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Research Paper

Effect of irrigation schedules on productivity, quality and water use of Indian mustard (*Brassica juncea*) under staggered sowing in Northwest India

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ABSTRACT

A field experiment was conducted during the winter *(rabi)* seasons of 2019–20 and 2020–21 at the Guru Kashi University, Talwandi Sabo, Bathinda (Punjab), to study the effect of irrigation schedules on different growth, yield-attributing characters, yield, quality and water use in Indian mustard [*Brassica juncea* (L.) Czern.] in relation to sowing time. Results revealed that, early-sown crop, i.e. 10 October, recorded the higher growth parameters, viz. plant height, dry-matter accumulation, primary branches/plants, secondary branches/plant, and yield-attributing characters, viz. siliquae/plant, seeds/siliqua, siliqua length and 1,000-seed weight of Indian mustard. The crop sown on 10 October gave the highest seed yield (1449 kg/ha) which was significantly higher than the crop sown on 25 October (1,171 kg/ha) and 10 November (643 kg/ha). Oil yield, nitrogen content and protein content were also significantly higher in 10 October sown crop. Early-sown crop, i.e. 10 October, resulted in the 21.2 and 119.5% higher water-use efficiency (7.55 kg/ha/mm) than 25 October (6.23 kg/ha mm) and 10 November (3.44 kg/ha/mm) sown crop. Application of 3 irrigations, viz. at branching, flowering and siliqua-formation stages, resulted in higher plant height, dry matter, primary and secondary branches/plant, siliquae/plant, 1,000-seed weight, stover yield and harvest index in Indian mustard. Three irrigations at branching, flowering and siliqua-formation stages resulted in significantly higher seed yield (1,658 kg/ha), oil content (42.2%), oil yield (699.7 kg) and protein content (22.3%). This treatment resulted in the 23.3% higher water-use efficiency (6.50 kg/ha/mm) than the control (5.27 kg/ha/mm).

***Key words*:** Indian mustard, Irrigation, Protein, Seed yield, Sowing date, Water-use efficiency

India is one among the leading oilseed-producing countries in the world. In India, Indian mustard [*Brassica juncea* (L.) Czern.] is the second important edible oilseed crop after groundnut. It plays an important role in the oilseed economy of the country (Singh *et al*., 2017). It is predominantly cultivated in the states of Rajasthan, Uttar Pradesh, Haryana, Madhya Pradesh, Gujarat, West Bengal, Assam, Bihar and Punjab. Growth and yield in the crop which mostly impacted by the adopting changing management, viz. sowing dates and irrigation, under changing the climate (Singh *et al.,* 2014). It is highly sensitive to climate change and soil fertility (Mandal *et al.,* 2006). Sowing dates affect crop performance by altering weather conditions prevailing during the crop growth, especially germination and maturity period and consequently affecting crop duration (Dhillon and Ram, 2020). Temperature, effective sunshine hours and light intensity differ with varying planting dates. Planting on optimum date results in adequate vegetative growth, i.e. biomass production, to support reproductive structures, resulting in production of more number of yield-contributing traits and consequently higher yield and better quality of seeds.

Scheduling irrigation is one of the useful technologies which can enhance crop production (Michael, 2014) and water productivity (WP). Many researchers did experiment on scheduling irrigation with different crops (Liu and Kang, 2006). Adequate supply of moisture in soil helps in proper utilization of plant nutrients, resulting in proper growth and high yield. The frequency of irrigation and the amount of water required depend on such factors as cultivar, soil type, season, amount of rainfall and diseases; therefore, it is difficult to give definite recommendation. Over-irrigation, as well as under-irrigation may lower yields. Efficient water management thus plays a vital role in production of Indian mustard. This can be achieved by adopting improved irrigation practices. Although both timing and the amount of water applied affect irrigation

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efficiency, timing has greater effect on the yield and quality of a crop. Therefore, a judicious irrigation schedule is needed to avoid over- or under-irrigation and for profitable cultivation of Indian mustard.

