The productivity of any crop is a complex phenomenon which is governed by numerous endogenous and exogenous factors. It can be enhanced by 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 weeds, insect-pests and diseases. Among various agronomical factors responsible for increasing productivity of any crop, fertilizer management plays important role for harvesting potential production of any crop including Indian mustard.

An attempt has been made to review the available literatures concerning the present investigation are presented in this chapter. The work done, especially on these aspect of mustard is very meagre; 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 scientists in India and abroad on related aspects has been highlighted and reviewed under the following broad topics.

2.1 **Effect of source of sulphur**
   2.1.1 Growth parameters
   2.1.2 Yield and Yield attributes
   2.1.3 Quality parameters
   2.1.4 Nutrient content and uptake by plant
   2.1.5 Soil analysis after harvest of the crop

2.2 **Effect of levels of sulphur**
   2.2.1 Growth parameters
   2.2.2 Yield and Yield attributes
   2.2.3 Quality parameters
   2.2.4 Nutrient content and uptake by plant
   2.2.5 Soil analysis after harvest of the crop

2.3 **Combine effect of sources and levels of sulphur**
2.4 Economics

2.1 Effect of source of sulphur

2.1.1 Growth parameters

The effect of gypsum as sulphur fertilizer on the growth was also tested on other crops such as cereals (Withers et al., 1995), cabbage (*Brassica oleracea* L. var. capitata) (Sandreson et al., 1996) and sunflower (*Helianthus annuus* L.) (Intodia and Tomar, 1997)

Sarmah and Debnath (1999) conducted field experiment entitled Response of toria (*Brassica compestris* sub sp. *Oleifera* var. toria) to sources and levels of sulphur fertilization at Kalyani (West Bengal) using three different sources of Sulphur (Gypsum, Bentonite and Pyrite). They reported that the difference in plant height, number of primary and secondary branches of mustard was not significant due to use of different sources of sulphur. Gypsum and bentonite sulphur were found to be better source as compared to pyrite.

Kalaiyarasan *et al.* (2003) carried out an experiment on red lateritic soil of Guntur (Andhra Pradesh) during the year 2000-01. They found that the application of sulphur significantly enhanced the growth of groundnut. The application of sulphur @ 45 kg ha\(^{-1}\) as gypsum resulted in the highest plant height (66.4 cm) and dry matter production (5.99 t ha\(^{-1}\)).

Rao *et al.* (2013) conducted a field experiment at Seethampeta (Andhara Pradesh) during the year 2011-12. Result revealed that sulphur application significantly influenced the growth of groundnut over control regardless of sources of sulphur. Application of sulphur @ 45 kg ha\(^{-1}\) through gypsum recorded highest plant height (70.66 cm) and other growth parameters. However, it was at par to application of sulphur at 30 and 45 kg ha\(^{-1}\) through elemental sulphur and bentonite sulphur.

A field experiment conducted by Katiyar *et al.* (2014) at Ujhani (Badaun) during *Rabi* season of 2010-11 and 2011-12 using “Pusabold” variety of mustard. The result revealed that growth parameters of mustard like as plant height (150.2 cm) and length of silique (6.5 cm) were influenced significantly due to application of different sulphur containing fertilizers. Maximum plant height was recorded with dual application of sulphur as basal along with 80% WP sulphur @ 1.25 kg ha\(^{-1}\) foliar sprayed at 75 DAS closely followed by application of sulphur as basal + 80% WP @ 5 kg ha\(^{-1}\) applied with urea broadcasting at 45 DAS.
A pot experiment conducted at Junagadh (Gujarat) during the year 2013 by Sisodiya (2014). He found that plant height (38.80 cm) of groundnut significantly increased with the application of elemental sulphur as compared to other sources used viz., Cosawet, Gypsum and Bentonite sulphur.

A field experiment conducted by Arun Babu (2014) at Acharya N. G. Ranga Agricultural University, Hyderabad (Telangana) during rabi 2013. He reported that application of ammonium sulphate as a source of sulphur produced significantly higher plant (78.3 cm), leaf area index (3.51), dry matter production per plant (89.3 g), primary (8.7) and secondary (17.5) branches per plant at harvest of safflower as compared to other sources of sulphur used in investigation viz., single superphosphate and gypsum.

Kumar (2015) conducted a field experiment at Sabour (Bihar) during the year 2013-14. Result revealed that growth parameters like plant height at harvest (165.8 cm), leaf area index per plant (6.03), number of primary branches per plant (7.0) and dry matter production per plant (81.3 gm) of Indian mustard was observed highest with bentonite S as compared to other sources of sulphur used viz., Gypsum and Iron pyrite.

An experiment conducted by Kumar (2015) at Varanasi (Uttar Pradesh) during the rabi season of 2014 showed that elemental sulphur recorded significantly higher plant height at harvest (188.41 cm), number of green leaves plant per plant (73.65), total number of branches per plant (70.07) and leaf area index (5.59) of mustard as compared to Bentonite sulphur.

2.1.2 Yield attributes and yield

Patel (1982) conducted an experiment at sandy loam soils of Anand during the year of 1981. He obtained maximum yield of mustard under application of 36 kg sulphur ha⁻¹. The seed and straw yields of mustard increased significantly when sulphur was applied through ammonium sulphate as compared to the other sources of sulphur. Relative efficacy of different sources of sulphur in producing seed yield of mustard was in order of ammonium sulphate (100%) > gypsum (97.3%) > SSP (97.1%) > pyrite (91.8%). These results are in conformity with the report of Tiwari et al. (1992).

Singh and Agarwal (1998) conducted an experiment at Bichpuri (U.P) during the year 1993. Among the different three sources of sulphur (Elemental Sulphur,
Pyrite and Gypsum) used, gypsum application reflected in better pod length, seeds per pod, grain weight and yield of black gram as compared to other sources of sulphur tested i.e. elemental sulphur and pyrite.

Sarmah and Debnath (1999) reported that sulphur fertilization significantly improved most of the yield attributes and seed yield of toria as compared to no sulphur. Application of gypsum and bentonite sulphur indicated their superiority in increasing the seed yield over pyrite. Significantly higher number of branches per plant, siliqua per plant, test weight, seed yield and stover yield were observed due to application of gypsum or bentonite sulphur as compared to pyrite. Average increase of seed yield over control was 12.9, 29.5 and 32.2 per cent due to application of pyrite, gypsum and bentonite sulphur, respectively.

Rao and Shaktawat (2002) revealed that gypsum application (250 kg ha$^{-1}$) reflected in significant improvement in yield attributes of groundnut like as number of pods per plant, number of seeds per pod, test weight and kernel yield as compared to other sources of sulphur used.

A field experiment conducted by Singh and Chauhan (2002) at Bulandsahar (Uttar Pradesh). They found that gypsum proved significantly superior with respect to yield attributes and yield like as pods per plant (102), number of seeds per pod (6.20), test weight (20.3 g), grain (12.22 t ha$^{-1}$) and straw yield (26.51 t ha$^{-1}$) and harvest index (31.55 %) of Lentil as compared to other sources of Sulphur.

Kowalenko (2004) investigated response of forage grass to sulphur applications on coastal British Columbia soil during the year 2003, among the different levels of gypsum application tested, gypsum application @ 134 kg ha$^{-1}$ yield higher dry matter of the grass (5.20 t ha$^{-1}$).

Piri and Sharma (2006) conducted a field experiment on effect of sources of sulphur on yield attributes, yield and quality of Indian mustard during the year 2004-05 at IARI, New Delhi. Different sources of sulphur used like gypsum and cosavet did not differ significantly with regard to seed and stover yield of mustard.

