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Effect of Irrigation Scheduling and Drought Alleviating Microbes on Growth and Yield of Indian Mustard (*Brassica juncea* L.)

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ABSTRACT

A field experiment was conducted at Agronomy Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar during rabi season of October, 2022 to February, 2023 to identify strategies using to improve plant growth under water deficit stress. The experiment was laid out in a split plot design with four replications, consisting of twelve treatment combinations comprising three irrigation schedules in main plot viz. 0.6 IW/CPE ratio, 0.8 IW/CPE ratio and 1.0 IW/CPE ratio and four drought alleviating microbes in sub plot viz. Control (without microbes), MRD-17, CRIDA MI-I and CRIDA MI-II. The results indicated that significantly higher growth and yield parameters viz. plant height at harvest (184.4 cm) was recorded with irrigation scheduled at 1.0 IW/CPE ratio and, CGR, RGR, dry matter accumulation at harvest (54.02, 54.20 g plant^{-1}), number of secondary branches plant^{-1} (15.92 and 15.84), number of siliquae plant^{-1} (303.3 and 286.3), seed yield (2045 and 2018 kg ha^{-1}), crop productivity (17.94 and 17.70 kg ha^{-1} day^{-1}) with irrigation scheduled at 1.0 IW/CPE and CRIDA MI-I, individually. Number of seeds per siliqua, siliqua length, test weight and harvest index of mustard were not affected by irrigation scheduling and drought alleviating microbes. Maximum net return (₹ 71486 and 71999 ha^{-1}), crop profitability (₹ 627 and 632 ha^{-1} day^{-1}) and BCR (2.68 and 2.77) was secured with irrigation scheduled at 1.0 IW/CPE and seed inoculated with CRIDA MI-I.

KEYWORDS: Irrigation scheduling, drought alleviating microbes, mustard and profitability

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

In the last three decades, the oilseeds sector has been one of the most active components of world agriculture, growing at a rate of 4.1% per year, outpacing the growth of agriculture and livestock products. The oilseeds account for 13% of the gross cropped area, 3% of the Gross National Product (GNP) and 10% value of all the agricultural commodities of the country (Anonymous, 2022b). Productivity has improved significantly in India over the last ten years, from 1185 kg ha^{-1} in 2008–09 to 1511 kg ha^{-1} in 2018–19, and production has increased from 7.20 mt in 2008–09 to 9.26 mt in 2018–19 (Anonymous, 2018–19). After the United States, China, and Brazil, India became the world's fourth largest vegetable oil economy. Mustard (*Brassica* sp.) is one of the most widely grown oilseed crop and third most prominent source of vegetable oil in the world (Jat et al., 2018). Mustard oil is used in many industrial products, oil cake is used as cattle feed and also as manure while the green leaves are used as vegetable (Patel et al., 2023). Globally, vegetable oil has one of the highest shares (40%) of the production of all agricultural commodities. Among the seven oil seeds cultivation in India, the Brassica species only contribute the 28.6% in total oil seed production (Kumar et al., 2021). India is the largest importer of edible oils ($10.5 billion) in the world followed by China and USA. India's share of world edible vegetable oil imports is about 15% (Anonymous, 2019, Rathore et al., 2020). Thus, there is inevitable need to boost the oilseed production either through area expansion or productivity enhancement. Indian mustard (*Brassica juncea* L.) is a winter season oilseed crop which thrives best in light to heavy loam soils in areas having 25–40 cm rainfall. The major constraint attributing to low production of mustard are scare and inadequate water supply, poor fertility status of soil and weed management. Generally, mustard is grown on conserved moisture and farmers apply one or two irrigations depending on the availability of water. Irrigation scheduling is one of the important managerial activities and affects the effective and efficient utilization of water by crops. It determines the process to decide when to irrigate the crop and how much water is to be applied. It optimizes agricultural production with minimizing yield loss due to water shortage and improving performance and sustainability of any irrigation system through conserving the moisture. In the recent scenario of agriculture, drought stress is considered one of the major problems reducing crop yield and productivity in various arid and semi-arid regions of the world (Vurukonda et al., 2016). Several strategies to improve the plant's potential to tolerate drought stress, such as improved agronomic practices, traditional breeding and transgenic approach, have been explored. However, these strategies involve high technical aspect and are labor and cost-intensive (Niu et al., 2018). An efficient alternative to combat drought stress in plants is the use of plant growth promoting *rhizobacteria* (PGPR). PGPRs inhabit the *rhizosphere* of the plants or are endophytic. These confer beneficial effects to the plants under drought stress conditions by various direct and indirect mechanisms (Lim and Kim, 2013, Jayakumar et al., 2020). Hence, identification and development of eco-friendly strategies using microbes that can improve plant growth under water deficit stress are an immediate need in agricultural systems.

