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A.J. MILA AND M.H. ALI

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IRRIGATION-YIELD RESPONSE FACTOR OF MUSTARD AT DIFFERENT GROWTH PHASES

A.J. MILA[1*] AND M.H. ALI[2]

[1]Irrigation and Water Management Division, Bangladesh Agricultural Research Institute (BARI), Gazipur-1701, Bangladesh; [2]Agricultural Engineering Division, Bangladesh Institute of Nuclear Agriculture (BINA), P.O. Box 04, Mymensingh 2200, Bangladesh.

*Corresponding author & address: Afrin Jahan Mila, E-mail: afrinbau@gmail.com
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ABSTRACT

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Yield response factor (k_y) of Mustard (*Brassica rapa* L.) was determined from field experimental data at Bangladesh Agricultural Research Institute, Gazipur during two consecutive years (2012 to 2013). There were six irrigation treatments: sprinkler irrigation at vegetative stage; sprinkler irrigation at pre-flowering stage; sprinkler irrigation at pod formation stage; sprinkler irrigation at vegetative + pod formation stage; sprinkler irrigation at pre-flowering + pod formation stage; and basin irrigation at vegetative, pre-flowering, and pod formation stage; respectively. The k_y value varies depending on growth stages as well as among seasons. Overall, the k_y for pre-flowering + pod formation, vegetative + pod formation, vegetative + pre-flowering, pre-flowering, and vegetative stages were 0.15, 0.16, 0.27, 0.03, and 0.08, respectively. According to the value of yield response factor, the most critical growth stages were in the order: vegetative + pre-flowering>vegetative + pod formation>pre-flowering + pod formation>vegetative>pre-flowering stage. For the whole growing period, the k_y values 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. There were no statistical difference in paired't' test at 5% level of significant for individual growth stages and entire growth period. The sensitivity index (lembda i, of Jensen model) for pre-flowering + pod formation, vegetative + pod formation, vegetative + pre-flowering, pre-flowering, and vegetative stages were 0.07, 0.08, 0.13, 0.009, and 0.03, respectively. Therefore, vegetative and pre-flowering stages were the critical stages to water deficit and water supply is utmost important to reduce excessive yield loss.

Key words: *mustard, yield response factor, sensitivity index, deficit irrigation*

INTRODUCTION

Decreasing water resources and unavailability of natural rainfall creates a big threat for agricultural crop production. The main reason is that most of the rainfall occurs during the month of June to September and no or very little amount occurs at the month of October to February i.e., winter season. At that time, agricultural crop production is mainly depend on irrigation water, which mainly comes from groundwater. Due to huge pressure on groundwater, this resource is decreasing and creates salinity and arsenic problem (Ashraf and Ali, 2015; Ali *et al.* 2012; Chowdhury 2010; Sarkar *et al.* 2010; Haque 2006 and Ahmad 2004). As water is the main input for agricultural crop production all over the world, so it is necessary to give importance to its efficient utilization. At the same time, water scarcity reduced irrigated crop production to a large extent. To cope with this, we need to find out crop yield response factor (k_y) for individual crop what Doorenbos and Kassam (1979) did for some crops. Its value more than one indicate more stress and from this value, critical stage can be determined. By knowing this value, farmers can get optimum yield without withdrawing irrigation water at that stage if water scarcity persist. Therefore, for proper scheduling of irrigation water, to know the k_y value for individual and entire growth stage is utmost important. It also helps to save irrigation water cost and minimize excessive groundwater withdrawal.

Crop yield response factor vary from location, variety, season, and also for individual growth stages as well as entire growing period. Therefore, it is necessary to find out location specific crop response factor for economic water management. For both adequate and limited water supplies in field situation, Doorenbos and Kassam (1979) develop an empirical relationship to quantify crop yield response factor, which is the relationship between relative yield decrease and relative evapotranspiration deficit. Therefore, for optimum crop production and water productivity, this equation can give an outline for water management planning (Ali 2009).

Mustard (*Brassica rapa* L.) is an important, short durated oilseed crop (Naznin *et al.* 2015). It can easily be fitted in any cropping pattern across Bangladesh (Rahman *et al.* 2015; Ali *et al.* 2013 and Sarkar *et al.* 2013). It is also a winter loving crop which contributes to meet countries oil demand. Therefore, the information on crop yield response factor or sensitivity factor is essential to minimize yield loss of mustard under water scarce situation with the objective of proper water management. Hence, this study has been undertaken to determine yield response factor (for each growth periods and entire growing season) and sensitivity index (for each growth periods) of mustard under water scarce situation and to find out water sensitive growth stage.

