Effect of irrigation regimes on growth, yield attributes and productivity of mustard
Since, mustard is predominantly a winter crop cultivated on residual moisture of south west monsoon with limited or no additional irrigation which restricts its yield to below potential; hence, proper irrigation scheduling could play a major role in enhancing growth of mustard. More favorable irrigation regimes maintained under regular watering results in higher soil moisture content in rhizosphere promoting cellular activity of enlargement, expansion and multiplication with synergistic impact on leaf water potential, stomatal conductance and photosynthetic activity. These conditions in conjunction enhances uptake, translocation and assimilation of nutrients facilitating increased plant height, higher leaves and branches plant⁻¹, leaf area index and dry matter accumulation. These beneficial effects of irrigation on growth parameters are also supported by following study:

In a study conducted by Yadav (2005) in arid area of Bikaner, irrigation was observed to improve growth characters and application of irrigation at three stages of crop growth viz., branching, flowering and pod filling recorded higher plant height, dry matter accumulation...
Plant, chlorophyll content, number of primary and secondary branches plant$^{-1}$. Ghanbahadur and Lanjewar (2006) observed higher number of siliquae plant$^{-1}$, pod length, number of seeds pod$^{-1}$ and test weight with irrigation at 0.6 IW: CPE than at 0.4 IW: CPE resulting in increment of seed, stover and biological yield over 0.4 IW: CPE ratio.

Piri and Sharma (2006) when made an assessment of effect of different irrigation regimes in north western plains vouched for the fact that increasing the frequency of irrigation from 0 to 2 and applying them at 30 and 60 DAS culminated in significantly better performance of mustard with respect to plant height, dry matter accumulation, secondary branches plant$^{-1}$ and relative growth rate.

Meena (2011) noted improvement in total number of siliquae plant$^{-1}$, length of siliqua, number of seeds siliqua$^{-1}$, test weight and seed yield with increasing IW/CPE ratio and maximum values of these parameters were recorded under 0.8 IW/CPE ratio. Parmar et al. (2016) studied the yield attributing traits such as number of siliquae plant$^{-1}$, number of seeds siliqua$^{-1}$ and 1000-seed weight as affected by irrigation regimes and found considerable increase in them with increase in IW: CPE ratio from 0.60 to 1.0.

Jat et al. (2018) and Rathore et al. (2019) in separate field experiments evaluated the effect of differential irrigation regimes and confirmed about the significant positive impact of irrigation on agronomic traits such as plant height, dry matter plant$^{-1}$, number of primary and secondary branches plant$^{-1}$.

Effect of irrigation regimes on quality and nutrient uptake
At Jobner, in a field study by Kumawat (2004), application of three irrigations at branching, flowering and siliqua development stages significantly increased N, P and K concentrations in seed and stover as well as their uptake in comparison to less frequent irrigation.

Similar effect of irrigation regimes was also noticed by Ghanbahadur and Lanjewar (2006) who observed significantly higher uptake of both N and P in 0.6 IW: CPE ratio as compared to 0.4 IW: CPE. Three irrigation given to mustard crop at branching, flowering and siliqua development stages recorded marked improvement in quality of seed and showed higher content of oil and protein in a study by Nagdive et al. (2007). Meena (2010) observed that with application of three irrigations at branch initiation, 50% flowering and 50% pod development stages, significantly higher values of nitrogen content in seed and stover as well as nitrogen uptake by respective parts were noticed. Similar results were also reported by Meena (2011) but irrigation regimes were based on IW/CPE ratio.

Ray et al. (2015) in a study observed increase in glucosinolate with increasing irrigation levels and concluded that double irrigation recorded highest values of sinigrin, gluconapin and progoitrin along with maximum values for fatty acid thus bringing qualitative changes in mustard seed. Successive increment in oil content was noticed by Singh et al. (2018) with increasing IW/CPE ratio from 0.2 to 0.4.