2. MATERIALS AND METHODS

A field experiment was conducted during rabi season of October to February month of 2022–23 at Agronomy Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar (24°19' North latitude and 72°19' East longitude, with an elevation of 154.52 m above the mean sea level), Gujarat, India. The soil of the experimental field was loamy sand in texture with pH 7.3, having normal EC (0.11 ds m^{-1}), low in available nitrogen (158.60 kg ha^{-1}) and organic carbon (0.30 %), medium in available phosphorus (38.50 kg ha^{-1}), available potassium (230.00 kg ha^{-1}) and available sulphur (9.55 mg kg^{-1}). The mean maximum temperature ranged between 24.6 to 36.2°C, while mean minimum temperature ranged between 4.9 to 16.7°C during the period of experimentation. The experiment consisted twelve treatment combinations with comprised three irrigation schedules viz. I1: 0.6 IW/CPE ratio, I2: 0.8 IW/CPE ratio and I3: 1.0 IW/CPE ratio in main plots and four drought alleviating microbes viz., D_1: Control (without microbes), D_2: MRD-17, D_3: CRIDA MI-I and D4: CRIDA MI-II in sub-plots was undertaken in split-plot design (SPD) with three replications. Mustard variety GDM 4 was selected for experimental purpose. Microbes @ 75 g kg^{-1} seeds were dipped into each microbial suspension as per treatment and incubated for 4–5 hours in shed. Seeds without microbial culture served as control. The recommended dose of fertilizer for mustard crop i.e N_{50}, P_{50}, K_0 and S_{40} kg ha^{-1} was applied full dose of phosphorus, sulphur and half dose of nitrogen were applied at the time of sowing and remaining half dose of the nitrogen was top dressed at 30–40 DAS in moisturized field. First 50 mm irrigation was given immediately after sowing for proper germination. For uniform crop establishment, one common irrigation of 40 mm was applied at 5 DAS to crop irrespective of the treatment, thereafter 50 mm each flood irrigations were given as per treatments with following IW: CPE ratio. Quantity of irrigation water was measured by Parshall flume. Economics like cost of cultivation and net return were worked out by considering prevailing local market prices of inputs during the period of investigation. Net return was estimated by subtracting total cost of cultivation from gross return. Benefit: cost ratio (BCR) was worked out through dividing gross return by total cost of cultivation. Crop productivity and crop profitability was calculated by using the following formulae:

$$\text{Crop productivity (kg ha}^{-1}\text{ day}^{-1}) = \frac{\text{Seed yield (kg ha}^{-1})}{\text{Crop duration (days)}}$$

$$\text{Crop productivity (₹ ha}^{-1}\text{ day}^{-1}) = \frac{\text{Net return (₹ ha}^{-1})}{\text{Crop duration (days)}}$$

The data recorded for various parameters during the course of investigation were statistically analysed by a procedure appropriate to the design of experiment as described by (Gomez and Gomez, 1984). The significance of difference was tested by "F" test at 5 per cent level. The critical difference was calculated when the differences among treatments were found significant under "F" test. In remaining cases, only standard error of mean was worked out.

3. RESULTS AND DISCUSSION

3.1. Growth parameters

3.1.1. Effect of irrigation scheduling

Different irrigation schedules significantly influenced the crop growth viz. plant height, dry matter accumulation, CGR of mustard. Irrigation applied at 1.0 IW/CPE ratio recorded significantly higher plant height of 35.07, 134.6 and 184.4 cm respectively, which remained statistically at par with 0.8 IW/CPE ratio at 30, 60 DAS and at harvest, respectively and significantly higher dry matter accumulation of 3.60, 19.09 and 54.02 g plant^{-1} were recorded at 30, 60 DAS and at harvest, while dry matter accumulation at 30 DAS was remained at par with 0.8 IW/CPE ratio (Table 1). Such increase in plant height was due to sufficient moisture availability in *rhizosphere* providing congenial growth environment which improved the cell elongation, cell turgidity, opening of stomata and finally partitioning of photosynthates efficiently to the sink. More or less similar with (Barman et al., 2021). Accumulation of more dry matter per plant with increment in irrigation application could be attributed to the increased plant height and more number of branches per plant arising out of the better growth and development conditions facilitated desirable moisture supply at various growth stages of plant. Similar finding was also reported by (Kashved et al., 2010, Jat et al., 2018) in mustard with higher value of yield attributes and yield under 0.8 IW/CPE ratio. Significantly higher crop growth rate of 0.52 and 0.65 g m^{-2} day^{-1} was recorded with 1.0 IW/CPE at 60 DAS and at harvest respectively. Development of the roots leads to better penetration of roots to spread into deeper layers of soil so that it can uptake more nutrients from soil cause more dry matter accumulation which results into better crop growth rate. The results are conformity with (Digra et al., 2016, Barman et al., 2021). Irrigation scheduling was found non-significant for relative growth rate at 60 DAS and at harvest.

