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Effect of irrigation scheduling based on water limiting conditions to growth, yield and yield response factor for mustard crop

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Abstract
Field studies were conducted at the IRS of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (Allahabad, Uttar Pradesh, India) for two consecutive seasons; November 2020 to April 2021 and November 2021 to April 2022 to investigate the effect of irrigation scheduling based on water limiting conditions on crop growth, yield and yield response factor for mustard (varuna T-59). Treatments consisted of five irrigation schedules *viz*., the I1 (irrigation at zero percent water stress of 60 mm designed depth of irrigation), I2 (irrigation at 20% water stress of 60 mm designed depth of irrigation), I3 (irrigation at 40% water stress of 60 mm as designed depth of irrigation), I4 (irrigation at 60% water stress of 60 mm as designed depth of irrigation) and I5 (Irrigation at 80% water stress of 60 mm as design depth of irrigation water).
The experiment was conducted in Random block design with three replications. All the growth, yield attributes and yield parameters were increased significantly with I3 treatment (irrigation at 40% water stress of 60 mm as designed depth of irrigation) which was significantly superior over rest of treatments. For calculation of yield response factor dependent variable, actual crop yield and independent variable including climate data were obtained from Metrological department of SHUATS (Prayagraj, UP) between 2020-2022. Potential evapotranspiration calculated by Penman-Monteith method. Actual evapotranspiration (ETa) based on irrigation scheduling was calculated at the field. Yield response factor (Ky) was obtained for five water limiting conditions *viz*., irrigation at 0%, 20%, 40%, 60%, 80% water stress of 60 mm as design depth of irrigation i.e. 60mm, 48 mm, 36 mm, 24 mm and 12mm depth of water respectively. The yield response factor (KY) was obtained by relative yield decreases to relative crop water use deficit (water stress) by regression analysis. The relative yield decreases of the mustard crop with increases in evapotranspiration deficit (water stress). It shows the response of yield with respect to the decreases in water consumptions. Yield response factor for mustard crop was determined as 1.23, 0.70, 0.29, 0.60, 0.75 for treatments I1, I2, I3, I4 and I5 (average of both year 2020-21 and 2021-22). The yield response factors developed in this study could be used in irrigation design and scheduling for mustard in the study area.

Keywords: Mustard, yield, irrigation schedule, water limiting conditions, yield response factor

Introduction

Resources of water for irrigated agriculture are militated and are gradually diminishing. "Abiotic stresses can directly or indirectly affect the physiological status of an organism by altering its metabolism, growth and development and adversely affect the agricultural productivity "(Bartles and Sunkar 2005, Vibhuti *et al*., 2015, Shahi *et al*., 2015a) [1, 14, 11]. Therefore, in irrigation-agriculture practices, there is need to emphasis on reducing water losses, increase water productivity and water reallocation. Demand of water can be minimized up to maximum extent by increasing agricultural productivity with respect to water (FAO Water reports, 2012) [4]. Agriculture is backbone of Indian economy in which Irrigation scheduling is one of the best decisions in order to save water and energy. Basically, Irrigation scheduled is a decision of when and how much water to apply to a field/ agriculture crop. Purpose of irrigation scheduling is to maximize irrigation efficiencies without comprising yield reduction by maintaining the appropriate moisture level in the soil with suitable depth of water (Geerts *et al*., 2010) [5]. There are several approaches for scheduling of irrigation-based on soil water depletion approach (water limiting conditions), plant basis/ plant indices, climatic approaches, critical growth stage approach etc., "water limiting conditions is the practice of irrigating crops deliberately below their water requirements. Such practice is aimed at minimizing water applied to the crop so as to maximize crop yield per unit of water applied." This may however lower the yield per unit area'' (FAO-56).

