India with corresponding 93, 68 and 32 per cent of global production, respectively. However, the growth rate of area under pulse crops was just 0.04 per cent during the period 1967-68 to 2001-02, as a result, the share of pulses in the total food grain production reduced from 17.0 per cent in 1961 to 7.0 per cent in 2006. The net availability of pulses has come down from 61g in 1951 to 29 g day\(^{-1}\) person\(^{-1}\) in 2008, whereas the net availability of rice increased from 158.9 to 206.4g day\(^{-1}\) person\(^{-1}\) and wheat from 65.7 to 160.1 g day\(^{-1}\) person\(^{-1}\). The annual compound growth rate of pulse production was only 0.11 per cent compared to that of rice (0.78) and wheat (2.11) during 1950 to 2008. As a result, annual growth rate of per capita consumption of pulses was negative (-0.015 g day\(^{-1}\) person\(^{-1}\)). Due to the mismatch of supply and demand of pulses (i.e., shortage of supply of pulses) the prices of pulses increased exorbitantly over the years.

To meet the high demand for pulses, India has been importing a large quantity of pulses in the recent years (0.65 million tonnes costing about $168 million). The import of pulses increased from 1396.6 tonnes in 1960-65 to
765150 tonnes in 1995-2000, whereas pulse exports increased from 10052 tonnes to 60863 tonnes in the same period. This high dependence on the global market for essential source of protein to the mass vegetarian population of India is a serious concern. This eventually affects low consumption levels of pulses in the Indian diet compared to the standards prescribed by the Indian Council of Medical Research (ICMR).

Pulses are an integral part of Indian diet. They are an important source of protein, especially for vegetarian and economically poor and rural population of the country. Pulses are generally two to three times richer in protein than cereals and hence a cheap source of protein. They are also rich in lysine and tryptophan, the essential aminoacid in which cereals are deficient and thus, they complement in aminoacid profile available for cereal based diet. There is a pressure to stimulate the consumption of pulses. National Commission on Agriculture (NCA) suggested that the consumer demand for pulses of 20.70 to 24.70 million tonnes in 2000 has to be raised to 25.56 to 30.49 million tonnes because of post harvest losses and requirement of seed and feed. According to the NCA projection, the country has the potential to meet the anticipated demand of pulses through domestic production. NCA projected that pulse production in India can reach 35.0 million tones in 2000 AD, but this projection has not come true anywhere near target even now.

Mungbean (*Vigna radiata* L. wilczek) is an important food legume of many tropical and sub-tropical parts of the world. It is very rich in high-quality protein (24 per cent), least producer of intestinal gas or flatulence and is most easily digestible among all the legumes. It is primarily used as
dal (whole, split or husked). Preparations such as wearing foods (porridge, dry mix), snacks (cookies and breakfast bun), sprouts, noodles, biscuits, textured meat are prepared from it. Green pods are cooked as vegetables. The seed coat and broken cotyledons after decortications are fed to livestock and poultry. The dried straw including the top one third portion of summer mungbean crop, the rest of the standing plants are buried as green manure and rice is immediately transplanted to obtain a bumper crop.

Mungbean is an important pulse crop of India grown on about 2.53 million hectares with annual production of 0.86 million tonnes. The crop has its own uniqueness in the sense that no other pulse crop matures in 60-65 days. It fits well in various systems, without any major competition with the main crop. Due to availability of short duration varieties of mungbean with synchronous maturity, the crop has been successfully introduced in spring/summer season in various cropping systems prevalent in northern India.

The capacity of pulses for symbiotic fixation of nitrogen is the major factor responsible for improving soil nitrogen fertility. Estimates of $N_2$ fixed by pulses vary greatly with soil type, crop species, agro-climatic conditions, crop management practices etc. The $N_2$ fixation estimates also vary with the method of estimation. George et al. (1995) reported considerable genotypic variation of nitrogen fixation by two cultivars of mungbean. Genotype Pagasa 2 fixed higher nitrogen (90 kg nitrogen ha$^{-1}$) than Pagasa 1 (61 kg N ha$^{-1}$). Ganeshamuthy et al. (2003) reported that nitrogen derived from well managed experiments varied from 0 to 100 per cent. In kharif and
Discussion

spring/summer mungbean this variation is mainly due to fluctuation in soil
temperature and moisture.