MATERIALS AND METHODS

The field experiment was conducted during 2012 and 2013 at the research fields of Bangladesh Agricultural Research Institute, Gazipur (latitude $23^o99^{\prime\prime}$N, longitude $90^o41^{\prime\prime}$E, and elevation of 8.40 m above mean sea level). The soil texture of the study fields are sandy clay loam with upper and lower limits of available water were 0.30 and 0.14 m^3m^{-3} for Gazipur (Mila *et al.* 2015). The soil characteristic was acidic (pH = 5.98), low in organic matter (0.74%), and with basic infiltration rate of 4.0 mm/hr.

The local climate is subtropical monsoon, with average annual rainfall of about 1898 mm. The mustard which is normally grown from November to February, is characterized by dry winter with 12 and 0 mm rainfall in the year 2012 and 2013, respectively (Fig. 1). At the initial stage reference ET_0 was higher and decreased at the mid-stage and again raised at the late stage (Fig. 1).

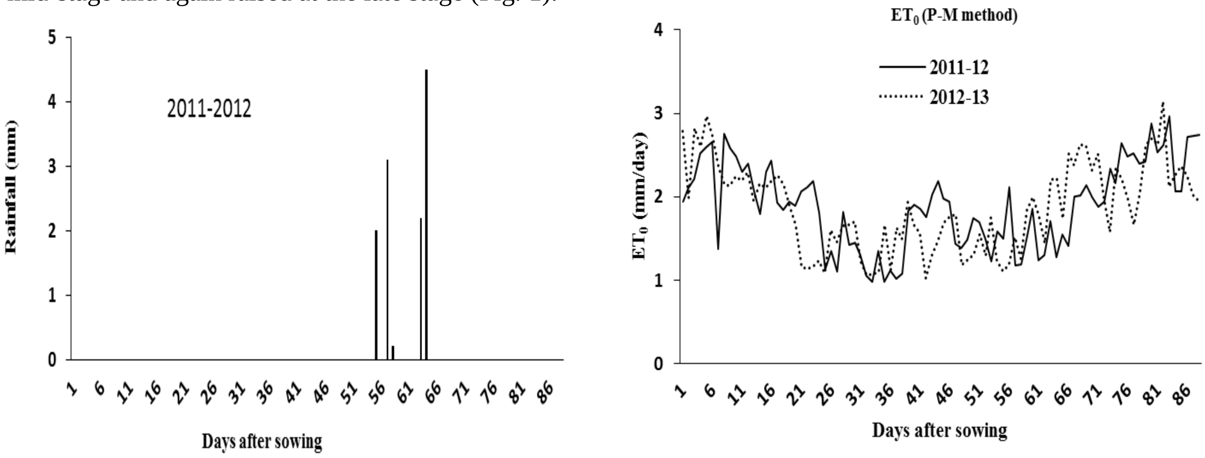

Fig. 1. Rainfall and reference evapotranspiration (ET_0, Penman-Monteith method) during the study period

The mustard variety (BARI Sarisha-14) is characterized by short durated and high yield potential (average 1.4 to1.6 tha^{-1}) (ATHB 2014). Total growing period of this crop is 80 to 90 days depending on cultivar, climatic conditions etc. There were three phonological stages which are vegetative, pre-flowering and pod formation stages. The water deficit was imposed at various phonological stages with the design of the treatments. Irrigation treatments were arranged as full irrigation (basin method), 100% water deficit at single and two stages by keeping rest of the stages well irrigated (sprinkler irrigation). The detailed irrigation treatments along with different growth phases are given in Table 1.

Water deficit was created by keeping no irrigation at different growth stages. Irrigation was applied up to field capacity considering effective root zone depth of 60 cm (where 80% of the root is concentrated (Ali 2009). The experimental design was Randomized Complete Block (RCB) with three replications. The plot size and spacing were 3.9 m × 4.95 m and 30 cm ×15 cm, respectively. The crop was harvested manually and yield data was taken by adjusting soil moisture at 12%.

Table 1. Definition of irrigation treatments according to plant growth phases (with different DC)

Treatments	Irrigation at 3 plant growth phases with DC		
	Vegetative	Pre-flowering	Pod formation
T_1	1	0	0
T_2	0	1	0
T_3	0	0	1
T_4	1	0	1
T_5	0	1	1
T_6	1	1	1

Note: DC = 1 means irrigating 100% of the root zone deficit (i.e. FC–Mc) and 0 means no irrigation or water deficit

Crop yield response factor (k_y), expresses crop sensitivity to water deficit (drought/stress) can arise throughout the entire cropping period as well as individual growth periods was calculated by following Stewart model (Stewart *et al.* 1977). By contrast, Jensen model (Jensen 1968) can calculate only individual growth stages sensitivity index (λ_i). The detailed procedure of both models is discussed below.