Mustard (*Brassica juncea* L.) belongs to the 'Cruciferae' family. In India, the mustard crop is one of the most important oilseed crops. India is the world's fourth-largest producer of oilseeds, with rapeseed and mustard accounting for 28.6% of total oilseed production (review article open 2012). During 2018-19, the world's estimated rapeseed- mustard acreage, output, and yield were 36.59 million hectares, 72.37 million tonnes, and 1980 kg/ha, respectively (Kaliya, *et al*., 2021) [6]. During the last eight years, there has been a considerable increase in productivity from 1840 kg/hain 2010-11 to 1980 kg/ha in 2018-19 and production has also 1145 kg/ ha ((Kaliya, *et al*., 2021) [6]. In Uttar Pradesh, a significant rise has been sighted in the last ten years of Mustard's area, production and yield, the production has almost become doubled. (Kaliya, *et al*., 2021) [6]. Rajasthan is the India's top producer of rapeseed and mustard, followed by Uttar Pradesh. The demand for rapeseed and mustard comes primarily from the eastern and northern parts of the country. Uttar Pradesh and Rajasthan produce more than half of the country's increased from 61.64 Mt in 2010-11 to 72.42 Mt in 2018-19. The productivity of India is the lowest among the major mustard growing countries. As against the China with highest productivity of 4.10 tones/ha, the Indian average yield was only 1.4 tonnes/ha during 2019-20. There has been a decline in area and production in Uttar Pradesh since that time (2015-16) (Rana *et al*. 2019) [10]. This downfall might be due to improper management of water and contrast shifting in micro climate pattern particularly in eastern part of Uttar Pradesh. Production and productivity of the mustard crop may be enhanced with proper management of water/ irrigation scheduling research topic, entitled "To investigate the effect of irrigation scheduled based on water limiting conditions on crop growth, yield and yield response factor for mustard crop''.

Materials and method

Field studies were conducted at research farm of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (Allahabad, Uttar Pradesh, India) for two consecutive seasons; November 2020 to April 2021 and November 2021 to April 2022. Allahabad is situated in the South -eastern part of the State Uttar Pradesh. It lies between the parallels of 24°77´ and 25°47´ north latitudes and 81°21´and 82°21´ east longitudes. The climate of a UP is mainly characterized by humid subtropical climate in which summers are typically long, hot and humid. Summers are extremely hot, while winters are fairly cool. During the experiment, maximum duration of sunshine and depth of pan evaporation were recorded in the month of April, while the minimum duration of sunshine and depth of pan evaporation were recorded in the month of December and January. Soil of the experiment field was sandy loam in texture. At 0 -15 cm depth, soil contains 64.9% sand, 21.8% silt, 13.3% clay, 0.17 ds/m electric conductivity, 1.19 g/cm-3 bulk density with 8.0 pH of soil. The experiment was laid out in random block Design with 3 replications and five treatments. The treatments comprised of 5 irrigation schedules *viz*., I1(irrigation at zero percent water stress of 60 mm designed depth of irrigation), I2 (irrigation at 20% water stress of 60 mm designed depth of irrigation), I3(irrigation at 40% water stress of 60 mm as designed depth of irrigation), I4 (irrigation at 60% water stress of 60 mm as designed depth of irrigation) and I5 (Irrigation at 80% water stress of 60 mm as design depth of irrigation water).

The soil water availability for sandy loam soil at research station was found to be 120mm. The soil moisture at field capacity was found to be at 35%. The total available water (TAW) was calculated using the methodology to understand maximum amount of water that can be evaporated (FAO-56). This part of research intends to quantify the average fraction of the total available soil water that can be depleted from the root zone before moisture stress. This depleted fraction referred as a function of the evaporating power of atmosphere. It is also called depletion fraction as per the experimental design and recommended by the FAO-560 in the chapter of evaporation under soil stress conditions. The depletion for mustard is taken as 0.5 with a maximum rooting depth of 1 to 1.5 metre. In the first treatment the mustard plants are made to experience no stress or 0% water stress of60 mm as designed depth of irrigation. However, for the remaining four treatment the irrigation amount is reduced by 20%, 40%, 60% and 80% of 60 mm as designed depth of irrigation. In first treatment the values of depletion faction (p) remain at 0.5 while the sought-after depletion fraction lies beyond 0.5 to that value of which (TAW) when applied, does have an influenced upon the yield but insignificant. This can be seen in the results (Table 1.0), while in first treatment the depth of irrigation remains at 60 mm. The second, third, fourth and fifth treatment received 48 mm, 36 mm, 24mm and I2 mm respectively. Thus, creating moisture stress from 0% to the lower limit of radial available water. In all the cases the irrigation depth doesn't cross total available water depth (120 mm). However, in the second treatment it is deemed that beyond the maximum allowable deficit of 60mm depth, the second treatment may be extracting water 12 mm beyond the maximum allowable deficit level. Similarly, the third, fourth, and fifth treatment may be extracting water beyond maximum allowable deficit by 24mm, 36mm and 48mm. Under all the conditions moisture is made available in the root zone however moisture stress varying.

