CHAPTER-II

REVIEW OF LITERATURE

The productivity of any crop is a complex phenomenon which is governed by numerous and exogenous factors. It can be adopting suitable agro-techniques viz., use of improved varieties, timely sowing, appropriate spacing, fertilizer management, proper irrigation scheduling and proper measures to minimize losses through weed, insect-pest and disease. Among various agronomical factors responsible for increasing productivity of any crop, fertilizer management play an important role for harvesting potential production of any crop including fenugreek.

An attempt has been made to review the available literature concerning the present investigation are presented in this chapter. The work done, especially on these aspect of fenugreek is very meager; hence, similar work on other crops has also been included whenever felt necessary. A brief summary on research work done in the past by eminent scientist in India and abroad on related aspects has been highlighted and reviewed under the following broad topics.

2.1 Effect of levels of phosphorus
   2.1.1 Growth parameter
   2.1.2 Yield and yield attributes
   2.1.3 Quality parameter
   2.1.4 Economics
   2.1.5 Nutrient content and uptake by plants
   2.1.6 Soil analysis after harvest of the crops

2.2 Effect of levels of sulphur
   2.2.1 Growth parameter
   2.2.2 Yield and yield attributes
   2.2.3 Quality parameter
   2.2.4 Economics
   2.2.5 Nutrient content and uptake by plants
   2.2.6 Soil analysis after harvest of the crops

2.3 Interaction effect of levels of phosphorus and sulphur
2.1 Effect of levels of phosphorus

Phosphorus is required for nitrogen metabolism and hence for synthesis of protein. It play important role in energy transfer. It involve in a wide range of process from cell division to the penetration and development of root system. It is a constitute of ADP and ATP which are the most important substances in plant life process. The important finding regarding response of fenugreek to phosphorus are summarized here.

2.1.1 Growth parameter

Bothe et al. (2000) conducted a field experiment at Pune (Maharashtra) to study the effect of phosphorus (0, 25, 50 and 75 kg P₂O₅ ha⁻¹), plant population and P-solubilizer on soybean-fenugreek cropping system. Results indicated that increase in phosphorus up to 75 kg P₂O₅ ha⁻¹ significantly increased plant height and dry matter per plant of fenugreek as compared to application of 50 and 25 kg P₂O₅ ha⁻¹ and control.

A field experiments under taken at Dharwad (Kamataka) by Krishnamoorthy and Madalageri (2000) to evaluate the interaction effect of nitrogen and phosphorus on seed yield and essential oil yield of ajwain (Trachyspermum ammi L.) genotypes. They revealed that number of tertiary branches increased significantly under application of 50 kg P₂O₅ ha⁻¹ and 100 kg N ha⁻¹ in the genotypes BEN-I and BEN-2.

An experiment conducted at Fatehpur on loamy sand soil during 1997-98 and 1998-99. Jat and Shaktawat (2001) reported that the branches per plant, length of pod per plant and pods per plant of fenugreek significantly increased with increasing dose of phosphorus up to 80 kg P₂O₅ ha⁻¹.

A field trial carried out on sandy loam soil of Hisar showed that application of phosphorus up to 40 kg P₂O₅ ha⁻¹ significantly increased plant height, LAI, LAD, CGR and dry matter accumulation of fenugreek over the lower doses of phosphorus at all the stages of crop growth except early stage 30 DAS (Khiriya et al., 2001).

Nataraja et al. (2003) conducted a field experiment to assess the influence of nitrogen, phosphorus and potassium on growth and seed yield of black cumin at Bangalore during 2000-01 with three levels each of nitrogen (0, 50 and 100 kg ha⁻¹), phosphorus (0, 20 and 40 kg ha⁻¹) and potassium (0, 30 and 60 kg ha⁻¹). They reported that size of pods (3.84 cm²) and plant spread (427.75 cm²) significantly increased under treatment of 50:40:30 kg NPK ha⁻¹ as compared to other treatments.

Jat (2004) conducted a field experiment during two consecutive years 1997–98
and 1998–99 to investigate the effect on nodulation in fenugreek as affected by phosphorus, sulphur and bio-fertilizers on saline loamy sand soils of Rajasthan. Results indicated that application of 80 kg P$_2$O$_5$ ha$^{-1}$ significantly increased the dry matter accumulation per 0.5 m row length at 30, 60, 90 DAS and at harvest (22.38%, 20.09%, 27.74 and 22.72 %, respectively) and plant height at 60, 90 DAS and at harvest (9.06%, 17.20% and 15.74 %, respectively) as compared to other treatments.

Bhunia et al. (2006) conducted a field experiment at Sriganganagar (Rajasthan) to study the effect of phosphorus, irrigation and rhizobium inoculation on seed yield, economics, water use efficiency and nutrients uptake of fenugreek. Results revealed that application of 40 kg P$_2$O$_5$ ha$^{-1}$ significantly increased the branches per plant, pods per plant and pod length per plants over 20 kg P$_2$O$_5$ ha$^{-1}$.

A field experiment conducted at New Delhi during the winter season of 2004-05 to assess the performance of fenugreek under the different treatments (control, 50 kg P$_2$O$_5$ ha$^{-1}$, 25 kg P$_2$O$_5$ ha$^{-1}$ + PSB, 25 kg P$_2$O$_5$ ha$^{-1}$ + VAM and 25 kg P$_2$O$_5$ ha$^{-1}$ + PSB+VAM) and cutting management practices. Kumar and Singh (2007) reported that application of 50 kg P$_2$O$_5$ ha$^{-1}$ being at par with application of PSB + VAM + 25 kg P$_2$O$_5$ ha$^{-1}$ was recorded significantly maximum branches per plant and nodules per plant.

Hans Raj and Thakral (2008) observed the effect of nitrogen (N), phosphorus (P) and potash (K) on growth, seed yield and quality of fennel at Hisar (Haryana) during 2002-03 and 2003-04. The experiment consisted of 16 treatment combinations with four levels each of N (25, 50, 75 and 100 kg ha$^{-1}$), P (25 and 50 kg P$_2$O$_5$ ha$^{-1}$) and K (25 and 50 kg ha$^{-1}$). They showed that the application of 100 kg N ha$^{-1}$, 50 kg P$_2$O$_5$ ha$^{-1}$ and 50 kg K$_2$O ha$^{-1}$ were recorded significantly maximum values of plant height, flowering and umbels per plant.

Two years field trial taken at Bikaner (Rajasthan) to evaluate the effect of phosphorus and zinc application on growth and yield of fenugreek and their residual effect on succeeding pearl millet crop on loamy sand soil. Sammauria and Yadav (2008) observed significant improvement in branches per plant and pods per plant of fenugreek under application of 40 kg P$_2$O$_5$ ha$^{-1}$.

Alemu and Pant (2009) carried out an experiment during main cropping season of 2008-09 at Sinana to investigate the effect of phosphorus and rhizobium inoculation on nodulation, yield and yield related traits of fenugreek (Trigonella foenum-graecum L.). The experiment was laid out with assigning two varieties of
fenugreek to main plot and four levels of P (0, 13, 26, 39 kg P ha\(^{-1}\)) and two levels of *rhizobium* (with and without inoculation) in sub plot. Results indicated that application of 26 kg P ha\(^{-1}\) was recorded significantly higher plant height and number of primary branches per plant.

Jan *et al.* (2011) conducted a field trial at Peshawar (Pakistan) during the year 2002-03 to investigate the response of coriander to levels of phosphorus (0, 15, 30 and 45 kg P\(_2\)O\(_5\) ha\(^{-1}\)) and row spacing (15, 25, 35 and 45 cm). Results indicated that significantly maximum numbers of umbels per plant (47.00) recorded under the treatment of 45 kg P ha\(^{-1}\) with 45 cm row spacing. Whereas, the significantly maximum days to first umbel maturity (30 days) and days to last umbel maturity (25.33) recorded under control treatment.

A field experiment taken by Meena *et al.* (2012) at Bikaner during *rabi* season of the years 1999-2000 to evaluate the effect of phosphorus, molybdenum and PSB levels on growth, productivity and nutrient uptake of fenugreek (*Trigonella foemangraecum* L.). They observed that application of 40 kg P\(_2\)O\(_5\) ha\(^{-1}\), 0.5 kg Mo ha\(^{-1}\) and inoculation with PSB significantly increased the plant height, number of branches per plant and dry matter accumulation per meter.

Mehta *et al.* (2012) conducted a field experiment at Sardarkrushinagar (Gujarat) during 2006-07 and 2007-08 to study the response of nitrogen, phosphorus and bio-fertilizers on fenugreek. They noticed that application of 20 kg N and 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) gave significantly higher plant height at all the growth stages as compared to 10 kg N and 20 kg P\(_2\)O\(_5\) ha\(^{-1}\).

A field experiment carried out by Rana *et al.* (2012) during *rabi* season of 2010-11 to find out the effect of nitrogen and phosphorus on growth, yield and quality of black cumin. They reported that significantly maximum plant height at harvest (45.95 cm), number of branches per plant at harvest (17.30), fresh weight per plant at 60 DAS (13.08 g) and dry weight of shoot per plant at 60 DAS (3.21 g) were recorded under application of 60 kg N and 120 kg P\(_2\)O\(_5\) ha\(^{-1}\) followed by 45 kg N and 90 kg P\(_2\)O\(_5\) ha\(^{-1}\) and the lowest in control at all the growth stages.

Mehta *et al.* (2013) conducted a field experiment at Tabiji (Ajmer) during *rabi* season of 2003-06 to assess the growth and productivity of fenugreek as influenced by irrigation and nutrient levels with varying crop geometry. In these experiment three irrigation levels (8, 12 and 15 days interval) in main plot, nutrient levels (N P each of 20+10, 30+20 and 40+25 kg ha\(^{-1}\)) in sub plot and crop geometry (20 x 10, 25 x 10
and 30 x 10 cm) in sub-sub plots were tested. Results showed that significantly maximum plant height and dry matter accumulation per plant at all the growth stages as well as number of branches per plant at harvest (3.84) in fenugreek obtained under application of irrigation at 12 days interval with application of 30 kg N and 20 kg P₂O₅ ha⁻¹.

Koyani et al. (2014) conducted a field experiment during rabi season of the year 2011-12 to evaluate the response of direct-seeded rabi fennel (Foeniculum vulgare Mill.) to varying levels of nitrogen and phosphorus. There was a significant effect of 120 kg N ha⁻¹ and 60 kg P₂O₅ ha⁻¹ increased plant height, number of branches per plant, number of umbels per plant and umbellates per umbel as compare to 90 kg N and 30 kg P₂O₅ ha⁻¹.

A field experiment conducted at Varanasi (U. P.) to study the effect of nitrogen (0, 30, 60 kg N ha⁻¹) and phosphorus (0, 30, 60 kg P₂O₅ ha⁻¹) in different combinations on growth, leaf and seed yield of fenugreek (Trigonella foenum-graecum L.). They observed that plant height, number of leaves per plant, number of pods per plant and pod length were significantly increased with the increases in nitrogen and phosphorus levels (Srivastava et al., 2014).

Eetela et al. (2015) conducted a field experiment during rabi season of 2014-15 at Akola (Maharashtra) to find out the effect of nutrient levels on growth and yield of ajwain. The experiment consisted of five levels each of nitrogen (0, 20, 40, 60 and 80 kg ha⁻¹), phosphorus (0, 10, 20, 30 and 40 kg ha⁻¹) and potassium (0, 10, 20, 30 and 40 kg ha⁻¹). Results indicated that increasing application of N, P and K significantly increased plant height, stem diameter, number of branches per plant, number of umbels per plant and plant spread.