The results arrived and their interpretations on various aspects of
experimentation are as under:

EFFECT OF RHIZOBIUM STRAINS AND DIFFERENT DOSES OF
SULPHUR AND PHOSPHORUS ON GRAIN YIELD AND ITS COMPONENT
TRAITS

(i) Number of pods per plant

It is evident from the results presented in previous chapters that among
the strains, KM₃ proved to be better alongwith the application of sulphur or
phosphorus, sulphur and phosphorus during zaid as well as kharif seasons.
Sulphur applied @ 20 kg ha⁻¹ and phosphorus @ 60 kg ha⁻¹ appeared to be
signficantly better over the other doses of this nutrient. Thus, it is concluded
that for obtaining higher number of pods plant⁻¹, which is one of the most
important yield contributed traits, one should use the rhizobium strain KM₃
and basal application of 20 kg of sulphur and 60 kg of phosphorus ha⁻¹. This
treatment combination holds true if the mungbean is grown either in zaid or
kharif season. So far as the doses of sulphur and phosphorus are concerned
similar results have also been obtained in All India Coordinated Research
Programme on MULLaRP (Mungbean, Urdbean, Lentil, Lathyrus, Rajmash
and Pea) where the multilocational trials over the seasons have been
conducted. Similar results have also been reported by Basu and
Bandyopadhyay (1990), Lee et al. (1990), Ardesha et al. (1993), Singh et al.
(1993), Singh et al. (1999), Noureldin et al. (2000), Meena et al. (2001), Malik
et al. (2002), Srinivas et al. (2002), Ashraf et al. (2003), Dost et al. (2004),
Hossain and Solaiman (2004), Nadeem et al. (2004), Tomar et al. (2004), Khanna and Sharma (2005), Potdukhe et al. (2005), Sharma et al. (2005), Anjum et al. (2006) and Bahadur et al. (2009).

(ii) **Number of seeds per pod**

Number of seeds pod\(^{-1}\) is another important yield contributing trait, like number of pods plant\(^{-1}\). Application of 20 kg of sulphur and use of *rhizobium* strain KM\(_3\) significantly increased the number of seeds pod\(^{-1}\) during both the seasons. The application of 60 kg of phosphorus ha\(^{-1}\) has been found to be beneficial along with seed inoculation with mixed strain of *rhizobium* KM\(_1+3\). The interaction effects of *rhizobium* strain and different levels of sulphur and phosphorus clearly brought about that seed inoculation with *rhizobium* strain KM\(_3\) and sulphur and phosphorus applied @ 20 kg and 60 kg ha\(^{-1}\), respectively during *zaid* and *kharif* seasons are effective treatment combinations for improving the number of seeds per pod. The mixture of the two *rhizobium* strains proved to be better along with the phosphorus application, but along with the sulphur and phosphorus, KM\(_3\) strain showed its better impact.

The present findings are in conformity with the results of multilocational trials conducted across the seasons under All India Coordinated Mungbean Improvement Programme of Indian Council of Agricultural Research. Similar results have also been reported by Basu and Bandyopadhyay (1990), Singh et al. (1993), Singh et al. (1999), Noureldin et al. (2000), Meena et al. (2001), Srinivas et al. (2002), Dey and Basu (2004), Nadeem et al. (2004), Singh et al. (2004), Tomar et al. (2004), Khanna and Sharma (2005), Potdukhe et al. (2005), Sharma et al. (2005), Anjum et al.
In order to obtain comparatively bolder grains, one should inoculate the seed with *rhizobium* strain KM$_1$ and application of 20 kg of sulphur and 60 kg of phosphorus ha$^{-1}$ at the time of sowing of the crop during *zaid* season. Similar results have been obtained with respect to doses of sulphur and phosphorus during *kharif* season as well but the *rhizobium* strain differed in their efficacy when applied along with sulphur and phosphorus during *kharif* season. KM$_{1+3}$ was the best when used along with either sulphur or phosphorus but when sulphur and phosphorus were used together as is being done also, KM$_3$ proved to be the best. Thus, in two seasons differential response of *rhizobium* strain have been observed. The differences in the efficacy of *rhizobium* strains may be due to differences in adaphic factors in two seasons. Similar results have also been reported by different workers like Basu and Bandyopadhyay (1990), Lee *et al.* (1990), Singh *et al.* (1993), Singh *et al.* (1999), Meena *et al.* (2001), Malik *et al.* (2002), Srinivas *et al.* (2002), Ved *et al.* (2002), Dey and Basu (2004), Hossain and Solaiman (2004), Singh *et al.* (2004), Tomar *et al.* (2004), Khanna and Sharma (2005), Potdukhe *et al.* (2005), Sharma *et al.* (2005), Anjum *et al.* (2006), Kavya *et al.* (2006), Bahadur *et al.* (2009), Kumar *et al.* (2009), Patel *et al.* (2009), Singh *et al.* (2009) and Sundaravarathan *et al.* (2009).
(iv) **Grain yield per plant**