Crop yield response factor to water: The yield response factor (Ky) is ratio of "relative yield reduction to relative evapotranspiration deficit. It is the factor that integrates the weather, crop and soil conditions that make crop yield less than its potential yield in the case of deficit evapotranspiration. The upper limit for yield is set by soil fertility, climatic conditions and management practices. Where all of these are optimal throughout the growing season, yield reaches the maximum value as does evapotranspiration. Any significant decrease in soil water storage has an impact on water availability for a crop and subsequently, on actual yield and actual evapotranspiration. A standard formulation relates these four parameters to a fifth: the yield response factor, which links relative yield decrease to relative evapotranspiration deficit, as follows:

The yield response factor was computed by using the Doorenbos and Kassam (1979) equation rearranged as,

$$\left(\mathbf{1}-\frac{Ya}{Ym}\right) = \boldsymbol{ky}\left(\mathbf{1}-\frac{ETa}{ETm}\right) \ldots\ldots\ldots (1.0)$$

Ya = actual yield (t/ha), Ym = maximum yield (t/ha), ETa = actual evapotranspiration (mm), ETm = maximum evapotranspiration (mm). Ky = yield response factor of mustard crop to deficit irrigation. yield response factor, (Ky) "captures the essence of the complex linkage between production and water use by a crop, where many biological, physical and chemical processes are involved". The relationship has shown a remarkable validity and allowed a workable procedure to quantify the effects of water deficits on yield. Ky values are crop specific and vary over the growing season according to growth stages. If, Ky > 1 crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced because of stress. Ky < 1 crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use. Ky = 1 yield reduction is directly proportional to reduced water use. ETa: Actual evaporation is a major component of the hydrological cycle and one of the most important physical processes in natural ecosystems. It explains the exchange of water and energy between the soil, land surface and atmosphere. In this research total depth of water taken as actual ETa. Actual ETa was obtained for five water limiting conditions *viz*., irrigation at 0%, 20%, 40%, 60%, 80% water stress of 60 mm as design depth of irrigation i.e., 360mm, 288mm, 216mm, 144 mm and 72mm depth of water respectively for six irrigation frequency (Table: 4.0). Maximum ETm or potential evapotranspiration, is a measure of the ability of the atmosphere to remove water from the surface by evapotranspiration when there is ample water and calculated from the formula given in FAO-56.

Results and Discussion

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads:

Table 1: Irrigation details of all treatments influenced by soil-water limiting conditions

Total available water (TAW) =120 mm Depletion fraction = 0.5 Depth of irrigation =60 mm				
Treatment	**Level of irrigation**	**Depth of irrigation (mm)**	**Irrigation frequency**	**Total depth of irrigation (mm)**
I1	1	60	6	360
I2	0.8	48	6	288
I3	0.6	36	6	216
I4	0.4	24	6	144
I5	0.2	12	6	72