Calculation of crop response factor from Stewart model

According to Stewart model sensitivity differs significantly with the growth phases and this model runs well in this situation. His equation derives from the relationship between relative yield decrease and relative evapotranspiration deficit in assuming all production factors at their optimum level. The ratio of actual to maximum evapotranspiration (ET/ET_m) is called water deficit factor which regulates the final yield.

$$\frac{Y}{Y_m} = \prod_{n=1}^{m}\left[\mathbf{1} - K_y(n)\left(\mathbf{1} - \frac{ET}{ET_m}\right)n\right] - - - - - - - - - - - - (\mathbf{1})$$

Where, Y is the actual yield, Y_m is the maximum yield without water deficit during the growing season, ET is the actual evapotranspiration and ET_m is the maximum evapotranspiration, *n* is generic/total growth stage, *m* is the number of growth stage considered, and k_y is the yield response factor. Here, Stewart used different coefficient for each growth stage.

Therefore, k_y was determined by following the procedure given by (Doorenbos and Kassam, 1979). As this is the best method and many scientists are till now rely on this in calculating crop yield response factor for different crops (Majnooni-Heris *et al.* 2014; Ali 2009; Demir *et al.* 2006; FAO 2002 and Kirda *et al.* 1999). The procedure was as follows:

- At first, maximum yield (Y_m) of mustard was determined which influenced by climate, in assuming other factors such as water, fertilizer, pests and diseases do not limit yield.
- After that, maximum evapotranspiration (ET_m) was calculated when available water supply and crop water requirement are coincide in one point.
- Actual evapotranspiration (ET_a) was calculated depending on factors relating to available water supply to the crop.
- Finally, actual seed yield (Y_a) under water deficit condition was derived by the relationship of relative yield decrease with relative ET deficit.

$$1 - \frac{Y_a}{Y_m} = K_y\left(1 - \frac{ET_a}{ET_m}\right) ---------- (2)$$

or,

$$K_y = \frac{1 - \frac{Y_a}{Y_m}}{1 - \frac{ET_a}{ET_m}} ------------ (3)$$

To know more about this, please refer to Doorenbos and Kassam (1979). They determined k_y values for individual growth stages as well as for entire cropping period, for different crops. However, for whole growing period, k_y value was determined on the effect of evapotranspiration under water stress by using equation 2. On the other hand, for individual growth period (i), k_y value was determined on the effect of stage specific evapotranspiration under water stress by using equation 3. This value varies according to various species, variety, irrigation method and management practices, and different phenological stages when deficit evapotranspiration is imposed (Kirda 2002).

Calculation of Crop sensitivity index from Jensen model

According to Jensen model (Jensen 1968), crop sensitivity to water deficit was determined by using a production function for individual growth stages on grain yield was

$$\frac{Y}{Y_m} = \prod_{i=1}^{n}\left(\frac{ET_i}{ET_m}\right)^{\lambda_i} -----------(4)$$

where, Y is grain yield under water deficit condition, Y_m is the maximum yield with the situation of maximum evapotranspiration (ET_m) under no water deficit during the entire crop cropping period, ET_i is the actual evapotranspiration during the growth stage *i*, λ_i is the sensitivity index of crop to water deficit at *i*-th stage, and *i* the individual growth stage (for mustard it was 3).

For easy application of irrigation practice, Tsakiris (Tsakiris 1982) proposed a modified method from Jensen model. He illustrated the procedure of this model using data for grain sorghum. However, crop sensitivity index, λ_i, was determine by following the procedure derived by Tsakiris. Therefore, the equation (4) can be written as:

$$\frac{Y_i}{Y_m} = \prod_{i=1}^{m}(\omega_i)^{\lambda_i} \qquad 0 < \omega i < 1 ---------- (5)$$

Where, ω_i is the relative evapotranspiration (= $\frac{ET_i}{ET_m}$) which is the ratio of evapotranspiration for i-th stage and maximum evapotranspiration for the crop period.

If water deficit is imposed to a specific growth stage, consider, i-th stage, then, ω_i is equal to 1(one) for all growth stages except i-th stage. Hence, the equation (5) can be written as:

$$\frac{Y_i}{Y_m} = \omega_i^{\lambda_i}$$

or,

$$Log\left(\frac{Y_i}{Y_m}\right) = \lambda_i \; Log\; \omega_i ------------ (6)$$

Therefore, by knowing all the parameters from equation 6, λ_i value for each growth stages can be calculated.