Grain yield is the resultant of a number of its contributing traits. Use of 20 kg of sulphur ha\(^{-1}\) and seed inoculation with strain KM\(_3\) in *zaid* season and KM\(_{1+3}\) in *kharif* season gave the highest yield, so far as sulphur application and seed inoculation is concerned. The experiments conducted under All-India Coordinated Research Project (AICRP) at Regional Research Stations as well as at farmers’ fields throughout the country showed variable response of mungbean to inoculation. However, the response of inoculation varies with strain, location, crop management, host genotype etc. Mean yield data of mungbean trial conducted during 1999-2004 indicated higher grain yield of mungbean ranging from 15.6 per cent (Ludhiana) to 31.7 per cent (Vamban) due to inoculation. Application of 60 kg of phosphorus and use of mixed strain KM\(_{1+3}\) during both the seasons proved to be significantly better over other treatment combinations. When all the treatments i.e. *rhizobium* strains and different levels of sulphur and phosphorus applications were considered together, seed inoculation with mixed strain KM\(_{1+3}\) and basal application of 20 kg of sulphur and 60 kg of phosphorus ha\(^{-1}\) during both the seasons appeared to be the best. The results of multilocational trials on mungbean of All India Coordinated Programme of ICAR indicated that use of 20 kg of sulphur ha\(^{-1}\) is a beneficial dose for enhancing grain yield. Since now days our soils have become deficient with respect to phosphorus, a dose of 60 kg ha\(^{-1}\) (against the recommended 40-45 kg ha\(^{-1}\)) is useful. The present results are in conformity with those reported by Basu and Bandyopadhyay (1990), Azad and Gill (1991), Mahadkar and Saraf (1991), Mondal and Ray (1991), Yadav *et al.* (1992), Ardesha *et al.*
Ho-Huu Tien et al. (2002) observed negative effects of inoculation on grain yield. Since yield components have competition for photosynthates, correlation between them are mostly negative (Malhotra et al. 1974; Raje and Rao, 2000). Joshi and Kabaria (1973) found that pods per plant are positively and significantly correlated with seeds per plant, seeds per pod, days to flower and days to maturity, while seed weight has been shown to be negatively correlated with seeds per pod, days to flower, pods per plant. Negative correlation of 100 seed weight with days to flower and plant height and positive association with pod length have also been reported. Yohe and Poehlman (1975) reported that seed yield is positively correlated with pods per plant, seeds per pod, seed weight and plant height.

Application of *rhizobium* with increasing level of phosphorus up to 60 kg showed an improvement in morphological attributes viz. seeds per pod, 100-seed weight and finally seed yield per plant. *rhizobium*, sulphur @ 20 kg ha\(^{-1}\) and phosphours @ 60 kg ha\(^{-1}\) increased grain yield over control. Similar results have also been reported by Singh et al. (2004).
Verma and Yadav (2005) reported that application of sulphur improves mungbean growth in terms of plant height, pod length and number of seeds per pod. Total chlorophyll content in leaves and protein content in matured seeds also enhanced with application of sulphur.

Attaining higher grain yield is a complex process which requires regulation of processes limiting sink development, triggering the productivity by making critical use of nutrients which influence plant architecture and growth habits. Molecular markers closely linked with important sink development processes need to be identified for marker assisted breeding. The combined efforts of physiologist and plant breeders may be able to break the current yield plateau in mungbean.

INTERACTION EFFECTS OF RHIZOBIUM STRAINS, SULPHUR AND PHOSPHORUS DOSES ON PHENOLOGICAL AND STRUCTURAL TRAITS

(A) PHENOLOGICAL TRAIT

Days to 50 per cent flowering:

Significant increase in days to 50 per cent flowering was observed during both zaid and kharif seasons when the seeds were inoculated with rhizobium strain KM1 and 20 kg of sulphur and 60 kg of phosphorus ha⁻¹ was applied at the time of the sowing. Similar interaction effects were observed during both the seasons with respect to rhizobium strain and sulphur and rhizobium strain and phosphorus. In mungbean short duration varieties are preferred for which early maturing and consequently early flowering varieties are required. Therefore, increased days to 50 per cent flowering is not considered a desirable trait in mungbean. Uninoculated seed sown
along with no application of sulphur and phosphorus presented minimum number of days to 50 per cent flowering in both the seasons. The yield and its contributing traits showed that for getting higher yields 20 kg sulphur, 60 kg of phosphorus and seed inoculation with an efficient rhizobium strain is a must. Therefore, a genotype needs to develop which responses to seed inoculation and application of sulphur and phosphorus which requires lowest number of days to 50 per cent flowering. The present results are in conformity those earlier reported by Shukla and Dixit (1996) Khanna and Sharma (2005), Potdukhe et al. (2005) and Sharma et al. (2005),