Singh and Singh (2007) conducted a field experiment at Bichpuri (U.P) during the year 2001-02. Result revealed that various yield attributes, seed and stover yields of linseed increased significantly when sulphur was applied through gypsum as compared to the other sources of sulphur. This increase in yield might be attributed to easy availability of $SO_4^{2-}$ present in gypsum as compared to sulphide form in pyrite,
which essentially requires its oxidation to be converted into $\text{SO}_4^{2-}$ prior to its absorption by the crop.

Ceh et al. (2008) conducted a field experiment at Zalec (Slovakia) during the year 2007 to detect the impact of fertilization by K$_2$SO$_4$ and gypsum on the yield of oilseed rape. The sources of sulphur (K$_2$SO$_4$ and gypsum) did not impact positively the yield, but a negative impact of fertilization by sulphur was detected. Positive impact of gypsum was detected when it was fertilized at sowing.

Higher yield with increased application of sulphur also attributed protein and enzyme synthesis as it is a constituent of sulphur containing amino acids namely methonine, cysteine and cystine (Kumar et al., 2011). On the other hand, the sources of sulphur (gypsum, bentonite S, pyrite) did not influence significantly the yield attributes and yield of Indian mustard (Brassica juncea L.) in the experiment by Kumar et al. (2011). Chattopaddhyay and Ghosh (2012) studied the response of rapeseed (Brassica juncea L.) to various sources and levels of sulphur in red and lateritic soils of West Bengal during the year 2001-2002. They reported that sources viz. single super phosphate (SSP), phosphogypsum, pyrites and elemental S have significant influence on seed yield and total biological yield. The maximum seed yield was recorded with SSP followed by phosphogypsum and pyrite. The lowest yield was observed with elemental S. Amongst the various sources of S tested, single superphosphate was the best with respect to seed yield followed by phosphogypsum, pyrites and elemental S.

A field experiment conducted by Das and Ghosh (2012) at Shriniketan (West Bengal) during the year 2005-06 in typical lateritic soil. They found that magnesium sulphate significantly increased the seed yield (18.28 q ha$^{-1}$) of rapeseed as compared to gypsum.

Kumar and Trivedi (2012) conducted a field experiment at Gwalior (M.P) during the year 2007-08. Ammonium sulphate, gypsum, single super phosphate and pyrite were used as a source of sulphur. Result revealed that highest seed (14.25 t ha$^{-1}$) and stover yield (29.36 t ha$^{-1}$) of mustard were observed with use of ammonium sulphate which was significantly higher over other sources used.

Arun Babu (2014) reported that ammonium sulphate recorded significantly higher number of capitulum per plant (22.4), number of seeds per capitulum (21.0), weight of capitulum per plant (35.1 g), test weight (4.75 g), seed yield per plant
Review of literature

(16.7 g), seed (1471 kg ha⁻¹) and stalk (3376 kg ha⁻¹) yield of safflower as compared to other sources of sulphur.

Katiyar et al. (2014) conducted a Field experiment at farm of KVK Ujhani (Uttar Pradesh) during Rabi season of 2011-12. The treatments consisting commercial grade sulphur fertilizers viz. use of 90 % DP sulphur @ 25 kg ha⁻¹ basal, 80 % WP sulphur @ 5 kg ha⁻¹ applied with urea broadcasting at 45 DAS, sulphur 80 % WP @ 1.25 kg ha⁻¹ foliar sprayed at 75 DAS, sulphur 80 % WP @5 kg ha⁻¹, sulphur basal + 80 % WP @5 kg ha⁻¹ applied with urea broadcasting at 45 DAS, sulphur basal + 80 % WP @ 1.25 kg ha⁻¹ foliar sprayed at 75 DAS, no use of sulphur (farmers practice). The results showed that application of sulphur had significant influence on yield attributes, seed & oil yield of mustard. Maximum values of seeds per pod (17), test weight (6.54 g), seed yield (21.94 q ha⁻¹) were recorded with dual application of S as basal along with 80 % WP sulphur @ 1.25 kg ha⁻¹ foliar sprayed at 75 DAS closely followed by application sulphur basal + 80 % WP @ 5 kg ha⁻¹ applied with urea broadcasted at 45 DAS.

A pot experiment conducted by Sisodiya (2014) at Junagadh (Gujarat) during the year 2013. He tested four different sources of sulphur (Cosavet Sulphur, Gypsum, Bentonite Sulphur and Elemental Sulphur) and found that pod yield (13.14 gm per plant), total biomass (36.31 gm per plant) and test weight (48.13 g) of groundnut were significantly improved by the application of elemental Sulphur.

Kumar (2015) noticed that Bentonite sulphur recorded significantly higher number of seeds per siliqua (13.5), seed (15.4 q ha⁻¹) and stover (39.1 q ha⁻¹) yield of mustard as compared to other sources of sulphur used in the experiment viz, Gypsum, Iron Pyrite.

Kumar (2015) showed that elemental sulphur can give significantly higher length of siliqua (4.54 cm), number of siliqua per plant (541.3), test weight (3.96 g), seed yield (1541 kg ha⁻¹) and stover yield (5919 kg ha⁻¹) of mustard as compared to Bentonite sulphur.

Nevase et al. (2016) carried out an experiment entitled Effect of different sources and rates of sulphur application on quality Parameters of the Soybean during the year 2006 on black soil of Parbhani (Maharastra). Among the different sources of sulphur used in investigation elemental sulphur recorded significantly higher seed...
(24.97 q ha\(^{-1}\)) and straw yield (26.70 q ha\(^{-1}\)) as compared to other source of sulphur viz., Gypsum and Bentonite sulphur.

### 2.1.3 Quality Parameters

Chauhan *et al.* (2002) conducted a field experiment at Gwalior (Madhya Pradesh) during the year 1996-97 and proved that oil content of mustard significantly increased with the use of gypsum as a source of sulphur as compared to single super phosphate.

A field experiment was taken by Mani *et al*. (2006) during the *rabi* season of the year 2004-05 at Allahabad (Uttar Pradesh). They noted that ammonium sulphate significantly increased the oil content of mustard (40.43%) as compared to other source.

Das and Ghosh (2012) noticed that oil content (47.02%) of rapeseed significantly influenced by the magnesium sulphate used as source of sulphur as compared to gypsum.

Kumar and Trivedi (2012) reported that the highest oil and protein content of mustard seed was observed with use of ammonium sulphate (39.2%) which was significantly higher over other sources followed by gypsum (38.5%), SSP (38.4%) and pyrite (38.0%).

Rao *et al*. (2013) reported that sulphur application significantly influenced the oil content of groundnut over control regardless of the sources among the different sources of sulphur used in investigation Elemental Sulphur (49.93%) recorded significantly higher oil content as compared to Bentonite Sulphur (49.07%) and Gypsum (49.57%).

Arun Babu (2014) revealed that significantly higher oil content (31.2%), oil yield (464.3 kg ha\(^{-1}\)) and protein content (15.0%) of safflower can obtained under application of ammonium sulphate.

Katiyar *et al*. (2014) reported that application of sulphur 90% DP @ 25 kg ha\(^{-1}\) as basal had significant influence on oil content of mustard. Maximum oil content (42.4%) was recorded with dual application of S as basal along with 80% WP @ 1.25 kg ha\(^{-1}\) foliar sprayed at 75 DAS closely followed by application of sulphur as basal + 80% WP @ 5 kg ha\(^{-1}\) applied with urea broadcasted at 45 days after sowing.
Sisodiya (2014) found that different sources of sulphur (Cosawet Sulphur, Gypsum, Bentonite Sulphur and Elemental sulphur) did not influence the oil and protein content of groundnut seed. 