Water productivity is an important matter for anticipating future water demands (Amarasinghe *et al*., 2004). Scheduling irrigation plays an important role with the increase of water productivity. It is necessary to increase water productivity by decreasing the applied water volume without affecting crop yield, especially in water-scarce regions (Bebhoudian and Singh, 2002). All the studies were done previously with the objective of either minimizing evapo-transpiration loss or increasing production with the application of increased irrigation water. Therefore, this study is as undertaken to investigate the growth, yield response, quality and water-use efficiency of Indian mustard, to schedule irrigation application under staggered sowing.

MATERIALS AND METHODS

The field experiment was conducted during the winter (*rabi*) seasons of 2019–20 and 2020–21 at the research farm of College of Agriculture, Guru Kashi University, Talwandi Sabo, Bathinda (29º33' N, 74º38' E, 208 m above the mean sea-level). The experimental site belongs to semi-arid climate, where both summers and winters are acute. A maximum temperature of about 45^{o}C is common during the summer, while freezing temperature accompanied by frost happening may be there in the months of December and January. The experimental soil had *p*H 7.6 and 7.4, containing 0.18 and 0.20% organic carbon, 200.1 and 214.5 kg/ha available N, 12.8 and 16.5 kg/ha available P and 216.1 and 224.7 kg/ha available K during the growing season of 2019–20 and 2020–21 respectively. Field capacity, permanent wilting point and bulk density recorded were 15.0% (w/w), 8.3% (w/w) and 1.42 g/cm, respectively, in 0–15 cm soil depth. The experiment was laid out in a split-plot design, comprising of 3 sowing dates, viz. D_1, 10 October; D_2, 25 October and D_3, 10 November, in the main plot and 4 irrigation schedules, viz. I_1, control; I_2, irrigation at branching stage; I_3, 2 irrigations at branching and flowering stage; I_4, 3 irrigations at branching, flowering and siliqua-formation stages, in subplots were replicated thrice.

Crop was grown as per recommended package of practices (PAU, 2020). The experimental field was prepared by ploughing with tractor-drawn harrow followed by cultivator and planking to make the fine tilth to ensure germination and establishment of the crop plant. Recommended dose of NPK, viz. 80 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha was applied uniformly through urea, diammonium phosphate and muriate of potash, respectively. The sowing of Indian mustard variety RCH 1 was done by drill method with row-to-row spacing of 30 cm and plant-to-plant spacing of 10–15 cm on different sowing dates as per treatments with seed rate 3.75 kg/ha to maintain required plant population and plant-to-plant distance. Weeding was done manually to manage weeds in the experimental crop. The crop was harvested at maturity with the help of sickle and harvested produced of net plot was kept for sun-drying. The harvested crop was tied in labelled bundles and kept for sun-drying. Then the threshing was carried out. The observations were recorded on the different growth parameters, viz. plant height, dry-matter accumulation, number of primary and secondary branches. Yield attributes, seed yield, stover yield and biological yield were recorded at harvest during both the years.

To calculate the oil content, seed samples were kept in the electric oven at 65°C for removal of moisture thereafter, the seeds were ground in a pestle mortar for extraction of oil. The oil content was estimated with the help of Soxhlet's extraction method (AOAC, 1970). Total oil yield was computed by multiplying the seed yield with oil content. Oil yield was computed as:

$$\text{Oil yield (kg/ha)} = \frac{\text{Seed yield (kg/ha)} \times \text{Oil content (\%)}}{100}$$

Nitrogen content in seeds was determined by Micro-Kjeldahl's method (Subbiah and Asija, 1956). For determination of protein content, seed samples of different treatments were analysed for nitrogen content in seeds by multiplying with a constant factor 6.25 and expressed in percentage. The protein yield was calculated by multiplying the seed yield with protein content in seeds. The consumptive use of water was worked out for different treatments by summing up the soil moisture depleted from the profile for different periods. The periodical effective rainfall was also added to compute the consumptive water use of the corresponding period. Consumptive use of water was calculated as per the formula of Michael *et al.,* (1977).

$$\text{WUE (kg/ha/mm)} = \frac{\text{Economic yield (kg/ha)}}{\text{Total consumptive use of water (mm)}}$$

Analysis of variance was performed using Proc GLM procedure of SAS version 9.4 (SAS, 2017) and significant mean differences were tested using Fisher's protected least significant difference (LSD) test at P = 0.05.

