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Yield Response Factor of Sunflower under Deficit Irrigation 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), BAU Campus, Mymensingh 2202, Bangladesh.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors designed the study, analyzed and interpret the data and prepared the manuscript. Finally, both authors read and approved the final manuscript.

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ABSTRACT

Field experiments were conducted during two consecutive years (2014 and 2015) on Sunflower (variety: BARI Surjomukhi-2) crop at Bangladesh Agricultural Research Institute, Gazipur and Agricultural research station, Banerpota, Satkhira, to estimate yield response factor (k_y) and drought sensitivity index (λ_i) at various phenological stages and k_y for entire cropping period. There were nine irrigation treatments including full irrigation, 80% and 60% of root zone deficit at three growth stages (vegetative, pre-flowering and heading stage), 100%, 80% and 60% of root zone deficit at two growth stages except heading; and 100%, 80% and 60% of root zone deficit at two growth stages except pre-flowering. Results reveal that the values of k_y and λ_i increased with the increase of intensity of water deficit at different growth stages. There were no statistical difference in paired 't' test for individual growth stages and entire growth period. Overall, the k_y values in Gazipur for 20% water deficit at three growth stages were 0.13, 0.09, and 0.11, while for 40% water deficit were 0.16, 0.12, and 0.15, respectively. For Satkhira, the k_y values were 0.10, 0.06, and 0.09 for 20% water deficit at three growth stages, while 0.13, 0.08, and 0.12 for 40% water deficit. The k_y

**Corresponding author: E-mail: afrinbau@gmail.com;*

value for 100% water deficit at pre-flowering and heading stage were 0.23 and 0.16 for Gazipur, while 0.16 and 0.13 for Satkhira, respectively. At 20% water deficit, sensitivity index (λ_i) at three growth stages were 0.058, 0.021, and 0.048 for Gazipur, while 0.046, 0.019 and 0.036 for Satkhira, respectively. For 40% water deficit, λ_i values were 0.063, 0.029, and 0.053 at Gazipur, while, 0.06, 0.024 and 0.045 at Satkhira, respectively. The λ_i values for 100% water deficit at pre-flowering and heading stage were 0.12 and 0.10 for Gazipur and 0.069 and 0.06 for Satkhira. The highest k_y values for entire growing period (irrigating 60% root zone deficit at vegetative and heading stage) was 0.54 and 0.64, followed by 80% and 100% of root zone deficit at vegetative and heading stageat Gazipur and Satkhira, respectively. This value was very close to 80% and 100% of the root zone deficit in terms of entire growing period k_y value. Therefore, pre-flowering stage was the critical stage and irrigation should not be applied at 100%, 80% and 60% of the root zone deficit at vegetative and heading stage, rather it should be applied at 80% and 60% of the root zone deficit at vegetative and pre-flowering stage, respectively, for water limiting areas.

Keywords: Sunflower; yield response factor; sensitivity index; deficit irrigation.

1. INTRODUCTION

Agriculture is the main user of water which is about 90% of regional water used [1]. This water is decreasing day by day due to unavailability of natural rainfall, excessive withdrawal of ground water, population growth, and increased use of irrigation water [2-6]. This decreasing water resource creates a problem on long term sustainability of agricultural crop production [7,8]. Under this situation we have to rely on deficit irrigation technique for optimum crop production with increased net income as a result of water saving [9]. In this strategy crop can face water deficit (drought or stress) during the selected individual growth periods or throughout the total growing period [10]. Deficit irrigation causes yield reduction to some extent which depends on both the severity and timing of the water deficits [11]. In water deficit condition (when it occurs during the life cycle) plant can achieve maximum water productivity [12].

As crop experienced different degree of water stress during the crop cycle, so it is necessary to monitor crop response to water stress at different growth stages [13] as well as total growth period. [10] developed an empirical relationship between relative yield decrease and relative evapotranspiration deficit to quantify crop yield response to water under both adequate and limited water supplies in field situation. [14] also used this simple linear equation to describe crop yield response to deficit irrigation. Furthermore, [15] found out crop response factor, which is the relationship between relative yield decreases to relative evapotranspiration deficit. Therefore, this formula can give an outline for water management planning by providing directives for optimum crop production and water productivity [12].

