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SOIL & CROP SCIENCES | RESEARCH ARTICLE

Effects of deficit irrigation on yield, water productivity and economic return of sunflower

Afrin Jahan Mila^{1*}, Md. Hossain Ali², Abdur Razzaque Akanda¹, Md. Harun Or Rashid³ and Md. Atikur Rahman⁴

Abstract: Field experiments were conducted at two locations (one at normal soil, BARI Gazipur and another at saline soil, ARS, Benarpota, Satkhira) during two consecutive years (2014 and 2015) to study the effects of deficit irrigation (DI) on yield, water productivity and economics on sunflower production. Design was RCB and irrigation treatments were: FI-100 (T_1), DI-80 (T_2) and DI-60 (T_3) at vegetative, pre-flowering and heading stages, FI-100 (T_4), DI-80 (T_5) and DI-60 (T_6) at vegetative and pre-flowering stages, and FI-100 (T_7), DI-80 (T_8) and DI-60 (T_9) at vegetative and heading stages. Results indicated that DI treatments significantly reduced plant growth parameters (canopy coverage, and biomass except root length density), yield attributes and seed yield compared to full irrigation (FI) (T_1). Pre-flowering stage was the critical stage to DI. DI-60 at vegetative and pre-flowering stages (T_6) produced 2.18 and 2.53 t ha⁻¹ seed yields by saving 68.15 and 54.75% water at normal and at saline soil. This treatment (T_6) also gave the highest water productivity, irrigation water productivity, and net financial return. The results will be helpful for taking policy decision regarding efficient irrigation and water management under prevailing water scarce situation.



Afrin Jahan Mila

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PUBLIC INTEREST STATEMENT

Deficit irrigation (DI) is necessary in situation where land is available but water is scarce. Deficit Irrigation means applied less amount of water than the crop's actual need. It reduces crop yield than that of full irrigation. Full irrigation defines as the application of water at the crop root zone that is required to fulfill the crop water demand. Deficit irrigation also increases water productivity by utilizing reduced water. Water productivity of a crop means utilizing unit volume of water to produce yield. The aim of this study is to estimate the effect of deficit irrigation on yield, water productivity and financial feasibility of sunflower. Deficit irrigation decreases crop growth and yield than full irrigation. It is economically feasible because saved water can be used to cultivate more land. Therefore, this technique is suitable for successful utilization of limited water for increasing crop production both in normal and saline soil.

Subjects: Environment & Agriculture; Environmental Studies & Management; Mathematics & Statistics

Keywords: root length density; biomass; canopy coverage; soil salinity; relative yield decrease; relative water saving; evapotranspiration; yield components

1. Introduction

Fresh water scarcity and salinity is a main problem for agricultural crop production specially, in arid and semi-arid regions. In Bangladesh, this problems is getting severe during winter season because of very little or no rainfall. In southern part of Bangladesh, where most of the regions of Satkhira experiences different degrees of saline both in surface and ground water as well as in the soil surface which affects 20% of net cultivable land (Karim, Hussain, & Ahmed, 1990). Besides, availability of ample saline water makes fresh water scarce for agricultural usage (El-Beltagy, 2004). So, it will be wise to use saline water for the expansion of irrigated cropping system in those regions (El-Beltagy, 2004). This water can be a feasible substitute for fresh water to irrigate moderately tolerant oleic sunflower crop (Francois, 1996) by maintaining proper management practices. Therefore, proper water management is crucial both for saline and non-saline environments in Bangladesh. So, deficit irrigation can be used as an alternate strategy to reduce irrigation water use as well as improve irrigation efficiency. In this technique, water applied is less than the crop's actual need (Fererres & Soriano, 2007) so that more land can cover by producing optimum yield (Ali, Hoque, Hassan, & Khair, 2007; English & Raja, 1996; Todorovic, Albrizio, & Zivotic, 2007) with the objectives of increasing water productivity and food security. It is also necessary to evaluate the economic analysis of this strategy as it utilizes less water to optimize yield (English & Raja, 1996) as well as irrigation scheduling.

Sunflower is one of the most important oilseed crops which can tolerate low to medium drought (Todorovic et al., 2007). There is a lot of scope to include sunflower into the major cropping patterns in Bangladesh (like, T. Amon – Sunflower – T. Aus in the coastal areas of Barisal, Patuakhali, and Satkhira as well as T. Amon – Sunflower – Boro in the Gazipur area). Numerous authors did experiment on DI strategies either saline or non-saline environment under sunflower crop (Demir, Göksoy, Büyükcangaz, Turan, & Köksal, 2006; Göksoy, Demir, Turan, & Dağüstü, 2004; Karam et al., 2007; Sezen, Yazar, Kapur, & Tekin, 2011; Sezen, Yazar, & Tekin, 2011; Todorovic et al., 2007). Chen, Kang, Wan, and Liu (2009) did two years field experiment on olic sunflower crop, by applying five different types of salinity level including 1.6, 3.9, 6.3, 8.6, and 10.9 dSm⁻¹. They found that salinity level in irrigation water increases with the decrease in the amount of applied water. Karam et al. (2007) did two years field study on sunflower response to DI at Tal Amara Research Station, Bekaa Valley, Lebanon. They found that applying irrigation at early seed formation until physiological maturity increased seed yield by allocating the fraction of assimilate to the head as a result, lower number of seed but increased seed weight produced. Göksoy et al. (2004) did three years field experiment on sunflower response to full and limited irrigation at three growth stages (heading, flowering, and milking) at Turkey. They found that FI at three growth stages produced maximum seed yield. Demir et al. (2006) did two years field study on effect of sunflower to DI at sub-humid climate in Turkey. They found that three irrigations at heading, flowering and milking stage produced highest seed yield and ET. Todorovic et al. (2007) found that DI is an acceptable strategy for sunflower and irrigation is highly important between flowering and maturity stage. Although many researchers did research on sunflower but the topography, location, weather everything differed with what we designed. Besides, economic analysis under water limiting condition was examined for this crop but most of the author's emphasis on the increasing water productivity. Moreover, this type of research was not done previously in Bangladesh on this particular crop. Therefore, this study was done on both saline and non-saline locations to evaluate DI effect on growth and yield, critical stage to DI, water productivity, and financial feasibility under water limiting condition compared to FI.