Effect of irrigation regimes on profitability
Enhanced growth and yield obtained under well irrigated condition ultimately results in higher profitability. In continuance to this, Mehta (2004) reported increment in net returns and benefit-cost ratio with increase in number of irrigations from 0-3 and found that mustard irrigated thrice at different stages gave highest net returns and B: C ratio in comparison to preceding levels of irrigation. While, Karoria (2008) concluded that two irrigations provided at flowering and siliqua development stage result in maximum net returns and benefit cost ratio followed by crop with single irrigation at flowering stage.

Similarly in an experiment by Piri et al. (2011) increase in irrigation frequency from nil to two reported to increase gross returns, net returns and B: C ratio and two irrigations gave highest net return and B: C ratio over one irrigation and no irrigation.

Parmar et al. (2016) concluded that application of irrigation at higher IW/CPE ratio gave higher net returns in comparison to less frequent irrigation associated with lower IW/CPE ratio. Similar treatment also provided better production efficiency, profitability and relative economic efficiency. In another study, increase in number of irrigation in mustard brings increment in the cost of cultivation, gross and net income along with benefit: cost ratio and higher values were observed with application of irrigation thrice at 0-35 DAS, flowering and siliqua development (Shivran et al., 2018).

Effect of improved cultivars on growth, yield attributes and productivity
Improved cultivars and hybrids offers better genetic makeup, ensures uniform germination and emergence maintaining optimum plant stand, higher survival under temperature stress during vegetative phase, resistance to major pests and diseases and efficient translocation and assimilation of assimilates which ultimately results in improved growth, yield contributing characters and productivity of mustard as also supported by following:

Ghanbahadur (2002) found superior performance of ‘Pusa Bold’ over other varieties with respect to plant height, number of leaves, leaf area and LAI. Goyal et al. (2006) recorded highest seed yield with variety Varuna followed by Kranti. Singh et al. (2007) in Kanpur concluded that ‘Varuna’ proved superior over ‘Rohini’, ‘Kranti’ and ‘Urvashi’ for plant height, dry matter m$^{-2}$, row length and number of primary branches plant$^{-1}$ and this superior performance in growth manifested in higher seed yield of ‘Varuna’ over remaining varieties.

Scrutiny of observations by Kumari (2009) revealed significantly higher plant height, dry matter, number of primary and secondary branches plant$^{-1}$ at all growth stages with mustard hybrid ‘DMH-1’. Similar superiority of hybrid ‘DMH-1 was also exhibited in form of higher siliqua plant$^{-1}$, test weight, seed weight plant$^{-1}$ and seed yield. Singh et al. (2010) concluded that ‘NRCHB-101’ with higher siliqua plant$^{-1}$, seeds siliqua$^{-1}$ and test weight was proved significantly superior to ‘Varuna’, ‘Kranti’ and ‘Vardan’. Similar trend was also observed in seed and stover yield which is dependent on said yield attributes.

Pachauri et al. (2012) observed that ‘Pusa Bold’ with maximum number of siliquae plant$^{-1}$, number of seeds siliqua$^{-1}$ and siliqua length produced maximum seed yield followed by ‘Varuna’, ‘Rohini’ and ‘Kranti’. Similarly, Meena et al. (2013) also reported varietal effect on growth parameters and ‘DMH 1’ outperformed ‘NRCHB-506’, ‘PAC-37’ and ‘Kranti’.