Demir et al. [16] estimated yield response factor (k_y) of sunflower to deficit irrigation in a sub-humid climate (Bursa, Turkey). They found k_y of 0.8382 for the total growth period, and 0.7859, 0.9159, 0.8971, 0.9022, 0.8945 and 0.7708 for flowering, heading, milk ripening, heading + flowering, heading + milk ripening and flowering + milk ripening stage, respectively. [17] found k_y value of 0.91 for whole growing season and 0.83 for vegetative + yielding stage when furrow irrigation method was used on sunflower crop. International Atomic Energy Agency (IAEA) coordinated research project (CRP) showed k_y value of 0.91 for whole growing season and 1.19, 0.94 and 1.14 for initial, crop development and mid-season respectively, [18].

Hence, it is clearly understandable that response factor differs from location to location depending on weather, soil, variety, crop, season and also for individual growth stage to total growing season as [12] explained in his winter wheat experiment in Bangladesh in determining response factor. Therefore, it is utmost important to estimate location specific response factor for efficient management of water. Here sunflower crop was used to estimate crop response factor as it can tolerate low to medium water and salinity stress [19]. We mainly focus on water stress imposed by deficit irrigation. But this type of study was not done previously in context of Bangladesh for sunflower. Therefore, for proper water management with a view to minimize yield losses under this water scarce situation, information on the effect of water deficit on sunflower yield (yield response factor or sensitivity factor) is necessary. In consideration of above thing, this study has been undertaken to determine yield response factor (for individual growth stages and whole growing season) and sensitivity index (for individual growth stages) of sunflower under water deficit condition and to find out water sensitive growth stage.

2. MATERIALS AND METHODS

The field studies were conducted during 2014 and 2015 growing season at the research fields of Bangladesh Agricultural Research Institute, Gazipur (latitude: 23°99 ´´N, longitude: 90°41 ´´E), and Agricultural Research Station, Benarpota, Shatkhira (latitude:22°43 ´´N, longitude:89°05 ´´E). The soil texture of the study fields are sandy clay loam and silty clay loam, respectively. The soil is of acidic (pH = 6.03), low in organic matter (1.22%), and with basic infiltration rate of 4.25 mm/hr. The upper and lower limits of available water were 0.30 and 0.14 m^3m^{-3} for Gazipur and 0.31 and 0.15 m^3m^{-3} for Satkhira, respectively.

The local climate is subtropical monsoon, with average annual rainfall of about 1898 mm and 1895 mm, respectively. The sunflower–growing period, November to March, is characterized by dry winter with 41 and 9 mm rainfall in the year 2014 and 2015 at Gazipur and 32.2 and 94 mm at Satkhira, respectively (Fig. 1).

The sunflower cultivar (BARI Surjomukhi-2) is characterized by drought and salinity tolerant, and high yield potential (average 2 - 2.30 tha^{-1}). Total growing period of this crop is 110-120 days depending on cultivar, climatic condition etc. The water deficit of different degrees was imposed at different phonological stages with the treatments. There were three phonological stages which are vegetative, pre-flowering and heading stage. Irrigation treatments were arranged full irrigation, 20% water deficit, 40% water deficit through the growing season; single deficit (100%) at different stages (pre-flowering and heading), 20% and 40% water deficit at different growth stages (Table 1). Deficit irrigation was imposed according to the design of the treatments. Irrigation was applied up to field capacity to meet effective root zone depth of 60 cm where 80% of the root is concentrated. The layout of the experiments was completely randomized block design with three replications, with additional spare plot of 7 m^2 area. The plot size and spacing were 4 m × 2 m and 70 cm × 25 cm. The crop was harvested manually and yield data was taken at about 8.5% grain moisture.