(B) STRUCTURAL TRAIT

Plant height

Seed inoculation with mixed strain of rhizobium KM$_{1+3}$ responded significantly in improving plant height with sulphur and phosphorus application in zaid as well as kharif seasons. Twenty kg of sulphur ha$^{-1}$ and phosphorus @ 60 kg ha$^{-1}$ along with the seed inoculation responded well in increasing plant height in both the seasons. Similar results have also been obtained by Liouch et al. (1983), Ardeshna et al. (1993), Shukla and Dixit (1996), Singh and Sharma (1997), Singh and Yadav (1997), Noureldin et al. (2000), Sharma et al. (2000), Ashraf et al. (2003), Dost et al. (2004), Hossain and Solaiman (2004), Nissa and Ram (2004), Singh et al. (2004), Tomar et al. (2004), Singh et al. (2009) and Sundararavathan et al. (2009).

Plant height has been reported to be positively associated with grain yield in most of the studies except a few (Holker and Raut, 1992; Pathak and Patel, 1993).
Leaf Area Index

Mungbean is C₃ plant with respect to photosynthetic activity. Seed yield is an end product of photosynthesis (source), translocation and storage of assimilates (sink). The amount of photosynthesis is a function of total leaf area and total solar radiation intercepted. Mungbean is grown in summer season where it receives abundance of sunshine as well as in kharif season when the solar radiation is diminished by cloud / cover.

Mungbean grown in zaid with high solar radiation had higher crop growth rate and leaf area index than the crop grown during kharif season with cloudy weather (Singh et al. 1985). In a study on fruit formation and seed yield in mungbean, fruiting began at the fourth node and was highest at fifth node and then decreased from fifth node onwards. Seed weights at different nodes were correlated with leaf area at that node, indicating that large leaf area that intercepts maximum light is needed to obtain high seed yield. Mungbean plants grown under reduced light intensity by shading to about 40 per cent of total intensity recorded reduced photosynthetic rate, nodulation and leaf nitrogen.

Inoculation with rhizobium resulted in increased leaf area which is associated with higher leaf photosynthetic rate.

Application of 20 kg sulphur ha⁻¹ and mixed strain KM₁+₃ significantly improved leaf area index in both the seasons. Strains KM₁ and KM₃ were at par. Further addition of sulphur could not create any significant impact in improving leaf area index similar results have also been reported by Nemat et al. (2000), Singh et al. (2004) and Shukla and Dixit (1996).
Likewise, phosphorus applied at the rate of 40 kg ha\(^{-1}\) alongwith seed inoculation with mixed strain proved to be the best in significantly improving the leaf area index in both the seasons. The performance of strains KM\(_1\) and KM\(_3\) was at par and further addition of phosphorus doses could not create any significantly impact on improving leaf area index. The present findings are in conformity with those earlier reported by Menaria et al. (2003), Nemat et al. (2000), Singh et al. (2004), Shukla and Dixit (1996) and Tomar et al. (2004) in mungbean.

The interaction effects of rhizobium strains, different doses of sulphur and phosphorus application indicated that mixed strain KM\(_{1+3}\) and application of 20 kg sulphur and 40 kg phosphorus per hectare was best during both the seasons in enhancing leaf area index over other combinations. Similar results have also been reported by Singh et al. (2004), Shukla and Dixit (1996) and Tomar et al. (2004).

