Original Research Article

EFFECT OF IRRIGATION SCHEDULING AT DIFFERENT PHENOLOGICAL PHASES ON GROWTH AND YIELD OF MUSTARD (*Brassica juncea* L.) IN NORTHERN TELANGANA

ABSTRACT

A field experiment was conducted during *rabi,* 2021-22 at Agricultural college, Jagtial to investigate the effect of irrigation scheduling at different phonological phases on growth and yield of mustard. The experiment was laid out in randomized complete block design with twelve treatments and replicated thrice. Treatments includes two irrigations each at vegetative and flowering stage (T_1), two irrigations each at vegetative and siliqua development (T_2), two irrigations each at flowering and siliqua development (T_3), three irrigations each at vegetative, flowering and siliqua development (T_4), three irrigations each at vegetative, pre-flowering and siliqua development (T_5), three irrigations each at pre-flowering, siliqua initiation and siliqua development (T_6), four irrigations each at vegetative, pre-flowering, flowering and siliqua development (T_7), four irrigations each at vegetative, pre-flowering, flowering and siliqua initiation (T_8), four irrigations each at vegetative, pre-flowering, siliqua initiation and siliqua development (T_9), four irrigations each at pre-flowering, flowering, siliqua initiation and siliqua development (T_{10}), five irrigations each at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development (T_{11}) and scheduling of irrigation at IW/CPE ratio of 1.0 (T_{12}). The results of the experiment revealed that maximum plant height (146), LAI (0.89), dry matter accumulation (416 g m^{-2}), number of siliquae plant $^{-1}$ (124), number of filled seeds siliquae^{-1} (13.65), seed yield (1113 kg ha^{-1}) and stover yield (2224 kg ha^{-1}) were recorded with five irrigations each at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development (T_{11}). However, it was on par with irrigation scheduled at IW/CPE ratio of 1.0 (T_{12}).

Key words: Mustard; irrigation scheduling; Dry matter accumulation; Seed yield

INTRODUCTION

Oilseeds are immensely significant to the Indian economy, contributing 5% of India's GDP and 10% of the value of agricultural products. Oilseeds are India's second most important agricultural commodity after grains, accounting for roughly 13.5 percent of the country's total cropped area [1]

Mustard (*Brassica juncea* L.) belong to the family Cruciferae. The seed contains 40-45% oil and 20-25% protein. The seed and oil of mustard are used as a condiment in the preparation of pickles, flavoring curries and vegetables as well as for cooking and frying purposes. Mustard oil is utilised in a variety of industrial applications, while the oil cake is used as cattle feed and manure and the green leaves are used as a vegetable and green fodder [2]. Indian mustard has recently gained popularity among farmers due to its adaptability to both irrigated and rainfed environments, as well as its appropriateness for both single and mixed cropping. Furthermore, it provides a larger return because to its low production cost and low water consumption. It has a greater potential to boost the supply of edible oil from domestic production because it is a major winter season oilseed crop with the advantage of grown under stored soil moisture.

Optimum crop yield is not possible without the timely application and right amount of irrigation water. Since rainfall during *rabi* is inadequate and unpredictable, mustard requires supplemental irrigation for its proper growth and development otherwise; the crop may suffer from water stress and reduce ultimately the yield [1]. Scheduling of irrigation during critical stages could boost the growth, yield and water productivity of mustard. Hence the present study was conducted to determine the performance of mustard under different irrigation schedules at phenological stages

2. MATERIALS AND METHODS

The current investigation was carried out at College Farm, Agricultural College, Jagtial, Professor Jayashankar Telangana State Agricultural University. The farm is geographically situated at 18º 50’37.0” N latitude and 78º 57’00.6” E longitude with an altitude of 243.4 m above mean sea level. The soil of the experiment field was sandy clay loam in texture. The cultivar under study was Pusa Mustard-25 at a seed rate is around 5kg ha^{-1}. The applied dose of fertilizer for the cultivar i.e., 135 N, 250 P_2O_5 and 65 K_2O kg ha^{-1}. Half of the nitrogen, entire P and K are applied as basal at the time of sowing, remaining nitrogen applied just before flowering stage.