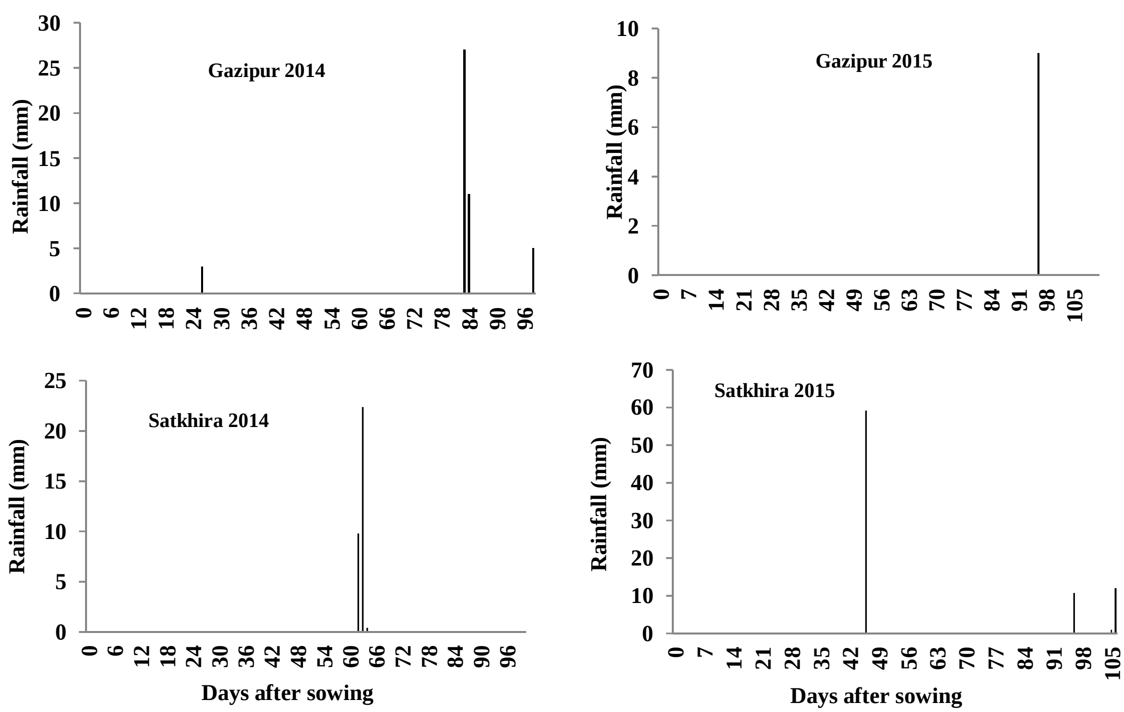

Fig. 1. Rainfall during the study period

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

Treatments	Irrigation at 3 plant growth phases with DC		
	Vegetative	Pre-flowering	Heading
T_1	1.0	1.0	1.0
T_2	0.8	0.8	0.8
T_3	0.6	0.6	0.6
T_4	1.0	1.0	-
T_5	0.8	0.8	-
T_6	0.6	0.6	-
T_7	1.0	-	1.0
T_8	0.8	-	0.8
T_9	0.6	-	0.6

Note: DC =1 means irrigating 100% of the root zone deficit (i.e. FC – Mc) (that is, no deficit), DC = 0.8 means irrigating 80% of the root zone deficit, DC = 0.6 means irrigating 60% of the root zone deficit

Crop sensitivity to water deficit throughout the growing season and individual growth stages were evaluated by Stewart [14], while Jensen [20] model was used to calculate individual growth stages.

2.1 Calculation of Crop Response Factor from Stewart Model

This model fits well in conditions where sensitivity varies significantly according to phenological growth stages. The equation was derived from the relationship of relative yield decrease with relative evapotranspiration deficit in considering all production factors at their optimum level. The water deficit factor, determined as the ratio of actual to potential evapotranspiration (ET/ET_m) that control the final yield.

$$Y/Y_m = \prod_{n=1}^{m} [1-k_{y(n)}(1-ET/ET_m)_n] \quad (1)$$

where Y is the actual yield, Y_m is the maximum yield with no 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. In this equation Stewart used varied coefficient for individual growth stage.

Therefore, k_y was determined by following the procedure given by [10]. At first, maximum yield (Y_m) of sunflower was determined which influenced by climate, in considering water, fertilizer, pests and diseases do not restrict yield. After that, maximum evapotranspiration (ET_m) was calculated when crop water requirement is equal to available water supply. Actual evapotranspiration (ET_a) was calculated depending on factors relating to available water supply to the crop. Finally, actual yield (Y_a) under water deficit condition was derived by the relationship between relative yield decrease and relative ET deficit.

$$1 - Y_a/Y_m = k_y(1 - ET_a/ET_m) \quad (2)$$

or,

$$k_y(i) = \frac{1-\frac{Y_a(i)}{Y_m(i)}}{1-\frac{ET_a(i)}{ET_m(i)}} \quad (3)$$

These equations were used previously by many scientists [12,16,21,13] across the world for calculating crop response factor for different crop. For more details, please refer to [10]. [10] estimated k_y values for each phenological periods and also for whole growing period, for different crops. k_y value for whole growing period was estimated on the effect of seasonal water used under water stress by using equation 2. On the other hand, stage specific k_y value was estimated on the effect of water stress for each growth period (i) by using equation 3. The k_y is a crop yield response factor that varies according to different species, variety, irrigation method and management practices, and different growth stages when deficit evapotranspiration is imposed [22]. The value of k_y represents an indication of whether the crop is tolerant to water stress.