Kumar (2015) noticed that Bentonite sulphur gave significantly higher oil content (40.5%) of mustard as compared to other sources of sulphur used in the experiment viz, Gypsum and Iron pyrite.

Kumar (2015) found that source of sulphur (Elemental sulphur and Bentonite sulphur) did not cause significant effect on the oil and protein content of mustard seed.

2.1.4 Nutrient content and uptake by plant

Sreemannarayan and Raju (1995) conducted a field experiment at Rajendranagar (Hyderabad) to evaluate the effect of sources and levels of sulphur on the uptake of S, Cu, Fe and Mn of sunflower. Result revealed that the uptake of S by sunflower was higher when ammonium sulphate was the source followed by gypsum and SSP, respectively.

An field experiment entitled “Efficacy of phosphogypsum as source of sulphur for mustard” conducted by Ghosh et al. (1999) during the rabi season of 1996-97 at Kolkata (West Bengal). They found that higher S content in seed (0.53%) and stover (0.35%) and total uptake (27.05 kg ha$^{-1}$) by mustard with sulphur application.

Raut et al. (2000) reported that different sources of sulphur (gypsum, SSP and pyrite) had no significant effect on sulphur uptake by seed (18.56 kg ha$^{-1}$) and stover (7.70 kg ha$^{-1}$). Piri and Sharma (2006) reported that sources of sulphur (gypsum and cosavet sulphur) did not influence sulphur content of seed (0.53%) and stover (0.32%).

Chattopaddhyay and Ghosh (2012) reported the highest S uptake by rapeseed plant (29.1 kg S ha$^{-1}$) with single superphosphate followed by phosphogypsum (28.9 kg S ha$^{-1}$), pyrites (26.3 kg S ha$^{-1}$) and elemental S (23.1 kg S ha$^{-1}$). The maximum concentration of sulphur in seed (0.32%) and stover (0.51%) was recorded in single superphosphate treatment followed by phosphogypsum and pyrite and the least with elemental S.

Das and Ghosh (2012) noticed that magnesium sulphate application significantly increase the sulphur content in seed (0.62%) and stover (0.32%) and also
sulphur uptake by seed (11.69%) and stover (11.90%) as compared to gypsum application in rapeseed.

Kumar and Trivedi (2012) conducted a field experiment at Gwalior (Madhya Pradesh) in the year 2007-08. They reported that higher N (92.52 kg ha\(^{-1}\)), P (21.42 kg ha\(^{-1}\)), K (47.20 kg ha\(^{-1}\)) and S (21.25 kg ha\(^{-1}\)) uptake of mustard were obtained with ammonium sulphate emphasized its superiority over other sources of Sulphur. Second best source observed was gypsum in affecting the uptake of nutrients by mustard.

Arun Babu (2014) showed that significantly higher total uptake of N (43.34 kg ha\(^{-1}\)), P (18.44 kg ha\(^{-1}\)), K (67.31 kg ha\(^{-1}\)) and S (25.54 kg ha\(^{-1}\)) by safflower was recorded under application of ammonium sulphate as compared to other sources of sulphur used in an investigation i.e SSP and gypsum.

Sisodiya (2014) found that different sources of sulphur imparted their significant effect on various nutrient content and uptake by groundnut plant. Among the various sources of sulphur, elemental sulphur recorded significantly higher content of macro nutrients like as N (1.19%), P (0.113%), K (0.541%), and S (0.194%) at harvest. He also noticed significantly the highest uptake of N (435.82 mg plant\(^{-1}\)), P (41.15 mg plant\(^{-1}\)), K (196.73 mg plant\(^{-1}\)) and S (71.08 mg plant\(^{-1}\)) under elemental S.

Kumar (2015) indicated that Bentonite sulphur recorded significantly higher sulphur content (0.59%) and uptake (30.71 kg ha\(^{-1}\)) by mustard plant as compared to other sources used in investigation viz, Gypsum and Iron pyrite.

Kumar (2015) showed elemental sulphur recorded significantly higher value of phosphorus content in seed (0.75%) and stover (0.28%), sulphur content in seed (0.30%), nitrogen content in stover (0.71%) as compared to Bentonite sulphur in mustard. They also reported that total sulphur uptake by plant (36.28 kg ha\(^{-1}\)) was higher under the elemental sulphur.

2.1.5 Soil analysis after harvest of the crop

Ghosh et al. (1999) stated that sources of S application not only increase the available S status over control, but also over initial soil S status. The results clearly showed that all the sources of sulphur have acidifying effect on soil pH indicating the need of liming along with the application of S to soils which not only neutralized the soil acidity but favoured S availability.
Das and Ghosh (2012) noticed that magnesium sulphate significantly increased the available sulphur content (36.1 mg kg\(^{-1}\)) in soil after harvest of the mustard over initial status of soil (9.1 mg kg\(^{-1}\)).

Arun Babu (2014) concluded that application of ammonium sulphate recorded significantly higher available N (210.33 kg ha\(^{-1}\)) and S (21.04 kg ha\(^{-1}\)) content in soil after harvest of safflower.

Sisodiya (2014) found that available nutrient status of soil after harvest of groundnut crop significantly affected by the different sources of sulphur. Among the different sources used in the investigation, gypsum recorded significantly higher available N (86.98 ppm), K (125.47 ppm) and S (12.84 ppm) after harvest of the groundnut crop. While available P, Fe, Mn, Zn and Cu were found non-significant.

Kumar (2015) reported that different sources of sulphur viz, Gypsum, Bentonite sulphur and Iron pyrite failed to bring any significant change in N, P, K and S content in soil after harvest of the mustard crop but status of soil after harvest was improved over initial nutrient status of soil (227.2, 24.27 and 162.1 kg NPK ha\(^{-1}\) and 10.31 ppm S).

### 2.2 Effect of levels of sulphur

#### 2.2.1 Growth parameters

At Udaipur (Rajasthan), Khanpara \textit{et al}. (1993) conducted a field trial during \textit{rabi} season of 1988-89. They found that application of sulphur up to 100 kg ha\(^{-1}\) significantly increased leaf area index (6.03), plant height at harvest (164.99 cm), primary (7.00) and secondary branches (20.00) of mustard.

Davaria (1998) conducted an investigation on effect of phosphorus and sulphur on yield, quality and nutrient uptake by Indian mustard at Junagadh (Gujarat) during the \textit{rabi} season of 1997. Result showed that application of sulphur @ 100 kg ha\(^{-1}\) recorded significantly higher leaf area index (2.36%).

Mani \textit{et al}. (2006) conducted an experiment on mustard at Allahabad (U.P) during year 2004-05, with three different levels of sulphur (0, 20 and 30 kg ha\(^{-1}\)) and result revealed that sulphur increase plant height at harvest (162.33 cm) by 1.8% as the dose of sulphur increased from 0 to 30 kg S ha\(^{-1}\).

During the \textit{rabi} season of 2001-02, Kumar and Yadav (2007) conducted a field experiment at Faizabad (U.P). Among three levels of sulphur application (0, 15,
30 and 45 kg ha\(^{-1}\), dose of 45 kg S ha\(^{-1}\) significantly increased the various growth parameters like as plant height at different stages, number of branches per plant (20.45) and leaf area index (5.94) as compared to other levels of sulphur application.

Makeen \textit{et al.} (2008) took an experiment at Allahabad (U.P) during year of 2003-04. There were six different levels of sulphur tested (0, 40, 20+20, 20+20+20, 60, 30+30 and 30+15+15 kg ha\(^{-1}\)) and report showed that the impact of different levels of sulphur on the dry weight of mustard was favorable at 60 kg S ha\(^{-1}\).