2. Materials and methods

2.1. Study area, soil and weather conditions

The experiments were conducted at the research fields of Irrigation and Water Management Division 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), during 2014 and 2015. These areas are characterized by subtropical monsoon climate, with average annual rainfall of about 1,898 and 1,895 mm, respectively. The soil characteristics of the experimental fields are sandy clay loam and silty clay loam in texture, respectively. The field capacity, permanent wilting point, and bulk density were 0.295 cm³ cm⁻³, 0.141 cm³ cm⁻³, and 1.50 g cm⁻³ for Gazipur, while at Satkhira it was 0.4088 cm³ cm⁻³, 0.16 cm³ cm⁻³, and 1.50 g cm⁻³, respectively. The weather parameter values of two locations are given in Table 1.

2.2. Agronomic practices and measurements

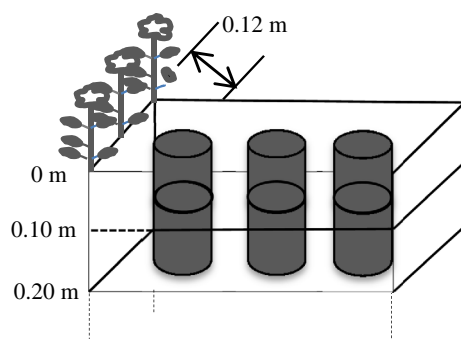
The sunflower (Variety: BARI Surjomukhi-2) was sown on 25 November 2013, and 16 November 2014 at Gazipur and 15 December 2013, and 18 November 2014 at Satkhira on a total surface area of 641.7 m² of a rectangular shape (31 × 20.7 m). The plant density was of 5.71 plants per m² with maintaining a spacing of 0.70 × 0.25 m. Proper land preparation and recommended fertilization was applied. The emergence, pre-flowering, flowering, and heading of the plant were noticed at about 10–12, 40–45, 50–55, and 70–75 days after sowing. About 25–30 days after head formation, it reached its physiological maturity and harvesting was done on 18 March 2014, and 15 March 2015 at Gazipur, and 27 March 2014, and 5 March 2015 at Satkhira, respectively.

Root length density, bio-mass, and canopy coverage data were collected according to different days after sowing from plant establishment up to maturity. Three representative plants were selected from destructive plot (3.5 × 2 m) to collect the growth data. Each experimental plot was composed by five sunflower lines (0.70 m between rows) that were 2 m in length. Middle three rows were used for the collection of sample to minimize border effect. Depending on the crop growth, soil core

Table 1. Weather parameter values of Gazipur and Satkhira over two years during the crop period

Location	Year	Month	Temperature (°C)		RH (%)	Sunshine (h)	Evaporation (mm/day)	Rainfall (mm)
			Max	Min				
Gazipur	2013–2014	November	29.37	15.18	76.75	8.1	3.05	0
		December	26.16	13.74	79.24	4.38	2.13	3
		January	24.33	11.96	76.50	3.78	2.09	0
		February	26.96	13.65	69.16	5.79	3.72	38
		March	32.06	19.37	61.14	8.39	5.17	5
	2014–2015	November	28.49	15.28	77.2	3.21	2.11	0
		December	24.22	13.58	79.82	3.11	1.77	0
		January	24.54	12.78	75.81	4.6	2.41	0
		February	27.95	14.66	72.27	5.37	3.04	9
		March	31	16.39	65.67	8.34	5.37	0
Satkhira	2013–2014	December	25.44	13.64	71.24	2.69	5.44	0
		January	23.69	12.66	73.89	2.53	5.76	0
		February	29.08	16.24	68.23	2.83	6.82	32.6
		March	31.52	19.13	68.59	3.33	7.49	0
	2014–2015	November	29.01	14.35	71.04	3.06	6.67	0
		December	25.76	13.58	71.13	2.70	5.09	0
		January	24.95	13.64	73.89	2.61	5.88	59.2
		February	29.08	16.24	68.23	2.87	6.55	10.8
		March	30.50	19.68	70.50	2.62	7.74	13

Figure 1. Site of the root assessment by using COR (conventional soil core sampling) method.



samplers were inserted in to the soil of maximum 9 numbers by using the conventional soil core-sampling (COR) method (0–0.12, 0.12–0.24 and 0.24–0.36 m from the row). In this method, soil samples were collected using soil core samplers with a known volume of 0.000516 m³ including a dimension of 0.074 m diameter and 0.12 m long (Figure 1) by following Azevedo, Chopart, and Medina (2011). Roots were extracted from the soil by washing with tap water, following separation using a 1 mm mesh sieve.