In our study, different degrees of water stress were imposed on three growth stages according to the arrangement of the treatments. Finally, total growing season and individual growth stages k_y values were calculated by using the above formula.

2.2 Calculation of Crop Sensitivity Index from Jensen Model

Crop sensitivity to water deficit was also examined by Jensen model [20]. Jensen proposed a production function for individual growth stages on grain yield is as follows

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

where, Y is grain yield under water deficit condition, Y_m is the maximum yield when maximum evapotranspiration (ET_m) occurred under no water deficit during the whole crop growing 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 sunflower it was 3).

Tsakiris [23] proposed a modified method from Jensen model for easy application of irrigation practice. He illustrated the procedure of this model using data for grain sorghum. However, crop sensitivity index, λ, was determined using the procedure derived by Tsakiris [23]. Therefore, the equation (4) can be written as:

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

Where ω_i is the relative evapotranspiration ($= \frac{ET_i}{ET_m}$).

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

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

or,

$$\log \left(\frac{Yi}{Y_m}\right) = \lambda_i \log \omega_i \tag{6}$$

Therefore, λ_i for individual growth stages can be calculated with the ratio of log ($\frac{Yi}{Y_m}$) and log ω_i

2.3 Uniformity Coefficient for the k_y and λ_i Values

The uniformity coefficient (UC) of the yearly k_y and λi values were determined by following [24] as

$$UC = 1 - (\text{standard deviation / mean}) \tag{7}$$

3. RESULTS AND DISCUSSION

3.1 Yield Response Factor for Individual Growth Stage

Table 2 a and 2 b represent yield response (k_y) factor for three growth stages at Gazipur and Satkhira. These values vary depending on season, location and intensity of water deficit. In vegetative stage, k_y value varies from 0.03 to 0.25 and 0.02 to 0.21 at Gazipur and satkhira, respectively. During 2014, the lowest value was found at 20% water deficit at vegetative stage and highest value was found at 40% water deficit. This trend was consistent during the year 2015 as the uniformity coefficients range varied from 0.80 to 0.96 at Gazipur which means closely uniform. In Satkhira, uniformity co-efficient also varies from 0.72 to 1.00. Non-significant differences were observed by paired '*t*' test at 5% level of significance among k_y values at different growth stages. Therefore, it can be reported that there was no statistical difference between two years data.

For pre-flowering and heading stage, 100% water deficit gave the comparatively higher value than 40% and 20% water deficit. On an average, the yield response factor of 0.13 and 0.16 was found at 20% and 40% water deficit at vegetative stage at Gazipur, whereas, at Satkhira, it was 0.10 and 0.13, respectively. In pre-flowering stage, 100% water deficit gave the highest value (0.23) followed by 40% water deficit (0.12) and the lowest were observed at 20% water deficit (0.09) at Gazipur. In Satkhira, this trend was also similar for both the years but the value was little bit lower than Gazipur. In heading stage, the trend was also consistent with pre-flowering stage. At 20% water deficit, vegetative stage faced 18.18% and 44.44% more stress than heading and pre-flowering stage at Gazipur, while in Satkhira it was 11.11% and 66.67%, respectively. At 40% water deficit, vegetative stage faced 6.67% and 33.33% more stress than heading and pre-flowering stage at Gazipur, while in Satkhira it was 8.33% and 62.50%, respectively. At 100% water deficit, pre-flowering stress faced 43.75% and 23.08% more stress than heading stage at Gazipur and Satkhira, respectively. The k_y values, found in Satkhira were little bit lower than Gazipur due to the effect of rainfall during the growth stages (Fig. 1). If we compare the k_y values against different growth stages, then the order for 20% and 40% water deficit can be written as: vegetative > heading

>pre-flowering stage, and for 100% water deficit : Pre-flowering > heading stage. Therefore, it can be said that different degrees of deficit irrigation at individual growth stages can give different k_y values. For 100% water deficit in treatment T_7 to T_9, pre-flowering stage exerted the highest k_y value with more yield loss (Table 3). Therefore, it can be said that pre-flowering stage was the critical stage for 100% water deficit. It was also proved that 80% and 60% irrigation at pre-flowering stage can minimize yield loss to a great extent (Table 3). In addition, vegetative stage was the critical stage for 20% and 40% water deficit.