Kumar et al. (2015) studied the effect of nutrient supplementation through organic sources on growth, yield and quality of coriander (Coriandrum sativum L.) during 2011-12 at Faizabad. Results showed that significantly higher plant height, number of primary and secondary branches per plant, number of umbels per plant and number of umbelets per umbel were recorded with application of better combination of organic sources i.e. application of 25 % FYM (5 t ha⁻¹) + 75 % Vermicompost (3.75 t ha⁻¹) + RDF @ 60:30:30 kg NPK ha⁻¹.

Lokhande et al. (2015) conducted a field trial during rabi season at Akola (Maharashtra) on effect of varying levels of nitrogen and phosphorus on growth and seed yield of coriander (Coriandrum sativum L.). Results revealed that
Review of literature

significantly maximum plant height, number of branches per plant, days to first flowering, days to 50% flowering and number of umbels per plant were recorded under application of 60 kg N and 30 kg P₂O₅ ha⁻¹ followed by application of 30 kg N ha⁻¹ and 45 kg P₂O₅ ha⁻¹ and control without application of fertilizers.

Muhammad et al. (2015) investigated the effects of nitrogen and phosphorus fertilizers in different ratio (0:0, 30:0, 10:30, 30:15, 30:30, 60:30, 60:60, 90:45 and 90:90 kg ha⁻¹) on growth, seed yield and quality of fennel during 2011-12 at Pakistan. Results indicated that the fertilizer dose 90:45 kg NP ha⁻¹ significantly increased plant height by 44% and number of leaves per plant by 76%.

Muvel et al. (2015) taken a field experiment during rabi season of 2012-13 at Mandsaur (Madhya Pradesh) to assess the effect of spacing and fertilizer levels on growth, yield and quality attributes of ajwain. The experiment consisting of three spacing (30 x 30 cm, 45 x 30 cm and 60 x 30 cm) and four levels of fertilizer (20:10:10, 40:20:20, 60:30:30 and 80:40:40 NPK kg ha⁻¹). Results revealed that among the various levels of fertilizer tried, application of 60:30:30 kg NPK ha⁻¹ with spacing of 45 x 30 cm significantly increased the plant height, fresh weight per plant, dry weight per plant, number of umbels per plant and number of umbellets per umbel of ajwain.

Srivastava et al. (2015) evaluated that the effect of nitrogen (0, 15 and 30 kg ha⁻¹) and phosphorus (0, 40 and 80 kg ha⁻¹) on growth, leaf and seed yield of fenugreek at Varanasi (U. P.). Results showed that plant height (at 45 and 90 DAS), number of leaves per plant and number branches per plant were significantly increased with the increase in nitrogen and phosphorus levels. Application of 30-80-40 kg NPK ha⁻¹ was more conducive for better growth and development of fenugreek than the lower levels.

A field experiment carried out at Babylon during the growing season of 2013-14 by Ali et al. (2016) to study the effect of five fertilization treatments [control, 200 kg ha⁻¹ of NPK (18-18-0 kg ha⁻¹), 4 and 8 t ha⁻¹ of compost of poultry] and its interaction with four treatments of foliar fertilizers [control, spray urea 1 g l⁻¹, spraying humic acid 2 ml l⁻¹ and spray polimet 2 ml l⁻¹] on growth and yield of fenugreek. Results showed that chemical fertilizer was superior significantly compared to other treatment in plant height, number of leaves and leaf area.
A field experiment conducted at Bhubaneswar (Odisha) to study the effect of nitrogen and potassium on growth and yield of coriander (Coriandrum sativum L.) cv. Super Midori during rabi season of 2013-14. They revealed that the treatment combinations of three levels of nitrogen (50, 60 and 70 kg N ha⁻¹) and two levels of potassium (50 and 60 kg K₂O ha⁻¹) with a common dose of phosphorous @ 40 kg P₂O₅ ha⁻¹ and FYM @ 20 t ha⁻¹ significantly increased number of leaves and average weight of plants (Mishra et al., 2016).

Datta et al. (2017) evaluated a field trial at Mohanpur (West Bengal) to investigate the effect of different levels of NPK for maximization of yield of fenugreek during 2013-14 and 2014-15. Three levels each of nitrogen (40, 60 and 80 kg N ha⁻¹) and phosphorus (60, 80 and 100 kg P₂O₅ ha⁻¹) and two levels of potassium (20 and 40 kg K₂O ha⁻¹) were tested in the investigation. They showed that different treatment combinations significantly maximized plant height of 44.28 cm at 45 DAS under treatment (80:80:40 kg NPK ha⁻¹), but at 105 DAS maximum plant height (108.17 cm) was observed under the treatment of 80:100:40 kg NPK ha⁻¹. Plants grown under 80:80:40 kg NPK ha⁻¹ combination exhibited significantly maximum number of secondary branches (15.94) per plant.

Javiya et al. (2017) conducted a field experiment on clayey soil of Junagadh during rabi season of 2014-15 on coriander (Coriandrum sativum L.) with four levels each of nitrogen (0, 20, 40 and 60 kg N ha⁻¹) and phosphorus (0, 20, 40 and 60 kg P₂O₅ ha⁻¹). Results indicated that application of phosphorus 60 kg P₂O₅ ha⁻¹ significantly enhanced growth parameters viz., plant height, plant spread and number of branches per plant.

A field experiment conducted at JAU, Junagadh by Solanki et al. (2017) to study the influence of drip irrigation and fertility levels on growth, yield and water use efficiency of drilled rabi fennel (Foeniculum vulgare Mill.) under South Saurashtra Agro Climatic Region. Results indicated that significantly higher plant height (125.5 cm), number of branches (5.6) and umbels per plant (16.0) were recorded under treatment of 120 kg N ha⁻¹ and 45 kg P₂O₅ ha⁻¹.

2.1.2 Yield and yield attributes

Bothe et al. (2000) conducted a field experiment at Maharashtra to study the effect of phosphorus (0, 25, 50 and 75 kg K₂O ha⁻¹), plant population and P-solubilizer on soybean-fenugreek cropping system. Results indicated that increase in phosphorus up to 75 kg P₂O₅ ha⁻¹ resulted in increase in seed and straw yields of
fenugreek. Application of phosphorus @ 75 kg ha\(^{-1}\) proved significantly superior over application of 50 and 25 kg P\(_2\)O\(_5\) ha\(^{-1}\) and control.

Datta and Verma (2000) observed that the effect of phosphorus (0, 26.4, 52.8 and 79.2 kg P\(_2\)O\(_5\) ha\(^{-1}\)) on the performance of seed crop of fenugreek during the winter season of 1996-97 on sandy-loam soil. They reported that the application of phosphorus @ 52.8 kg ha\(^{-1}\) obtained significantly more values of yield attributing characters and seed yield (2.113 t ha\(^{-1}\)) as compared to other levels of phosphorus.

A field experiment carried out at Dharwad (Karnataka) by Krishnamoorthy and Madalageri (2000) to evaluate the interaction effect of nitrogen and phosphorus on seed yield and essential oil yield of ajwain (Trachyspermum ammi L.) genotypes. They revealed that 1000 seed weight significantly increased in BEN-2 with increasing levels of phosphorus and nitrogen combinations. Seed yields were significantly increased under application of 50 kg N ha\(^{-1}\) and 100 kg P\(_2\)O\(_5\) ha\(^{-1}\) in BEN-1 (20.50 q ha\(^{-1}\)) and BEN-2 (14.61 q ha\(^{-1}\)), respectively.

Patel et al. (2000) conducted a field experiment during winter season of 1994-96 with fennel variety Guj. Fennel-1 (Foeniculum vulgare Mill.) grown on sandy-loam soil. They concluded that application of 90 kg N ha\(^{-1}\) and 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) gave significantly higher seed yield and biological yield under North Gujarat Agro-Climatic conditions.

An experiment conducted at Fatehpur on loamy sand soil during 1997-98 and 1998-99. Jat and Shaktawat (2001) observed that the seeds per pod and test weight of fenugreek were significantly increased with increasing application of phosphorus up to 80 kg P\(_2\)O\(_5\) ha\(^{-1}\).

A field trial conducted on sandy loam soil of Hisar (Haryana) to investigate the growth analysis of fenugreek under various levels of FYM and phosphorus (20, 40 and 60 kg ha\(^{-1}\)). They reported that application of phosphorus up to 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) significantly increased the 1000 seed weight and seed yield during both the years of experimentation, (Khiriya et al., 2001).

Rai et al. (2002) conducted a field experiment at Lucknow (U. P.) during 1998-99 to evaluate the performance of fennel (Foeniculum vulgare L.) with different nitrogen (30, 60 and 90 kg N ha\(^{-1}\)) and phosphorus (0, 25 and 50 kg P\(_2\)O\(_5\) ha\(^{-1}\)) levels on sodic soil. Results showed that application of 90 kg N ha\(^{-1}\) with 50 kg P ha\(^{-1}\) gave significantly maximum seed yield (13.022 q ha\(^{-1}\)) and proved superior to 60 kg N + 50 kg P\(_2\)O\(_5\) ha\(^{-1}\), 60 kg N ha\(^{-1}\) + 25 kg P\(_2\)O\(_5\) ha\(^{-1}\) and control.
Jat and Shaktawat (2003) investigated a field experiment at Fatehpur on loamy sand soil during 1997-98 and 1998-99. They revealed that application of phosphorus up to 35 kg P$_2$O$_5$ ha$^{-1}$ significantly increased the grain yield of fenugreek by 23.1 and 6.7 % as compared to control and 17.5 kg P$_2$O$_5$ ha$^{-1}$, respectively in both the years of experimentation.

Nataraja et al. (2003) carried out a field experiment to study the influence of nitrogen, phosphorus and potassium on growth and seed yield of black cumin at Sanjivini-vatika (Bangalore) during 2000-01. The experiment consisted of 27 treatment combinations with three levels each of nitrogen (0, 50 and 100 kg N ha$^{-1}$), phosphorus (0, 20 and 40 kg P$_2$O$_5$ ha$^{-1}$) and potassium (0, 30 and 60 kg K$_2$O ha$^{-1}$). They noticed that application of 50 kg N, 40 kg P$_2$O$_5$ and 30 kg K$_2$O ha$^{-1}$ gave significantly higher test weight (2.38 g) and seed yield (17.45 q ha$^{-1}$).

An experiment conducted at Mondouri (West Bengal) during rabi season of 1997-98 and 1998-99. Thapa and Maity (2003) evaluated the effect of nitrogen (30, 40 and 50 kg N ha$^{-1}$) and phosphorus (40 and 60 kg P$_2$O$_5$ ha$^{-1}$) with cutting treatments (0, 1 and 2 cuttings) on green and seed yield of fenugreek cv. pusa early bunching. Results indicated that significantly higher seed yield and 1000 seed weight were obtained under application of 60 kg P$_2$O$_5$ ha$^{-1}$.

Khan et al. (2005) observed the effect of different phosphorus levels (0, 30, 45, 60 kg P$_2$O$_5$ ha$^{-1}$) and spatial arrangement of 1.8 × 6 m, 2.4 × 6 m and 3 × 6 m with row spacing 30, 40, and 50 cm, respectively on growth and yield of fenugreek at Multan (Pakistan) during 2003-04. They concluded that application of 45 kg P$_2$O$_5$ ha$^{-1}$ significantly improved the performance of fenugreek for number of seeds per plant, 1000 seed weight, biological yield, seed yield and harvest index.

Bhunia et al. (2006) conducted a field experiment at Sriganganagar (Rajasthan) to evaluate the effect of phosphorus, irrigation and rhizobium inoculation on seed, economics, water use efficiency and nutrients uptake of fenugreek. Results showed that application of 40 kg P$_2$O$_5$ ha$^{-1}$ significantly increased the yield attributes, viz., seeds per pod, test weight and seed yield as compared to 20 kg P$_2$O$_5$ ha$^{-1}$.