Root lengths were calculated by following the modifying method (Habib, 1988). In this method, roots were separated according to diameter (L_1 (5–10 mm diameter), L_2 (1–2 mm diameter), L_3 (1–0.05 mm diameter), and L_4 (<0.05 mm diameter) which was measured by vernier calipers with 0.0001 m division and different mesh sized sieve. In each category, the length of 30 randomly selected roots were measured by using a scale and then dried and weighted. Finally, root length density was calculated by the ratio of root length and volume of core sampler. The proportion of ground covered with green leaves was measured in different growth stages by following a grid as suggested by Burstall and Harris (1983). In this experiment, a wooden frame divided into 100 equal sections of dimensions 0.70 × 0.50 m of the planting pattern was used. It was placed half way on each side of the row to sample one plant and on top of the plant canopy, and which section filled more than half leaves was counted to minimize parallax error. This data was collected during sunny day at noon time. Then canopy cover was calculated as the ratio of the area of grids counted to the area of the ground allocated to the crop and is expressed as a percentage. Plants from 1 square meter were randomly selected from each replicated plot for recording yield contributing data during and after harvest. Then total yield from each plot was recorded in keeping seed moisture content at about 8.5%.

Soil salinity was measured as electrical conductivity using EC meter, and the electrical conductivity of soil (ECs) in the nine experimental plots was measured by mixing the soil from different layer with the required proportion of fresh water. Canal water was used for irrigation in Satkhira and its salinity was measured by following Chen et al. (2009), while in Gazipur groundwater (GW) is used for irrigation. Soil properties in the experimental field and irrigation water quality of different source are given in Table 2.

2.3. Experimental design and treatments

The layout of the experiments was completely randomized block design with three replications, with additional spare plot of 7 m² area. Nine irrigation regimes were imposed and these were: FI-100 at vegetative, pre-flowering and heading stages (T_1), DI-80 at vegetative, pre-flowering and heading stages (T_2), DI-60 at vegetative, pre-flowering and heading stages (T_3), FI-100 at vegetative, and pre-flowering stages (T_4), DI-80 at vegetative, and pre-flowering stages (T_5), DI-40 at vegetative, and pre-flowering stages (T_6), FI-100 at vegetative, and heading stages (T_7), DI-80 at vegetative, and heading stages (T_8), and DI-60 at vegetative, and heading stages (T_9). DI-80 and DI-60 means that irrigating 80 and 60% of root zone deficit up to field capacity.

Table 2. Soil properties and irrigation water quality during the study period

Properties	Value	
	Gazipur	Satkhira
<i>Soil</i>		
pH	6.03	7.75
Organic matter (g kg ⁻¹)	1.22	1.96
EC (dSm ⁻¹)	0.51	9.28
Available N (%)	6.45	0.11
Available P (Bray)	1.98	28.99
Available K (ppm)	0.13	0.70
Textural class	Sandy clay loam	Silty clay loam
<i>Water</i>		
1st irrigation	0.321	4.00
2nd irrigation	0.310	5.04
3rd irrigation	0.309	5.78

Crop evapotranspiration (ET) was estimated by following the water balance equation.

$$ET = I + P \pm \Delta S - R - D$$

where ET is evapotranspiration (mm), *I* is the irrigation water (mm), *P* is the precipitation (mm), ΔS is the change in soil water storage (mm), *R* is the runoff, and *D* is the drainage below the root zone. Drainage and runoff was assumed to be zero as measured amount of water (field capacity minus observed soil moisture content) was applied. Prior to irrigation and every 10 days interval soil moisture was measured at different depth (0–0.15, 0.15–0.30, 0.30–0.60, 0.60–0.90 m) in each plot by gravimetric method and averaged it. Irrigation water was applied by furrow method to bring the soil moisture up to field capacity considering the effective root zone depth (0.90 m).

Water productivity (WP) and irrigation water productivity (IWP) were calculated as seed yield divided by seasonal ET and total seasonal irrigation water applied (Sezen, Yazar, Kapur et al., 2011). Marginal productivity of irrigation water (MP_{iw}) was calculated as additional seed yield divided by additional one unit of irrigation water in considering other inputs are constant (Ali et al., 2007).

The measured data were analyzed statistically by using R software (Version 3.1.1). Mean separation was done by duncan’s multiple range test (DMRT) at 1% level of probability.

2.4. Economic analysis

Economic analysis was done under water-limiting condition by following Ali et al. (2007) and English (1990). In this case, water applied less than the actual amount and saved water can be used to productive another land. The maximum increase in farm income from additional area coverage by saved water is an opportunity cost of irrigation water. Total cost was calculated by adding total operating cost, interest on operating cost (seasonal basis at the rate of 5%) and land use cost.

3. Results and discussion

3.1. Irrigation, evapotranspiration and water productivity

In the semi-arid climatic conditions, weather parameter values of temperature, relative humidity, sunshine hour and evaporation within the year 2014 and 2015 were followed the similar trend but rainfall varied during the crop season. In Gazipur, all treatments received 41 mm rainfall during the

year 2014, while in the year 2015 treatments received only 9 mm rainfall. In Satkhira, all treatments received 31 and 88 mm rainfall in the successive years.