Martyniak [25] reported that drought tolerance varies strongly between growth stages for many crops. [16] shown the k_y values of average two years. This may be they found consistent trend during the two years. They found k_y values of 0.7859, 0.9159, 0.8971 for flowering, heading, and milk ripening stage. They also found the heading and heading + flowering stage was more sensitive stage (in terms of k_y value) for sunflower. [17] found the k_y value of 0.83 for vegetative + yielding stage. [10] reported k_y values of 0.40, 1.0 and 0.8 for vegetative, flowering and heading stage. They found flowering stage was the most critical stage to sunflower cultivation for deficit irrigation but they did not mention the intensity of water deficit. IAEA coordinated research project (CRP) showed k_y value of 1.19, 0.94 and 1.14 for vegetative, flowering and heading stage [18]. It was also observed that vegetative stage was the most critical stage to deficit irrigation. Therefore, it can be concluded that crop response factor varied according to location with varying climatic conditions and also different treatment.

Table 2a. The yield response factors (k_y) for individual growth stages at Gazipur

Treatment	Growth stages	k_y at Gazipur		Mean	Standard deviation (SD)	Uniformity coefficient (UC)	Coefficient of variance (CV)
		2014	2015				
	Vegetative						
T_2	20% Water Deficit (WD)	0.03	0.04	0.035	0.0071	0.80	0.20
T_5	20% WD	0.13	0.15	0.14	0.014	0.90	0.10
T_8	20% WD	0.19	0.22	0.205	0.021	0.90	0.10
Mean		0.12	0.14	0.13			
T_3	40% WD	0.07	0.08	0.075	0.0071	0.91	0.09
T_6	40% WD	0.16	0.17	0.165	0.0071	0.96	0.04
T_9	40% WD	0.21	0.25	0.23	0.028	0.88	0.12
Mean		0.15	0.17	0.16			
	Pre-flowering						
T_2	20% WD	0.03	0.04	0.035	0.0071	0.80	0.20
T_5	20% WD	0.13	0.15	0.14	0.014	0.90	0.10
Mean		0.08	0.095	0.09			
T_3	40% WD	0.064	0.08	0.072	0.011	0.84	0.16
T_6	40% WD	0.16	0.17	0.165	0.0071	0.96	0.04
Mean		0.11	0.13	0.12			
T_7	100% WD	0.19	0.2	0.195	0.0071	0.96	0.04
T_8	100% WD	0.21	0.24	0.225	0.021	0.91	0.09
T_9	100% WD	0.23	0.27	0.25	0.028	0.89	0.11
Mean		0.21	0.24	0.23			
	Heading						
T_2	20% WD	0.03	0.04	0.035	0.0071	0.80	0.20
T_8	20% WD	0.17	0.20	0.185	0.021	0.89	0.11
Mean		0.1	0.12	0.11			
T_3	40% WD	0.065	0.08	0.073	0.011	0.85	0.15
T_9	40% WD	0.19	0.23	0.21	0.028	0.87	0.13
Mean		0.13	0.16	0.15			
T_4	100% WD	0.12	0.15	0.135	0.021	0.84	0.16
T_5	100% WD	0.14	0.17	0.155	0.021	0.86	0.14
T_6	100% WD	0.16	0.19	0.175	0.021	0.88	0.12
Mean		0.14	0.17	0.16			

Table 2b. The yield response factors (k_y) for individual growth stages at Satkhira