**EFFECT OF SULPHUR AND RHIZOBIUM INOCULATION ON NUMBER AND DRY WEIGHT OF NODULES**

**A) Number of nodules**

Under favourable conditions, crown nodulation on primary roots of mungbean is apparent within one week of emergence (Das 1982, Summerfield and Roberts, 1985) and measurable acetylene reduction activity can be detected within 10-25 days after sowing. Nodules number and fresh weight increases rapidly during vegetative phase, reach maximum at flowering or during early pod filling and decline thereafter due to nodules senescence. It is obvious from the data that application of sulphur @ 20 kg ha\(^{-1}\) significantly increased the number of nodules plant \(^{-1}\) both in kharif and
zaid seasons at all stages of crop growth i.e. at pre-flowering stage and at flowering stage. The further addition of sulphur could not create any substantial impact on enhancing the number of nodules at the both stages as well as in both the seasons. In general, the nodulation was better during kharif season as compared to zaid season. In zaid nodulation varies significantly under different dates of sowing. The crop sown in March produces more number of small nodules without leghaemoglobin. This decline in microbiological trait may be due to low temperature. On the other hand April sown crop produces less number of large nodules which are pinkish due to leghaemoglobin. Drastic decrease in nodule number has also been observed in crop sown in May and June which is attributed in increase in temperature during these months. Nodulation is remarkably high in July sown crop which decreases drastically in August sown crop. Rhizobia are mesophiles and grow best at optimum temperature of 25-35 °C. Soil temperature above 50 °C at 5 cm depth is sufficient to kill rhizobia during summer. Excessive temperature can kill majority of rhizobia in surface layer of soil. At pre-flowering stage, strain KM$_{1+3}$ responded significantly better over the other two strains during zaid season while during kharif season all the strains were at par. At flowering stage KM$_3$ responded significantly better over the other strains during both the seasons. In general, it can be concluded that use of the rhizobium strain KM$_3$ in conjunction to basal application of sulphur significantly enhances the number of nodules over the control at both the stages of flowering in both the seasons. Similar results have also been reported by Fritz and Rosen (1991), Patel and Patel (1991), Yadav et al. (1992), Ardesha et al. (1993), Singh et al. (1993), Singh et al.

Nodules are phenotypic expression of two genotypes host legume (macrosymbiont) and rhizobium (microsymbiont), which serves as the seat of nitrogen fixation. The number of nodules of the root system also governs the extent of nitrogen fixation, besides, other factors.

(B) Dry weight of nodules

The nodule dry weight significantly increased with the application of 20 kg of sulphur ha$^{-1}$ at pre-flowering as well as at flowering stage in both the seasons. Further application of sulphur could not create any significant impact on nodules weight. Among the strains, KM$_{1+3}$ was significantly better followed by KM$_3$ and KM$_1$ during both the seasons as well as at both the stages of crop growth. Similar results have also been observed by Wange et al. (1996), Singh and Yadav (1997), Chaubey and Kaushik (2000), Balchandran and Nagarajan (2002), Ram et al. (2002), Zhang et al. (2002), Chandra and Pareek (2003), Dey and Basu (2004), Hossain and Solaiman (2004) and Sripriya et al. (2005), reported that on co-inoculation of mungbean seeds with Pseudomonas strains MRS 13, MRS 16 and Bradyrhizobium sp. (Vigna) strain 24, there was a significant increase in nodule weight, plant
dry weight and total plant nitrogen as compared to inoculation with *Bradyrhizobium* strain 24 alone. Ray and Dalei (1998) observed significant increase in mungbean yield with *rhizobium* to *mycorrhiza* as compared to *mycorrhiza* or *rhizobium* alone. Similar results were also reported by Das *et al.* (1997) in urchbean and Das *et al.* (1997), Gupta *et al.* (1998), Khanna and Sharma (2005), Potdukhe *et al.* (2005), Sharma *et al.* (2005), Kumar *et al.* (2009), Patel and Patel (2009), Singh *et al.* (2009) and Sundaravarathan *et al.* (2009) in mungbean.

From the overall results of the interaction effects of different doses of sulphur application and various strains of the *rhizobium* used, it is clearly evident that the use of the *rhizobium* strain KM$_3$ or in conjunction (mixture) with KM$_1$ alongwith the application of sulphur @ 20 kg ha$^{-1}$ significantly increases the number of nodules as well as nodule dry weight at both the stages of crop growth as well as in both the seasons.

**EFFECT OF PHOSPHORUS AND RHIZOBIUM INOCULATION ON NUMBER AND DRY WEIGHT OF NODULES**

(A) **Number of nodules**

Maximum numbers of nodules were obtained at pre-flowering as well as at flowering stage when phosphorus was applied as basal dose @ 60 kg ha$^{-1}$ both during *zaid* and *kharif* seasons. Strain KM$_{1+3}$ proved to the best during *zaid* season whereas during *kharif* season strain KM$_3$ was the best. Similar results have also been obtained during flowering stage with respect to strains used. The present results are in conformity with those earlier reported by Lee *et al.* (1990), Bhattacharya and Pal (2001), Praveen *et al.* (2002), Tomar *et al.* (2003), Patel and Patel (2009) and Singh *et al.* (2009).
From the over all the results it is concluded that use of the *rhizobium* strain KM$_{1+3}$ during *zaid* season and KM$_3$ during *kharif* season alongwith the application of 60 kg phosphorus ha$^{-1}$ significantly increases the number of nodules per plant at both the stages of crop growth.