Table 1: Effect of IW/CPE ratio and drought alleviating microbes on growth parameters of mustard

Treatments	Plant height (cm)			Dry matter accumulation (g)			Crop growth rate (g m^{-2} day^{-1})		Relative growth rate (g g^{-1} day^{-1})	
	30 DAS	60 DAS	At harvest	30 DAT	60 DAT	At harvest	30-60 DAS	60 DAS-At harvest	30–60 DAS	60 DAS-At harvest
IW/CPE ratio (I)										
I_1 : 0.6 IW/CPE	30.55	120.6	167.6	3.11	15.73	44.75	0.42	0.54	0.05	0.02
I_2 : 0.8 IW/CPE	33.52	128.2	177.7	3.48	17.63	50.15	0.47	0.60	0.05	0.02
I_3 : 1.0 IW/CPE	35.07	134.6	184.4	3.60	19.09	54.02	0.52	0.65	0.06	0.02
SEm±	0.99	2.85	3.63	0.07	0.31	1.11	0.01	0.02	0.00	0.00
CD (p=0.05)	3.41	9.87	12.58	0.25	1.31	3.83	0.04	0.06	NS	NS
Drought alleviating microbes (D)										
D_1 : Control	31.59	123.3	171.1	3.34	15.97	45.39	0.42	0.54	0.05	0.02
D_2 : MRD -17	31.68	126.1	175.2	3.31	17.41	48.96	0.47	0.58	0.05	0.02
D_3 : CRIDA MI - I	34.68	132.5	181.4	3.49	19.07	54.20	0.52	0.65	0.06	0.02
D_4 : CRIDA MI - II	34.23	129.2	178.5	3.44	17.49	50.00	0.47	0.60	0.05	0.02
SEm±	1.01	2.96	4.12	0.08	0.32	1.18	0.01	0.02	0.00	0.00
CD (p=0.05)	NS	NS	NS	NS	1.19	3.42	0.039	0.055	0.003	NS

3.1.2. *Effect of drought alleviating microbes*

Plant height was statistically equal under different drought alleviating microbes. Dry matter accumulation was found significant at 60 DAS and at harvest but at 30 DAS it was non-significant. Inoculation of seed with CRIDA MI-I recorded higher dry matter accumulation 19.07 and 54.20 g plant^{-1}, higher crop growth rate 0.52 and 0.65 g m^{-2} day^{-1} at 30–60 DAS and 60 DAS at harvest, respectively and relative growth rate 0.06 g g^{-1} day^{-1} at 30–60 DAS as compared to without microbes (Table 1). The increase in dry matter accumulation might be due to the ability of these *rhizobacteria* to produce phytohormones (IAA and GA) and ACC deaminase enzyme activity during plant-rhizobacteria association under drought stress. Several *rhizobacteria* are known to synthesize phytohormones namely IAA and GA which aid in root and shoot growth. ACC deaminase producing *rhizobacteria* have the ability to reduce ethylene levels, resulting in improved root growth, thus, enhancing dry matter accumulation in plant. The results obtained in the present investigation were in accordance with findings of Bandeppa et al., 2018 reported with inoculation of *Bacillus sp.* strains for mitigation of water deficit stress in mustard, Rathi et al., 2018 in cluster bean, Asha et al., 2021 reported in mustard and Vikram et al., 2022 reported with the inoculation of Bacillus spp. MRD-17 in mustard.