Plant height was measured from the base of the plant to the tip of the shoot before scheduling the irrigation and the average height was expressed in cm. Representative plant samples were collected from the border rows by the destructive sampling method and collected plant samples were shade dried for one day, discarding the roots, followed by oven drying at 60^{o}C for 48 hours till a constant weight was attained. These dried samples are weighed and dry matter accumulation expressed in g m^{-2}. Leaf area is measured by using the "Biovis Leaf Area meter" at various growth stages and expressed as cm^{2} plant^{-1} then LAI was calculated by dividing leaf area with unit ground area. Tagged plants, which were utilised for recording the plant height were, additionally utilised for counting the number of siliquae plant^{-1} present on branches and average siliquae plant^{-1} at harvest was worked out. The mean number of seeds siliquae^{-1} was calculated from twenty randomly chosen siliquae from five tagged plants were counted out of total siliquae. A thousand seeds were counted from the weighed sample and weight of 1000 seeds was recorded as the test weight. Plants from the net plot area (3.6 m X 3 m) were harvested, threshed, sun dried and winnowed separately. The yield obtained from each net plot was measured in grams and later converted to kg ha^{-1}.

The data obtained analysed statistically by Analysis of Variance utilizing Randomized Block Design [3]. Statistical difference (CD) will be tested by applying F test at 0.05 level of probability.

3. RESULTS AND DISCUSSION

3.1 PLANT HEIGHT (cm)

Observation of experimental data revealed that there was no significant difference in plant height when irrigation scheduled at vegetative stage (table 1). Plant height assumes significant part in the capture of light and sun-oriented radiation. Plant height is determined by cell division, cell enlargement and cell differentiation all of which requires sufficient water.

Plant height at flowering stage ranges from (56 to 85cm). Treatment with 5 irrigations each at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development (T_{11}) had the highest plant height (85 cm) and it was on par with treatments T_5 to T_{12}. While, the lowest plant height (56 cm) recorded in treatments with two irrigations each at flowering and siliqua development (T_3) in turn, it was on par with treatments provided two irrigations at vegetative and siliqua development (T_3) and two irrigations at vegetative and flowering stage (T_1).

Significantly higher plant height (140 cm) at siliqua development was observed in treatments when irrigation imposed at IW/CPE ratio of 1.0 which was on par with treatment (T_8 to T_{11}). The lower plant height (97 cm) was recorded in treatments provided with two irrigations at vegetative and siliqua development (T_2) due to moisture stress during flowering stage and siliqua stage which was on par with treatment (T_3) when irrigated each at flowering and siliqua development (107 cm).

At harvest the highest plant height was seen in treatment with an IW/CPE ratio of 1.0 (T_{12}) in turn, it was on par with treatments (T_8 to T_{11}). While, the treatment with two irrigations each at vegetative and siliqua development (T_2) had the lowest plant height (102 cm) which was on par with treatment (T_3) when irrigated each at flowering and siliqua development (Table 1).

The increased plant height with increasing number of irrigations might be due to increased water availability has caused progressive tissue initiation and cell expansion which may aided in nutrient mobilization and thereby making plant physiologically more active. Similar findings were reported with Yadav *et al*. [4], Mila *et al*. [5], Verma *et al.* [6], Chaudari *et al*. [7] and Rathore *et al*. [8].

3.2 LEAF AREA INDEX

Leaf area index increased progressively throughout different stages of the crop growth up to flowering, after which it began to decline. Mustard LAI growth trend might be linked to the plant's regular typical growth pattern, and the increase in LAI could be the consequence of the cumulative effect of increased leaf number and leaf growth as the plant ages. The decline in LAI was caused by the drying and fall of leaves when the senescence period began. Irrigation scheduled during vegetative has no significant different among treatments. It is evident from the data presented in Table 2.

When irrigation was set at an IW/CPE ratio of 1.0, a higher LAI (3.67) was observed during the flowering stage. However, it is at par with T_5, T_7, T_8, T_9, and T_{11}. Increased water availability at critical stages resulted in better nutrient uptake, cell growth and division, higher photosynthetic activity and thus resulted in superior growth indices. These results were in line with Puppala *et al*. [9].