Scrutiny of data recorded by Kumar et al. (2018) revealed distinguished effect of varieties on growth and yield attributes. However, varietal influence was observed to be non-significant with respect to harvest index.
Effect of improved cultivars on quality and nutrient uptake
Kumar et al. (2004) found superior quality of variety ‘RB9901’ over ‘RH 30’ and ‘Laxmi’ for oil yield and oil content. In another study, Kumar and Yadav (2007) reported ‘Varuna’ superior to ‘NDR 8501’ in terms of oil content. Kumari (2009) [15] noted that hybrid ‘DMH-1’ recorded higher oil and protein yield over other varieties. Similarly, Patel et al. (2009) [29] noticed marked difference in oil and protein content of variety and higher values for these characters were observed in ‘GM-1’ as compared to remaining variety. Archana and Singh (2011) [40] concluded that the hybrid ‘DMH-1’ was found superior with higher N, P and K uptake by both seed and stover at harvest as compared to ‘NRCHB-506’ and ‘Kranti’. Similarly, Pachauri and Trivedi (2012) [30] recorded significant variation in N, P and S removal because of varietal difference. Meena et al. (2013) [17] observed significant difference among varieties with respect to oil content and oil yield. In addition, hybrid ‘DMH-1’ outperformed ‘NRCHB-506’, ‘PAC-437’ and ‘Kranti’ for total N and P uptake due higher concentration of respective nutrients in seed and stover.

Varietal response for oil content and oil yield was studied by Kumar et al. (2018) [12] who observed higher values of the said parameters in ‘Giriraj’ among varieties. Further, total uptake of N, P and S was also noted higher in ‘Giriraj’ superior to ‘NRCHB-506’ and ‘Maya’.

Effect of improved cultivars on profitability
Difference in growth parameters and yield attributes produced due to varietal influence bring subsequent variation in economic returns associated with the cultivation of the variety. This result is well supported by Karoria (2008) [10] who found that variety ‘Pusa Bold’ fetched higher net return and benefit: cost ratio followed by ‘Laxmi’ and ‘Basundhara’. Similar varietal response for profitability was also studied by Patel et al. (2009) [29] who realized highest net returns and benefit: cost ratio with cultivation of ‘GM-3’ followed by ‘GM-1’ and ‘GM-2’.

Dashora (2013) observed that ‘NRCDR-2’ gave highest net returns and B: C ratio (3.74) and exhibited superiority over ‘Laxmi’, ‘NRCHB-101’ and ‘NPJ-112’ in economic terms. Similarly, Meena et al. (2013) [17] also noticed significant difference among mustard varieties and concluded that cultivation of hybrid ‘DMH-1’ was more beneficial with higher net profit and B: C ratio over other varieties.

Effect of sulphur on growth, yield attributes and productivity
Sulphur application reported to enhance cell metabolism which in turn promote meristematic activity resulting in improved growth characters such as plant height, foliage development, number of branches and dry matter accumulation. In addition, sulphur reduces soil pH which facilitate in greater nutrient availability and absorption by plants. Sulphur plays important role in oil and protein synthesis and hence, brings marked improvement in quality of seed. These functions of sulphur are well documented by the following:

Dongarkar et al. (2005) [3] found improvement in parameters like plant height, dry matter accumulation plant⁻¹, number of primary and secondary branches plant⁻¹ with application of sulphur at 40 kg ha⁻¹ lower or no dose of sulphur. Similar effect of sulphur on yield attributes was reported by Yogesh et al. (2009) [24] and Kapur et al. (2010) [9] who observed that higher level of sulphur (30 kg ha⁻¹) produced higher number of siliquae plant⁻¹, seeds siliqua⁻¹ and test weight leading to higher seed and stover yield as compared to restricted or no sulphur application.

Ray et al. (2014) [35] observed significant increment in different growth parameters (chlorophyll content, dry matter accumulation, number of primary and secondary branches plant⁻¹) with increasing in sulphur up to 40 kg ha⁻¹. In addition, application of sulphur also enhanced crop growth rate, relative growth rate and net assimilation rate.

Nath et al. (2018) [33] reported significant effect on plant height, leaf area index, dry matter accumulation plant⁻¹ and number of branches plant⁻¹ with increase in the levels of sulphur from 0-60 kg ha⁻¹. Further, Kumar et al. (2018) [12] and Rajput et al. (2018) [32] in separate field experiments revealed that different yield parameters as well as productivity of mustard were influenced significantly by sulphur levels and the higher length of siliqua, number of siliquae plant⁻¹, number of seeds siliqua⁻¹, seed and stover yield were associated with application of the highest sulphur level (60 kg S ha⁻¹) but significant difference was noticed up to 45 kg ha⁻¹.