3.2. *Yield attributes and yield*

3.2.1. *Effect of irrigation scheduling*

The results revealed that, different irrigation schedules didn't have any significant influence on number of seeds per siliqua, length of siliqua and 1000 seed weight (Table 2). Irrigation scheduled at 1.0 IW/CPE ratio produced significantly higher seed yield (2045 kg ha^{-1}) and crop productivity (17.94 kg ha^{-1} day^{-1}) it were remained statistically at par with 0.8 IW/CPE ratio. The positive influence of irrigation scheduling was due to adequate soil moisture in the *rhizosphere* of mustard crop which results in higher photosynthates and translocation of photosynthates towards reproductive structures. During linear phase of plant development at sufficient soil moisture status, excess photosynthates might have produced that exploited by the plant in the growth and development and thus, diverted in excess towards storage sites. But, at later phase for higher assimilate demand of plant sinks i.e., reproductive structures, more remobilization of storage compounds to active sites due to increased moisture in root zone might have enhanced the crop yield significantly. The highly significant and positive correlation established between seed yield and yield attributes confirmed the above findings by Chaudhari et al., 2016 in mustard, Digra et al., 2016 in rapeseed, Parmar et al., 2016 in mustard and Jat et al., 2018 reported higher seed yield (2539 kg ha^{-1}) of mustard was recorded with irrigation scheduled at 0.8 IW/CPE ratio.

3.2.2. *Effect of drought alleviating microbes*

Number of seeds/siliqua, length of siliqua and 1000 seed weight were found non-significant due to different drought alleviating microbes. Seed yield (2018 kg ha$^{-1)}$ and crop productivity (17.70 kg ha^{-1} day^{-1}) were significantly higher under CRIDA MI-I and it were remained statistically at par with CRIDA MI-II (Table 2). Higher seed yield and crop productivity in these treatments might be due to cumulative effect of elevated growth structure as well as yield structure. Increment in seed yield was mainly because of remarkable

Table 2: Effect of IW/CPE ratio and drought alleviating microbes on yield attributes, yield and economics of mustard

Treatments	Number of seeds siliqua^{-1}	Length of siliqua (cm)	1000 seed weight (g)	Seed yield (kg ha^{-1})	Crop productivity (kg ha^{-1} day^{-1})	Net return (₹ ha^{-1})	Crop profitability (₹ ha^{-1} day^{-1})	B:C ratio
IW/CPE ratio (I)								
I_1 : 0.6 IW/CPE	13.59	4.84	4.83	1722	15.11	57522	505	2.49
I_2 : 0.8 IW/CPE	13.76	4.98	5.17	1905	16.71	65713	576	2.62
I_3 : 1.0 IW/CPE	14.18	5.29	5.41	2045	17.94	71486	627	2.68
SEm±	0.29	0.14	0.14	53.63	0.47	2875.39	25	0.07
CD (*p*=0.05)	NS	NS	NS	185.58	1.63	9950.16	87	NS
Drought alleviating microbes (D)								
D_1 : Control	13.25	4.74	4.87	1762	15.45	57788	507	2.43
D_2 : MRD -17	13.92	5.02	5.02	1887	16.55	64610	567	2.59
D_3 : CRIDA MI - I	14.18	5.42	5.42	2018	17.70	71999	632	2.77
D_4 : CRIDA MI - II	14.01	5.24	5.24	1897	16.64	65229	572	2.60
SEm±	0.32	0.15	0.15	44.51	0.39	2402.70	21	0.06
CD (*p*=0.05)	NS	NS	NS	129.17	1.13	6971.97	61	0.17

improvement in plant height, number of secondary branches per plant, siliquae plant^{-1} and seeds siliqua^{-1} ultimately resulted from drought alleviating microbes could be producing osmolytes, which were small molecules that helped to protect plant cells from dehydration, increasing nutrient uptake and produced growth hormones that provide nutrition to the plant ultimately resulted in maximum seed yield. This result was corroborated by (Anonymous, 2021, Anonymous, 2022a, Vikram et al., 2022, Chaudhary et al., 2024) also found higher seed yield of mustard with the seed treatment of CRIDA MI-I.

3.3. *Economics*

In the different irrigation scheduling, maximum net returns of ₹ 71486 ha^{-1}, crop profitability of ₹ 627 ha^{-1} day^{-1} and B:C ratio (2.68) were obtained from irrigation given at 1.0 IW/CPE ratio followed by 0.8 IW/CPE and 0.6 IW/CPE ratio, respectively (Table 2). Among the various drought alleviating microbes, maximum net returns of ₹ 71999 ha^{-1}, crop profitability of ₹ 631 ha^{-1} day^{-1} and B:C ratio 2.77 were obtained under CRIDA MI–I followed by CRIDA MI–II.

4. CONCLUSION

Irrigation applied at 0.8 IW/CPE ratio to mustard and seed treatment with drought alleviating microbes either CRIDA MI-I or CRIDA MI-II recorded higher yield and profitability.

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