While, two irrigations each at flowering and siliqua development (T_3) results in much lower LAI (2.01) which was on par with treatments (T_2) with two irrigations each at vegetative and flowering stages (2.33). Water shortages have notably repressed leaf development through decrease of relative leaf turgidity. Similar results were reported with Verma *et al*. [6] and Tamboli *et al*. [10].

3.3 DRY MATTER ACCUMULATION (g m^{-2})

After respiration and anabolic processes, photosynthates accumulate as dry matter. A perusal of data summarized in Table 3, showed a consistent increase in dry matter accumulation up to siliqua development and then at slower rate till harvest. Data collected on dry matter accumulation at vegetative stage had no significant difference between treatments.

At flowering stage, irrigation scheduling at 1.0 IW/CPE (T_{12}) resulted in significantly higher dry matter accumulation (46.23 g m^{-2}), which was on par with treatments (T_5, T_7, T_8, T_9, T_{11}) with 43.67, 42.38, 43.13, 42.67, 42.45 g m^{-2} respectively. Treatment with two irrigations at flowering and siliqua development (T_3) had lower dry matter accumulation (25.33 g m^{-2}) due to lack of water availability during vegetative stage, which resulted in protoplasm dehydration, which decreased turgor potential and turgor-driven physiological processes and it was on par with the treatment (T_3) provided two irrigations at vegetative and siliqua development (29.33 g m^{-2}).

Treatments with irrigation imposed at an IW/CPE ratio of 1.0 had significantly higher dry matter accumulation (336.27 g m^{-2}) at siliqua development, which was on par with treatment (T_{11}) provided with five irrigations each at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development (333.33 g m^{-2}). While, lower dry matter accumulation (158.67 g m^{-2}) was attained in treatments provided with two irrigations at vegetative and siliqua development (T_2) due to moisture stress throughout flowering stage and siliqua initiation stage.

At harvest, dry matter accumulation ranges from (420.33 to 198.33g m^{-2}), irrigation scheduling at IW/CPE ratio of 1.0 (T_{12}) results in significantly higher dry matter accumulation (420.33 g m^{-2}) and it was on par with treatments (T_{11}) with five irrigations each at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development (416.67 g m^{-2}). It could be due to adequate and appropriate water supply to plants, which increased cell turgidity and cell enlargement as well as meristematic activity resulted in increased photosynthesis and bio mass accumulation. These results were in agreement with experimental findings of Puppala *et al.* (2019). While, the lowest dry matter (198.33 g m^{-2}) was observed in treatment that received two irrigation each at vegetative and siliqua development (T_2) due to devoid of water during flowering stage and siliqua initiation stage results in dehydration of protoplasm which results in decreased the turgor potential and turgor driven physiological processes such as cell division and cell elongation which affect the plant growth and eventually the total dry matter accumulation (Tyagi and Upadhyay [11]. Similar results were reported with Piri *et al.* [12], Verma *et al.* [13] and Rana *et al*. [14].

3.4 Yield attributes

Number of irrigations at different phenophases had a considerable impact on yield attributes of mustard (Table 4). Among the different irrigation scheduling treatments, highest number of siliqua plant^{-1} (135.67), number of seeds siliquae^{-1} (13.88) in mustard were recorded with irrigation scheduled at 1.0 IW/CPE which in turn, on par with treatment (T_{11}) provided with 5 irrigations each at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development stages (124.80 and 13.65 respectively). It is due to frequent irrigation application reduced water stress in the soils and generated a favourable environment for the plants in respect of water availability, providing congenial conditions for the growth and development of higher number of siliquae plant^{-1} and number of filled seeds siliqua^{-1}.

However, the highest test weight (5.65 g) was recorded with treatment (T_{11}) with five irrigations each at at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development stages. This might be due to higher photosynthesis and translocation of assimilates towards reproductive structures owing to adequate soil moisture. While, treatment (T_2) provided with two irrigations each at vegetative and siliqua development stage had lowest number of siliqua plant^{-1} (63.00), number of filled seeds siliquae^{-1}(10.43) and test weight (4.46 g) which was on par with treatment (T_1) with two irrigations each at vegetative and siliqua development. These findings were in accordance with Shivran *et al.* [15], Yadav *et al*. [16], Tripathi *et al*. [17], Ray *et al*. [18] and Nautilya *et al.* [19].