Tiwari et al. (2006) at Udaipur (Rajasthan) assessed the effect of phosphorus (control, PSB, 20 kg P$_2$O$_5$ ha$^{-1}$, 20 kg P$_2$O$_5$ ha$^{-1}$ + PSB, 40 kg P$_2$O$_5$ ha$^{-1}$ and 40 kg P$_2$O$_5$ ha$^{-1}$ + PSB) on fenugreek. They noticed that application of 40 kg P$_2$O$_5$ ha$^{-1}$ + PSB resulted significantly the highest grain yields (14.80 and 14.99 q ha$^{-1}$) and straw yields (41.95 and 42.35 q ha$^{-1}$) during the years of 2001-02 and 2002-03, respectively.
A field trial conducted at New Delhi during the winter season of 2004-05 to evaluate the performance of fenugreek under different fertilizer treatments (control, 50 kg P$_2$O$_5$ ha$^{-1}$, 25 kg P$_2$O$_5$ ha$^{-1}$ + PSB, 25 kg P$_2$O$_5$ ha$^{-1}$ + VAM) and 25 kg P$_2$O$_5$ ha$^{-1}$ + PSB + VAM and cutting management practices. Kumar and Singh (2007) observed that application of 50 kg P$_2$O$_5$ ha$^{-1}$ being at par with application of PSB + VAM + 25 kg P$_2$O$_5$ ha$^{-1}$ were recorded significantly maximum seeds per pod, 1000 seed weight and seed yield.

Basu et al. (2008) showed that the application of phosphate fertilizer (0, 30, 40, 50 and 60 kg ha$^{-1}$) and harvest management for improving fenugreek (Trigonella foenum-graecum L.) seed and forage yield at Canada. They showed that application of 40-50 kg phosphate ha$^{-1}$ gave significantly higher seed yield and forage yield over 50-60 kg phosphate ha$^{-1}$.

Hans Raj and Thakral (2008) investigated the effect of nitrogen (N), phosphorus (P) and potash (K) on growth, seed yield and quality of fennel at Hisar (Haryana) during 2002-03 and 2003-04. The experiment consisted of 16 treatment combinations with four levels each of N (25, 50, 75 and 100 kg N ha$^{-1}$), P (25 and 50 kg P$_2$O$_5$ ha$^{-1}$) and K (25 and 50 kg K$_2$O ha$^{-1}$). Results revealed that application of 75 kg N ha$^{-1}$, 50 kg P$_2$O$_5$ ha$^{-1}$ and 50 kg K$_2$O ha$^{-1}$ was recorded significantly maximum values of seeds per umbel, seed yield and harvest index.

A two years field trial taken at Bikaner (Rajasthan) to evaluate the effect of phosphorus and zinc application on growth and yield of fenugreek and their residual effect on succeeding pearl millet crop on loamy sand soil. Sammauria and Yadav (2008) observed that application of phosphorus up to 40 kg ha$^{-1}$ significant improvement in test weight, seed, straw and biological yields of fenugreek.

Alemu and Pant (2009) carried out an experiment during main cropping season of 2008-09 at Sinana to investigate the effect of phosphorus and rhizobium inoculation on nodulation, yield and yield related traits of fenugreek (Trigonella foenum-graecum L.). The experiment was laid out with assigning two varieties of fenugreek to main plot and four levels of P (0, 13, 26, 39 kg P$_2$O$_5$ ha$^{-1}$) and two levels of rhizobium (with and without inoculation). Results indicated that application of 26 kg P$_2$O$_5$ ha$^{-1}$ significantly improved number of pods per plant, number of seed per pod, above ground biomass, 1000 seed weight and seed yield (2042.9 kg ha$^{-1}$) over 0 and 13 kg P$_2$O$_5$ ha$^{-1}$.
Gour et al. (2009) conducted a field experiment at Mandsaur (Madhya Pradesh) to find out the effect of phosphorus and plant growth regulators on growth and yield of fenugreek (Trigonella foenum-graecum L.). The results indicated that significantly higher growth and yield (17.62 q ha\(^{-1}\)) observed under application of 60 kg P\(_2\)O\(_5\) ha\(^{-1}\).

Ahmed et al. (2010) studied the effect of bio and mineral phosphorus fertilizer on growth, productivity and nutritional value of some fenugreek cultivars (Giza-30) in newly cultivated lands at New Salheya Region, Sharkia Governorate. Results revealed that the addition of mineral P fertilizer @ 46.5 kg P\(_2\)O\(_5\) ha\(^{-1}\) was recorded significant increment in yield and yield attributing characters as compared to 15.5 and 31 kg P\(_2\)O\(_5\) ha\(^{-1}\).

Patel et al. (2010) conducted a field experiment during rabi season with cv. Gujarat Fennel-11 at N.A.U., Navsari to find out the effect of conjunctive use of bio-organics and inorganic fertilizers on growth, seed yield and economics of rabi fennel under vertisol of South Gujarat. Five treatment of bio-organics (B\(_1\) : Castor cake @ 0.5 t ha\(^{-1}\), B\(_2\) : Neem cake @ 0.5 t ha\(^{-1}\), B\(_3\) : bio-fertilizer seed inoculation, B\(_4\) : Castor cake @ 0.5 t ha\(^{-1}\) + bio-fertilizer seed inoculation and B\(_5\) : Neemcake @ 0.5 t ha\(^{-1}\) + bio-fertilizer seed inoculation) and three levels of inorganic fertilizer (F\(_1\) : 100% RDF 90:30:00 NPK kg ha\(^{-1}\), F\(_2\) : 75% RDF and F\(_3\) : 50% RDF) were tested. They reported that significantly higher and profitable yield of rabi fennel can be secured by application of either castor cake @ 0.5 t ha\(^{-1}\) + bio- fertilizer seed inoculation or neemcake @ 0.05 t ha\(^{-1}\) + bio- fertilizer seed inoculation along with 100% RDF (90-30-00 kg NPK ha\(^{-1}\)) under South Gujarat conditions.

Jan et al. (2011) conducted a field experiment at Peshawar (Pakistan) during the year 2002-03. Four levels of phosphorus (0, 15, 30 and 45 kg ha\(^{-1}\)) were applied with four different row spacing (15, 25, 35 and 45 cm) in these experiment. They noticed that significantly maximum 1000 seed weight (10.32 g) were obtained with 45 kg P\(_2\)O\(_5\) ha\(^{-1}\) at 45 cm row spacing. However, significantly maximum seed yield (1360.0 kg ha\(^{-1}\)) was obtained under treatment of 45 kg P\(_2\)O\(_5\) ha\(^{-1}\) at row spacing of 25 cm.

Meena et al. (2012) conducted a field experiment during rabi season of the year 1999-2000 at Bikaner (Rajasthan) to evaluate the effect of levels of phosphorus, molybdenum and PSB on growth, productivity and nutrient uptake of fenugreek. They
noticed that application of 40 kg P$_2$O$_5$ ha$^{-1}$, 0.5 kg Mo ha$^{-1}$ and inoculation with PSB significantly increased the seeds per pod and seed yield.

A field trial carried out during *rabi* season of 2003-06 to investigate the growth and productivity of fenugreek as influenced by irrigation and nutrient levels with varying crop geometry. Three irrigation levels (8, 12 and 15 days interval) in main plot, nutrient levels (N and P each of 20+10, 30+20 and 40+25 kg ha$^{-1}$) in sub plot and crop geometry (20 cm x 10 cm, 25 cm x 10 cm and 30 cm x 10 cm) in sub-sub plots. Results showed that application of 30 kg N and 20 kg P$_2$O$_5$ ha$^{-1}$ gave significantly higher yield attributes and seed yield (1121 kg ha$^{-1}$) and test weight (Mehta *et al*., 2012).

Mehta *et al*. (2012) conducted a field experiment at Sardarkrushinagar (Gujarat) during 2006-07 and 2007-08 to find out the response of nitrogen, phosphorus and bio-fertilizers on fenugreek. They reported that application of 20 kg N and 40 kg P$_2$O$_5$ ha$^{-1}$ gave significantly higher seed yields, straw yields and biological yield over 10 kg N and 20 kg P$_2$O$_5$ ha$^{-1}$.

A pot experiment was taken by Moslemi *et al*. (2012) to evaluate the effect of different levels of phosphorous on yield and yield components of coriander (*Coriandrum sativum* L.) at Jahrom (Iran). Four phosphorous levels (0, 10, 15 and 20 mg kg$^{-1}$ pot soil) as triple super phosphate were tested. Results showed that seeds per umbellate and seed yield significantly increased with increased application of phosphorous.

Rana *et al*. (2012) conducted a field experiment during *rabi* season of 2010-11 to find out the effect of nitrogen and phosphorus on growth, yield and quality of black cumin. Results revealed that application of 60 kg N ha$^{-1}$ and 120 kg P$_2$O$_5$ ha$^{-1}$ with the variety AN-1 gave significantly maximum seed yield and harvest index.

Taran and Sachan (2013) conducted a field experiment on clay loam soil of Pantnagar to appraise the productivity, nutrient uptake and soil fertility status in fenugreek under an integrated nutrient management module. They indicated that significantly the highest total biological yield (70.71 q ha$^{-1}$) was obtained under treatment of NPK+ *Sinorhizobium* + *Bacillus* + FYM @ 5.0 t ha$^{-1}$.

A field experiment conducted at Tabiji (Ajmer) by Mehta *et al*. (2013) during *rabi* season of 2003-06 to evaluate the effect of irrigation and nutrient levels with varying crop geometry on growth, yield and profitability of ajwain (*Trichospermum ammi* L.). Results showed that application of irrigation at 18 days interval with 25 kg
N ha\(^{-1}\) and 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) was recorded significantly higher yield attributes viz., umbel per plant (184.32), seeds per umbellate (16.97), umbellate per umbel (17.64), test weight (2.01 g) and seed yield (11.69 q ha\(^{-1}\)).

Bairagi (2014) conducted an experiment at Lakhaoti (U. P) during 2012-13 with an objective to standardize the optimum dose of phosphorus and ideal row spacing for obtaining maximum yield of good quality seed of fenugreek. Four different phosphorus dose (0, 30, 60, 90 kg P\(_2\)O\(_5\) ha\(^{-1}\)) and three different row spacing (20, 30, 40 cm) were tested. Result revealed that application of 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) significantly increased number of pods per plant (50.5), maximum test weight (18 gm) and seed yield (1575 kg ha\(^{-1}\)).

Koyani et al. (2014) conducted a field experiment during rabi season of the year 2011-12 to assess the response of direct-seeded rabi fennel (\textit{Foeniculum vulgare} Mill.) to varying levels of nitrogen and phosphorus. They noticed that significantly the highest seed yield (18.67 q ha\(^{-1}\)) was recorded under application of 120 kg N and 60 kg P\(_2\)O\(_5\) ha\(^{-1}\).

Sharma et al. (2014) studied the effect of different levels of phosphorus (20, 40 and 60 kg P\(_2\)O\(_5\) ha\(^{-1}\)), molybdenum and inoculation of PSB on yield and yield attributes of fenugreek. They reported that significantly higher number of pods per plant, number of seeds per pod and seed yield was recorded under the treatment combination of 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) + inoculation with PSB as compared to other treatments.

A field experiment investigated by Srivastava et al. (2014) at Varanasi to study the effect of different combination of nitrogen (0, 30, 60 kg N ha\(^{-1}\)) and P (0, 30, 60 kg P\(_2\)O\(_5\) ha\(^{-1}\)) on growth, leaf and seed yield of fenugreek (\textit{Trigonella foenum-graecum} L.). They observed that the test weight and seed yield were significantly increased with increases in nitrogen and phosphorus levels.