Tables 3a and 3b represent data about irrigation, rainfall, evapotranspiration, water productivity (WP) and irrigation water productivity (IWP), relative water saved in different treatments. Seasonal irrigation amount decreased with the increase of rainfall. Irrigation amount among treatments varied from 62 to 226 mm in the year 2014, while in the year 2015 this amount varied from 92 to 254 mm in Gazipur. In Satkhira, irrigation amount varied from 96 to 200 mm in 2014, while in 2015, this value varied from 72 to 141 mm. Treatment T₆ (DI-60 at vegetative and pre-flowering stages) saved 73 and 64% of irrigation than treatment T₁ (FI-100) in Gazipur. Similarly, in Satkhira, this treatment saved 52 and 57% of irrigation than FI. Evapotranspiration values varied from 153 to 310 mm in the year 2014, while in the year 2015 this value ranged from 157 to 300 mm in Gazipur. In Satkhira, this value varied from 179 to 273 mm and 188 to 255 mm in 2014 and 2015, respectively. These values increased with the increase in number and intensity of irrigation. Treatment T₆ utilized 51 and 48% less seasonal water use than FI in Gazipur, while in Satkhira this treatment saved 34 and 26% seasonal water use than FI in the year 2014 and 2015, respectively.

WP values varied from 0.85 to 1.46 kg m⁻³ in 2014 and 0.85 to 1.35 kg m⁻³ in 2015 at Gazipur. At Sakhira, these values varied from 1.02 to 1.35 kg m⁻³ in 2014 and 1.14 to 1.40 kg m⁻³ in 2015. The highest WP was found in treatment T₆ (DI-40 at vegetative and pre-flowering stages) in both years and locations. Irrigation water productivity (IWP) values varied from 1.17 to 3.61 kg m⁻³ in 2014 and 1.00 to 2.30 kg m⁻³ in 2015 for Gazipur region. For Satkhira, this value varied from 1.39 to 2.53 kg m⁻³ in 2014 and 2.06 to 4.38 kg m⁻³ in 2015. The treatment T₆ resulted in the highest IWP value in both years and locations. These values were influenced by seasonal rainfall and found higher values in

Table 3a. Seed yield, irrigation, evapotranspiration, water productivity (WP), irrigation water productivity (IWP), relative water saving (RWS), relative yield decrease (RYD), and marginal productivity of irrigation water (MPIW) at different irrigation treatments at Gazipur

Experimental year	Treatments	Seasonal irrigation (mm)	Rainfall (mm)	Water use (mm)	Seed yield (t ha ⁻¹)*	RYD (%)	RWS (%)	WP (kg m ⁻³)	IWP (kg m ⁻³)	MPIW (kg m ⁻³)
2013–2014	T ₁	226	41	310	2.65a	–	–	0.85	1.17	0.25
	T ₂	189	41	274	2.57b	3.02	16.3	0.94	1.36	0.26
	T ₃	145	41	235	2.48c	6.42	35.8	1.05	1.71	0.29
	T ₄	100	41	185	2.36d	10.9	55.7	1.27	2.35	0.31
	T ₅	83	41	170	2.30e	13.2	63.5	1.35	2.78	0.29
	T ₆	62	41	153	2.24f	15.5	72.6	1.46	3.61	
	T ₇	117	41	201	2.20g	17.0	48.1	1.10	1.88	–0.07
	T ₈	98	41	185	2.15h	18.9	56.8	1.16	2.20	–0.25
	T ₉	85	41	177	2.09i	21.1	62.4	1.18	2.46	–0.65
2014–2015	T ₁	254	8.54	300	2.54a	–	–	0.85	1.00	0.26
	T ₂	223	8.54	275	2.45b	3.54	12.2	0.89	1.10	0.25
	T ₃	182	8.54	241	2.34c	7.87	28.3	0.97	1.28	0.24
	T ₄	132	8.54	189	2.21d	13.0	48.2	1.17	1.68	0.23
	T ₅	115	8.54	175	2.17e	14.6	54.9	1.24	1.89	0.22
	T ₆	92	8.54	157	2.12f	16.5	63.7	1.35	2.30	
	T ₇	164	8.54	210	2.07g	18.5	35.3	0.99	1.26	–0.07
	T ₈	137	8.54	191	2.00h	21.3	45.9	1.05	1.46	–0.27
	T ₉	120	8.54	178	1.93i	24.0	52.7	1.08	1.61	–0.68

Notes: T₁, T₂, T₃ indicate 100, 80 and 60% of DI at vegetative, pre-flowering and pod formation stage; T₄, T₅, T₆ indicate 100, 80 and 60% of DI at vegetative and pre-flowering stage; T₇, T₈, T₉ indicate 100, 80 and 60% of DI at vegetative, and pod formation stage.

*Mean values followed by different letter within columns differ significantly at $p < 0.05$ according to Duncan's range test.

Table 3b. Seed yield, irrigation, evapotranspiration, water productivity (WP), irrigation water productivity (IWP), relative water saving (RWS), relative yield decrease (RYD), and marginal productivity of irrigation water (MPIW) at different irrigation treatments at Satkhira