(B) **Dry weight of nodules**

Similar to nodules number, nodule dry weight was also maximum when the phosphorus was applied at 60 kg ha$^{-1}$ at both the stages of crop growth. Strain KM$_{1+3}$ during both the seasons as well as at pre-flowering and flowering stages proved to be the best. Earlier workers like Das *et al.* (1997) in urdbean and Das and Ghos (1997), Gupta *et al.* (1998), Potdukhe *et al.* (2005), Sharma *et al.* (2005) and Kumar *et al.* (2009) in mungbean have also reported similar results.

Under favourable conditions, crown nodulation on primary roots is apparent within one week of emergence and measurable acetylene reduction activity can be detected within 10-25 days after sowing. Nodules number and fresh weight increases rapidly during vegetative phase, reach maximum at flowering or during early pod filling (Chen and Sang, 1982) and decline there after due to nodules senescence.

It is inferred that the use of the mixed strain of the *rhizobium* and application of 60 kg phosphorus ha$^{-1}$ is best to obtain the maximum nodule weight in either of the seasons and at either of the stages of the crop growth.
INFLUENCE OF RHIZOBIUM STRAINS, SULPHUR AND PHOSPHORUS ON NUMBER AND DRY WEIGHT OF NODULES

From the over all results of the interaction effects of the different strains of the rhizobium used and different levels of sulphur and phosphorus applied, it is evident that, in general, the use of the mixed strain of the rhizobium and use of the 20 kg of the sulphur and 60 kg of the phosphorus during both the seasons produces the maximum number of the nodules and consequently the maximum dry weight of the nodule which is one of the essential requirement for obtaining the maximum grain yield of the mungbean crop. The maximum nodule number at pre-flowering and flowering stages and maximum nodule weight can also be obtained by use of rhizobium strain KM3 during kharif season. Similar results have also been reported by Karwasra and Raj (1984), Khandekar et al. (1985), Sonboir and Sarawgi (1998), Singh et al. (1999), Tomar et al. (2004) and Mitra et al. (2006).

NITROGENASE ACTIVITY AS INFLUENCED BY USE OF DIFFERENT RHIZOBIUM STRAINS AND DIFFERENT LEVELS OF SULPHUR AND PHOSPHORUS

(A) Rhizobium strains and levels of sulphur application

It is evident from the results presented in previous chapter that during pre-flowering stage, application of the sulphur @ 20 kg ha\(^{-1}\) significantly improved nitrogenase activity during both zaid and kharif seasons. Among the strains used, the use of mixed strains KM\(_{1+3}\) in combination with said dose of sulphur application significantly enhanced nitrogenase activity. Similar results were obtained during flowering stage of the crop growth as well. Similar results have also been obtained by various

**(B) Rhizobium strains and levels of phosphorus application**

The application of the phosphorus @ 60 kg ha\(^{-1}\) as basal dose along with the seed inoculation with mixed strain KM\(_{1+3}\) significantly improved nitrogenase activity at pre-flowering stage during both *zaid* and *kharif* seasons. At flowering stage, similar results were obtained as that of pre-flowering stage. It is concluded that in order to achieve the maximum nitrogenase activity one should apply 60 kg of phosphorus and seed should be inoculated with *rhizobium* strain KM\(_{1+3}\). The present results are in conformity with those reported by Yadav *et al.* (1992) and Yadav *et al.* (2005).

**INTERACTION EFFECTS OF RHIZOBIUM STRAINS AND DIFFERENT LEVELS OF SULPHUR AND PHOSPHORUS APPLICATION ON NITROGENASE ACTIVITY**

At pre-flowering stage, seed inoculation with *rhizobium* strain KM\(_{1+3}\) and application of 20 kg of sulphur and 60 kg of phosphorus significantly enhanced the nitrogenase activity during both *zaid* and *kharif* seasons. Similar results were also obtained at flowering stage. Overall it can be inferred that maximum nitrogenase activity can be achieved in either of the seasons and at either of the stages of the crop growth by use of mixture of the *rhizobium* strains KM\(_{1}\) and KM\(_{3}\) and basal dose of 20 kg of sulphur and 60 kg of phosphorus ha\(^{-1}\).
EFFECT OF RHIZOBİUM STRAINS AND DIFFERENT DOSES OF SULPHUR AND PHOSPHORUS APPLICATION ON PROTEIN CONTENT OF GRAINS