Dar et al. (2015) at Aligarh (U. P.) tested four concentrations of irradiated chitosan (0, 40, 80 and 120 mg l\(^{-1}\)) individually as well as in combination with single dose of phosphorus 40 kg P\(_2\)O\(_5\) ha\(^{-1}\). They indicated that the application of phosphorus 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) with IC 40 mg l\(^{-1}\) significantly increased total seed yield by 125.4%.

A pot experiment conducted in the natural condition of net house at Aligarh (U. P) to evaluate the effect of four concentration of GA\(_3\) (0, 10\(^{-7}\) and 10\(^{-5}\) M) and in combination with 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) on growth, bio-chemical and yield attributes of fenugreek. Results showed that as compared to control, the combination of GA\(_3\) and
phosphorus (40 kg P$_2$O$_5$ ha$^{-1}$ + 10$^{-5}$ M GA$_3$) significantly recorded 140.6% higher seed yield (Dar et al., 2015).

A field experiment conducted during rabi season of 2014-15 at Akola (Maharashtra) to find out the effect of nutrient levels on growth and seed yield of ajwain. The treatment consisted of five levels each of nitrogen (0, 20, 40, 60 and 80 kg N ha$^{-1}$), phosphorus (0, 10, 20, 30 and 40 kg P$_2$O$_5$ ha$^{-1}$) and potassium (0, 10, 20, 30 and 40 kg K$_2$O ha$^{-1}$). Results showed that the highest seed yield (14.67 q ha$^{-1}$) and dry matter yield (5852 kg ha$^{-1}$) were obtained under application of 80 kg N ha$^{-1}$, 40 kg P$_2$O$_5$ ha$^{-1}$ and 40 kg K$_2$O ha$^{-1}$ (Eetela et al., 2015).

Kumar et al. (2015) carried out a field experiment on coriander (Coriandrum sativum L.) with combinations of nitrogen (0, 50 and 100 kg N ha$^{-1}$), phosphorus (0, 30 and 60 kg P$_2$O$_5$ ha$^{-1}$) and potassium (0, 20 and 40 kg K$_2$O ha$^{-1}$) at Kanke (Ranchi). Results revealed that significantly higher seed yield (18.84 q ha$^{-1}$), test weight (6.86 g) and straw yield per plant (24.33 g) were recorded under treatment of 100 kg N ha$^{-1}$ and 30 kg P$_2$O$_5$ ha$^{-1}$.

Kumar et al. (2015) observed that the effect of nutrient supplementation through organic sources on growth, yield and quality of coriander (Coriandrum sativum L.) during 2011-2012 at Faizabad. They noticed that significantly higher number of seeds per umbel, 1000 seed weight and seed yield (14.58 q ha$^{-1}$) recorded under application of 25 % FYM (5 t ha$^{-1}$) + 75 % Vermicompost, (3.75 t ha$^{-1}$) + RDF @ 60:30:30 kg NPK ha$^{-1}$.

A field experiment carried out by Lokhande et al. (2015) during rabi season of 2014-15 at Akola (Maharashtra) to evaluate the effect of varying levels of nitrogen and phosphorus on growth and seed yield of coriander (Coriandrum sativum L.). Results showed that significantly higher test weight and seed yield was recorded under application of 60 kg N ha$^{-1}$ and 30 kg P$_2$O$_5$ ha$^{-1}$ followed by 30 kg N ha$^{-1}$ and 45 kg P$_2$O$_5$ ha$^{-1}$ and control.

Muhammad et al. (2015) studied the effects of nitrogen and phosphorus fertilizers in different ratios (0:0, 30:0, 10:30, 30:30, 30:30, 60:30, 60:60, 90:45 and 90:90 kg NP ha$^{-1}$) on growth, seed yield and quality of fennel during 2011-12 at Faisalabad (Pakistan). They indicated that the fertilizer treatments (90:45 kg NP ha$^{-1}$) significantly increased 1000 seed weight by 44%, biological yield by 50%, seed yield by 296 % and harvest index by 162%.
Review of literature

A field experiment carried out during *rabi* season of 2012-13 at Mandsaur (Madhya Pradesh) by Muvel et al. (2015) to assess the effect of spacing and fertilizer levels on growth, yield and quality attributes of ajwain. The experiment consisting of three spacing (30 x 30 cm, 45 x 30 cm and 60 x 30 cm) and four levels of fertilizer (20:10:10, 40:20:20, 60:30:30 and 80:40:40 kg NPK ha\(^{-1}\)). Results showed that among the various levels of fertilizer tried, the level 60:30:30 kg NPK ha\(^{-1}\) with spacing of 45 x 30 cm significantly increased the 1000 seed weight, yield per plant, seed yield, straw yield and biological yield.

Singh. (2015) evaluated the effect of nutrient supplementation through organic manures on coriander at Dholi (Pusa) for three consecutive years 2009-2012. The treatments consisting of 100% FYM (10 t ha\(^{-1}\)), vermicompost (5 t ha\(^{-1}\)), 50% FYM + vermicompost (50%), 25% FYM + 75% vermicompost, 75% FYM + 25% vermicompost, RDF (50-40-30 kg NPK ha\(^{-1}\)), FYM (15 t ha\(^{-1}\)) + RDF (50-40-30 kg NPK ha\(^{-1}\)) and control in these experiment. Results revealed that the treatment FYM (15 t ha\(^{-1}\)) + RDF (50-40-30 kg NPK ha\(^{-1}\)) significantly increased the yield 105.26 % over control.

Srivastava et al. (2015) studied the effect of nitrogen (0, 15 and 30 kg ha\(^{-1}\)) and phosphorus (0, 40 and 80 kg ha\(^{-1}\)) with different combinations on growth, leaf and seed yield of fenugreek at Varanasi (U. P). They reported that the average pod weight, test weight of seed and seed yield increased with increasing levels of nitrogen and phosphorus. Application of N:P:K @ 30:80:40 kg ha\(^{-1}\) significantly more conducive for higher seed yield of fenugreek than the lower levels.

A two year field experiment conducted at Bikaner (Rajasthan) by Abha and Sharma (2016) to study the effect of vermicompost, phosphorus and zinc on yield and nutrient uptake of fennel. Results showed that application of 40 kg P\(_{2}O_{5}\) ha\(^{-1}\) significantly increased seed yield (43.16 %) and stover yield (25.89%) as compared to control. The combined application of vermicompost 2 t ha\(^{-1}\) + 40 kg P\(_{2}O_{5}\) ha\(^{-1}\) resulted significantly the highest seed yield (1377 kg ha\(^{-1}\)).

Ali et al. (2016) conducted a field experiment at Babylon during the growing season of 2013-14 to find out the effect of five soil fertilization treatments [control, 200 kg ha\(^{-1}\) of NPK (18-18-0 kg ha\(^{-1}\)), 4 and 8 t ha\(^{-1}\) compost of poultry] and its interaction with four treatments of foliar fertilizers [control, spray urea 1 g l\(^{-1}\), spraying humic acid 2 ml l\(^{-1}\) and spray polimet 2 ml l\(^{-1}\)] on growth and yield of fenugreek. The results showed that chemical fertilizer [200 kg ha\(^{-1}\) of NPK (18-18-0
20 kg ha$^{-1}$) was significantly superior compared to other treatment in number of seeds per pod, 1000 seed weight and seed yield.

A field experiment conducted during *rabi* seasons of 2012-13 and 2013-14 at Tabiji (Ajmer) to assess the yield and profitability of fenugreek as influenced by three fertility levels [60, 80 and 100 % RDF (40 kg N + 40 kg P$_2$O$_5$ + 10 kg S ha$^{-1}$)] and three bio-fertilizer inoculations (*rhizobium*, PSB and *rhizobium* +PSB). Results indicated that significantly the highest values of yield attributes *viz.*, seed yield (2245 kg ha$^{-1}$), haulm yield (5236 kg ha$^{-1}$) were recorded under application of 100 % RDF. Also the application of 100 % RDF + dual inoculation, being at par with 80 % RDF + dual inoculation gave significantly the highest seed yield of 2287 kg ha$^{-1}$ (Godara *et al.* 2016).

A field experiment conducted at Bhubaneswar (Odisha) to study the effect of nitrogen and potassium on growth and yield of coriander (*Coriandrum sativum* L.) cv. Super Midori during *rabi* season of 2013-14. They revealed that the treatment combinations of three levels of nitrogen @ 50, 60 and 70 kg N ha$^{-1}$, two levels of potassium @ 50 and 60 kg K$_2$O ha$^{-1}$ with a common dose of phosphorous @ 40 kg P$_2$O$_5$ ha$^{-1}$ and FYM @ 20 t ha$^{-1}$ significantly increased test weight (12.88 g) and the highest foliage yield of 15.90 t ha$^{-1}$ (Mishra *et al.*, 2016).

Shiurkar *et al.* (2016) conducted an experiment at Jabalpur (Rajasthan) to evaluate the effect of different levels of phosphorus and bio-fertilizers on yield and quality of fenugreek (*Trigonella foenum-graecum* L.). Results indicated that significantly the highest seed yield (13.73 q ha$^{-1}$) was recorded under application of 50 kg P$_2$O$_5$ ha$^{-1}$. Whereas, significantly the highest yield per plot (0.294 kg) was recorded under application of 30 kg P$_2$O$_5$ ha$^{-1}$ as compared to control.

At Solapur (Maharashtra) Vedpathak and Chavan (2016) conducted a field experiment to study the effects of organic and chemical fertilizer on growth and yield of fenugreek (*Trigonella foenum-graecum* L.). They reported that total weight of pods per plant (0.78 gm plant$^{-1}$) and mean weight per pods per plant (0.30 gm pod$^{-1}$ plant$^{-1}$) significantly increased with application of straight chemical fertilizers (80:40:40 kg NPK ha$^{-1}$). They also reported that application of chemical fertilizer is better and sustainable for significantly higher yield of fenugreek vegetable per plot than the other remaining fertilizer treatments.

Datta *et al.* (2017) laid out a field experiment at Mohanpur (West Bengal) on the performance of fenugreek under different levels of NPK for maximization of yield.
during 2013-14 and 2014-15. Three levels of each nitrogen (40, 60 and 80 kg N ha\(^{-1}\)), phosphorus (60, 80 and 100 kg P\(_2\)O\(_5\) ha\(^{-1}\)) and two levels of potassium (20 and 40 kg K\(_2\)O ha\(^{-1}\)) were tested in this experiment. Results showed that application of 60-80-40 kg NPK ha\(^{-1}\) significantly increased yield attributing parameters viz., number of seed per pod (15.32) and seed yield (17.20 q ha\(^{-1}\)).

A field trial was taken by Javiya et al. (2017) during rabi season of 2014-15 on clayey soil of Junagadh on coriander (Coriandrum sativum L.) with four levels each of nitrogen (0, 20, 40 and 60 kg N ha\(^{-1}\)) and phosphorus (0, 20, 40 and 60 kg P\(_2\)O\(_5\) ha\(^{-1}\)). Results indicated that application of phosphorus up to 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) significantly enhanced yield attributes viz., number of umbels per plant, number of umbellates per umbel, number of seeds per umbellate, seed weight per plant, 1000 seed weight, seed yield per hectare (1388 kg ha\(^{-1}\)) and stover yield (1613 kg ha\(^{-1}\)) of coriander.