Treatment	Growth stages	k_y at Satkhira		Mean	Standard deviation (SD)	Uniformity coefficient (UC)	Coefficient of variance (CV)
		2014	2015				
	Vegetative						
T_2	20% water deficit (WD)	0.03	0.02	0.025	0.0071	0.72	0.28
T_5	20% WD	0.12	0.11	0.115	0.0071	0.94	0.06
T_8	20% WD	0.15	0.15	0.15	0	1	0
Mean		0.10	0.09	0.10			
T_3	40% WD	0.04	0.06	0.05	0.014	0.72	0.28
T_6	40% WD	0.13	0.14	0.135	0.0071	0.95	0.05
T_9	40% WD	0.18	0.21	0.195	0.021	0.89	0.11
Mean		0.12	0.14	0.13			
	Pre-flowering						
T_2	20% WD	0.02	0.02	0.02	0	1	0
T_5	20% WD	0.12	0.09	0.105	0.021	0.8	0.2
Mean		0.07	0.055	0.06			
T_3	40% WD	0.04	0.06	0.05	0.014	0.72	0.28
T_6	40% WD	0.13	0.1	0.115	0.021	0.82	0.18
Mean		0.085	0.08	0.08			
T_7	100% WD	0.15	0.12	0.135	0.021	0.84	0.16
T_8	100% WD	0.18	0.13	0.155	0.035	0.77	0.23
T_9	100% WD	0.22	0.15	0.185	0.049	0.73	0.27
Mean		0.18	0.13	0.16			
	Heading						
T_2	20% WD	0.02	0.02	0.02	0	1	0
T_8	20% WD	0.14	0.15	0.145	0.0071	0.95	0.05
Mean		0.08	0.09	0.09			
T_3	40% WD	0.05	0.07	0.06	0.014	0.76	0.24
T_9	40% WD	0.17	0.16	0.165	0.0071	0.96	0.04
Mean		0.11	0.12	0.12			
T_4	100% WD	0.12	0.11	0.115	0.0071	0.94	0.06
T_5	100% WD	0.13	0.12	0.125	0.0071	0.94	0.06
T_6	100% WD	0.14	0.13	0.135	0.0071	0.95	0.05
Mean		0.13	0.12	0.13			

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

Treatment	Yield at Gazipur			Yield at Satkhira		
	2014	2015	Mean	2014	2015	Mean
T_1	2.65 A	2.54 A	2.60	2.78 A	2.90 A	2.84
T_2	2.57 B	2.45 B	2.51	2.73 B	2.85 B	2.79
T_3	2.48 C	2.34 C	2.41	2.66 C	2.74 C	2.70
T_4	2.36 D	2.21 D	2.29	2.51 D	2.70 D	2.61
T_5	2.30 E	2.17 E	2.24	2.46 E	2.65 E	2.56
T_6	2.24 F	2.12 F	2.18	2.44 EF	2.62 F	2.53
T_7	2.20 G	2.07 G	2.14	2.42 F	2.58 G	2.50
T_8	2.15 H	2.00 H	2.08	2.37 G	2.54 H	2.46
T_9	2.09 I	1.93 I	2.01	2.28 H	2.50 I	2.39
$LSD_{0.05}$	0.0243	0.032	-	0.027	0.026	-
CV	0.605	0.856	-	0.635	0.571	-

3.2 Yield Response Factor for Whole Growing Period

Table 4 represents yield response factor (k_y) for entire growing season at Gazipur and Satkhira. The different values of response factor were observed for individual treatments during total crop period. This was increased according to the intensity of imposing water deficit. No significant differences were observed by paired '*t*' test among k_y values for whole growth period at 5% level of significant for both locations. In addition to uniformity coefficient value was very close to one. Therefore, it can be reported that there was no statistical difference between two years data. The highest value was observed in treatment T_9 where irrigation was applied 60% of the root zone deficit at vegetative and heading stage. The lowest was observed in treatment T_2 where irrigation was applied 80% of the root zone deficit at vegetative, pre-flowering and heading stage. Compare with most stressed treatment, treatment T_2, T_3, T_4, T_5, T_6, T_7 and T_8 exerted 46.30%, 44.44%, 42.59%, 38.89%, 37.04%, 3.70% and 1.85% less stress in Gazipur and 51.56%, 46.88%, 43.75%, 40.63%, 39.06%, 3.13%, and 1.56% in Satkhira, respectively. Also, it was found that Satkhira experienced little bit more stress than that of Gazipur during the year 2014 and 2015. This may be the effect of both water deficit as well as the development of soil salinity at crop root zone might create unfavourable soil-water-plant relationship [26]. Therefore, the relative sensitivity to water deficit (k_y) for entire cropping period decreased followed by the order of water deficit treatment: $T_9>T_8>T_7>T_6>T_5>T_4>T_3>T_2$.

Demir et al. [16] found the k_y value of sunflower was 0.8382 for the whole growing period though they applied irrigation water keeping rainfed as a check including irrigation at each single stage, multi-stage with different degree of full irrigation and deficit irrigation. [10] reported a k_y value of 0.95 for the total growing season may be they applied equal amount of water deficit throughout the growing season. [17] obtained k_y value of 0.91 for entire growing season by applying furrow irrigation method. [18] reported k_y value of 0.91 for the entire growing period from International Atomic Energy Agency (IAEA) coordinated research project (CRP). Previous findings are varied with what we found because of the variation of imposing water deficit, soil type, climate, and cultivar.