Mungbean seeds on an average have about 24 per cent protein which is easily digestible but is deficient in sulphur based amino acids like cysteine and methionine, they respond to higher doses of sulphur application in enhancing the protein as well as amino acid content of the grains. Improvement in these amino acids without adversely affecting the easy digestibililty of seeds is the most important quality related objective. In contrast to grain yield and its contributing traits where 20 kg of sulphur ha⁻¹ has been found useful, in case of protein content sulphur application @ 40 kg ha⁻¹ proved better along with 60 kg of P₂O₅ ha⁻¹ during zaid as well as kharif seasons. The present results are in conformity with that earlier reported by Kamal et al. (1981).

During zaid season rhizobium strain KM₃ and during kharif season mixed strain KM₁+₃ gave the best response in improving the protein content of the grains. Differential response of the strains in different seasons have been observed which is expected too because of the differences in climatic and adaphic factors. Similar results have also been reported by Bira and Dixit (1990), Patel and Patel (1991), Singh and Yadav (1997), Meena et al. (2001), Singh and Tarafdar (2001), Malik et al. (2002), Shahi et al. (2002), Ved et al. (2002), Dey and Basu (2004), Hossain and Solaiman (2004), Nadeem et al. (2004), Utpal and Bandopadhyay (2004) Khanna and Sharma (2005), Potdukhe et al. (2005), Sharma et al. (2005), Kumar et al. (2009), Patel and Patel (2009), Singh et al. (2009) and Sundaravarathan et al. (2009).
NUTRIENTS UPTAKE

CONCENTRATION AND UPTAKE OF NITROGEN

(i) Nitrogen content in plants and grains

The content of the nitrogen decreased with the advancement of crop stage. Grains showed considerably higher N content in comparison to those in vegetative parts of the plants. At 30 days crop stage, the mean value of N content in grains was 3.53 and 3.49 per cent during *zaid* and *kharif* seasons, respectively. The nitrogen content in plants varied from 2.78 per cent in uninoculated to 3.5 per cent in KM$_3$, S$_4$ P$_6$ during *zaid* season. The value of this content increased with strain KM$_1$ and further with KM$_3$. During *kharif* season the value increased with KM$_{1+3}$ in comparison to KM$_1$. None of the interactions was found to be significant in either of the seasons.

At 45 days stage of the crop, nitrogen content in plants increased with strain KM$_1$, further with KM$_3$ and KM$_{1+3}$ during *zaid* season. During *kharif* season similar trend was observed. Only *rhizobium* and sulphur, among the interactions could show its significant impact during *zaid* season, it however, failed to show its significance during *kharif* season. The value of grain nitrogen content increased with strain KM$_3$ over strain KM$_1$ during both the seasons. The value decreased with strain KM$_{1+3}$ in comparison to strain KM$_3$ during *zaid* season and were *at par* during *kharif* season. None of the interaction could show its significance during both the seasons.

(ii) Nitrogen uptake in grains and stover

Uninoculated treatments showed the lowest value of nitrogen uptake both in stover and grains during both the seasons. The highest value was
recorded for strain KM$_3$ and S$_4$ P$_6$ in both the stover and grains across the seasons. The values of nitrogen uptake in grains increased with use of mixed strains KM$_{1+3}$ over KM$_1$ and KM$_3$ during *zaid* season. In *kharif* season the value of nitrogen uptake increased with strain KM$_3$ over strain KM$_1$ and further decreased with strain KM$_{1+3}$. Similarly, the value of nitrogen uptake in stover increased with strain KM$_3$ over strain KM$_1$ during both the seasons, although the value further decreased with strain KM$_{1+3}$ in comparison to strain KM$_3$ during both the seasons. The value of total nitrogen uptake was a bit higher in stover than in grains.

**CONCENTRATION AND UPTAKE OF PHOSPHORUS**

(i) Phosphorus content (%) in plants and grains

Phosphorus is the most critical plant nutrient and is directly involved in various metabolic plant processes. The process of biological nitrogen fixation has a very high requirement of ATP for the reduction of N$_2$ to NH$_3$. Approximately 21 mols of ATP are required for reducing one mol of N$_2$ (Shammugan *et al.* 1978). At 30 days stage, phosphorus concentration in plants increased with increasing level of *rhizobium* strains during both the seasons. Interaction effects of *rhizobium* strains and sulphur were significant in respect to their positive effect on phosphorus concentration in plants during both the seasons. While *rhizobium* strains and phosphorus was always significant during *zaid* season only.