A field experiment carried out at Akola (Maharashtra) during rabi season of 2014-15 to determine the requirement of nitrogen and phosphorus for coriander variety Hisar Anand for achieving maximum seed yield. Four different levels of nitrogen (40, 50, 60 and 70 kg N ha\(^{-1}\)) and three different levels of phosphorus (30, 40 and 50 kg P\(_2\)O\(_5\) ha\(^{-1}\)) in different combination were tested. Results showed that significantly maximum number of umbels per plant (17.93), umbellate per umbel (6.69), seeds per umbel (18.34), seed yield per plant (4.01 g), seed yield per plot (341 g) and seed yield per hectare (12.36 q ha\(^{-1}\)) were recorded under the treatment of 60 kg N ha\(^{-1}\) + 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) instead of the highest dose of both nutrients (Pooja et al., 2017).

Rumpa et al. (2017) conducted a field trial at Faridpur during rabi season 2013-14 and 2014-15 to study the effects of different row spacing (20, 30 and 40 cm) and phosphorus applications (0, 30, 60 and 90 kg P\(_2\)O\(_5\) ha\(^{-1}\)) on yield and yield attributes of fenugreek. Results revealed that in 2013-14, significantly the highest seed yield (2233 kg ha\(^{-1}\)) was obtained from 30 cm spacing with 90 kg P\(_2\)O\(_5\) ha\(^{-1}\), whereas the lowest seed yield (733 kg ha\(^{-1}\)) was obtained from 40 cm spacing with control. In 2014-15, the row spacing of 20 cm and 90 kg P\(_2\)O\(_5\) ha\(^{-1}\) gave significantly the highest seed yield (2033 kg ha\(^{-1}\)). The lowest seed yield (700 kg ha\(^{-1}\)) was obtained from 40 cm spacing with 0 kg P\(_2\)O\(_5\) ha\(^{-1}\).
Solanki et al. (2017) conducted a field experiment at JAU, Junagadh to study the influence of drip irrigation and fertility levels on growth, yield and water use efficiency of drilled rabi fennel (Foeniculum vulgare Mill.) under South Saurashtra Agro Climatic Region. Results showed that application of 120 kg N ha\(^{-1}\) and 45 kg P\(_2\)O\(_5\) ha\(^{-1}\) produced significantly higher seed yield (1373 kg ha\(^{-1}\)) and straw yield (2689 kg ha\(^{-1}\)).

An experiment conducted at Mandsaur (Madhya Pradesh) during rabi season of 2013-14 to assess the effect of row spacing and NPK levels on the growth and yield of fennel. The experiment consisted of three levels of row spacing (30, 45 and 60 cm) and four levels of NPK (0+0+0, 30+20+20, 60+40+40 and 120+60+60 kg NPK ha\(^{-1}\)). Results revealed that the various NPK levels tried, level 60+40+40 kg NPK ha\(^{-1}\) registered significantly maximum yield attributes and seed yield (12.29 q ha\(^{-1}\)) as compared to other levels of NPK (Waskela et al., 2017).

2.1.3 Quality parameter

Sharma et al. (1999) conducted a field experiment on loamy sand soil of Jobner during rabi season of 1995-96 to investigate the influence of phosphorus (0, 20, 40 and 60 kg P\(_2\)O\(_5\) ha\(^{-1}\)) and sulphur (0, 25, 50, 75 and 100 kg S ha\(^{-1}\)) on nutrient uptake and quality seed production of fenugreek. Results showed that application of phosphorus at 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) was recorded significantly higher protein contents in the seed as compared to 0 and 20 kg P\(_2\)O\(_5\) ha\(^{-1}\).

A field experiments conducted at Dharwad (Kamataka) to study the interaction of effect of nitrogen and phosphorus on essential oil and seed yields of ajwain (Trachyspermum ammi L.). Results revealed that the essential oil yield was significantly higher at 100 kg N ha\(^{-1}\) and 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) in BEN-1 (82.04 kg ha\(^{-1}\)) and BEN-2 (26.30 kg ha\(^{-1}\)), Krishnamoorthy and Madalageri (2000).

Hans Raj and Thakral (2008) at Hisar (Haryana) during 2002-03 and 2003-04 reported that the application of 100 kg N, 50 kg P\(_2\)O\(_5\) and 50 kg K\(_2\)O ha\(^{-1}\) significantly increased the seed germination and vigour index in fennel.

An experiment carried out at Sinana (South Eastern Ethiopia) during main cropping season of 2008-09 to investigate the effect of phosphorus and rhizobium inoculation on nodulation, yield and yield related traits of fenugreek (Trigonella foenum-graecum L.). Alemu and Pant (2009) reported that the crude protein content significantly maximum under application of 13 kg P\(_2\)O\(_5\) ha\(^{-1}\).
Dar et al. (2015) at Aligarh (U. P.) evaluated four concentrations of irradiated chitosan were used (0, 40, 80 and 120 mg l⁻¹) individually as well as in combination with single dose of phosphorus 40 kg P₂O₅ ha⁻¹. They noticed that application of phosphorus @ 40 kg ha⁻¹ + IC 40 mg l⁻¹ significantly increased total alkaloid content by 34.9% and trigonelline content by 17.8%.

Dar et al. (2015) conducted a pot experiment in the natural condition of net house at Aligarh, (U. P.) to evaluate the effect of four concentration of GA₃ (0, 10⁻⁷ and 10⁻⁵ M) and in combination with 50 kg P₂O₅ ha⁻¹ on quality of fenugreek. Results showed that as compared to the control, the combination of GA₃ and phosphorus (50 kg P₂O₅ ha⁻¹ + 10⁻⁵ M GA₃) significantly increased the content of total chlorophyll (28.5%) and carotenoids (26%). They also noticed that the content of trigonelline in seed (19.51%) was also significantly increased.

A field experiment conducted by Muhammad et al. (2015) at Faisalabad (Pakistan) study the effect of different ratio of nitrogen and phosphorus (0:0, 30:0, 10:30, 30:15, 30:30, 60:30, 60:60, 90:45 and 90:90 kg ha⁻¹) on quality of fenugreek during 2011-12. Results indicated that application of 90 kg N ha⁻¹ and 45 kg P₂O₅ ha⁻¹ significantly increased protein content by 6%.

Muvel et al. (2015) conducted a field experiment during rabi season of 2012-13 at Mandsaur to study the effect of fertilizer levels on quality attributes of ajwain. Results showed that application of 60:30:30 kg NPK ha⁻¹ significantly increased the chlorophyll content of leaves, carotenoids content of leaves and essential oil content in seed.

An field experiment conducted at Jabalpur (Rajasthan) to assess the effect of phosphorus and biofertilizers on quality parameters like chlorophyll and iron content of leaves in fenugreek (Trigonella foenum-graecum L.). Results revealed that the highest content of chlorophyll (1.84 mg g⁻¹), Fe (1.49 mg g⁻¹) and the lowest incidence of powdery mildew (15.51 %) was reported under the treatment of 50 kg P₂O₅ ha⁻¹ in fenugreek (Shiurkar et al., 2016).

2.1.4 Economics

Chaudhary (1999) at Rajasthan studied the effect of different seed ratio (15, 20, 25 or 30 kg seed ha⁻¹) and fertilizer doses (0:0, 20:20, 20:40, 20:60, 40:40 and 40:60 kg NP ha⁻¹) on fenugreek cv. RMT-1. They reported that application of 40 kg N ha⁻¹ and 40 kg P₂O₅ ha⁻¹ gave significantly the highest net return (₹8197 ha⁻¹) with a benefit cost ratio of 2.25.
Anilkumar (2004) at Dharwad (Karnataka) noticed that application of 125:63:25 kg NPK ha\(^{-1}\) to fenugreek crop was recorded significantly the highest benefit cost ratio (1:2.66) and net returns (Rs. 18,191 ha\(^{-1}\)) over control (100:50:0 kg NPK ha\(^{-1}\))

A field experiment conducted at New Delhi, during winter season of 2004-05 to study the performance of fenugreek (\textit{Trigonella foenum-graecum} L.) under different fertility regions. Results revealed that the benefit cost ratio ranged from 3.00 to 4.28 being significantly maximum at 25 kg P\(_2\)O\(_5\) ha\(^{-1}\) + PSB + VAM and the highest cost of cultivation (Rs 13500 ha\(^{-1}\)) noticed under the treatment of 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) (Kumar and Singh, 2007).

Gour et al. (2009) conducted a field experiment at Mandsaur (Madhya Pradesh) to assess the effect of phosphorus and plant growth regulators on growth and yield of fenugreek (\textit{Trigonella foenum-graecum} L.). Results indicated that the significantly the highest B:C ratio (4.20:1) was recorded under treatment of 60 kg P\(_2\)O\(_5\) ha\(^{-1}\) + 20 ppm NAA.

Singh et al. (2010) evaluated the performance of fenugreek varieties at various fertilizer level and biofertilizer inoculation. They reported that the application of 40 kg N and 17.2 kg P\(_2\)O\(_5\) ha\(^{-1}\) gave significantly higher net returns (Rs 25,640 ha\(^{-1}\)) and B: C ratio (2:49) as compares to 20 kg N and 8.6 kg P\(_2\)O\(_5\) ha\(^{-1}\) and control.

At Sardarkrushinagar (Gujarat) Mehta et al. (2012) conducted a field experiment during 2006-07 and 2007-08 to study the response of nitrogen, phosphorus and bio-fertilizers on fenugreek. Results showed that application of 30 kg N ha\(^{-1}\) and 20 kg P\(_2\)O\(_5\) ha\(^{-1}\) gave significantly higher net return (Rs 34465 ha\(^{-1}\)) and BCR (1.62 ) being at par with 40 kg N ha\(^{-1}\) and 25 kg P\(_2\)O\(_5\) ha\(^{-1}\).

A field experiment conducted by Mehta et al. (2013) at Tabiji (Ajmer) during rabi season of 2003-06 to find out the effect of irrigation and nutrient levels with varying crop geometry on growth, yield and profitability of ajwain (\textit{Trichospermium} L.). Results indicated that significantly higher net return of Rs 20320 ha\(^{-1}\) and BCR (0.97) in ajwain were obtained under treatment of 25 kg N ha\(^{-1}\) and 50 kg P\(_2\)O\(_5\) ha\(^{-1}\).

Muvel et al. (2015) conducted a field experiment during rabi season of 2012-13 at Mandsaur (Madhya Pradesh) to study the effect of spacing and fertilizer levels on growth, yield and quality attributes of ajwain. They showed that significantly
maximum B:C ratio (2.05:1) was recorded under treatment of 45 x 30 cm spacing with 60:30:30 kg NPK ha\(^{-1}\).

Singh (2015) conducted a field experiment at Dholi (Pusa) during three consecutive years (2009-2012) to evaluate the effect of nutrient supplementation through organic manures on coriander. Results revealed that application of FYM (15 t ha\(^{-1}\)) + RDF (50 kg N ha\(^{-1}\), 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) and 30 kg K\(_2\)O ha\(^{-1}\)) gave significantly the highest net return (Rs. 68,370 ha\(^{-1}\)) with benefit-cost ratio (2.67).

Srivastava et al. (2015) studied the effect of level of nitrogen (0, 15 and 30 kg N ha\(^{-1}\)) and phosphorus (0, 40 and 80 kg P\(_2\)O\(_5\) ha\(^{-1}\)) with different combinations on growth, leaf and seed yield and economics of fenugreek at Varanasi (U.P). They indicated that significantly maximum total income (Rs. 48399 ha\(^{-1}\)) was recorded under treatment of 30:40:40 kg NPK ha\(^{-1}\), whereas, the highest net returns (Rs. 31849 ha\(^{-1}\)) was recorded with treatment of 30:80:40 kg NPK ha\(^{-1}\) which was closely followed by the treatment of 30:40:40 kg NPK ha\(^{-1}\). However, significantly the highest B:C ratio of (2.23:1) was registered under the treatment of 30:0:40 kg NPK ha\(^{-1}\).