After conducting an experiment in 2004-05 at Allahabad (U.P) Khatkar \textit{et al.} (2009) found that sulphur @ 30 kg ha\(^{-1}\) recorded significantly higher plant height (190.39 cm), number of branches per plant (20.20), number of leaves per plant (48.70) and dry weight (48.80 gm per plant) of mustard.

An experiment conducted by Kapur \textit{et al.} (2010) during the year 2007-08 on the light textured soils of Sardarkrushinagar (Gujarat) with six different levels of sulphur (0, 15, 30, 45 and 60 kg ha\(^{-1}\)). Result revealed that plant height (158.8), number of primary (4.29) and secondary (10.56) branches of mustard were recorded significantly higher with application of 60 kg S ha\(^{-1}\) but it was at par with 45 kg S ha\(^{-1}\) and 30 kg S ha\(^{-1}\).

Jat \textit{et al.} (2012) conducted a field experiment on clay loam soil of Udaipur (Rajasthan) during year 2002-03. They reported that application of 60 kg S ha\(^{-1}\) significantly increased the plant height at 60 DAS (99.01 cm), at 90 DAS (166.40 cm) and at harvest (187.39 cm) over control.

Pachauri \textit{et al.} (2012) reported that various levels of sulphur significantly influenced the growth parameters viz., plant height and dry weight of plant. The plant height increased significantly with each increment in the dose up to 60 kg ha\(^{-1}\). However, the difference in plant height due to further increase in the dose of sulphur was not significant. Application of 60 kg S ha\(^{-1}\) produced more dry weight of plant at 90 DAS as compared to control and 30 kg S ha\(^{-1}\). Better nutrition to plant resulted in more height (171.33 cm) and number of branches (21.43) and other growth parameters, which resulted in higher dry weight of mustard plant.

Sah \textit{et al.} (2013) conducted field experiment at Aligadh (U.P) during the year 2004-05. They reported that application of sulphur resulted into significant variation in the growth characters of mustard. Plant height was significantly improved under 15 kg S ha\(^{-1}\) over control and remained unaffected with further increased up to 45 kg S.
Contrary to this, highest dose of sulphur i.e. 45 kg S ha$^{-1}$ produced higher plant height (204.13 cm) number of functional leaves at 90 DAS (19.66), LAI at flowering (19.66), number of branches per plant (9.45) and dry matter (140.68 gm per plant) over control.

Arun Babu (2014) reported that application of sulphur @ 60 kg ha$^{-1}$ recorded significantly higher plant height at harvest (80.9 cm), leaf area index at harvest (3.85), number of primary (9.6) and secondary (18.7) branches per plant at harvest, dry matter production per plant (95.5 g) in safflower as compared to other levels of sulphur application \textit{viz.}, 0, 20 and 40 kg ha$^{-1}$.

Ray \textit{et al.} (2014) conducted an experiment on typical red lateritic soil of Kolkata (West Bengal) during the \textit{rabi} season of the year 2009-10. They reported that application of sulphur @ 60 kg ha$^{-1}$ had significant beneficial effect on various growth parameters of mustard. This treatment was at par with 45 kg S ha$^{-1}$ for plant height at 75 DAS and at harvest and for LAI at 40 DAS. But there were no significant difference among 30, 45 and 60 kg S ha$^{-1}$ in increasing the LAI at 75 DAS, dry matter accumulation at 40 and 75 DAS and number of primary branches plant$^{-1}$. Application of 60 kg S ha$^{-1}$ attained appreciable more crop growth than 20 to 40 kg S ha$^{-1}$. Dry matter production increased with the age of plant and increase was accelerated between 45 and 90 DAS.

Sisodiya (2014) revealed that L$_5$ (20 ppm Sulphur) (soil application) produced significantly higher plant height at harvest (43.0 cm), total biomass production (38.30 gm per plant) of groundnut as compared to other levels of Sulphur application.

Kumar (2015) noticed that sulphur application @ 60 kg ha$^{-1}$ significantly increased the various growth parameters of mustard like as plant height at harvest (171.6 cm), number of leaves per plant at 90 DAS (22.7), dry matter production per plant (22.7gm), number of primary (7.3) and secondary (31.1) branches per plant.

Kumar (2015) showed that various growth parameters of mustard significantly influenced by various levels of Sulphur. Application of sulphur @ 60 kg ha$^{-1}$ reported significantly higher plant height at harvest (188.88 cm), number of green leaves per plant at 90 DAS (74.66), total number of branches per plant (70.56) and leaf area index (5.94) as compared to other levels of sulphur \textit{viz.}, 0, 30 and 60 kg S ha$^{-1}$.

After conducting an experiment in \textit{rabi} season of 2009-10 at Lakhoti (Uttar Pradesh) Singh and Thenua (2016) reported that application of sulphur @ 40 kg ha$^{-1}$
registered significantly higher plant height (145.12 cm), number of primary (6.51) and secondary (10.58) branches per plant, and dry weight (28.95 gm per plant) of mustard as compared to other levels of sulphur application viz., 0 & 20 kg ha\(^{-1}\).

**2.2.2 Yield attributes and yield**

Patel (1982) obtained maximum yield of mustard due to application of 36 kg S ha\(^{-1}\) on a sandy loam soil of Anand. The 100-siliqua weight of mustard did not differ significantly by varying levels of S but it increased with the increasing rates of S. However, test weight was significantly increased with the increasing levels of S. The highest test weight was noted at S\(_{45}\) (6.82 g), which being at par with S\(_{30}\) (6.65 g) but differed significantly from S\(_{15}\) (5.86 g) and S\(_{0}\) (5.42 g) levels.

Davaria (1998) noticed that application of 100 kg S ha\(^{-1}\) recorded highest seed yield (14.12 q ha\(^{-1}\)) of mustard as compared to other levels of sulphur viz., 0, 25, 50 kg ha\(^{-1}\).

Khan and Hussain (1999) recorded the highest seed yield in mustard (*Brassica juncea*) by applying 40 kg S ha\(^{-1}\). The seed yield increased progressively and significantly with each successive doses of sulphur application. In S\(_{0}\) level of sulphur, the seed yield was 16.8 as against 18.3, 19.3 and 18.8 q ha\(^{-1}\) recorded in S\(_{20}\), S\(_{40}\) and S\(_{60}\) levels of sulphur, respectively. Thus, the difference in yield resulting from S application was significant.

Sarmah and Debnath (1999) reported that sulphur fertilization significantly improved most of the yield attributes as well as seed yield (20.1%) of toria as compared to no sulphur application. Increasing levels of S increased the yield attributes viz., siliqua per plant, test weight, seed weight per plant as well as seed and stover yield. The increase in seed yield of toria due to application of 20 kg S ha\(^{-1}\) over control was 141.3 kg ha\(^{-1}\) (16.9%). The rate of increase in yield was very low due to further increase of sulphur levels beyond 20 kg S ha\(^{-1}\). The increase in seed yield due to sulphur fertilization @ 20, 40 and 60 kg ha\(^{-1}\) over control were 2.3 (25.4%), 3.0 (33.2%) and 3.3 q ha\(^{-1}\) (36.3%), respectively. The results conformed to the findings of Mahapatra and Chandra (1992).