At 45 days stage, the value of phosphorus concentration in plants increased with strain KM$_1$ over uninoculated, constraints with KM$_1$ and KM$_3$ and again increased with KM$_{1+3}$ over KM$_3$ in both the seasons. Maximum
phosphorus content in stover to the levels of 0.25 per cent in both the seasons was noted in mixed strain KM\textsubscript{1+3} which were higher than single inoculation of \textit{rhizobium} strain KM\textsubscript{1} or KM\textsubscript{3}.

**Phosphorus uptake in grains**

The concentration of phosphorus in seed is highly important for several reasons. Economic reasons favour selection of genotypes that achieve higher yields of seed with low concentration of phosphorus. Such crops would remove less phosphorus from soil and thereby reducing the cost of production of each tonne of seeds. However, there are several advantages to increase phosphorus concentration in seeds. Higher content of phiosphorus in seeds may increase essential aminoacid contents cystein and methionine. Thus, higher phosphorus content in seed may provide more nutritious products. An increase in seed phosphorus content particularly in protein rich crops may also be associated with more vigorous seedlings and higher seed yield if seed is used to grow the following crops.

The phosphorus uptake was 4.46 kg ha\textsuperscript{-1} during \textit{zaid} season and 4.43 kg ha\textsuperscript{-1} during \textit{kharif} season, the maximum phosphorus uptake was noted for mixed strain KM\textsubscript{1+3} during both the seasons. Although strain KM\textsubscript{3} significantly increased the phosphorus uptake in grains over control but it was \textit{at par} with that of strain KM\textsubscript{1}. Deka and Kakati, (1996) reported that seed yield and total N and P uptake were higher with seed inoculation compared with soil application and increased significantly upto 40 kg P\textsubscript{2}O\textsubscript{5} ha\textsuperscript{-1}. High nitrate content in soil decreases NR activity in root nodules of mungbean while glutamine synthetase activities increases (Atwal \textit{et al.})
1997). Nodulation, nodules number and seed yield increased in mungbean inoculated with \textit{rhizobium} + 25 kg urea ha\textsuperscript{-1} (Patra and Bhattacharya, 1997).

(ii) Phosphorus uptake in stover

The mean value of phosphorus uptake was 5.18 kg ha\textsuperscript{-1} during \textit{zaid} season and 5.25 kg ha\textsuperscript{-1} in \textit{kharif} season. Strain KM\textsubscript{1} and KM\textsubscript{3} significantly increased phosphorus uptake in comparison to uninoculation. Maximum phosphorus was recorded with mixed strain KM\textsubscript{1+3}. Strains KM\textsubscript{1} and KM\textsubscript{3} were statistically \textit{at par}.

CONCENTRATION AND UPTAKE OF SULPHUR

(i) Sulphur content in plants and grains

The sulphur content in grains varied from 0.17 per cent in uninoculated, S\textsubscript{0}P\textsubscript{0} to 0.39 per cent in strain KM\textsubscript{1+3}, S\textsubscript{4}P\textsubscript{6} during \textit{zaid} season and from 0.17 per cent to 0.36 per cent in same treatment combinations during \textit{kharif} season at 30 days. Such variation at 45 days was from 0.15 to 0.16 per cent and 0.23 per cent during two consecutive seasons. Maximum sulphur content in stover to the level of 0.23 per cent in \textit{zaid} season and 0.24 per cent in \textit{kharif} season was noted for mixed strain KM\textsubscript{1+3} which was significantly higher than single inoculation of \textit{rhizoibium} strains KM\textsubscript{1} or KM\textsubscript{3}.

(ii) Sulphur uptake in grains and stover

The maximum sulphur uptake in grains to the tune of 3.73 kg ha\textsuperscript{-1} and 3.84 kg ha\textsuperscript{-1} was noted in inoculation of strain KM\textsubscript{3} during both the season. Although the strain KM\textsubscript{3} significantly increased the sulphur uptake in grains over control but it was at par with that of strain KM\textsubscript{1}. 
Mean values of sulphur uptake in stover were 4.23 kg ha\(^{-1}\) and 4.37 kg ha\(^{-1}\) during zaid and kharif seasons, respectively. Strains KM\(_1\) and KM\(_3\) significantly increased sulphur uptake in comparison to uninoculation. Maximum sulphur uptake was recorded with mixed strain KM\(_{1+3}\) showing the synergistic effect of both the strains.

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