Effect of irrigation scheduling on growth parameter of mustard crop: Various irrigation schedule was affected significantly on the growth attributing characters *viz*., plant height, number of leaves, number branches per plant, leaf area index and dry matter accumulation per plant, of the crop. The data pertaining to growth attributes (pooled data of two-year experiment 2020-2021 and 2021-22) are given in Table 2.0. Among irrigation schedule, the highest plant height (151.7 cm at harvest time), number of leaves (35.7) per plant at 90 DAS and leaf area index (5.3) at 60 DAS, number of branches per plant (22.8) and dry matter accumulation per plant (40.7 g per plant),) at harvest time were recorded in treatment I3 (at irrigation level 0.6 with 40% moisture stress of design depth of irrigation) which was the significantly superior over rest of the irrigation schedule. Crop water requirement of mustard is low as compared to other crops. It is very sensitivity to water stress during vegetive to early flowering stage (Singh *et al*. 1991) [13]. Result revealed that irrigation level 0.6 with 40% moisture stress, is most optimal condition for growth parameter of mustard whilst minimum growth parameter observed in treatment I4 and I5 (at irrigation level 0.4 with 60% and at irrigation level 0.2 with 80% of moisture stress of design depth of irrigation) due to developed of moisture stress on crop. Highest dry matter accumulation was recorded due to increased plant height, number of leaves and branches. Growth parameter significantly increased at 60 to 90 days after sowing whilst in contrast number of leaves decreases very fastly between 90 to120 DAS due to abscission of mustard leaves. However, in case of number of branches, number of branches per plant in treatment I1and I4 was found at par to each other may be due to certation of same climate environment near surrounding to those plants. Leaf area index in two irrigation treatment I2 and I3 treatment was significantly superior as compared to other treatment at 60 and 90 DAS may be due to adequate moisture level, favourable climatic condition near the crop surrounding area. Patel *et al*. (2017) [8] recorded the significantly higher value of leaf area index of 4.5 of the Varuna T-59 at 60 DAS.

Table 2: Pooled analysis of growth characters of mustard as influenced by water limiting conditions.

Treatment	Plant height (cm) at harvest time	Number of leaves per plant at 90 DAS	Number of branches per plant at Harvest time	Leaf area index at 60 Days	Dry matter accumulation (g plant^{-1}) at harvest time
I1	120.0	32.0	18.7	0.31	36.0
I2	147.9	33.2	20.0	0.41	38.1
I3	151.7	35.7	22.8	0.69	40.7
I4	157.1	29.0	18.7	0.12	32.2
I5	142.7	28.0	17.0	0.09	30.1
S.E(m)	1.2	0.7	0.73	0.10	0.32
LSD (=0.05)	1.04	2.35	2.44	0.33	1.05

Effect of water limiting conditions on yield attributing and yield character: Effect on yield attributing character: It is evident from the data shown in Table-3.0 that irrigation schedule based on water limiting conditions influenced the yield attributing (Pooled data of two-year experiment 2020-2021 and 2021-2022) character like no. of siliqua plant-1, length of siliqua, number of seed siliqua-1 significantly. The maximum no. of siliquae plant-1 (338.0), length of siliqua (5.3 cm) and no. of seed siliqua-1 (16.13) were recorded in treatment I3 (at irrigation level 0.6 with 40% moisture stress of design depth of irrigation) which was the significantly superior over rest of the irrigation schedule. Minimum yield attributing character were observed in treatment in I5 (at irrigation level 0.2 with 80% water stress of design depth of irrigation). The characteristics of yield that determine yield are a by-product of the plant's vegetative growth. It may recall that the reproductive organs are mostly resulted by the vegetative growth that occurs at the beginning of floral primordia, which occurs considerably earlier than the emergence of siliqua. This may be the result of favourable vegetative growth and development with sufficient moisture in the soil. Increased in photosynthetic activity and the transfer of photosynthesis from source to sink occur in presence of adequate moisture. Nagdive *et al*. (2007) [7] and Phogat *et al*. (2009) [9] also outlined similar findings.