Effect of sulphur on quality and nutrient uptake
Mishra (2001) [21] observed successive increase in nutrient (N, P, K, S and Zn) content and uptake of crop with increase in level of sulphur from 0-60 kg ha⁻¹ however increase was found significant only up to 40 kg S ha⁻¹.

Singh (2005) [37] observed significant improvement in oil yield, content of oil and protein of mustard seed with increase in sulphur levels from nil to 60 kg S ha⁻¹ but increase in saponification, iodine and acid value was noted significant till 40 kg S ha⁻¹. Similar results were also reported by Karthikeyan and Shukla (2008) [11] who noted synergistic effect of sulphur fertilization on oil content and protein content of mustard.

Jat and Mehra (2007) [17] and Zizalla et al. (2008) [45] observed significant increase in N, P, K and S content with increase in sulphur rates up to 80 kg S ha⁻¹. While, Parmar and Parmar (2012) [28] on studying the effect of sulphur levels on quality of mustard seed found increment in palmitic, stearic, oleic and linoleic acid content with increase in sulphur level and decline in linolenic and erucic acid content with increase in sulphur level as also reported by Ray et al. (2015) [35]. In terms of glucosinolate content, Ray et al. (2015) [35] observed an increment in sinigrin and progoitrin with increased sulphur levels while gluconapin content declined with increase in S-levels.

Kabdal et al. (2018) concluded that application of 60 kg S ha⁻¹ showed highest uptake of N, P, K, S and C uptake by both seed and stover as compared to lower levels of sulphur. Sukirtee et al. (2018) noticed increase in oil content and oil yield increasing sulphur application from 0-50 kg ha⁻¹. In addition, it was also reported that increasing levels of sulphur also brought significant increment in N, P, K and S content in mustard seed up to the maximum sulphur level of 50 kg S ha⁻¹.

Effect of sulphur on profitability of mustard
Improvement in growth, yield attributes and productivity attained with higher sulphur application ultimately results in higher gross as well as net returns as also evident from following study:

Kumar et al. (2009) [15] recorded maximum net returns and benefit: cost ratio with 45 kg S ha⁻¹, followed by 30 and 15 kg S ha⁻¹. Similar results were also reported by Piri et al. (2011) [31] who also noticed that 45 kg S ha⁻¹ gave the maximum net return and benefit: cost ratio followed by 30 kg S ha⁻¹. In both
the studies, no sulphur application recorded least gross return, net return and benefit: cost ratio. Significant variation in gross and net returns was also observed by Ray et al. (2014) due to sulphur fertilization in which highest gross and net income with benefit: cost ratio was noticed with 30 kg S ha\(^{-1}\). Economics of mustard cultivation was also evaluated by Kabdal et al. (2018) [8] who found increase in returns with increasing levels of sulphur and application of sulphur at the rate of 60 kg ha\(^{-1}\) fetched maximum gross and net returns. Increase in sulphur fertilization though add to cost of cultivation but the consequent returns achieved with sulphur outnumbers the treatment cost and 60 kg S ha\(^{-1}\) fetched highest gross returns and benefit: cost ratio (Kumar et al., 2018) [12]. Similar results were also reported by Sahu et al. (2018) [36].

### Conclusion

Thus, it is evident that manipulation in irrigation regimes, selected variety and sulphur nutrition cause significant improvement in growth characteristics of mustard which further results in better yield contributing characters and productivity that can address the growing demand of vegetable oil as well as can bring down import expenditure on vegetable oil substantially. In addition, optimum use of the concerned inputs also improves the quality of seed and fetches higher economic value to the farmers improving their living standards markedly and thus increasing its share in gross national product.

### References


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