RESULTS AND DISCUSSION

Growth attributes

There was significant reduction in plant height with each successive delay in sowing from 10 October to 25 October followed by 10 November (Table 1). Crop sown on 10 October resulted in the highest plant height, dry matter, number of primary and secondary branches and it

Table 1. Effect of sowing time and irrigation scheduling on growth attributes of Indian mustard (pooled data of 2 years)

Treatment	Plant height (cm)	Dry-matter accumulation (g/plant)	Primary branches/ plant	Secondary branches/ plant
Sowing time				
10 October	160.2	89.4	7.8	36.5
25 October	143.4	82.3	6.0	28.3
10 November	126.7	71.8	4.8	24.1
SEm±	4.2	1.3	0.5	0.7
LSD (P=0.05)	14.9	4.2	1.6	2.5
Irrigation scheduling				
Control	122.8	71.0	4.2	25.5
Irrigation (branching stage)	136.9	79.7	6.7	30.8
2 irrigations (branching and flowering)	152.0	83.8	6.9	31.0
3 irrigations (branching, flowering and siliqua-formation)	161.9	90.2	7.0	31.1
SEm±	4.9	3.3	0.1	0.1
LSD (P=0.05)	15.3	9.5	0.2	0.2

was significantly higher than the crop sown on 25 October and 10 November during both the years. Congenial environmental conditions especially air temperature, more sunshine hours and low relative humidity during growth period at early stages in case of early sowing dates might have resulted in rapid cell-division in the meristematic tissues of the crop, whereas under delayed sowing, the growth ceased due to lower temperature and lesser number of sunshine hours, i.e. reduced the day-length. Early- sown crop got longer time period for synthesis of assimilates and sufficient time for efficient utilization of available resources compared to late-sown crop. Thus, longer crop duration tended to maintain leaf area for longer period of time, enabling the plants to accumulate more photosynthates than late sowing dates. It is well established that, plant height is governed by auxin levels which is strongly influenced by temperature. Auxin synthesis is promoted at higher temperatures. Thus, lower temperature particularly during early stages of crop growth under later sowing dates might have reduced the auxin biosynthesis and consequently, the plant height. Similar effects of sowing dates were reported by Rafiei *et al.,* (2011) in *Brassica juncea*. Increase in dry matter in early sowing dates could be owing to better establishment of seedlings and more plant height than late sowing dates. Reduced meristematic activity due to low temperature conditions under delayed sowing might have resulted in lower dry matter as compared to early sowing dates.

At maturity, 3 irrigations applied at branching + flowering + siliqua-formation stage (I_4) and 2 irrigations at branching + flowering (I_3) resulted in statistically similar plant height, dry matter, number of primary and secondary branches and were significantly higher than the control (no irrigation) (I_1) and 1 irrigation at branching (I_2). The lowest values of growth parameters were observed with no-irrigation treatment. Increased growth under more irrigations, i.e. up to 3 may be attributed to the fact that the loamy sand soil had limited water-holding capacity and increased moisture content in the soil might have resulted in better nutrient-use efficiency, thereby leading to profuse plant growth. Our results confirm the findings of Singh *et al*., (2014). The reduction in primary and secondary branches with delay in sowing may be attributed to reduced duration of vegetative growth period and early development of bolting under late-sown conditions.

Yield attributes

Yield-attributing characters of Indian mustard differed significantly with sowing dates and irrigation levels during both the years (Table 2). Crop sown on 10 October produced significantly more siliquae/plant and 1,000-seed weight than the crop sown on 25 October and 10 November, while number of seeds/siliquae in 10 October and 25 October sown crops were statistically similar. The higher number of primary and secondary branches/plant in early sowing dates led to increased number of siliquae/plant. The effect of different sowing dates on siliqua length of Indian mustard was non-significant. Our results confirm the findings of Akhter *et al.,* (2014) in *Brassica rapa*.