3.5 SEED YIELD

Yield is the result of coordinated interplay of growth characters and yield attributes. Significantly the highest seed yield (1143 kg ha^{-1}) was obtained with irrigation scheduled at IW/CPE ratio of 1.0 (T_{12}) which was on par with treatment (T_{11}) that received five irrigations each at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development stages (1113 kg ha^{-1}) and the lowest seed yield (431 kg ha^{-1}) when irrigated twice each at vegetative and siliqua development. Data pertaining to seed and stover yield represented in Table 5.

Seed yield is the function of dry matter and yield attributes of plant which have increased dramatically as the number of irrigations increased. This could be because it also be linked to increased photosynthates and photosynthetic translocation to reproductive structures in the mustard crop's rhizosphere due to adequate soil moisture. Adequate supply of moisture in soil helps in proper utilization of plant nutrients, resulting in proper growth and high yield. Whereas, irrigation imposed each at vegetative and siliqua development produced the lowest plant height, filled siliqua plant^{-1}, number of seed siliqua^{-1} and 1000-seed weight due to devoid of moisture throughout the flowering and siliqua initiation stage. These findings were in agreement with Hossain *et al*. [20], Dadich *et al*. [21], Singh and Thenua [22] and Shivran *et al*. [23].

3.6 STOVER YIELD

The stover yield grew substantially as number of irrigations increased. This rise was attributed to increased moisture availability, which resulted in a better nutritional environment during critical growth phases of the crop, resulting in improved vegetative growth. Irrigation with an IW/CPE ratio of 1.0 (T_{12}) resulted in the maximum stover output (2372 kg ha^{-1}) which was a par with treatment (T_{11}) in which imposed five irrigations each at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development stage (2224 kg ha^{-1}). Lower stover yield noticed in treatment (T_2) when irrigation scheduled each at vegetative and siliqua development. It might be due to extended moisture stress during flowering period.

Table 1: Plant height(cm) of mustard as influenced by irrigation scheduling at different phenophases

	Treatments	Plant height (cm)			
		Vegetative	Flowering	Siliqua development	Harvest
T_1	Two irrigations at Vegetative and Flowering stage	5.51	64.61	114.00	119.70
T_2	Two irrigations at Vegetative and Siliqua development	6.47	64.67	97.93	102.72
T_3	Two irrigations at Flowering and Siliqua development	6.69	56.67	107.60	112.98
T_4	Three irrigations at Vegetative, Flowering and Siliqua development	5.77	73.94	117.67	123.55
T_5	Three irrigations at Vegetative, Pre-flowering and Siliqua development	5.92	87.77	122.87	129.01
T_6	Three irrigations at Pre-flowering, Siliqua initiation and Siliqua development	6.70	84.26	124.60	130.83
T_7	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua development	5.57	86.67	128.07	134.47
T_8	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua initiation	6.97	83.27	131.60	138.16
T_9	Four irrigations at Vegetative, Pre-flowering, Siliqua initiation and Siliqua development	6.45	85.29	131.33	137.90
T_{10}	Four irrigations at Pre-flowering, Flowering, Siliqua initiation and Siliqua development	6.43	77.69	136.40	143.13
T_{11}	Five irrigations at Vegetative, Pre-flowering, Flowering, Siliqua initiation and Siliqua development.	6.50	85.92	139.80	146.79
T_{12}	Scheduling of irrigation at IW/CPE ratio of 1.0	5.85	84.33	140.67	147.70
	SEm±	0.555	2.991	3.831	3.522
	CD @ 5%	1.612	8.828	11.309	10.396
	CV (%)	15.408	6.647	5.335	4.672

Table 2: LAI of mustard as influenced by irrigation scheduling at different phenophases