Jat *et al.* (2003) conducted a field experiment on loamy sand soil at Jobner (Rajasthan) during year of 1999-2000. They reported that an increase in yield attributes and stover yield of Indian mustard with increasing level of sulphur up to 90 kg ha\(^{-1}\).
Piri and Sharma (2006) reported that seed and straw yield increased significantly with increasing level of sulphur up to highest level of 45 kg S ha$^{-1}$. Application of 15, 30 and 45 kg S ha$^{-1}$ increased the seed yield over the control by 9, 16 and 23%, respectively. Yield attributes like as seeds per siliqua (12.33), 1000-seed weight (4.45 g) of Indian mustard increased significantly with increasing doses of sulphur up to 45 kg ha$^{-1}$. However, the difference between 0 and 15 kg S ha$^{-1}$ for siliqua per plant and 1000-seed weight and between 15 and 30 kg S ha$^{-1}$ for seeds per siliqua and 1000-seed weight were not significant.

Malviya et al. (2007) conducted a field experiment at Faizabad (Uttar Pradesh) during the year of 2002-03. They noticed that application of 60 kg S ha$^{-1}$ showed slight improvement in production of siliquae per plant (336.78), number of seeds per siliqua (12.56), 1000-seed weight (5.03 g) and seed yield (16.78 q ha$^{-1}$) of mustard over those of 30 kg S ha$^{-1}$ but the differences were not significant.

Kumar and Yadav (2007) conducted field experiment at Faizabad (U. P) during the year of 2004-05. They reported that a significant response of crop was observed up to 30 kg S ha$^{-1}$ in seed and stover yield. Number of siliquae per plant significantly increased up to 30 kg S ha$^{-1}$. The highest number of siliquae (334.2 per plant) was recorded with 45 kg S ha$^{-1}$. The highest number of seeds per siliqua (13.43) was recorded at 45 kg S ha$^{-1}$, which was onpar with that of 30 kg S ha$^{-1}$ and was significantly superior over the control and 15 kg S ha$^{-1}$. The maximum test weight (4.63 g) was recorded with 45 kg S ha$^{-1}$. The seed and stover yields were significantly influenced by different sulphur levels. The highest seed yield and stover yield were recorded at 45 kg S ha$^{-1}$, which were on par with those of 30 kg S ha$^{-1}$ and these were significantly superior to the control. The increase in the seed yield due to application of 15, 30 and 45 kg S ha$^{-1}$ over control was 21, 42 and 48%, respectively.

Sarangthem et al. (2008) also confirmed that the seed yield of mustard significantly increased from 9.5 to 10.9 q ha$^{-1}$ with the increase in level of sulphur from 0 to 40 kg ha$^{-1}$.

Ceh et al. (2008) reported that application of 40 and 60 kg S ha$^{-1}$ gave significantly higher yield of mustard over 20 kg S ha$^{-1}$ and no S application. Khatkar et al. (2009) reported that more number of siliquae per plant (383.67), number of seed per siliqua (20) and the test weight (5.10 g) was also recorded higher with higher levels of sulphur fertilization which ultimately resulted in higher seed yield. Mustard
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crop produces more seed yield with S as compared to without S (Chand and Gautam, 2009).

Makeen et al. (2008) reported that number of siliquae per plant, number of seeds per siliqua, weight of 1000 seeds, seed yield and harvest index of mustard were significantly influenced by application of sulphur in mustard. Application of sulphur @ 60 kg ha⁻¹ recorded the highest values with respect to these parameters. The seed yield up to 25.5 q ha⁻¹ was obtained at 60 kg S ha⁻¹ as compared to 11.1 q ha⁻¹ in control. These results are in agreement with the findings of Raut et al. (2000), Sharma (1994) and Sarma and Dehnath (1999). Harvest index increased significantly and the highest was observed at 60 kg S ha⁻¹.

Zizale et al. (2008) conducted field experiment on loamy sand soil of Anand (Gujarat) during the year 2003-04. They used “GM-2” variety of mustard for sowing. Result revealed that there was significant difference in seed and stover yield of mustard under different levels of S. The seed yield was significantly increased under all levels of sulphur over control. The S₄₅ (18.98 q ha⁻¹) was at par with S₃₀ (18.12 q ha⁻¹), produced significantly higher seed yield than S₁₅ and control S₀, the maximum stover yield was registered under S₄₅ (39.20 q ha⁻¹).

Singh et al. (2009) reported that the yield attributes of mustard like as number of siliquae per plant (393.00), number of seeds per siliqua (12.87) and test weight (4.96 g) of seeds responded positively to sulphur application. Increase in the yield attributes as well as maximum seed yield (17.45 q ha⁻¹), biological yield (54.78 q ha⁻¹) and harvest index (31.85%) was noticed with 60 kg S ha⁻¹.

Kapur et al. (2010) noticed that number of siliquae per plant, number of seeds per siliqua and test weight of mustard were recorded significantly higher with 60 kg S ha⁻¹ but it was at par with 45 and 30 kg S ha⁻¹. The significantly higher seed yield was recorded with sulphur @ 60 kg ha⁻¹ and higher stover yield was recorded with 45 kg S ha⁻¹ which was at par with 60 kg and 30 kg S ha⁻¹. The increase in seed yield under S levels at 60, 45, 30 and 15 kg ha⁻¹ was 45.0, 44.9, 41.0 and 23.0%, respectively over control.

Parmar et al. (2010) conducted a field experiment at Dantiwada (Gujarat) during the year of 2007-08. They reported that significantly the highest test weight (4.89 g), seed (17.22 q ha⁻¹) and stover yield (35.05 q ha⁻¹) of mustard was recorded.
with 45 kg S ha\(^{-1}\). However, the control and 15 kg S ha\(^{-1}\) were found at par with each other.

A field experiment entitled effect of different levels of sulphur and biofertilizer on the yield of Indian mustard was conducted by Yadav et al. (2010) at Allahabad (Uttar Pradesh) during the *rabi* season of 2002-03. They reported significantly the higher seed yield (19.33 q ha\(^{-1}\)) under sulphur application @ 40 kg ha\(^{-1}\) as compared to other levels of sulphur *viz.*, 0, 20 and 60 kg ha\(^{-1}\).

Chattopaddhyay and Ghosh (2012) reported that the increase in seed yield was significant in S treated plots over control but higher S level i.e. 60 kg S ha\(^{-1}\) failed to register higher yield over 45 kg S ha\(^{-1}\). Seed yield of mustard increased significantly with increased levels of S up to 45 kg S ha\(^{-1}\), above which decreasing trend was observed.

Jat et al. (2012) reported that all the yield attributes and yield like as siliquae per plant (374.30), seeds per siliqua (17.88) and test weight (6.01 g) seed yield (22.54 q ha\(^{-1}\)) and stover yield (63.82 q ha\(^{-1}\)) increased significantly with increasing rates of sulphur up to 60 kg ha\(^{-1}\).

Baudh and Prasad (2012) conducted a field experiment at Azamgadh (Uttar Pradesh). They noticed that productivity of mustard increased with increasing level of Sulphur. Application of 60 kg S ha\(^{-1}\) recorded significantly higher attributes like as biomass production (13.90 gm per plant) and number of siliquae per plant (645) and test weight of seed (10.78 g) and seed yield (16.30 q ha\(^{-1}\)) than 20 to 40 kg S ha\(^{-1}\).

Pachauri et al. (2012) reported that seed yield of mustard recorded at 90 kg S ha\(^{-1}\) was higher by 30.6, 21.1 and 3.7% over 0, 30 and 60 kg S ha\(^{-1}\), respectively. The seed yield of mustard significantly increased up to 60 kg S ha\(^{-1}\), however, the stover yield of mustard increased significantly up to 90 kg S ha\(^{-1}\). The number of siliquae per plant significantly increased up to 60 kg S ha\(^{-1}\). The highest number of seeds per siliqua was recorded at 90 kg S ha\(^{-1}\), which was at par with 60 kg S ha\(^{-1}\) and this was significantly superior over control and 30 kg S ha\(^{-1}\).