The effect of irrigation scheduling on number of siliquae/plant was significant during both the years. The highest number of siliquae/plant, siliqua length and 1,000-seed weight were obtained with treatment I_4 i.e. when 3 irrigations were applied at branching, flowering and siliqua-formation stages and it was significantly higher than the other treatments of irrigation schedules. The lowest yield attributes were observed with no-irrigation. Application of 3 irrigations resulted in the highest and signifi-

Table 2. Effect of sowing time and irrigation scheduling on yield attributes of Indian mustard (pooled data of 2 years)

Treatment	Siliquae/ plant	Siliquae length (cm)	Seeds/ siliqua	1,000-seed weight (g)
Sowing time				
10 October	332	5.3	13.5	4.16
25 October	306	5.2	13.0	3.96
10 November	265	4.9	12.5	3.70
SEm±	6	0.3	0.2	0.04
LSD (P=0.05)	21	NS	0.5	0.14
Irrigation scheduling				
Control	248	4.4	12.3	3.55
Irrigation (branching stage)	275	5.0	12.9	3.89
2 irrigations (branching and flowering)	320	5.4	13.1	4.09
3 irrigations (branching, flowering and siliqua-formation)	363	5.7	13.7	4.23
SEm±	9	0.1	0.1	0.03
LSD (P=0.05)	29	0.2	NS	0.10

cantly more yield-attributing characters as compared to no and 1 irrigation. Effect of irrigation schedules on number of seeds/pod in Indian mustard was non-significant. Increased number of siliquae/plant under more irrigations, i.e. up to 3 may be attributed to the fact that the loamy sand soil had limited water-holding capacity and increased moisture content in the soil might have resulted in better nutrient-use efficiency thereby leading to profuse plant growth. Singh *et al*., (2014) also reported positive effect of irrigations on yield attributes of mustard.

Productivity

Productivity of Indian mustard decreased significantly and progressively with each delay in sowing (Table 3). Crop sown on 10 October resulted in the highest seed yield (1,449 kg/ha) which was significantly higher than 25 October (1,171 kg/ha) and 10 November (643 kg/ha). Thus, 10 October sowing resulted in 23.7 and 125.1% more seed yield than 25 October to 10 November sowing dates respectively. This might be owing to improvement in yield attributes like number of siliquae/plant, seeds/siliqua and 1,000-seed weight in early sowing dates compared to late sowing ones. Sowing on 10 October also ensured the highest biological and stover yields which were significantly higher than 25 October and 10 November sowing. Such increase in earlier sowing dates accrued from more accumulation of dry matter and greater time available for dry matter in early sowing as compared to late sowing, while crops sown on 10 October and 25 October recorded statistically similar harvest indices. The positive effect of early sowing on yield was also reported by Singh *et al*. (2014) in *Brassica juncea* and Akhter *et al.* (2014) in *Brassica rapa*.

The highest seed, stover and biological yields were obtained with 3 irrigations at branching, flowering and siliqua formation stages (I_4) and it was significantly higher than the other treatments of irrigation schedules. The lowest

Table 3. Effect of sowing time and irrigation scheduling on productivity of Indian mustard (pooled data of 2 years)

Treatment	Biological yield (kg/ha)	Seed yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)
Sowing time				
10 October	5,507	1,449	4,058	26.31
25 October	4,343	1,171	3,172	26.96
10 November	2,609	643	1,966	24.65
SEm±	306	90	206	0.10
LSD (P=0.05)	802	205	718	0.42
Irrigation scheduling				
Control	2,135	553	1,582	25.90
Irrigation (branching stage)	3,425	895	2,530	26.13
2 irrigations (branching and flowering)	4,733	1,245	3,488	26.30
3 irrigations (branching, flowering and siliqua-formation)	6,319	1,658	4,661	26.24
SEm±	410	122	301	0.03
LSD (P=0.05)	1,245	290	990	NS

seed yield (553 kg/ha) was obtained with the control plots (I_1). Application of 3 irrigations resulted in the 199.2% more seed yield than the control and this treatment also resulted in the highest and significantly higher yield attributes than the control, 1 and 2 irrigations treatments. This is owing to adequate supply of water which might have kept all the nutrient ions in proper available form.