	Treatments	Leaf area Index (LAI)			
		Vegetative	Flowering	Siliqua development	Harvest
T_1	Two irrigations at Vegetative and Flowering stage	0.95	2.43	1.40	0.48
T_2	Two irrigations at Vegetative and Siliqua development	0.92	2.33	1.13	0.42
T_3	Two irrigations at Flowering and Siliqua development	0.88	2.01	1.28	0.52
T_4	Three irrigations at Vegetative, Flowering and Siliqua development	0.79	2.54	1.57	0.59
T_5	Three irrigations at Vegetative, Pre-flowering and Siliqua development	0.97	3.46	1.91	0.71
T_6	Three irrigations at Pre-flowering, Siliqua initiation and Siliqua development	0.94	2.80	1.98	0.74
T_7	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua development	0.93	3.36	1.94	0.72
T_8	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua initiation	0.89	3.42	2.16	0.73
T_9	Four irrigations at Vegetative, Pre-flowering, Siliqua initiation and Siliqua development	0.86	3.38	1.97	0.80
T_{10}	Four irrigations at Pre-flowering, Flowering, Siliqua initiation and Siliqua development	0.91	2.95	2.21	0.83
T_{11}	Five irrigations at Vegetative, Pre-flowering, Flowering, Siliqua initiation and Siliqua development.	0.87	3.36	2.38	0.89
T_{12}	Scheduling of irrigation at IW/CPE ratio of 1.0	0.90	3.67	2.40	0.89
	SEm±	0.056	0.135	0.042	0.016
	CD @ 5%	0.163	0.397	0.124	0.046
	CV (%)	10.776	7.838	3.901	3.899

Table 3: Dry matter production (g m^{-2}) of mustard as influenced by irrigation scheduling at different phenophases

	Treatments	Dry matter production (g m^{-2})			
		Vegetative	Flowering	Siliqua development	harvest
T_1	Two irrigations at Vegetative and Flowering stage	5.77	30.67	196.53	224.33
T_2	Two irrigations at Vegetative and Siliqua development	5.60	29.33	158.67	198.33
T_3	Two irrigations at Flowering and Siliqua development	5.35	25.33	179.47	245.67
T_4	Three irrigations at Vegetative, Flowering and Siliqua development	4.82	32.00	220.36	275.45
T_5	Three irrigations at Vegetative, Pre-flowering and Siliqua development	5.87	43.67	267.73	334.67
T_6	Three irrigations at Pre-flowering, Siliqua initiation and Siliqua development	5.73	35.33	277.33	346.67
T_7	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua development	5.63	42.38	272.27	340.33
T_8	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua initiation	5.43	43.13	302.51	345.33
T_9	Four irrigations at Vegetative, Pre-flowering, Siliqua initiation and Siliqua development	5.25	42.67	276.27	378.13
T_{10}	Four irrigations at Pre-flowering, Flowering, Siliqua initiation and Siliqua development	5.52	37.20	310.40	388.00
T_{11}	Five irrigations at Vegetative, Pre-flowering, Flowering, Siliqua initiation and Siliqua development.	5.29	42.45	333.33	416.67
T_{12}	Scheduling of irrigation at IW/CPE ratio of 1.0	5.45	46.23	336.27	420.33
	SEm±	0.341	1.698	5.876	7.346
	CD @ 5%	0.990	5.014	17.344	21.683
	CV (%)	10.776	7.838	3.900	3.901

Table 4: Yield attributes of mustard as influenced by irrigation scheduling at different phenophases

	Treatments	Number of Siliqua plant $^{-1}$	Number of filled seeds siliquae^{-1}	Test weight(g)
T_1	Two irrigations at Vegetative and Flowering stage	75.33	10.87	4.76
T_2	Two irrigations at Vegetative and Siliqua development	63.00	10.43	4.46
T_3	Two irrigations at Flowering and Siliqua development	84.07	11.24	4.92
T_4	Three irrigations at Vegetative, Flowering and Siliqua development	88.67	11.47	5.21
T_5	Three irrigations at Vegetative, Pre-flowering and Siliqua development	101.00	11.97	5.17
T_6	Three irrigations at Pre-flowering, Siliqua initiation and Siliqua development	110.33	12.18	5.49
T_7	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua development	94.40	11.51	5.24
T_8	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua initiation	98.67	11.59	5.44
T_9	Four irrigations at Vegetative, Pre-flowering, Siliqua initiation and Siliqua development	112.67	12.18	5.55
T_{10}	Four irrigations at Pre-flowering, Flowering, Siliqua initiation and Siliqua development	116.27	12.28	5.64
T_{11}	Five irrigations at Vegetative, Pre-flowering, Flowering, Siliqua initiation and Siliqua development.	124.80	13.65	5.65
T_{12}	Scheduling of irrigation at IW/CPE ratio of 1.0	135.67	13.88	5.54
	SEm±	4.168	0.270	0.238
	CD @ 5%	12.303	0.796	0.702
	CV (%)	7.190	3.913	7.834