Experimental year	Treatments	Seasonal irrigation (mm)	Rainfall (mm)	Water use (mm)	Seed yield (t ha ⁻¹)*	RYD (%)	RWS (%)	WP (kg m ⁻³)	IWP (kg m ⁻³)	MPIW (kg m ⁻³)
2013–2014	T ₁	200	31	273	2.78a			1.02	1.39	0.35
	T ₂	184	31	259	2.73b	1.80	8.0	1.05	1.49	0.35
	T ₃	157	31	238	2.66c	4.32	21.3	1.12	1.69	0.39
	T ₄	123	31	199	2.51d	9.71	38.4	1.26	2.04	0.33
	T ₅	109	31	187	2.46e	11.5	45.3	1.31	2.25	0.29
	T ₆	95.5	31	179	2.42ef	13	52.1	1.35	2.53	
	T ₇	135	31	217	2.44f	12.2	32.3	1.12	1.81	-0.18
	T ₈	122	31	206	2.37g	14.8	38.8	1.15	1.94	-0.19
	T ₉	102	31	187	2.28h	18	48.9	1.22	2.24	-2.15
2014–2015	T ₁	141	88	255	2.90a			1.14	2.06	0.35
	T ₂	123	88	240	2.85b	1.72	12.5	1.19	2.32	0.36
	T ₃	91.6	88	213	2.74c	5.52	34.9	1.29	2.99	0.38
	T ₄	83.1	88	207	2.70d	6.90	40.9	1.31	3.25	0.34
	T ₅	72.1	88	198	2.65e	8.62	48.7	1.34	3.68	0.25
	T ₆	59.9	88	188	2.62f	9.66	57.4	1.40	4.38	
	T ₇	89.1	88	215	2.58g	11.0	36.6	1.20	2.90	-0.14
	T ₈	77.1	88	204	2.54h	12.4	45.2	1.24	3.30	-0.47
	T ₉	65.1	88	194	2.50i	13.8	53.7	1.29	3.84	-2.31

*Mean values followed by different letter within columns differ significantly at $p < 0.05$ according to Duncan's range test.

more wet season. For Gazipur higher value was found in 2014 and for Satkhira, it was 2015. Marginal productivity of irrigation water is an excellent tool for evaluating the performance of deficit irrigation strategies. Negative value indicate that additional one unit increase in irrigation water is not increase the yield whereas, positive value indicate that this additional unit of water are actively responsible for increasing yield. The more stress treatments (T₇, T₈ and T₉) resulted in higher IWP values in the year 2014 for Gazipur and 2015 for Satkhira because of rainfall. Sezen, Yazar, and Tekin (2011) reported IWP values varied from 0.39 to 0.97 kg m⁻³ in different treatments and experimental seasons.

3.2. Soil water content variation under different treatments

Soil moisture statuses in 90 cm soil depth for all treatments in the year 2014 and 2015 are presented in Figures 2a and 2b. Some similarities were observed in the trend of soil moisture and changes occurred due to rainfall. Before irrigation soil water content in the 90 cm soil depth was similar for all treatments and variation was observed due to different irrigation treatments and seasonal variability of rainfall. Treatment T₁-T₃ fluctuated within the available soil moisture (ASM) zone in the year 2014 and 2015 at Gazipur. In treatment T₄-T₆, soil moisture was fluctuated within the ASM until 60 DAS, after that these treatments drop very close to the wilting point at 80 DAS, and again rose to 50% ASM at 90 DAS because of rainfall. On the other hand, soil moisture in treatment T₇-T₉ was decreased after 50 DAS because of no irrigation. Again these treatments received irrigation at 80 DAS (pod formation stage) and rainfall at 90 DAS. Relative yield decrease in treatment T₇-T₉ was varied from 12.2 to 18% (Table 3a), and treatment T₄-T₆ was varied from 9.71 to 43% (Table 3b) than FI treatment. This higher yield reduction was the omission of irrigation at critical stage (pre-flowering stage). On the other hand, in the year 2015, at Gazipur, soil moisture in treatment T₄-T₆ decreased gradually from pre-flowering stage to until maturity.

Figure 2a. Variation of soil moisture content during crop period at Gazipur.

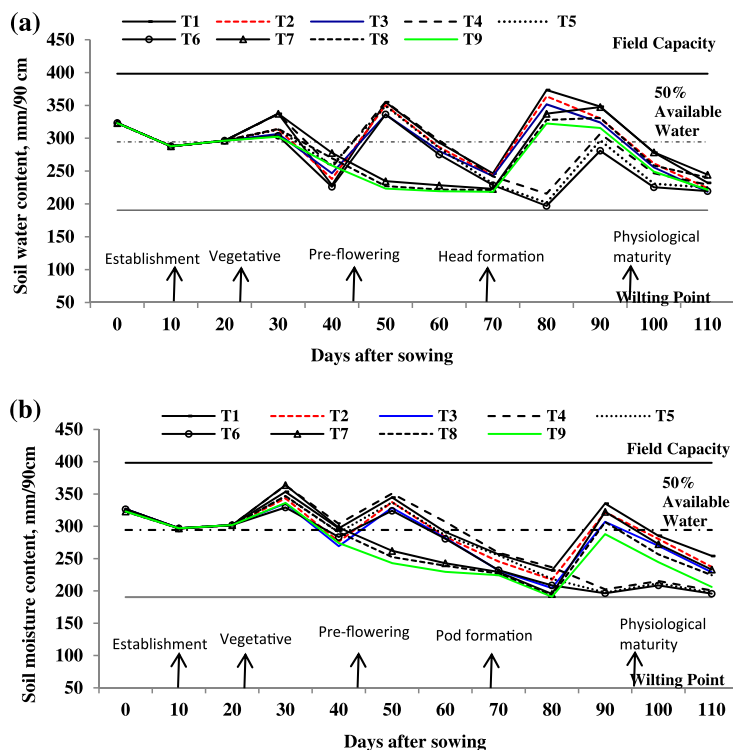
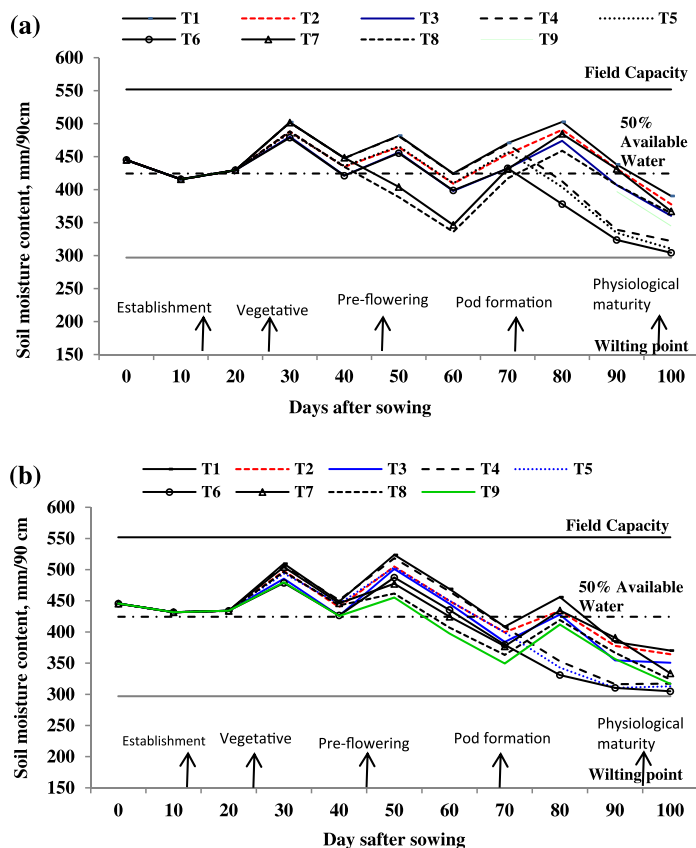