A field experiment was conducted at Tabiji (Ajmer) during rabi seasons of 2012-13 and 2013-14 by Godara et al. (2016) to assess the yield and profitability of fenugreek as influenced by three fertility levels [60, 80 and 100 % RDF (40:40:10 kg NPS ha\(^{-1}\))] and three bio-fertilizer inoculations (rhizobium, PSB and rhizobium + PSB). Results revealed that significantly the highest values of net returns (Rs. 56200 ha\(^{-1}\)) and B:C ratio (1.88) were recorded under the treatment of 100 % RDF (40 kg N ha\(^{-1}\) + 40 kg P\(_2\)O\(_5\)ha\(^{-1}\) + 10 kg S ha\(^{-1}\)).

A field experiment conducted during rabi season of 2014-15 on clayey soil of Junagadh on coriander (*Coriandrum sativum* L.) with four levels of nitrogen viz.,(0, 20, 40 and 60 kg N ha\(^{-1}\)) and four levels of phosphorus viz., (0, 20, 40 and 60 kg P\(_2\)O\(_5\) ha\(^{-1}\)). Javiya et al. (2017) revealed that significantly maximum net realization (Rs. 61008 ha\(^{-1}\)) was obtained with 60 kg P\(_2\)O\(_5\) ha\(^{-1}\), whereas, B:C ratio was significantly maximum (3.26) under 40 kg P\(_2\)O\(_5\)ha\(^{-1}\).

Pooja et al. (2017) at Akola (Maharashtra) during the rabi season of 2014-15 reported that significantly the highest net return, gross return and benefit cost ratio were recorded under treatment of 60 kg N and 50 kg P\(_2\)O\(_5\) ha\(^{-1}\) of coriander.

Waskela et al. (2017) conducted a field experiment at Mandsaur (Madhya Pradesh) during the *rabi* season of 2013-14 to study the effect of row spacing and
NPK levels on economics of fennel. Results showed that among the various NPK levels tried, 60-40-40 kg NPK ha$^{-1}$ exhibited significantly maximum B: C ratio of 3.45.

### 2.1.5 Nutrient uptake and content by plants

Sharma et al. (1999) conducted a field experiment on loamy sand soil at Jobner (Rajasthan) during rabi season of 1995-96 to investigate the influence of P (0, 20, 40 and 60 kg P$_2$O$_5$ ha$^{-1}$) and S (0, 25, 50, 75 and 100 kg S ha$^{-1}$) on nutrient uptake and quality seed production of fenugreek. Results showed that application of phosphorus at 40 kg P$_2$O$_5$ ha$^{-1}$ significantly improved N in the seed as compared to 0 and 20 kg P$_2$O$_5$ ha$^{-1}$. They also reported that increasing levels of phosphorus up to 40 kg ha$^{-1}$ significantly enhanced total N uptake by the crop.

Khiriya et al. (2003) reported that application of 60 kg P$_2$O$_5$ ha$^{-1}$ significantly increased N, P and K content and N and P uptake by seed and straw in both the genotypes RMT-1 and RMT-2 of fenugreek.

Bhunia et al. (2006) conducted a field experiment at Sriganganagar (Rajasthan) to study the effect of phosphorus (20, 40 and 60 kg P$_2$O$_5$ ha$^{-1}$), irrigation and rhizobium inoculation on seed yield, economics, water use efficiency and nutrients uptake of fenugreek crop. They revealed that application of phosphorus @ 40 kg P$_2$O$_5$ ha$^{-1}$ significantly increased N (31.6 kg ha$^{-1}$), P$_2$O$_5$ (5.5 kg ha$^{-1}$) and K$_2$O (37.9 kg ha$^{-1}$) the uptake of in fenugreek.

Deora and Singh (2008) reported that increase in the level of phosphorus up to 60 kg ha$^{-1}$ significantly increased the N, P, K contents and their uptake by seed and straw of fenugreek cv. Kasuri over control.

Patil et al. (2008) observed that the treatments of organic manure and inorganic fertilizer significantly influenced the N and P contents in seed of fenugreek. They concluded that application of FYM @ 5 t ha$^{-1}$ + 75% RDF was recorded significantly the highest N content in seed and straw. It was statistically at par with FYM @ 2.5 t ha$^{-1}$ + 75% RDF and CC @ 0.5 t ha$^{-1}$ + 75% RDF.

An experiment carried out by Alemu and Pant (2009) during main cropping season of 2008-09 at Sinana to investigate the effect of phosphorus and rhizobium inoculation on nodulation, yield and yield related traits of fenugreek (*Trigonella foenum-graecum* L.). The experiment was laid out with assigning two varieties of fenugreek to main plot and four levels of P (0, 13, 26, 39 kg P ha$^{-1}$) and two levels of rhizobium (with and without inoculation) in sub plot. Results indicated that
application of 26 kg P₂O₅ ha⁻¹ recorded significantly higher nitrogen uptake and phosphorus content in seeds of fenugreek as compared to 0 and 13 kg P₂O₅ ha⁻¹.

Tarun and Sachan (2009) reported that the integrated use of recommended dose of chemical fertilizers (30:60:40 kg NPK ha⁻¹) in combination with microbial inoculants (Sinorhizobium and Bacillus) and FYM resulted in significantly increased nutrient uptake by seed and straw of fenugreek.

Meena et al. (2012) conducted a field trial during rabi season of year 1999-2000 at Bikaner (Rajasthan) to find out the effect of phosphorus, molybdenum and PSB on growth, productivity and nutrient uptake of fenugreek (Trigonella foeman-graecum L.). Results showed that significantly increased N, P and Mo content and total uptake by seeds and straw of fenugreek under the treatment of 40 kg P₂O₅ ha⁻¹. Whereas P and Mo content and their uptake increased significantly under treatment up to 60 kg P₂O₅ and 1 kg Mo ha⁻¹.

Kumar et al. (2014) conducted a field experiment on loamy sand soil during rabi season of 2009-10 to evaluate the effect of vermicompost and phosphorus on nutrient content, uptake and quality in fenugreek (Trigonella foenum-graceum L.). They indicated that application of 40 kg P₂O₅ ha⁻¹ significantly increased the nitrogen content in seed and straw, phosphorus content in straw, nitrogen uptake by seed and straw, total uptake and phosphorus uptake by straw. They also reported that application of 60 kg P₂O₅ ha⁻¹ significantly increased phosphorus content and uptake in seed as well as total uptake of fenugreek.

Abha and Sharma (2016) conducted a two year field trial at Bikaner (Rajasthan) to find out the effect of vermicompost, phosphorus and zinc on yield and nutrient uptake of fennel (Foeniculum vulgare Mill.). Results indicated that phosphorus uptake in seed and stover significantly increased under the treatment of 40 kg P₂O₅ ha⁻¹. They also noticed that the treatment combination of 40 kg P₂O₅ ha⁻¹ and 6.0 kg Zn ha⁻¹ found significantly superior for phosphorus uptake by seed.

2.1.6 Soil analysis after harvest of the crops

Tarun et al. (2006) noticed that the integrated use of NPK resulted in significantly highest post-harvest soil fertility status along with high values for residual organic carbon content, available N, P and K in fenugreek.

An experiment conducted on effect of crop geometry, balanced fertilization (40:17.5:20:30 kg NPKS ha⁻¹) and agro-chemicals on productivity, nutrient uptake and residual soil fertility of fenugreek by Chaudhary (2007). They reported that
application of 40 kg N and 17.5 kg P$_2$O$_5$ ha$^{-1}$ significantly increased the availability of nitrogen and potassium after harvest of the crop.

Singh et al. (2010) evaluated the performance of fenugreek varieties at various fertilizer level and bio-fertilizer. They concluded that the application of 30 kg N and 17.2 kg P$_2$O$_5$ ha$^{-1}$ significantly improved the soil nitrogen and phosphorus status after harvest of the crop.

Deora and Singh (2008) reported that increased the level of phosphorus fertilizer up to 60 kg ha$^{-1}$ significantly increased the phosphorus and potassium content in the soil after harvest of fenugreek crop as compared to control.

2.2 Effect of levels of sulphur

Sulphur plays an important role in enhancing the productivity and quality of legumes by providing proper nutritional environment in the soil. Sulphur being the constituent of some amino acids, promotes the biosynthesis of protein. Application of sulphur is a key component of modern pulse production technology. The importance of sulphur in balance plant nutrition is realized with increasing sulphur deficiency in several areas due to intensive agriculture, less addition of organic manures and extensive use of sulphur free fertilizers.

2.2.1 Growth parameter

Pratap et al. (2003) conducted a field experiment at Bikaner (Rajasthan) to study the effect of nitrogen and sulphur on growth and yield of fennel. Results revealed that application of sulphur up to 60 kg S ha$^{-1}$ significantly increased the number of branches per plant, number of umbels per plant and plant height.

Jat (2004) conducted a field experiment during two consecutive years 1997-98 and 1998-99 at Udaipur to investigate the effect on nodulation in fenugreek as affected by phosphorus, sulphur and bio-fertilizers. They reported that application of 100 kg S ha$^{-1}$ significantly increased the mean dry matter accumulation at 30, 60, DAS and at harvest by 6.87%, 6.25% and 5.10%, respectively as compared to other treatments.

A field experiment conducted by Ruveyde and Murat (2011) at Turkey to determine the effect of nitrogen and sulphur application on yield and quality of fenugreek (*Trigonella foenum-graecum* L.). Results indicated that application of 90 kg N and 40 kg S ha$^{-1}$ significantly increased the plant height and length of pod during both the years of experimentation.

Tuncturk et al. (2011) during 2006-07 at Van (Turkey) conducted a field
experiment to study the effects of nitrogen and sulphur applications on yield and quality of fenugreek. Results revealed that application of 90 kg N and 20 kg S ha$^{-1}$ significantly increased plant height, number of branches per plant and first pod length during both the years of experimentation.

A field experiment conducted at Udaipur during *rabi* season of 2010-11 by Jat *et al.* (2012) to assess the effect of phosphorus and sulphur level on growth and yield of fenugreek. They noticed that application of 45 kg S ha$^{-1}$ significantly increased the plant height, dry matter accumulation and branches per plant of fenugreek.

Lal *et al.* (2014) conducted a field trial to study the effect of soil application of sulphur (20, 30 and 40 kg S ha$^{-1}$) and foliar application of zinc (0.4, 0.5 and 0.6 %) in fenugreek during 2012-13 at Ajmer (Rajasthan). Results revealed that soil application of 40 kg S ha$^{-1}$ significantly increased plant height at 60 DAS, higher number of primary and secondary branches per plant.

Verma *et al.* (2014) studied the effect of vermicompost and sulphur on growth, yield and nutrient uptake of fenugreek with four levels of each vermicompost (0, 2, 4, and 6 t ha$^{-1}$) and sulphur (0, 20, 40 and 60 kg S ha$^{-1}$). They reported that application of 40 kg S ha$^{-1}$ registered significantly higher plant height (34.06, 50.20, and 59.00 cm at 30, 60 DAS and at harvest, respectively) and branches per plant (3.53, 5.67 and 8.00 at 60, 90 DAS and at harvest, respectively).

Meena *et al.* (2015) evaluated the effect of plant growth regulator and sulphur on productivity and nutrient concentration in coriander. They reported that application of sulphur up to 40 kg ha$^{-1}$ significantly increased plant height, dry matter accumulation per plant and number of primary and secondary branches per plant as compared to the control and 20 kg S ha$^{-1}$.