Uniformity coefficient for the k_y and λ_i values

The uniformity coefficient (UC) of the yearly k_y and λ_i values were determined by following (Devitt *et al*. 1992) as

$$UC = 1 - \left(\frac{standard\ deviation}{mean}\right) ------------(7)$$

RESULTS AND DISCUSSION

Yield response factor for individual growth stage

Table 2 represents yield response (k_y) factor for three growth stages. This value varies depending on season, location and intensity of water deficit. During 2012, the highest k_y value was found at vegetative + pre-flowering stage followed by vegetative + pod formation stage. The lowest value was found at pre-flowering stage. This result was consistent with the year 2013. This was also proved by the value of uniformity coefficient which was very close to 1. In addition to, non-significant variation was found in paired '*t*' test at 5% level of significant between two years data. Therefore, it can be reported that there was no statistical difference between two years data. Within two years k_y value was found comparatively higher in the year 2013. This was because of no rainfall during this season consequently no water is supplemented.

On an average, the highest yield response factor of 0.27 was found at vegetative + pre-flowering stage. The water stress at vegetative + pod formation, pre-flowering + pod formation, vegetative and pre-flowering stage exerted 40.74%, 44.44%, 70.37%, and 88.89% less stress than most stressed treatment (T_3). Therefore, the order of water deficit for individual growth stages can be written as: vegetative + pre-flowering>vegetative + pod formation>pre-flowering + pod formation>vegetative>pre-flowering. Martyniak (2008) reported that drought tolerance varies strongly between growth stages for many crops. Therefore, water stress at vegetative + pre-flowering stage will not be allowed because of yield reduction was found higher than other stages (Table 3). Flowering stage was the critical stage to water deficit for oil seed rape (Istanbulluoglu *et al.* 2010). Michael (2014) found that pre-flowering stage was the most sensitive to water deficit followed by pod formation stage on the basis of crop yield response factor.

Previously, Doorenbos and Kassam (1979) determined the response factor of some oil seed crop. They determined the k_y value of safflower at vegetative, flowering and yield formation stage was 0.3, 0.55, and 0.6, while for soybean 0.2, 0.8, and 1.0 and for sunflower 0.25, 1.0 and 0.8, respectively. It was observed that yield formation stage was the most critical stage to deficit irrigation followed by flowering stage for safflower and soybean white, flowering stage was the most critical stage to deficit irrigation for sunflower cultivation.

Table 2. Yield response factors (k_y) of mustard at different growth stages

Treatments	Growth	k_y value		Mean	Standard deviation (SD)	Uniformity coefficient (UC)	Coefficient of variance (CV)
		2012	2013				
T_1	Pre-flowering + pod formation	0.15	0.14	0.15	0.0071	0.95	0.047
T_2	Vegetative + pod formation	0.16	0.15	0.16	0.0071	0.96	0.044
T_3	Vegetative + pre-flowering	0.26	0.27	0.27	0.0071	0.97	0.026
T_4	Pre-flowering	0.02	0.03	0.03	0.0071	0.76	0.24
T_5	Vegetative	0.07	0.08	0.08	0.0071	0.91	0.088

Table 3. Grain yield (ton/ha) under different treatments

Treatments	Grain yield (t/ha)		
	2012	2013	Mean
T_1	1.23C	1.19C	1.21
T_2	1.21C	1.17C	1.19
T_3	1.09D	1.03D	1.06
T_4	1.38A	1.34A	1.36
T_5	1.31B	1.28B	1.30
T_6	1.41A	1.37A	1.39
LSD (5%)	0.036	0.036	-
CV	1.57	1.63	-

Yield response factor for whole growing period

The different values of response factor were observed for individual treatments during total crop period (Table 4). This was increased according to the intensity of imposing water deficit. During 2012, the yield response factor (k_y) for entire growing period varied from 0.1 to 1.10, while during 2013 it varied from 0.16 to 1.24, respectively. The highest value was observed in treatment T_3 where sprinkler irrigation was applied at pod formation stage followed by treatment T_2. The lowest was observed in treatment T_4 where sprinkler irrigation was applied at vegetative + pod formation stage. This result was consistent with the year 2013. The uniformity coefficient value ranges from 0.67 to 0.84 and non-significant variation was observed in paired '*t*' test at 5% level of significant at two years data. Therefore, it can be reported that there was no statistical difference between two year's data.

On an average, treatment T_1, T_2, T_4 and T_5 exerted 79.53%, 56.30%, 94.88% and 70.47% less stress compare to most stressed treatment. Also, it was observed that higher stress was observed in the year 2013 than in the year 2012. This was due to the effect of no rainfall in the year 2013. Therefore, the order of relative sensitivity to water deficit treatment for entire cropping period can be written as: $T_3 > T_2 > T_5 > T_1 > T_4$.