Figure 2b. Variation of soil moisture content during crop period at Benarpota, Satkhira.



In Satkhira, in the year 2014, soil moisture in the 90 cm soil profile was above 50% available water (AW) for treatment T_1 – T_3 until 90 DAS, while for treatment T_4 – T_6 it was above 50% AW until 70 DAS. All treatments received some amount of rainfall after pre-flowering stage. In the year 2015, similar trend was observed as found in the year 2014, but continuous rainfall after pre-flowering stage kept soil moisture favourable for plant growth and yield in the saline soil.

3.3. Canopy coverage, biomass, and root length density of sunflower

Crop canopy coverage, biomass and root length density was examined from crop establishment up to harvest and expressed as days after sowing (DAS). Initially canopy coverage (CC) was same (avg. 3.12 and 2.99% for Gazipur and Satkhira) at 14 and 15 DAS. After irrigation these values were changed according to the intensity of DI and ranking was $T_1 > T_2 > T_3 > T_4 > T_5 > T_6 > T_7 > T_8 > T_9$. The maximum CC was recorded in treatment T_1 (avg. 78.87 and 75.46%) and the minimum in treatment T_9 (avg. 67.96 and 53.74%) at 68 and 65 DAS for Gazipur and Satkhira, respectively. Mazaherilagnab, Noorizare, and Vafaie (2001) reported that less irrigation application during the crop period was responsible for reduced leaf area. Biomass was also fluctuated according to the intensity of DI and ranking was similar from T_1 to T_9 . The maximum biomass was recorded in treatment T_1 (avg. 15.13 and 15.05 t ha⁻¹) at 90 and 63 DAS for Gazipur and Satkhira, while the minimum was recorded for treatment T_9 (avg. 14.08 and 12.30 t ha⁻¹). After 114 and 102 days, its value decreased to 9.55–8.53 and 9.29–8.04 t ha⁻¹ which was the period of maturity. In Satkhira, crop faces two types of stress one for soil salinity and another for water stress which creates an adverse situation for plant root system. The highest root length density (RLD) was found at 24 cm soil depth, after that it was decreased. It was also found that treatment T_1 had experienced the lowest figure among all the treatments for different depth, whereas treatment T_9 had the highest. This was due to the effect of irrigation treatments, as T_1 received three irrigations up to 100% FC at vegetative, pre-flowering and heading stage, while T_9 received up to 60% of FC at vegetative and heading stage, which significantly affect the plant root. It was due to imbalanced soil water content in the plant root zone which enhanced plants ability to improve water uptake via enlarging their root system, hence result was an increased RLD (Turner, 1986). Glinka (1980) reported that excessive production of abscisic acid (ABA) was responsible for increasing cell's root hydraulic conductivity.

3.4. Effect of irrigation on seed yield

Results of Tables 3a and 3b show that irrigation significantly ($p < 0.05$) affect seed yield in the year 2014 and 2015 in Gazipur and Satkhira. The significantly highest seed yield (avg. 2.60 t ha⁻¹ and 2.84 t ha⁻¹ for Gazipur and Satkhira) was found in treatment T_1 (FI-100), whereas lowest was found in treatment T_9 (avg. 2.01 and 2.39 t ha⁻¹ for Gazipur and Satkhira). Treatment T_1 used highest amount of water (avg. 305 and 300 mm for two locations) for producing highest yield. Treatment T_6 used the least amount of water to produce optimum yield (avg. 2.18 and 2.53 t ha⁻¹ for two locations), as the strategy of deficit irrigation is to optimize production. This treatment saved average 68.15 and 54.75% of water, with yield decreased average 16.00 and 11.33% than treatment T_1 for Gazipur and Satkhira, respectively. In Satkhira, seed yield was found comparatively higher in both years than that of Gazipur. This was due to the effect of rainfall (Table 1) as well as irrigation (Table 3b) during the crop period which significantly provide salts leaching facilities in the plant root zone. Besides, irrigation water salinity ranged from 4.00 to 5.78 dSm⁻¹ (Table 2) which was not hampered seed yield in the low to moderate salinity reason of Benarpota, Satkhira. Demir et al. (2006) also got the highest yield (3.95 t ha⁻¹) by applying three irrigations at H (heading), F (flowering), and M (milk ripening) stages in non-saline soil.