Boori *et al.* (2017) at Jobner (Rajasthan) conducted a field experiment during *rabi* season of 2013-2014 to evaluate the effect of intercropping and sulphur in different row ratios on fenugreek with three intercropping systems (sole fenugreek, fennel + fenugreek in 1:1 and 1:2 row ratios) and four sulphur levels (0, 20, 40 and 60 kg S ha$^{-1}$). Results showed that application of sulphur up to 40 kg S ha$^{-1}$ significantly increased plant height, dry matter accumulation and number of branches per plant.

Solanki *et al.* (2017) conducted a field experiment on clayey soil of Junagadh during *rabi* season of 2014-15 to study the effect of potassium (0, 20, 40 and 60 kg K$_2$O ha$^{-1}$) and sulphur (0, 20 and 40 kg S ha$^{-1}$). They indicated that application of 40
kg Šha⁻¹ significantly enhanced growth parameters viz., plant height, plant spread and number of branches per plant.

### 2.2.2 Yield and yield attributes

Jat *et al.* (1998) conducted a field experiment at Jobner (Rajasthan) on loamy soil with four levels of sulphur (0, 30, 60 and 90 kg S ha⁻¹) in fenugreek. Results revealed that application of sulphur @ 90 kg ha⁻¹ significantly enhanced the yield attributes viz., seed yield and straw yield of fenugreek.

Manure *et al.* (2000) at Calicut (Kerala) reported that yield attributes, seed yield, oil yield and oil content enhanced by the application of nitrogen, sulphur and zinc fertilizer in coriander crop. They reported that application of 80 kg N and 12 ppm S ha⁻¹ were recorded significantly higher seed yield.

A field experiment conducted by Pratap *et al.* (2003) at Bikaner (Rajasthan) to study the effect of nitrogen and sulphur on growth and yield of fennel. Results showed that application of 60 kg S ha⁻¹ significantly increased the grain yield (53.0%).

A field experiment conducted at Sardarkrushinagar by Patel (2005) to determine the response of *rabi* drilled fennel to different level of nitrogen (30, 60 and 90 kg N ha⁻¹) and sulphur (0, 20 and 40 kg S ha⁻¹). They reported that application of 40 kg S ha⁻¹ significantly increased the seed and stover yield.

Bochalia *et al.* (2011) conducted a field experiment at Udaipur (Rajasthan) during winter season of 2005-06 to evaluate the response of fenugreek genotype to planting geometry, agro-chemicals and sulphur level (0, 20 and 40 kg S ha⁻¹). Results indicated that application of 40 kg S ha⁻¹ exhibited significantly higher seed yield (1.36 t ha⁻¹) and haulm yields as compared to other level of sulphur.

Meena *et al.* (2011) at Bikaner (Rajasthan) conducted a field trial during *rabi* season of 2000-01 and 2001-02 to study the effect of phosphorus, sulphur and PSB on fenugreek. Results revealed that application of sulphur up to 60 kg S ha⁻¹ + inoculation of PSB significantly increased seed and straw yield.

A field experiment conducted at Turkey to determine the effect of nitrogen and sulphur on yield and quality of fenugreek. Results indicated that application of 90 kg N and 40 kg S ha⁻¹ significantly increased seed yield and test weight in both the experimental year 2006-07 (Ruveyde and Murat, 2011).

Tuncturk *et al.* (2011) conducted a field trial to study the effects of nitrogen and sulphur applications on yield and quality of fenugreek during 2006-07 at Van (Turkey). They indicated that application of 90 kg N and 20 kg S ha⁻¹ significantly
increased the number of seeds per pod, 1000 seed weight, seed yield (853.0 and 815 kg ha\(^{-1}\)) were recorded in both the years 2006 and 2007 of experimentation, respectively.

A field experiment conducted at Udaipur during *rabi* season 2010-2011 to evaluate the effect of phosphorus and sulphur level on growth and yield of fenugreek. The results indicated that application of 45 kg S ha\(^{-1}\) significantly increased seed, straw and biological yield and harvest index of fenugreek (Jat *et al*., 2012).

Patel *et al.* (2013) at Sardarkrushinagar (Gujarat) conducted a field experiment during *rabi* season of 2009-10 to study the effect of different levels of nitrogen (20, 40, 60 and 80 kg N ha\(^{-1}\)) and sulphur (0, 10, 20 and 30 kg S ha\(^{-1}\)) on growth and yield of coriander (*Coriandrum sativum* L.). Results indicated that soil application of sulphur @ 30 kg ha\(^{-1}\) recorded significantly higher seed yield (1184 kg ha\(^{-1}\)) and straw yield (1577 kg ha\(^{-1}\)).

An experiment conducted on the effect of soil application of sulphur (20, 30 and 40 kg S ha\(^{-1}\)) and foliar application of zinc (0.4, 0.5 and 0.6 % zinc) on fenugreek during 2012-13 at Ajmer (Rajasthan) by Lal *et al.* (2014). Results indicated that soil application of 40 kg S ha\(^{-1}\) significantly higher seed yield (1991 kg ha\(^{-1}\)).

Manohar *et al.* (2014) conducted a field experiment during *rabi* season of 2011-12 on sandy laom soil to study the effect of sulphur and molybdenum on yield attributes and yield of fenugreek. They reported that application of sulphur @ 60 kg S ha\(^{-1}\) and molybdenum 1.5 kg ha\(^{-1}\) significantly increased the pods per plant, seeds per pod, seed yield (15.22 q ha\(^{-1}\)) and straw yield (38.80 q ha\(^{-1}\)) over control and 60 kg S ha\(^{-1}\).

Verma *et al.* (2014) studied the effect of vermicompost and sulphur on growth, yield and nutrient uptake of fenugreek with four level of vermicompost (0, 2, 4, and 6 t ha\(^{-1}\)) and four level of sulphur (0, 20, 40 and 60 kg S ha\(^{-1}\)). They reported that application of sulphur @ 40 kg S ha\(^{-1}\) were recorded significantly higher seed yield (15.05 q ha\(^{-1}\)) and straw yield (38.80 q ha\(^{-1}\)) over control and 60 kg S ha\(^{-1}\).

Meena *et al.* (2015) evaluated the effect of plant growth regulator and sulphur (0, 20 and 40 kg S ha\(^{-1}\)) on productivity and nutrient concentration in coriander. Results indicated that application of sulphur up to 40 kg S ha\(^{-1}\) significantly increased the number of umbels per plant, umbellates per umbel, seeds per umbellate, seed, straw and biological yields as compared to control and 20 kg S ha\(^{-1}\).

A field experiment conducted at Jobner (Rajasthan) during *rabi* seasons of 2006-07 and 2007-08 to study the effect of clay-mixing, irrigation and sulphur on
growth and yield of fenugreek. The results indicated that application of sulphur @ 40 kg S ha$^{-1}$ gave significantly higher yield attributes and yield on pooled basis as compared to 0 kg S ha$^{-1}$ and 20 kg S ha$^{-1}$ (Ramkishor et al., 2015).

Meena et al. (2017) studied the effect of two varieties, four levels of each of sulphur (0, 20, 40 and 60 kg S ha$^{-1}$) and zinc (0, 2.5, 5.0 and 7.5 kg ha$^{-1}$) on coriander (*Corianderum sativum* L.) at Jobner (Rajasthan). They showed that application of sulphur @ 40 kg S ha$^{-1}$ significantly increased umbels per plant, umbellets per umbel, seeds per umbel, test weight, seed yields (1406 kg ha$^{-1}$), stover and biological yields as compared to control and 20 kg S ha$^{-1}$. They also noticed that application of 40 kg S ha$^{-1}$ was recorded 20.8% significantly higher seed yield.

Boori et al. (2017) conducted a field trial at Jobner (Rajasthan) during *rabi* season of 2013-14 to evaluate the effect of intercropping and sulphur in different row ratios on fenugreek with three intercropping systems (sole fenugreek, fennel + fenugreek in 1:1 and fennel + fenugreek in 1:2 row ratios) and four sulphur levels (0, 20, 40 and 60 kg S ha$^{-1}$). Results showed that application of sulphur up to 40 kg S ha$^{-1}$ significantly increased number of seeds per pod, seed yield (11.32 q ha$^{-1}$), straw yield (26.73 q ha$^{-1}$) and biological yields (38.05 q ha$^{-1}$) of fenugreek. They also reported that application of 40 kg S ha$^{-1}$ was recorded 31.78% significantly higher seed yield as compared to control and 20 kg S ha$^{-1}$.

A field experiment conducted by Solanki et al. (2017) on clayey soil of Junagadh during *rabi* season of 2014-15 to study the effect of potassium (0, 20, 40 and 60 kg ha$^{-1}$) and sulphur (0, 20 and 40 kg ha$^{-1}$) on growth and yield of fennel. Results revealed that application of sulphur @ 40 kg S ha$^{-1}$ significantly enhanced yield and yield attributes *viz.*, number of umbels per plant, number of umbellates per umbel, number of seeds per umbellate, seed weight per plant, test weight, seed yield per hectare (1534 kg ha$^{-1}$) and stover yield per hectare (1653 kg ha$^{-1}$).

### 2.2.3 Quality parameters

Sivakumaran et al. (1996) at Bangalore studied the nutrient uptake, seed and oil yield of coriander as influenced by the application of nitrogen, phosphorus and sulphur. They concluded that application of 10 kg S ha$^{-1}$ was recorded significantly the highest oil yield (2.48 kg ha$^{-1}$).

Sharma et al. (1999) evaluated the influence of level of phosphorus (0, 20, 40 and 60 kg ha$^{-1}$) and sulphur (0, 25, 50, 75 and 100 kg ha$^{-1}$) on nutrient uptake and quality seed production of fenugreek at Jobner (Rajasthan) during *rabi* season of
Results indicated that application of 50 kg S ha\(^{-1}\) significantly increased protein content of in seed as compared to other level of sulphur.

Manure et al. (2000) at Calicut (Kerala) reported that oil yield and oil content were significantly enhanced by the application of nitrogen, sulphur and zinc fertilizer in coriander crop. Results showed that application of 80 kg N and 12 ppm S ha\(^{-1}\) was recorded significantly higher essential oil content of coriander seed as compared to without nutrient application.

A field experiment conducted at Bikaner (Rajasthan) to study the effect of nitrogen and sulphur on growth and yield of fennel. Results showed that application of 60 kg S ha\(^{-1}\) significantly increased essential oil content and oil yield in seed of fennel (Pratap et al., 2003).

A field experiment conducted by Patel (2005) at Sardarkrushinagar on loamy sand soil to evaluate the response of rabi drilled fennel (Foeniculum vulgare Mill.) to different levels of nitrogen and sulphur (0, 20, 40 kg S ha\(^{-1}\)). Results revealed that application of sulphur up to 40 kg ha\(^{-1}\) significantly increased protein and volatile oil contents in seed as well as oil yield.

Tuncturk et al. (2011) studied the effects of nitrogen and sulphur on quality of fenugreek at Van (Turkey) during growing seasons of 2006 and 2007. Results indicated that application of 90 kg N and 40 kg S ha\(^{-1}\) was recorded significantly the highest protein content (24.2 %) in both the experimental years.

Patel et al. (2013) conducted a field experiment at Sardarkrushinagar during rabi season of 2009-10 to investigate the effects of level of nitrogen (20, 40, 60 and 80 kg N ha\(^{-1}\)) and sulphur (0, 10, 20 and 30 kg S ha\(^{-1}\)) on growth and yield of coriander (Coriandrum sativum L.). Results indicated that application of sulphur @ 30 kg ha\(^{-1}\) was recorded significantly higher protein content, volatile oil content and total oil yield in coriander.