3.3 Sensitivity Index of Jensen Model

Tables 5a and 5b represents the drought sensitivity index (lambda i, λ_i) of sunflower for three growth stages according to the treatment. This value was dictated by timing and amount of water stress. At Gazipur, the uniformity co-efficient varies 0.53 to 1.00 except 20% water deficit at heading (0.29) in treatment T_2, while at Satkhira, it was 0.49 to 1.00. Paired 't' test was done at 5% level of significant between two years and non-significant variation was observed. Therefore, the λ_i values among three growth stages with different degrees of water deficit

Table 4. The yield response factors (k_y) for the total growth period of sunflower

Treatment	k_y at Gazipur		Mean	Standard deviation	Uniformity coefficient	Coefficient of variance
	2014	2015				
T_2	0.25	0.32	0.29	0.049	0.83	0.06
T_3	0.26	0.33	0.3	0.049	0.84	0.059
T_4	0.27	0.35	0.31	0.057	0.82	0.069
T_5	0.29	0.36	0.33	0.049	0.85	0.058
T_6	0.31	0.37	0.34	0.042	0.88	0.048
T_7	0.46	0.57	0.52	0.078	0.85	0.091
T_8	0.47	0.58	0.53	0.078	0.85	0.091
T_9	0.48	0.59	0.54	0.078	0.86	0.091
	k_y at Satkhira					
T_2	0.32	0.3	0.31	0.014	0.95	0.015
T_3	0.33	0.34	0.34	0.007	0.98	0.007
T_4	0.36	0.36	0.36	0	1	0
T_5	0.37	0.38	0.38	0.007	0.98	0.007
T_6	0.38	0.39	0.39	0.007	0.98	0.007
T_7	0.61	0.62	0.62	0.007	0.99	0.007
T_8	0.62	0.63	0.63	0.007	0.99	0.007
T_9	0.63	0.64	0.64	0.007	0.99	0.007

were varied during two years but there was no statistical difference between two years data. In addition to, the trend was also similar. In vegetative stage, 40% water deficit gave the higher λ_i value than 20% water deficit. In pre-flowering and heading stage, 100% water deficit gave the highest λ_i value than that of 40% and 20%. It was proved that drought sensitivity index increases with the increase of intensity of water deficit irrespective of growth stages.

At 20% and 40% water deficit, vegetative stage gave higher λ_i value than heading and pre-flowering stage. Therefore, the order can be written as: vegetative > heading > pre-flowering stage. In contrast, at 100% water deficit, pre-flowering stage gave the higher λ_i value than that of heading stage and the order can be arranged as: pre-flowering > heading stage. Therefore, it can be reported that pre-flowering stage was the critical stage for 100% water deficit, while vegetative stage was the sensitive stage for 20% and 40% water deficit. This result was similar with the result obtained from yield response factor (k_y) for individual growth stages.

Table 5a. Sunflower sensitivity index (λ, of Jensen model) to water deficit at individual growth stages at Gazipur

Treatment	Growth stages	λ at Gazipur		Mean	Standard deviation (SD)	Uniformity coefficient (UC)	Coefficient of variance (CV)
		2014	2015				
	Vegetative						
T_2	20% water deficit (WD)	0.029	0.032	0.031	0.0021	0.93	0.07
T_5	20% WD	0.06	0.064	0.062	0.0028	0.95	0.05
T_8	20% WD	0.076	0.084	0.08	0.0057	0.93	0.07
Mean		0.055	0.06	0.058			
T_3	40% WD	0.033	0.037	0.035	0.0028	0.92	0.08
T_6	40% WD	0.066	0.072	0.069	0.0042	0.94	0.06
T_9	40% WD	0.08	0.09	0.085	0.0071	0.92	0.08
Mean		0.06	0.066	0.063			
	Pre-flowering						
T_2	20% WD	0.007	0.007	0.007	0	1	0
T_5	20% WD	0.034	0.035	0.035	0.00071	0.98	0.02
Mean		0.021	0.021	0.021			
T_3	40% WD	0.014	0.019	0.017	0.0035	0.79	0.21
T_6	40% WD	0.035	0.045	0.04	0.0071	0.82	0.18
Mean		0.025	0.032	0.029			
T_7	100% WD	0.09	0.11	0.1	0.014	0.86	0.14
T_8	100% WD	0.10	0.12	0.11	0.014	0.87	0.13
T_9	100% WD	0.13	0.14	0.14	0.0071	0.95	0.05
Mean		0.11	0.12	0.12			
	Heading						
T_2	20% WD	0.03	0.01	0.02	0.014	0.29	0.71
T_8	20% WD	0.08	0.07	0.075	0.0071	0.91	0.09
Mean		0.055	0.04	0.048			
T_3	40% WD	0.04	0.02	0.03	0.014	0.53	0.47
T_9	40% WD	0.08	0.07	0.075	0.0071	0.91	0.09
Mean		0.06	0.045	0.053			
T_4	100% WD	0.11	0.068	0.089	0.03	0.67	0.33
T_5	100% WD	0.13	0.077	0.104	0.037	0.64	0.36
T_6	100% WD	0.16	0.088	0.124	0.051	0.59	0.41
Mean		0.13	0.078	0.10			