Treatment T_4 – T_6 received less water to produce optimum yield compared to treatment T_7 – T_9 (Tables 3a and 3b) though number of watering was same but stages of application was varied. Therefore, it can be concluded that pre-flowering stages was the critical stage to deficit irrigation and some water must be ensured at this stage to get optimum yield under water scarce region for both fresh and medium salinity region in Bangladesh.

3.5. Effect of irrigation on yield components

Results in Table 4 shows that irrigation was significantly affected on yield and yield components of sunflower. Full irrigation produced significantly highest number of seed per head, seed weight per head and 100 seed weight in the year 2014 and 2015 for both locations. Number of seed per head decreased with the increase in intensity of deficit irrigation. Seed weight was also influenced by the intensity of deficit irrigation. This was directly influenced by seed yield because potential gradient occurred due to soil water deficit in the root zone. As a result, reduction in plant growth and seed weight happened. Yield component values were higher in the year 2014 in Gazipur and 2015 in Satkhira because of rainfall. Sezen, Yazar, and Tekin (2011) found that water deficit resulted in lower seed weight and result in lower yield.

3.6. Variation of salinity

Figure 3 shows data about soil salinity at various growth stages at Satkhira during 2014 and 2015. At the time of sowing, the salinity level was minimum (average 2.55 dSm⁻¹) and it was gradually increased and finally reached to 11.0 and 7.5 dSm⁻¹ at the maturity stage in the year 2014 and 2015, respectively. This was due to the effect of rainfall in the year 2015 (Table 1). As a result, significant increase in yield of sunflower under all the treatments (Table 3b) was produced. Chen et al. (2009) found that the final emergence percentage was not changed when salinity level of irrigation water was less than 6.3 dSm⁻¹ and after that every unit increase in salinity level decreased the emergence percentage by 2.0%. The average soil salinity at pre-flowering (PF) stage was found highest in treatments T₇, T₈, and T₉ in 2014 whereas, the variation of value for other treatments was minimal. This may be due to the fact that irrigation up to 100, 80 and 60% of the root zone deficit were applied only for vegetative (V) and heading (H) stages. Karim and Rahman (2012) found that the yield of

Table 4. Effect of DI on yield component of sunflower at Gazipur and Satkhira

Year	Treatments	Gazipur			Satkhira		
		No of seed/head*	Seed weight/head (g)*	100 seed weight (g)*	No of seed/head*	Seed weight/head (g)*	100 seed weight (g)*
2013-2014	T ₁	876a	68.7a	9.83a	884 a	78.0a	12.1a
	T ₂	826b	66.3b	9.58b	874b	77.7b	11.9 b
	T ₃	798c	66.2b	9.49c	861c	76.5c	11.7c
	T ₄	778d	65.7b	9.35d	846d	74.3d	11.6d
	T ₅	764e	64.1c	9.25e	830e	72.7e	11.2e
	T ₆	759f	59.7d	9.24e	813f	70.8f	10.9f
	T ₇	743g	58.0e	9.13f	803g	69.7f	10.7g
	T ₈	733h	56.3f	9.03g	781h	67.7g	10.5h
	T ₉	721i	51.8g	8.88h	765i	66.7g	10.1i
2014-2015	T ₁	880a	69.7a	10.2a	927a	84.0a	12.3a
	T ₂	832b	68.7a	9.78b	906b	80.0b	12.0ab
	T ₃	820c	67.8ab	9.70b	890c	78.4c	11.7abc
	T ₄	795d	66.0bc	9.42c	878d	77.5d	11.7abc
	T ₅	779e	65.1c	9.26cd	852e	76.5e	11.3bcd
	T ₆	769f	61.6d	9.26cd	849f	74.1f	11.0cde
	T ₇	751g	60.5de	9.13de	848g	73.8g	10.7def
	T ₈	740h	58.8e	9.10de	823h	73.6h	10.3ef
	T ₉	725i	53.6f	8.98e	785i	72.4i	10.0f

Notes: T₁, T₂, T₃ indicate 100, 80 and 60% of DI at vegetative, pre-flowering and pod formation stage; T₄, T₅, T₆ indicate 100, 80 and 60% of DI at vegetative and pre-flowering stage; T₇, T₈, T₉ indicate 100, 80 and 60% of DI at vegetative, and pod formation stage.

*Mean values followed by different letter within columns differ significantly at $p < 0.05$ according to Duncan's range test.

Figure 3. Variation of crop soil salinity at different growth stages at Benarpota, Satkhira.

Note: Error bar indicates SE ± 0.05.