Table 5: Yield (kg ha^{-1}) of mustard as influenced by irrigation scheduling at different phenophases

	TREATMENTS	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})
T_1	Two irrigations at Vegetative and Flowering stage	546	1113
T_2	Two irrigations at Vegetative and Siliqua development	431	923
T_3	Two irrigations at Flowering and Siliqua development	582	1161
T_4	Three irrigations at Vegetative, Flowering and Siliqua development	618	1300
T_5	Three irrigations at Vegetative, Pre-flowering and Siliqua development	653	1297
T_6	Three irrigations at Pre-flowering, Siliqua initiation and Siliqua development	831	1591
T_7	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua development	728	1488
T_8	Four irrigations at Vegetative, Pre-flowering, Flowering and Siliqua initiation	765	1577
T_9	Four irrigations at Vegetative, Pre-flowering, Siliqua initiation and Siliqua development	902	1907
T_{10}	Four irrigations at Pre-flowering, Flowering, Siliqua initiation and Siliqua development	968	1945
T_{11}	Five irrigations at Vegetative, Pre-flowering, Flowering, Siliqua initiation and Siliqua development.	1113	2224
T_{12}	Scheduling of irrigation at IW/CPE ratio of 1.0	1143	2372
	SEm±	33	59
	CD @ 5%	97	175
	CV (%)	7.4	6.5

4. CONCLUSIONS

The present investigation found that deficit and optimum irrigation schedules had a substantial impact on growth, yield attributes and yield of mustard. It is concluded that irrigation scheduled with five irrigation each at vegetative, pre-flowering, flowering, siliqua initiation and siliqua development results in highest seed output. Further, under limited water supply, schedule four irrigations each during pre-flowering, flowering, siliqua initiation, and siliqua development, if three irrigations are available schedule at pre-flowering, siliqua initiation and siliqua development for higher growth and yield of mustard in Northern Telangana Zone

5. REFERENCES

1. Mishra J, Singh RK, Yadav D, Saho S, Mishra AP. Quality of Indian mustard as influenced by tillage and irrigation frequency. Journal of Pharmacognosy and Phytochemistry.2019; 8(1): 2280-2283.
2. AnupDas, Devi T, Dey U, Layek J, Ramakrishna GI., Krishnappa R, Babu S. No- till rapeseed- mustard, production technology in rice fallow. *Lal Bahadur Shasthri Young Scientist Award Project.* ICAR Research complex for NEH region, Umiam, Meghalaya.2018.
3. Panse VC and Sukhatme PV. Statistical Methods for Agricultural Workers. *Indian Council of Agricultural Research*, New Delhi. 1978; 87-89.
4. Yadav M, Yadav KK, Singh DP, Lakhawat SS, Vyas AK. Effect of irrigation frequency and zinc fertilization on growth and yield of Indian mustard (Brassica juncea (L.). The Pharma Innovation Journal.2021; 10(9): 1427-1431
5. Mila AJ, Akanda AR, Biswas SK, Sarkar PK and Pervin S. Yield and water productivity of mustard under sprinkler and basin irrigation systems. Bangladesh Journal of Scientific Research.2015; 28(2):137-149.
6. Verma HK, Singh MM, Singh MK, Kumar S. Response of Indian mustard (*Brassica juncea* L.) varieties to irrigation for better growth, yield and quality of mustard crop. International Journal of Agriculture Sciences.2014; 10(1): 426–429.
7. Chaudhari DM, Sadhu AC, Patel HK. Role of irrigation scheduling and weed management on growth, yield attributes and yield of Indian mustard (*Brassica juncea* L.). Research in Environment and Life Sciences.2016; 9(6): 731-733.