Oil quality

Oil content and yield of Indian mustard differed significantly with sowing time (Table 4). The crop raised on 10 October ensured significantly higher oil yield than the other sowing dates, whereas oil contents of 10 October and 25 October sown crops were statistically similar with each other. But nitrogen and protein content were not significantly influenced by sowing time. Oil content, oil yield and protein content in Indian mustard were significantly influenced by different treatments of irrigation schedules. The I_4 treatment resulted in the highest oil content, oil yield and protein content which were significantly higher than the other treatments of irrigation schedules. No-irrigation treatment resulted in the lowest oil content because minimal stress conditions should be maintained for at least half of the ripening stage in order to produce large seeds. With increasing water stress, seed size was decreased and oil content was also reduced. Kadayifci and Yildirim (2000) and Kazi *et al.,* (2002) found increased oil content of sunflower seeds by irrigation.

Water use

Sowing date had non-significant effect on consumptive use of water (Table 5). With delayed in the sowing from 10 October to 10 November, significantly reduced the water-use efficiency which might be due to reduction in the seed

Table 4. Effect of sowing time and irrigation scheduling on oil content, oil yield, nitrogen content and protein content of Indian mustard (pooled data of 2 years)

Treatment	Oil content (%)	Oil yield (kg/ha)	Nitrogen content (%)	Protein content (%)
Sowing time				
10 October	39.6	573.8	3.55	22.2
25 October	40.1	469.6	3.47	21.7
10 November	37.7	242.4	3.39	21.2
SEm±	0.2	21.2	0.04	0.1
LSD (P=0.05)	0.8	85.7	NS	NS
Irrigation scheduling				
Control	37.4	206.8	3.26	20.4
Irrigation (branching stage)	38.2	341.9	3.38	21.1
2 irrigations (branching and flowering)	39.6	493.0	3.44	21.5
3 irrigations (branching, flowering and siliqua-formation)	42.2	699.7	3.57	22.3
SEm±	0.2	37.5	0.03	0.1
LSD (P=0.05)	0.9	112.4	NS	0.6

Table 5. Effect of sowing time and irrigation scheduling on consumptive use of water and water use efficiency of Indian mustard (pooled data of 2 years)

Treatment	Consumptive use of water (cm)	Water-use efficiency (Kg/ha/mm)
Sowing time		
10 October	19.2	7.55
25 October	18.8	6.23
10 November	18.7	3.44
SEm±	0.2	0.30
LSD (P=0.05)	NS	1.20
Irrigation scheduling		
Control	10.5	5.27
Irrigation (branching stage)	15.7	5.70
2 irrigations (branching and flowering)	23.2	5.14
3 irrigations (branching, flowering and siliqua-formation)	26.5	6.50
SEm±	0.2	0.10
LSD (P=0.05)	1.1	0.32

yield with delayed sowing. Further, pooled data of 2 years indicated that consumptive use of water increased significantly with increasing number of irrigation up to 3, i.e. at branching, flowering and siliqua formation stages (I_4). Irrigation schedules treatments I_2, I_3 and I_4 led to 49.5, 120.9 and 152.3%, respectively, higher total consumptive use of water over no irrigation (I_1). Higher consumptive use under irrigated crop than unirrigated 1 and observed that, higher availability and higher rate of evaporation to meet the vapour pressure gradient were mainly responsible for higher values under resulted in marked increase in the total consumptive use of water over no-post sowing irrigation (Thakral *et al.,*1997). The water-use efficiency was the highest (6.50 kg/ha/mm) in I_4 treatment, being significantly higher than the other treatments of irrigation schedules. Three irrigations at branching, flowering and siliqua formation stages (I_4) resulted in the 23.3% higher water-use efficiency (6.50 kg/ha/mm) than the control (5.27 kg/ha/mm). It might be owing to the increase in seed yield due to irrigation could not compensate for the total consumptive use of water under irrigated conditions. However, plants under unirrigated conditions used water more rationally due to limited availability.

Thus, early sowing of Indian mustard with 3 irrigations at branching, flowering and siliqua-formation stages was found to be most suitable and realize better growth as well as productivity, oil quality and water-use efficiency.

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