Verma et al. (2014) determined the effect of vermicompost and sulphur on growth, yield and nutrient uptake of fenugreek with four level of vermicompost (0, 2, 4, and 6 t ha\(^{-1}\)) and sulphur (0, 20, 40 and 60 kg S ha\(^{-1}\)). They reported that application of 40 kg S ha\(^{-1}\) was recorded significantly higher leghaemoglobin content in root nodules (1.91 mg g\(^{-1}\)).

2.2.4 Economics

A field experiment conducted during rabi season of 2011-12 on sandy laom soil to evaluate the effect of sulphur and molybdenum on economics of fenugreek by
Manohar et al. (2014). Results indicated that application of sulphur @ 60 kg and molybdenum @ 1.5 kg ha$^{-1}$ were recorded significantly higher net returns (Rs. 39244 and 38504 ha$^{-1}$ in both season, respectively).

Verma et al. (2014) observed that the effect of vermicompost and sulphur on economic of fenugreek with four level of vermicompost (0, 2, 4, and 6 t ha$^{-1}$) and sulphur (0, 20, 40 and 60 kg S ha$^{-1}$). They reported that application of sulphur 40 kg ha$^{-1}$ resulted in significantly higher net returns (Rs 35,311 ha$^{-1}$).

Meena et al. (2017) at Jobner (Rajasthan) studied the effect of two varieties of coriander with four levels of sulphur (0, 20, 40 and 60 kg S ha$^{-1}$) and zinc (0, 2.5, 5.0 and 7.5 kg ha$^{-1}$). They observed that application of 40 kg S and 5.0 kg Zn ha$^{-1}$ was registered significantly higher net returns (Rs. 39309 ha$^{-1}$).

Solanki et al. (2017) conducted a field experiment on clayey soil of Junagadh during *rabi* season of 2014-15 to evaluate the four levels of potassium (0, 20, 40 and 60 kg ha$^{-1}$) and three levels of sulphur (0, 20 and 40 kg ha$^{-1}$) on fennel (*Foeniculum vulgare* Mill.). Results showed that application of 20 kg S ha$^{-1}$ significantly maximum net returns (59,639 Rs. ha$^{-1}$) and B:C ratio (2.78).

### 2.2.5 Nutrient content and uptake by plants

Sharma et al. (1999) conducted a field experiment on loamy sand soil at Jobner (Rajasthan) during *rabi* season of 1995-96 to investigate the influence of P (0, 20, 40 and 60 kg ha$^{-1}$) and S (0, 25, 50, 75 and 100 kg ha$^{-1}$) on nutrient uptake and quality seed production of fenugreek. They reported that application of sulphur @ 75 kg ha$^{-1}$ significantly improved N in seed as compared to 0 and 20 kg S ha$^{-1}$.

Tripathi (2006) conducted a field experiment at Gwalior (M. P.) during *rabi* season to evaluate the effect of potassium and sulphur levels on seed yield of coriander. Results revealed that increasing level of sulphur significantly increased the total uptake of N, P and K.

A field experiment conducted at Navsari during 2007-08 to study the effect of potash and sulphur on growth and seed yield of coriander under South Gujarat conditions (Bhoya, 2008). Results revealed that application of sulphur up to 40 kg S ha$^{-1}$ significantly increased uptake of N, P, K and S by seed.

At Bikaner (Rajasthan) Meena et al. (2011) conducted a field trial during *rabi* season of 2000-01 and 2001-02 to determine the effect of phosphorus, sulphur and PSB on fenugreek. Results showed that application of 60 kg S ha$^{-1}$ significantly enhanced sulphur and phosphorus content and their uptake in seed and straw.
Review of literature

Vidyathi et al. (2011) concluded that application of sulphur up to 30 kg S ha\(^{-1}\) along with organic manure resulted significantly higher uptake of N, P, K and other micronutrient in fenugreek cropping system in *rabi* seasons of 2009-10.

### 2.2.6 Soil analysis after harvest of the crops

Chaudhary (2007) studied the effect of crop geometry, balanced fertilization (40:17.5:20:30 kg NPKS ha\(^{-1}\)) and agro-chemicals on productivity, nutrient uptake and residual soil fertility of fenugreek. They showed that the application of 40 kg S ha\(^{-1}\) significantly increased availability of nitrogen of experimental soils after harvest of fenugreek crop.

A three-years field trial conducted during 2000 to 2002 at North-East Poland by Skwierawska et al. (2008) to evaluate the effect of different levels (40, 80 and 120 kg S ha\(^{-1}\)) and forms (sulphate sulphur and Elemental sulphur) of sulphur tested on changes of soil agro-chemical properties. Results indicated that application of 120 kg S ha\(^{-1}\) sulphate sulphur significantly increase in the concentration of available phosphorus in soil in the 0 to 40 and 40 to 80 cm layers of soil.

Vidyathi et al. (2011) concluded that application of sulphur up to 30 kg S ha\(^{-1}\) along with organic manure resulted significantly improved soil fertility status after harvest of fenugreek crops.

Vaishali et al. (2013) this might have contributed towards increased organic carbon and available N, P, K and S status of soil after harvest of niger slightly increased with increasing levels of sulphur.

Verma et al. (2014) studied the effect of vermicompost and sulphur on growth, yield and nutrient uptake of fenugreek (*Trigonella foenum-graecum* L.). They indicated that application of sulphur up to 40 kg ha\(^{-1}\) significantly increased available nitrogen (140.97 kg ha\(^{-1}\)) content in soil after harvest of the crop over lower levels of sulphur application.

### 3. Interaction effect of level of phosphorus and sulphur

A field experiment conducted at Bangalore by Sivakumaran et al. (1996) during 1992-93 to evaluate the two levels of nitrogen (0 and 10 kg N ha\(^{-1}\)), phosphorus (0 and 10 kg P ha\(^{-1}\)) and sulphur (0 and 10 kg S ha\(^{-1}\)). They reported that application of 10:10:10 kg NPS ha\(^{-1}\) significantly increased yield of coriander.

Sharma et al. (1999) carried out a field trial on loamy sand soil of Jobner (Rajasthan) during *rabi* season of 1995-96 to investigate the influence of P (0, 20, 40 and 60 kg ha\(^{-1}\)) and S (0, 25, 50, 75 and 100 kg ha\(^{-1}\)) on nutrient uptake and quality
seed production of fenugreek. Results showed that application of 40 kg P$_2$O$_5$ and 75 kg S ha$^{-1}$ significantly enhanced seed yield as compared to other treatments.

Jat (2004) at Jobner (Rajasthan) conducted a field experiment during two consecutive years 1997–98 and 1998-99 to study the effect of phosphorus, sulphur and bio-fertilizers on nodulation of fenugreek on saline loamy sand soil. Results revealed that application of 80 kg P$_2$O$_5$ ha$^{-1}$, 100 kg S ha$^{-1}$ and seed treatment with rhizobium + PSB significantly increased seed yield.

Nehara et al. (2006) at Jobner (Rajasthan) conducted a field trial on loamy sand soil to evaluate the response of fenugreek under different levels of phosphorus (0, 25 and 50 kg P$_2$O$_5$ ha$^{-1}$) and sulphur (0, 25 and 50 kg S ha$^{-1}$). Results indicated that application of 50 kg P$_2$O$_5$ and 25 kg S ha$^{-1}$ was recorded significantly higher seed yield.

Chaudhary (2007) evaluated the effect of crop geometry, balanced fertilization (40:17.5:20:30 kg NPKS ha$^{-1}$) and agro-chemicals on productivity, nutrient uptake and residual soil fertility of fenugreek. They noticed that application of 40-17.5-20-30 kg NPKS ha$^{-1}$ significantly increased seed yield.

Noor et al. (2007) at Faridpur (Bangladesh) studied the effect of nutrient management for black cumin. Results showed that application of fertilizer 100-31-56-25 kg NPKS ha$^{-1}$ significantly increased seed yield of black cumin.

A field experiment conducted during rabi season of 2005-06 at Ajmer (Rajasthan) to investigate the response of Nagauri Methi to phosphorus and sulphur. There are three levels of phosphorus (0, 40 and 60 kg ha$^{-1}$) and sulphur (0, 30 and 45 kg ha$^{-1}$) tested in these investigation. Results revealed that application of 60 kg P$_2$O$_5$ and 45 kg S ha$^{-1}$ significantly increased growth parameters and yield of dried leaves of the crop as compared to other treatments (Godara et al., 2013).

Moniruzzaman et al. (2014) studied the response of coriander seed crop to nitrogen, phosphorus, potassium and sulphur. They revealed that the combined application of NPKS (80-40-40-20 kg NPKS ha$^{-1}$) with a blanket dose of 5 t cow dung gave significantly maximum number of leaves per plant, primary and secondary branches per plant, umbels per plant, seeds per umbel, 1000 seed weight, seed yield (1.94 t ha$^{-1}$) and harvest index.

Yousuf et al. (2014) conducted a field experiment at Bogra (Bangladesh) during rabi seasons of 2008-09 and 2009-10 to find out the effect of N, P, K and S on
coriander (BARI Corinader-1) for achieving satisfactory seed yield. Different levels of nitrogen (0, 40, 70, and 100 kg ha\(^{-1}\)), phosphorus (0, 25, 50, and 70 kg ha\(^{-1}\)), potassium (0, 30, 60, and 90 kg ha\(^{-1}\)) and sulphur (0, 10, 20, and 30 kg ha\(^{-1}\)) were distributed in the plot. Results indicated that application of 70-50-30-20 kg NPKS ha\(^{-1}\) significantly increased seed yield (2.06 t ha\(^{-1}\) and 2.09 t ha\(^{-1}\) in the years 2008-09 and 2009-10, respectively).

Godadra et al. (2016) at Ajmer (Rajasthan) investigated a field experiment during the winter seasons of 2012–13 and 2013–14 to assess the response of fenugreek (Trigonella foenum-graecum L.) to fertility levels, bio-fertilizers and brassinosteroid. Three fertility levels [60, 80 and 100% RDF (40-40-10 kg NPS ha\(^{-1}\))] and 3 bio-fertilizer inoculations [rhizobium, PSB and rhizobium + PSB] in main-plots and three concentrations of brassinosteroid (BR), viz. water spray, BR 0.25 ppm and BR 0.50 ppm, in sub plots. They concluded that application of 100% RDF was recorded significantly the highest values of growth parameters, nodules per plant, yield attributes, seed yield (2.24 t ha\(^{-1}\)), haulm yield (5.24 t ha\(^{-1}\)). They also noticed that application of 100% RDF + dual inoculation, being at par with 80% RDF + dual inoculation, gave significantly the highest seed yield (2, 287 kg ha\(^{-1}\)).

Rahman et al. (2018) carried out field trial at Dhaka (Bangladesh) during 2016-17 to investigate the effect of four levels of phosphorous (0, 20, 30, 40 kg P\(_2\)O\(_5\) ha\(^{-1}\)) and three levels of sulphur (0, 10 and 20 kg S ha\(^{-1}\)) on seed yield of fenugreek (cv. BARI Methi-1). Results indicated that application of 40 kg P\(_2\)O\(_5\) and 20 kg S ha\(^{-1}\) significantly higher number of pods per plant (23.08), weight of straw per plot (172.59 g per 3.6 m\(^2\)) and 1000 seed weight (9.98 g). They also noticed that application of 40 kg P\(_2\)O\(_5\) and 10 kg S P\(_2\)O\(_5\) ha\(^{-1}\) produced significantly maximum seed yield (770.0 kg ha\(^{-1}\)) which was statistically at par with 30 kg P and 10 kg S ha\(^{-1}\) (767.2 kg ha\(^{-1}\)) and 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) and 20 kg S ha\(^{-1}\) (765.3 kg ha\(^{-1}\)).