8. Rathore SS, Shekhawat K, Babu S, Singh VK. Mitigating moisture stress in Brassica juncea through deficit irrigation scheduling and hydrogel in ustocherpts soils of semi-arid India. Heliyon. 2020; *6*(12): 5786.
9. Puppala S, Akula B, Reddy K, Jaya TS. Variation in dry matter accumulation and growth indices of mustard as influenced by irrigation regimes and fertilizer levels. The Pharma Innovation Journal .2021;10(7): 838-841
10. Tamboli YA, Yadav JS, Kumar P, Dahiya R, Kumar A. Growth and phenological responses of Indian mustard (Brassica juncea L.) to different irrigation levels, varieties and antitranspirants. The Pharma Innovation Journal. 2021;10(7): 920-926
11. Tyagi PK, Upadhyay AK. Growth, yield and water use efficiency of Indian mustard (Brassica juncea L.) as influenced by irrigation frequency and row spacing. Journal of Oilseed Brassica. 2017; 1(1): 27-36.
12. Piri I, Nik MM, Tavassoli A, Rastegaripour F, Babaeian M. Effect of irrigation frequency and application levels of sulphur fertilizer on water use efficiency and yield of Indian mustard (Brassica juncea). African Journal of Biotechnology. 2011;*10*(55): 11459-11467.
13. Verma O, Singh S, Pardhan S, Kar G, Rautaray SK. Irrigation, nitrogen and sulphur fertilization response on productivity, water use efficiency and quality of Ethiopian mustard (*Brassica carinata*) in a semi-arid environment.2018;10 (2): 593 - 600
14. Rana K, Parihar M, Singh JP, Parihar M. Effect of sulphur fertilization, varieties and irrigation scheduling on growth, yield, and heat utilization efficiency of Indian mustard (*Brassica Juncea* L.). Communications in Soil Science and Plant Analysis.2020; 51(2):265-275
15. Shivran H, Kumar S, Tomar R, Chauhan GV. Effect of various irrigation schedule and sulphur levels on economics of Indian mustard [*Brassica juncea* L.]. The Pharma Innovation Journal.2021; 10(12): 2102-2104
16. Yadav RP, Tripathi ML, Trivedi SK. Yield and quality of Indian mustard (Brassica juncea) as influenced by irrigation and nutrient levels. Indian Journal of Agronomy.2010; 55: 56-59.
17. Tripathi ML, Dixit JP, Prajapati BL, Tripathi P, Singh YK. Response of Indian Mustard (Brassica juncea) to Irrigation Scheduling and Zinc Levels in Chambal Command Area of Madhya Pradesh. Journal of Soil Salinity and Water Quality.2014; 6(2):107-111.

18. Ray K, Sengupta K, Pal AK, Banerjee H. Effects of sulphur fertilization on yield, S uptake and quality of Indian mustard under varied irrigation regimes. Plant Soil Environment.2015; 61(1): 6-10
19. Nautiyal A, Barthwal A, Saxena AK. Growth and yield attributes of mustard (*Brassica juncea* (L.), *Var*. pant *Brassicca*-21 scheduled on irrigation level and row spacing. Journal of Pharmacognosy and Phytochemistry.2020; 9(2): 300-303
20. Hossain MB, Alam MS, Ripon MA. Effect of irrigation and sowing method on yield and yield attributes of mustard. Rajshahi University journal of life and earth and Agricultural Sciences.2013; 41: 65-70
21. Dadhich RK, Meena RS, Reager ML, Kansotia B. Response of bio-regulators to yield and quality of Indian mustard (*Brassica juncea* L.) under different irrigation environments. Journal of Applied and Natural Science.2015;7 (1): 52 - 57
22. Singh S, Thenua OVS. Effects of irrigation schedules and nutrient levels on mustard (*Brassica juncea L*.). National Conference on Climate Change and Agricultural Production.2017. 427-428.
23. Shivran, Kumar S, Tomar R Chauhan GV. Effect of irrigation schedules on productivity and water use efficiency in Indian mustard (*Brassica juncea L*.). International Journal of Chemical Studies.2018; 6 (4): 15-17.