Kumar and Trivedi (2012) reported that seed and stover yields of mustard increased significantly with increasing level of sulphur up to 60 kg S ha\(^{-1}\). Application of 20, 40 and 60 kg S ha\(^{-1}\) increased the seed yield over the control by 13.9, 28.1 and 28.4%, respectively.
Sah et al. (2013) conducted an investigation on growth and yield of Indian mustard \( (Brassica \text{juncea} \ (L.) \ czern \ & \ coss) \) with different weed control measures and sulphur levels at Aligadh (Uttar Pradesh) during the year 2004-05. They showed that application of sulphur @ 45 kg ha\(^{-1}\) increased number of siliquae per plant (341.77), test weight (5.14 g), seed (19.23 q ha\(^{-1}\)) and stover yield (36.30 q ha\(^{-1}\)).

Arun Babu (2014) reported that sulphur @ 60 kg ha\(^{-1}\) significantly increased various yield attributes of safflower like as number of capitulum per plant (21.5), number of seeds per capitulum (22.2), weight of capitulum per plant (37.6 g), test weight (5.25 g), seed yield per plant (19.2 g), seed (1561 kg ha\(^{-1}\)) and stalk yield (3683 kg ha\(^{-1}\)) as compared to other levels of sulphur application used in experiment (0, 20 and 40 kg S ha\(^{-1}\)).

Neha et al. (2014) conducted a field experiment at Udaipur (Rajasthan) during the year 2011. They reported that application of 40 kg S ha\(^{-1}\) recorded significantly higher seed (19.6 q ha\(^{-1}\)) and stover (70.9 q ha\(^{-1}\)) yield of mustard over 20 kg S ha\(^{-1}\) and no Sulphur. Application of 40 kg S ha\(^{-1}\) gave significantly higher seed and stover yield by registering 12.9 and 13.5% higher over no sulphur. Further, increase in sulphur levels up to 60 kg S ha\(^{-1}\) remained at par with above level.

Kumar (2015) reported that application of sulphur @ 40 kg ha\(^{-1}\) registered significantly higher number of siliquae per plant (322.1), length of siliqua (5.3 cm), number of seeds per siliqua (13.6), test weight (4.43 g), seed yield (16.9 q ha\(^{-1}\)) and stover yield (42.3 q ha\(^{-1}\)) of mustard and found statistically at par with application of sulphur @ 60 kg ha\(^{-1}\).

Kumar (2015) noticed that application of sulphur @ 60 kg ha\(^{-1}\) showed their significant superiority in various yield attributing characters and yield of mustard like as number of siliquae per plant (553.1), number of seeds per siliqua (15.12), test weight (4.09 g), seed yield (1583 kg ha\(^{-1}\)) and stover yield (6105 kg ha\(^{-1}\)) and found statistically at par with application of sulphur @ 40 kg ha\(^{-1}\).

Singh and Thenua (2016) concluded that application of sulphur @ 40 kg ha\(^{-1}\) proved their significant effect on number of siliquae per plant (232.14), number of seeds per siliqua (11.44), test weight (4.28 g), biological yield (37.22 q ha\(^{-1}\)) and seed yield (10.31 q ha\(^{-1}\)) of mustard as compared to other levels of sulphur.
2.2.3 Quality parameters

Davaria (1998) concluded that different levels of sulphur fertilization i.e. (0, 25, 50, 100 kg ha\(^{-1}\)) could not impart their significant effect on protein content, oil content, oleic acid, linoleic acid content in oil of mustard. While significantly higher oil yield (5.45 q ha\(^{-1}\)) were recorded under application of 100 kg S ha\(^{-1}\).

Singh et al. (2005) conducted a field experiment at Bichpuri (U.P) during the year of 2002. They observed that the oil content in mustard seed increased significantly by 6.3% with 60 kg S ha\(^{-1}\) over no sulphur application. Piri and Sharma (2006) reported that oil content of mustard increased significantly with increasing level of sulphur up to highest 45 kg ha\(^{-1}\). Application of 15, 30 and 45 kg S ha\(^{-1}\) increased the oil content by 13, 22 and 33%, respectively.

Singh and Singh (2007) reported that each successive increase in the level of sulphur up to 60 kg ha\(^{-1}\) significantly increased the oil content of the linseed by 36.7% over control.

Malviya et al. (2007) found that sulphur applied at the rate of 60 kg S ha\(^{-1}\) produced significantly higher oil (41.20%) and protein content (20.02%) of mustard over than 30 kg S ha\(^{-1}\).

Kumar and Yadav (2007) showed that the increase in oil content due to application of 30, 60 and 90 kg S ha\(^{-1}\) over control was 4.5, 9.6 and 11.3%, respectively in mustard.

Zizale et al. (2008) reported that the oil content of mustard increased with increasing level (0 to 45 kg) of S but increase was non-significant.

Kumar and Trivedi (2012) noted that the oil content of mustard increased significantly with increasing level of sulphur. Application of 60 kg S ha\(^{-1}\) increased the oil content by 7.8, 4.8 and 3.9% over 0, 20 and 40 kg S ha\(^{-1}\), respectively. While protein content in seed was also found maximum at 60 kg S ha\(^{-1}\) (22.43%).

Sah et al. (2013) showed that the application of sulphur @ 45 kg ha\(^{-1}\) significantly increased the oil content (40.05%) of mustard as compared to other levels of sulphur application.

Neha et al. (2014) indicated that an application of 40 kg S ha\(^{-1}\) significantly enhanced the oil content by 5.0 and 8.7% in comparison to 20 kg S ha\(^{-1}\) and no sulphur.
Arun Babu (2014) noted that the oil content, oil yield and protein content of safflower increased significantly with increasing levels of sulphur. Application of 60 kg S ha\(^{-1}\) recorded significantly higher oil content (32.6%), oil yield (510.7 kg ha\(^{-1}\)) and protein content (15.8%).

Kumar (2015) recorded significantly higher oil content (42.4%) of mustard seed under the application of sulphur @ 60 kg ha\(^{-1}\).

Kumar (2015) reported that significantly higher oil content (39.40%), oil yield (625 kg ha\(^{-1}\)), protein content (26.90%) and protein yield (426 kg ha\(^{-1}\)) of mustard could be obtained when sulphur was applied @ 60 kg ha\(^{-1}\). The minimum value of above mentioned quality parameter was recorded under control treatment.

Singh and Thenua (2016) showed that application of sulphur @ 40 kg ha\(^{-1}\) significantly enhanced the oil content of mustard (39.04%) and remain statistically at par with 20 kg S ha\(^{-1}\) (39.00%).

**2.2.4 Nutrient content and uptake by plant**

Davaria (1998) reported that increasing application of sulphur at 100 kg ha\(^{-1}\) in mustard significantly increased the N content (0.400%), sulphur content (0.720%) in stover and also total N uptake (60.49 kg ha\(^{-1}\)), total P uptake (15.95 kg ha\(^{-1}\)) and total S uptake (43.62 kg ha\(^{-1}\)) and remain statistically at par with 50 kg S ha\(^{-1}\).

Chaubey and Dwivedi (1995) reported that the maximum sulphur content in mustard plant was observed at early stages of growth and it decreased gradually with the advancement of crop growth stages. The results showed that the total uptake of S (13.4 to 21.1 kg ha\(^{-1}\)) increased significantly and linearly with increasing S levels from 0 to 60 kg ha\(^{-1}\).