Effect on yield: Irrigation scheduling based on water limiting conditions significantly affected the stover yield and grain yield and Pooled data of two-year experiment 2020-2021 and 2021-2022 are presented in the Table-3.0. The maximum seed yield (2.25 t ha-1) and stover yield (7.0 t ha-1) were recorded under treatment I3 (at irrigation level 0.6 with 40% moisture stress of design depth of irrigation) which was significantly superior over rest of the irrigation schedule. Seed yield was 22.02, 34.73, 47.05 and 125.0% more than I2(at irrigation level 0.8 with 20% moisture stress of design depth of irrigation), I1 (at 1.0 irrigation level with zero percent moisture stress of design depth of irrigation), I4 (at 0.4 irrigation level with 60% moisture stress of design depth of irrigation) and I5 (at 0.2 irrigation level with 80% moisture stress of design depth of irrigation) respectively. Among all treatments minimum yield was recorded under treatment I5. Minimum stover yield 4.69 ton /ha was also observed in treatment I5. For yield and yield attributes, most appropriate condition was observed in treatment I3 (irrigation level 0.6 with 40% moisture stress) whilst most unfavourable condition for production of mustard was observed in treatment I5(irrigation level 0.2 with 80% moisture stress) due to higher moisture stress rather than other treatments. The yield of any crop species depends upon the source-sink relationship and is the cumulative function of various growth parameters and yield attributing characters *viz*., number of branches at harvest, siliquae length (cm), numberof siliquae per plant, number of seed per siliquae, 1000-seed weight (g), seed yield (ton ha-1), harvest index. Stronger source is required to develop stronger sink. Maximum (24.53) and minimum (16.93) harvest index observed under treatment I3 (irrigation level 0.6 with 40% moisture stress) and I5(irrigation level 0.2 with 80% moisture stress) respectively. Higher values of harvest index were recorded at appropriate frequency of irrigation because of the fact adequate moisture might have helped in more translocation of photosynthesis leading to more harvest index. Since, economic yield is only a fraction of dry matter produced, the harvest index forms a useful measure of yield potential and is relatively easy to measure on a large number of plants (Bhatt,1976) [3]. Singh and Stockpof (1971) [12] also conducted reduction in plant height lowered the stalk yield which reflected in an increased harvest index. They also reported that harvest index was positively correlated with grain yield but negatively correlated with vegetative growth.

Table 3: Effect of water limiting conditions on yield attributing of mustar dcrop

Treatment	No. of siliquae plant^{-1}	Length of siliqua (cm)	No. of seeds siliqua^{-1}	1000 seed weight (g)	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Harvest index%
I1	284.0	4.5	12.9	5.1	1.67	6.5	20.6
I2	298.83	4.8	14.6	5.3	1.85	6.5	22.0
I3	338.0	5.3	16.1	5.3	2.25	7.0	24.4
I4	265.33	4.3	11.9	4.4	1.53	6.2	19.4
I5	209.67	4.1	9.8	3.9	0.96	4.7	16.9
S.E(m)	0.39	0.01	0.09	0.13	0.189	0.37	1.09
LSD (=0.05)	1.31	0.02	0.28	0.43	0.057	0.11	0.33

Yield Response factor for mustard crop influenced by water limiting condition

The yield response factor (Ky) indicates a linear relationship between the decrease in relative water consumption and decrease in relative yield (Bhagyawanta *et al*. 2015) [2]. It shows the response of yield with respect to the decrease in water consumption. In other words, it explains the decrease in yield caused by the per unit decrease in water consumption. Hence regression analysis was used to find the values of Ky. The different values of pooled (mean of two-year experiment 2020-21 and 2021-22) yield response factor was observed for individual treatments during total crop period for water limiting conditions Plot presented in Table: 4.0. The yield response factor (Ky) for entire growing period varied from 0.29 to 1.23. The highest value of (Ky) 1.23 was recorded in treatment I1 whilst lowest 0.29 was observed in treatment I3 with ETa values 360 mm and 216 mm respectively. Which quantify less moisture stress regarding yield. From Fig.1.0., concept of yield response factor quantifies that, the crop with higher value of Ky suffered a greater yield loss than the crop with a lower Ky value. Therefore, the order of relative sensitivity to water deficit treatment for entire cropping period can be written as: I1>I5>I2>I4>I3. Both the likely losses in yield and adjustment required in water supply to minimize such losses can be quantified. Similarly, such quantification is possible when the likely yield losses arise from differences in the Ky of individual growth periods. Irrigation water applied when soil moisture reached up to 16-18%. The variation in yield response factor may be due to the effect of the variation of water stress, soil type, climate, and cultivar. The yield response to water deficit of different crops is a of major importance in production planning. Milla, AJ., *et al*. (2016) reported about Ky values of mustard for the whole growing period, were 0.52, 0.96, 1.17, 0.13, and 0.75 for water deficit at pre-flowering + pod formation, vegetative + pod formation, vegetative + pre-flowering, pre-flowering, and vegetative stages, respectively.