Table 5b. Sunflower sensitivity index (λ, of Jensen model) to water deficit at individual growth stages at Satkhira

Treatment	Growth stages	λ at Satkhira		Mean	Standard deviation (SD)	Uniformity coefficient (UC)	Coefficient of variance (CV)
		2014	2015				
	Vegetative						
T_2	20% Water Deficit (WD)	0.019	0.023	0.021	0.0028	0.87	0.13
T_5	20% WD	0.054	0.049	0.052	0.0035	0.93	0.07
T_8	20% WD	0.067	0.061	0.064	0.0042	0.93	0.07
Mean		0.047	0.044	0.046			
T_3	40% WD	0.029	0.032	0.031	0.0021	0.93	0.07
T_6	40% WD	0.059	0.067	0.063	0.0057	0.91	0.09
T_9	40% WD	0.079	0.085	0.082	0.0042	0.95	0.05
Mean		0.06	0.061	0.06			
	Pre-flowering						
T_2	20% WD	0.006	0.005	0.006	0.00071	0.87	0.13
T_5	20% WD	0.04	0.024	0.032	0.011	0.65	0.35
Mean		0.023	0.015	0.019			
T_3	40% WD	0.014	0.012	0.013	0.0014	0.89	0.11
T_6	40% WD	0.045	0.023	0.034	0.016	0.54	0.46
Mean		0.03	0.018	0.024			
T_7	100% WD	0.074	0.043	0.059	0.022	0.63	0.37
T_8	100% WD	0.086	0.048	0.067	0.027	0.6	0.4
T_9	100% WD	0.111	0.052	0.082	0.042	0.49	0.51
Mean		0.09	0.048	0.069			
	Heading						
T_2	20% WD	0.008	0.011	0.0095	0.0021	0.78	0.22
T_8	20% WD	0.047	0.074	0.061	0.019	0.68	0.32
Mean		0.028	0.043	0.036			
T_3	40% WD	0.02	0.03	0.025	0.0071	0.72	0.28
T_9	40% WD	0.06	0.07	0.065	0.0071	0.89	0.11
Mean		0.04	0.05	0.045			
T_4	100% WD	0.056	0.052	0.054	0.0028	0.95	0.05
T_5	100% WD	0.06	0.06	0.06	0	1	0
T_6	100% WD	0.064	0.068	0.066	0.0028	0.96	0.04
Mean		0.06	0.06	0.06			

4. CONCLUSION

Yield response factor and sensitivity index varies with location, intensity of water deficit, and growth stages. For individual growth stage, 20% and 40% water deficit at vegetative stage exerted more stress (in terms of k_y and λ_i) than that of heading and pre-flowering stage. For 100% water deficit at pre-flowering stage gave higher value than that of heading stage. The order of sensitive growth stages to 20% and 40% water deficit were vegetative, heading and pre-flowering, while for100% water deficit were pre-flowering and heading at Gazipur and Satkhira, respectively.

Irrigating 60% of root zone deficit at vegetative and heading stage was the most stressed treatment in consideration of response factor (k_y) for enter growing period. The order of sensitive treatment to water deficit for entire growing season were irrigating 60%, 80% and 100% of root zone deficit at vegetative and heading stages; irrigating 60%, 80% and 100% of root zone deficit at vegetative and pre-flowering stages; and irrigating 60%, 80% of root zone deficit at three stages. Some water must be ensured at pre-flowering stage and it may be recommended at either 80% or 60% of root zone deficit instead of 100% of root zone deficit for water scarce region to avoid severe yield loss.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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