Lanjewar *et al.* (2005) conducted a field experiment at Nagpur (Maharashtra) during the year 2001-02. They found that increasing application of sulphur in mustard significantly increased the nutrient uptake and content of S up to 60 kg S ha\(^{-1}\). However, 60 kg S ha\(^{-1}\) was better than 20 kg S ha\(^{-1}\) in these respects. Thus, 60 kg S followed by 40 kg S ha\(^{-1}\) appeared to be appropriate dose to increase the uptake. N, P and K content and uptake also increased with increased in levels of sulphur. Application of sulphur @ 60 kg ha\(^{-1}\) recorded significantly higher uptake of N (78.20 kg ha\(^{-1}\)), P (21.24 kg ha\(^{-1}\)) and K (40.85 kg ha\(^{-1}\)) by mustard.

Piri and Sharma (2006) showed that 30 kg S ha\(^{-1}\), being at par with 15 kg S ha\(^{-1}\), significantly increased sulphur content in seed (0.32%) over no sulphur, whereas
sulphur content increased with increasing dose of sulphur up to 30 kg S ha\(^{-1}\). Further increase in the dose of sulphur from 30 to 45 kg S ha\(^{-1}\) did not increase sulphur content in seed.

Singh and Singh (2007) noted that the sulphur content in seed of linseed increased significantly with increasing levels of S up to 60 kg ha\(^{-1}\). Application of S increased sulphur content in seeds from 0.40% in control to 0.49% with 60 kg S ha\(^{-1}\).

Kumar and Yadav (2007) reported that uptake of S increased with increase in the level of S. Further increase in the dose of S did not result in significant increase in S uptake by the crop. However, the differences were significant only up to 30 kg S ha\(^{-1}\). Application of S also resulted in significant increase in the S uptake over the control only. Its application at 45 kg S ha\(^{-1}\) also showed significant S uptake over 15 kg S ha\(^{-1}\). P uptake also increased with the increased in sulphur application. Sulphur application @ 30 kg ha\(^{-1}\) and remain statistically at par with control and 15 kg S ha\(^{-1}\).

Zizale et al. (2008) concluded that total uptake of S increased significantly with increase in dose of S up to 45 kg ha\(^{-1}\). The per cent increase in total S uptake by mustard was 11.2 and 66.0 over control with application of sulphur at 30 and 45 kg S ha\(^{-1}\), respectively. The maximum S uptake (34.5 kg ha\(^{-1}\)) was recorded with 45 kg S ha\(^{-1}\). The highest S content in seed was recorded at 45 kg S ha\(^{-1}\), which was significantly higher over rest of the treatments. The similar trend was found for S content of stover.

Chattopaddhyay and Ghosh (2012) reported that S content in seed (0.94%) and stover (0.35%) of rapeseed increased significantly with increasing S levels up to 60 kg S ha\(^{-1}\), irrespective of sources of S. Results indicated that the crop responded to S application since soil was deficient in available S. Total S uptake continued to increase with the increase in levels of S irrespective of its source.

Kumar and Trivedi (2012) reported that application of S at the dose of 20, 40 and 60 kg ha\(^{-1}\) led to an increase in sulphur uptake of 33.5, 68.7 and 95.0% over control respectively. They also found that application of S @ 60 kg ha\(^{-1}\) significantly increase the total uptake of N (80.25 kg ha\(^{-1}\)), P (22.54 kg ha\(^{-1}\)) and K (70.54 kg ha\(^{-1}\)) by mustard.

Pachauri et al. (2012) concluded that the increasing levels of sulphur significantly increased the uptake of S. The maximum uptake of 27.4 S kg ha\(^{-1}\) was recorded with 90 kg S ha\(^{-1}\), which was significantly superior to all other sulphur
treatments. Significantly higher uptake of N (62.21 kg ha$^{-1}$), P (24.21 kg ha$^{-1}$) and K (51.24 kg ha$^{-1}$) also recorded under application sulphur @ 90 kg ha$^{-1}$. However the minimum uptake of N (49.54 kg ha$^{-1}$), P (16.87 kg ha$^{-1}$), K (39.87 kg ha$^{-1}$) and S (11.2 kg ha$^{-1}$) was recorded under control treatment.

Arun Babu (2014) concluded that the increasing levels of sulphur significantly increased the total uptake of N, P, K and S by safflower. Application of 60 kg S ha$^{-1}$ recorded significantly higher total uptake of N (53.73 kg ha$^{-1}$), P (21.35 kg ha$^{-1}$), K (78.63 kg ha$^{-1}$) and S (28.27 kg ha$^{-1}$).

Neha et al. (2014) noticed that application of 60 kg S ha$^{-1}$ improved concentration of sulphur in seed and stover. Similarly, application of 40 kg S ha$^{-1}$ recorded 13.6 and 38.2% of S over 20 kg S ha$^{-1}$ and no sulphur, respectively. However, the further increase in sulphur level was statistically at par with this level. The results are in close conformity with findings of Abraham (2001).

Sisodiya (2014) reported that significantly highest concentration of macro nutrient (N, P, K and S) and micro nutrient (Fe and Zn) content in plant were observed with the application of sulphur @ 20 ppm. Significantly higher uptake of (N (446.18 mg per plant), P (43.29 mg per plant), K (213.79 mg per plant), S (79.35 mg per plant), Ca (504.66 mg per plant), Mg (218.67 mg per plant), Fe (14.93 mg per plant), Mn (4.13 mg per plant) and Cu (1.273 mg per plant) was recorded at 20 ppm sulphur application in groundnut.

Kumar (2015) showed that increasing levels of sulphur significantly increased the uptake of sulphur by mustard. The maximum uptake (31.53 kg ha$^{-1}$) of sulphur was recorded under the application of sulphur @ 60 kg ha$^{-1}$.

Kumar (2015) concluded that application of sulphur @ 60 kg ha$^{-1}$ recorded significantly higher content of N, P and S content in seed and stover and also total uptake of N (115.23 kg ha$^{-1}$), P (29.76 kg ha$^{-1}$) and S (37.81 kg ha$^{-1}$) by mustard.

Singh and Thenua (2016) reported that application of sulphur @ 40 kg ha$^{-1}$ recorded significantly higher total uptake of N (39.34 kg ha$^{-1}$), total uptake of P (10.67 kg ha$^{-1}$) and total uptake of S (17.73 kg ha$^{-1}$) by mustard as compared to other levels of sulphur application used in investigation viz., 0 and 20 kg S ha$^{-1}$. 

Review of literature
2.2.5 Soil analysis after harvest of the crop

Davaria (1998) showed increase in available phosphorus (35.82 kg ha\(^{-1}\)) and sulphur (16.79 ppm) after harvest of mustard by application of sulphur @ 100 kg ha\(^{-1}\) as compared to initial status of soil i.e. initial P\(_2\)O\(_5\) (33.20 kg ha\(^{-1}\)) and sulphur (9.90 ppm).

Balanagoudar et al. (1999) concluded that available S in the soil after harvest of greengram was affected significantly due to sulphur levels. Plots fertilized with 40 kg S ha\(^{-1}\) had significantly highest S content over 20 kg S ha\(^{-1}\) and no sulphur by 9.8 and 11.4%, respectively. Increase in the sulphur content assured the availability of these nutrients in adequate amount and remained in soil in substantial quantity after fulfilling the crop requirement that ultimately improved soil fertility status.

Yadav et al. (2010) reported that the slight decrease in pH and EC and increase in organic carbon, available nitrogen, phosphorus, potassium and sulphur after harvest of mustard was recorded by application of sulphur @ 40 kg ha\(^{-1}\).

Arun Babu (2014) founded that 60 kg S ha\(^{-1}\) recorded significantly higher value of available N (232.89 kg ha\(^{-1}\)) and S (25.76 kg ha\(^{-1}\)) in soil.