Table 4: Pooled analysis of Yield response factor for mustard crop influenced by water limiting conditions.

Treatment	Actual yield (Ya.) ton/ha	Potential yield (Ym) ton/ha	Actual ET (ETa) Mm	Potential ET (ETm) mm	(1-Ya/Ym)	(1-ETa/ETm)	Pooled (Ky)
I1	1.67	2.7	360	519.11	0.381	0.31	1.23
I2	1.85	2.7	288	519.11	0.316	0.45	0.7
I3	2.25	2.7	216	519.11	0.166	0.58	0.29
I4	1.53	2.7	144	519.11	0.432	0.72	0.6
I5	0.96	2.7	72	519.11	0.645	0.86	0.75

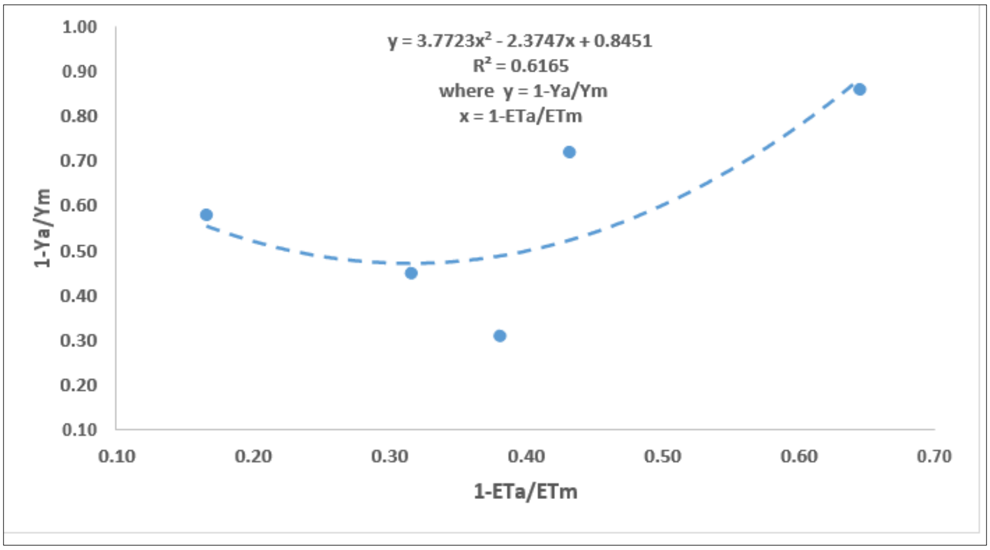

Fig 1: The Relation between reduction in relative mustard yield (1-Ya/Ym) to reduction in relative evapotranspiration (1-ETa/ Etm) (average)

Conclusions

Conclusively maximum plant height (151.7 cm), number of leaves (35.7) per plant and leaf area index (5.3) at 60 DAS, number of branches per plant (22.8) and dry matter accumulation per plant(40.7 g per plant),) were recorded in treatment I3 (at irrigation level 0.6 with 40% moisture stress of design depth of irrigation). The maximum no. of siliquae plant-1 (338.0), length of siliqua (5.3 cm) and no. of seed siliqua-1 (16.13) were recorded at irrigation level 0.6 with 40% moisture stress of design depth of irrigation. The maximum seed yield (2.25 t ha-1) and stover yield (7.0 t ha-1) were also recorded under treatment I3.Result revealed that irrigation level at 0.6 with 40% moisture stress, is most optimal condition for growth parameter of mustard. Highest dry matter accumulation was recorded due to increased plant height, number of leaves and branches. Higher values of harvest index were recorded at appropriate frequency of irrigation because of the fact adequate moisture might have helped in more translocation of photosynthesis leading to more harvest index. The highest value of Ky 1.23 was recorded in treatment I1 whilst lowest 0.29 was observed in treatment I3 with ETa values 360 mm and 216 mm respectively. Concept of yield response factor quantifies that, the crop with higher value of Ky suffered a greater yield loss than the crop with a lower Ky value. Yield response factor shows the response of yield with respect to the decrease in water consumption. In other words, it explains the decrease in yield caused by the per unit decrease in water consumption.

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