Majnooni-Heris (2014) found the canola k_y value of 0.93 for whole growing season. Istanbulluoglu *et al.* (2010) found the seasonal yield response factor of 0.87 for oilseed rape. The yield response factor of some oil seed crop for entire cropping season was determined by Doorenbos and Kassam (Doorenbos and Kassam, 1979). They found the k_y value of safflower, soybean, and sunflower of 0.8, 0.85, and 0.95 for entire cropping period. In our study, the highest value of k_y was 1.17 by imposing water deficit at critical growth stages (vegetative + pre-flowering). This variation with previous findings was due to the effect of the variation of water deficit, soil type, climate, and cultivar.

Table 4. Yield response factors (k_y) of mustard for entire growth stages

Treatments	**Growth**	**k_y value**		**Mean**	**Standard deviation (SD)**	**Uniformity coefficient (UC)**	**Coefficient of variance (CV)**
		2012	**2013**				
T_1	Pre-flowering + pod formation	0.46	0.58	0.52	0.085	0.84	0.16
T_2	Vegetative + pod formation	0.85	1.07	0.96	0.156	0.84	0.16
T_3	Vegetative + pre-flowering	1.10	1.24	1.17	0.099	0.92	0.08
T_4	Pre-flowering	0.1	0.16	0.13	0.042	0.67	0.32
T_5	Vegetative	0.58	0.92	0.75	0.24	0.68	0.32

Sensitivity index of Jensen model

Table 5 represents the drought sensitivity index (lambda i, λ_i) of mustard for three growth stages. This value was dictated by timing and amount of water stress. The λ_i values varied with different growth stages according to the arrangement of the treatments. For individual growth stages, the λ_i value varies from 0.008 to 0.13, depending on season and growth stage. During 2012, the highest value was observed at vegetative + pre-flowering stage followed by vegetative + pod formation stage and lowest was observed at pre-flowering stage. This result was also similar with the year 2013. This was because of uniformity coefficient which varies from 0.76 to 0.95. Besides, non-significant differences were observed by paired '*t*' test at 5% level of significance among λ_i values in two years. Therefore, it can be concluded that there was no statistical difference between two years data.

On an average, the highest sensitivity index of 0.13 was found at vegetative + pre-flowering stage. The λ_i value at pre-flowering + pod formation, vegetative + pod formation, pre-flowering, and vegetative stage were 46.15%, 38.46%, 93.08% and 76.92% lower compared to the most stressed treatment (T_3). Hence, the order of sensitive stage to water deficit can be arranged as: vegetative + pre-flowering > vegetative + pod formation> pre-flowering + pod formation> vegetative> pre-flowering stage. Therefore, it can be reported that vegetative + pre-flowering stage was the critical stage to deficit irrigation for mustard cultivation. This result was also consistent with the result obtained from yield response factor (k_y) for individual growth stages.

Table 5. Sensitivity index (λ_i, of Jensen model) of mustard to water stress at different growth stage

Treatments	**Growth**	**λ_i– value**		**Mean**	**Standard deviation (SD)**	**Uniformity coefficient (UC)**	**Coefficient of variance (CV)**
		2012	**2013**				
T_1	Pre-flowering + pod formation	0.06	0.07	0.07	0.0071	0.9	0.1
T_2	Vegetative + pod formation	0.07	0.08	0.08	0.0071	0.91	0.09
T_3	Vegetative + pre-flowering	0.12	0.13	0.13	0.0071	0.95	0.05
T_4	Pre-flowering	0.008	0.01	0.009	0.0071	0.84	0.16
T_5	Vegetative	0.02	0.03	0.03	0.0071	0.76	0.24

CONCLUSION

The results based on yield response factor k_y for individual growth stages showed that the order of sensitive growth stages to water deficit were: vegetative + pre-flowering, vegetative + pod formation, pre-flowering + pod formation, vegetative, and pre-flowering. The sensitivity index (λ_i) for individual growth stages followed the order of sensitive growth stages to water deficit were vegetative + pre-flowering, vegetative + pod formation, pre-flowering + pod formation, vegetative, and pre-flowering. The response factor for total growth period was 0.52, 0.96, 1.17, 0.13, and 0.75 for pre-flowering + pod formation, vegetative + pod formation, vegetative + pre-flowering, pre-flowering, and vegetative stage, respectively. The more the response factor and sensitivity index indicates the more water stress thus water supply must be ensured at vegetative and pre-flowering stage.

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