Sisodiya (2014) concluded that control treatment (0 ppm sulphur) recorded significantly higher value of available N (89.75 ppm), P (16.71 ppm), K (126.31 ppm) while significantly higher content of S (13.61 ppm) was recorded with application of 20 ppm sulphur after harvest of the groundnut.

Kumar (2015) showed that different levels of sulphur impart their significant effect on available N, P and K content in soil after harvest of the mustard. Application of 40 kg S ha\(^{-1}\) recorded significantly higher N (237.86 kg ha\(^{-1}\)), P (28.13 kg ha\(^{-1}\)) and K (169.97 kg ha\(^{-1}\)) while significantly higher S content in soil found at 60 kg S ha\(^{-1}\) (11.80 ppm) over initial nutrient status of soil (227.2, 24.27 and 162.1 kg NPK ha\(^{-1}\) and 10.31 ppm S).

2.3 Combine effect of sources and levels of sulphur

Patel (1982) obtained maximum yield of mustard due to application of 36 kg S ha\(^{-1}\) on a sandy loam soil of Anand. The seed and stover yields of mustard increased significantly when sulphur was applied through ammonium sulphate as compared to the other sources of sulphur. Relative efficacy of different sources of sulphur in producing seed yield of mustard was ammonium sulphate (100%) > gypsum (97.3%) > SSP (97.1%) > pyrite (91.8%), respectively.
Rao and Shaktawat (2002) concluded that gypsum application @ 250 kg ha\(^{-1}\) reflected in significant improvement in attributes like as plant height (40.75 cm), number of leaf per plant (61.00) and seed yield (25.42 q ha\(^{-1}\)) of groundnut.

Ceh et al. (2008) reported that gypsum @ 50 kg ha\(^{-1}\) gives better result in case of seed yield and oil yield of oilseed rape as compared to K\(_2\)SO\(_4\) fertilization. While protein yield was higher in case of K\(_2\)SO\(_4\) @ 50 kg ha\(^{-1}\).

Mustard crop produces higher plant height (Kashved et al., 2010) and primary branches per plant (Piri et al., 2011) as compared to the crop grown without S. The source of sulphur (elemental sulphur, bentonite S and cosavet) did not influence the growth parameters of Indian mustard (Brassica juncea L.) as reported by Kumar et al. (2011).

Rao et al. (2013) stated that sulphur application significantly influenced the yield attributing characters and yield over control of groundnut. Application of sulphur @ 45 kg ha\(^{-1}\) through gypsum recorded highest number of filled pods per plant, 100 pod weight, 100 kernel weight, pod yield, haulm yield of the kernels. Application of gypsum at 45 kg ha\(^{-1}\) has increased the pod yield to the tune of 52.2%.

Jaga (2013) found that application of phosphogypsum @ 60 kg ha\(^{-1}\) found superior in case of seed yield (17 q ha\(^{-1}\)), stover yield (42.4 q ha\(^{-1}\)), oil content (40.5 kg ha\(^{-1}\)), S content in seed & stover of mustard as compared to other levels of sulphur application.

Katiyar et al. (2014) reported that application of 90 % DP sulphur @ 25 kg ha\(^{-1}\) basal had significant influence on yield attributes and seed yield of mustard. Maximum value of seeds per pod, 1000 seed weight and seed yield were recorded with dual application as basal along with 80% WP @ 1.25 kg ha\(^{-1}\) foliar spray at 75 DAS.

Sisodiya (2014) concluded that significant interaction effect of sources and levels of sulphur was observed in case of pod yield, dry matter at 30 and 60 days, nutrient content and uptake of groundnut crop.

Kumar (2015) concluded that Bentonite S application @ 60 kg ha\(^{-1}\) found superior in case of growth parameters like as plant height at 60 DAS (142.3 cm), dry matter production per plant at harvest (85.0 g), yield attributing character like as number of seeds per siliqua (14.6) and seed yield (17.3 q ha\(^{-1}\)) of mustard.
2.4 Economics

2.4.1 Effect of source of S on economics

Kumar and Trivedi (2012) reported that ammonium sulphate produced maximum net return (₹ 23,469 ha\(^{-1}\)) and benefit: cost ratio (3.58) followed by gypsum, single super phosphate and pyrite, respectively in mustard crop. Despite highest cost of cultivation of mustard due to use of ammonium sulphate as compared with any sources of S, it fetched net profit when applied equivalent to 40 kg S ha\(^{-1}\). Among different sources of fertilizers, ammonium sulphate was found most economical, followed by SSP, gypsum and pyrite, respectively. Application of 40 kg S ha\(^{-1}\) through ammonium sulphate is better for improving the profitability of mustard.

Kumar (2015) showed that elemental sulphur produced maximum net return (₹ 36873 ha\(^{-1}\)) and B:C ratio (1.51) as compared to bentonite sulphur in mustard crop.

Kumar (2015) reported that Bentonite sulphur produced maximum net return (₹ 30518 ha\(^{-1}\)) and B:C ratio (1.71) in mustard as compared to other sources of sulphur used in experiment viz., gypsum and iron pyrite.

2.4.2 Effect of levels of S on economics

Davaria (1998) found that maximum net return (₹ 8874 ha\(^{-1}\)) and B:C ratio (3.18) was recorded with 100 kg S ha\(^{-1}\) in mustard.

Singh and Singh (2007) stated that net returns increased with the increase in S dose up to 60 kg ha\(^{-1}\) and this dose resulted in the highest net returns of linseed. The benefit: cost ratio in sulphur fertilizer was 1.75, 1.84 and 1.96 due to application of 20, 40 and 60 kg S ha\(^{-1}\), respectively.

Malviya et al. (2007) found that sulphur application at 60 kg S ha\(^{-1}\) was found remunerative by ₹ 483 ha\(^{-1}\) over 30 kg S ha\(^{-1}\) in mustard.

Kumar and Yadav (2007) showed that highest net return of ₹ 13,734 ha\(^{-1}\) was recorded with 45 kg S ha\(^{-1}\) in mustard. However, B:C ratio was highest (1.18) at 30 kg S ha\(^{-1}\). Net returns were also higher with increasing S levels.

Kumar and Trivedi (2012) reported that the highest net return (₹ 25,098 ha\(^{-1}\)) and B:C ratio (3.73) was recorded at 40 kg S ha\(^{-1}\) application. This may be because of the difference in yield between 40 and 60 kg S ha\(^{-1}\) was at par and cost of cultivation was lesser with 40 kg S ha\(^{-1}\).
Pachauri *et al.* (2012) reported that the highest net return of Rs 42,018 was recorded with the application of 90 kg S ha\(^{-1}\). However, B:C ratio of 4.34 was higher at 60 kg S ha\(^{-1}\). Whereas 90 kg S ha\(^{-1}\) gave B:C ratio of 4.25 followed by 4.06 (30 kg S ha\(^{-1}\)) and 4.04 (control).

Sah *et al.* (2013) reported that application of 45 kg S ha\(^{-1}\) gave maximum net return (Rs 25599 ha\(^{-1}\)) which was followed by 30 kg S ha\(^{-1}\) (23365 ha\(^{-1}\)) and 15 kg S ha\(^{-1}\) (Rs 19221 ha\(^{-1}\)) and gave highest B:C ratio of 3.89.

Kumar (2015) found that sulphur application @ 40 kg ha\(^{-1}\) produced maximum net return (Rs 35630 ha\(^{-1}\)) with highest B:C ratio (2.6).

Kumar (2015) concluded that application of sulphur @ 30 kg ha\(^{-1}\) in mustard produced maximum net return (Rs 34139 ha\(^{-1}\)) and B:C ratio (1.40).