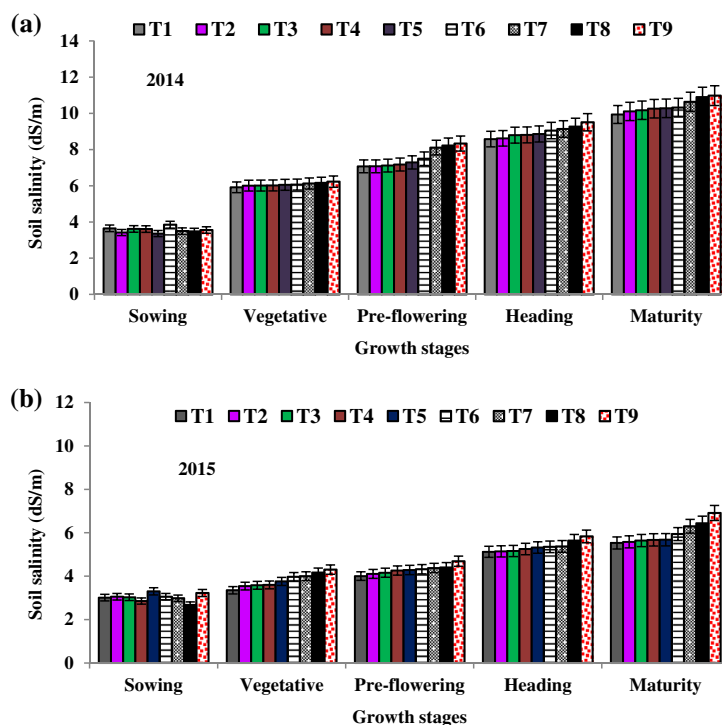


Table 5a. Total cost, gross return and net return of BARI Surjomukhi-2 under water-limiting condition (US\$ 24.02 ha cm of water) at Gazipur (average of years)

Treatment	Land under irrigation (ha)	Gross return from sunflower and straw (\$ha ⁻¹)	Total operating cost (\$ha ⁻¹)	Interest on operating cost (\$ha ⁻¹)	Land-use cost (\$ha ⁻¹)	Total cost (\$ha ⁻¹)	Net return (\$ha ⁻¹)
T ₁	1	3,530	1,274	42.42	463.2	1,779	1,751
T ₂	1.17	4,012	1,424	47.41	541.9	2,013	1,999
T ₃	1.48	5,001	1,713	57.05	685.5	2,456	2,545
T ₄	2.1	6,922	2,279	75.90	972.6	3,328	3,594
T ₅	2.48	8,081	2,624	87.36	1,149	3,860	4,222
T ₆	3.21	10,275	3,255	108.4	1,487	4,851	5,425
T ₇	1.74	5,531	1,928	64.21	805.9	2,799	2,732
T ₈	2.08	6,514	2,243	74.68	963.4	3,281	3,233
T ₉	2.39	7,352	2,525	84.08	1,107	3,715	3,637

Notes: T₁, T₂, T₃ indicate 100, 80 and 60% of DI at vegetative, pre-flowering and pod formation stage; T₄, T₅, T₆ indicate 100, 80 and 60% of DI at vegetative and pre-flowering stage; T₇, T₈, T₉ indicate 100, 80 and 60% of DI at vegetative, and pod formation stage. ‘\$’ means US\$; 1 US\$ = 78.34BDT.

BARI Surjomukhi-2 was increased from 2.61 to 2.95 t ha⁻¹ by applying underground saline irrigation water three times with 3–8 or 4–6 dSm⁻¹ and soil salinity was about 6 dSm⁻¹.

3.7. Economic analysis under water-limiting condition

Tables 5a and 5b compare total cost, revenue from sunflower and its by product, and net return under different deficit irrigation treatments with full irrigation in considering water scarce condition at Gazipur and Satkhira. Revenue from sunflower and straw was increased in the deficit irrigated

Table 5b. Total cost, gross return and net return of BARI Surjomukhi-2 under water-limiting condition (US\$ 17.01 ha cm of water) at Satkhira (average of years)

Treatment	Land under irrigation (ha)	Revenue from sunflower and straw (\$ha ⁻¹)	Total operating cost (\$ha ⁻¹)	Interest on operating cost (\$ha ⁻¹)	Land-use cost (\$ha ⁻¹)	Total cost (\$ha ⁻¹)	Net return (\$ha ⁻¹)
T ₁	1	3,706	815.2	27.15	217.0	1,060	2,646
T ₂	1.12	4,061	884.5	29.45	243.0	1,157	2,904
T ₃	1.41	5,016	1,059	35.24	305.9	1,400	3,616
T ₄	1.66	5,723	1,190	39.62	360.2	1,590	4,134
T ₅	1.89	6,400	1,329	44.25	410.1	1,784	4,616
T ₆	2.22	7,394	1,523	50.71	481.8	2,056	5,338
T ₇	1.53	5,021	1,118	37.20	332.0	1,487	3,535
T ₈	1.73	5,560	1,235	41.11	375.4	1,651	3,909
T ₉	2.06	6,439	1,429	47.58	447.0	1,923	4,516

treatments in comparison with full irrigation. This was due to the effect of more land under cultivation by applying saved water. The highest gross return was obtained in treatment T₆ by applying 60% DI up to field capacity at vegetative (V) and pre-flowering (PF) stage with three times yield increased as well as 3 times area coverage by saving more than 50% water compared to full irrigation (Tables 3a and 3b). Similarly, total operating cost was found highest in DI compared to FI. The highest total cost was found in treatment T₆ which was about double in compared to FI because cost of cultivating more than twice land by supplying all inputs including, seed, fertilizer, labor, insect, irrigation cost. Finally, net revenue was found highest in treatment T₆ which was more than three times (Gazipur) and two times (Satkhira) in compared to FI. This result was in agreement with Ali et al. (2007) though they applied DI on wheat crop and evaluates economics of DI under both water and land limiting conditions. Therefore, it can be said that 60% DI at V and PF stage was found more beneficial among other DI strategies in considering additional land under irrigation which satisfied the objectives of DI.

4. Conclusions and recommendations

Deficit irrigation is an effective technique to utilize scarce water for increasing water productivity in the semi-arid climatic conditions of Bangladesh. From the two years field observations, it was found that deficit irrigation had significant negative effect on growth and yield of BARI Surjomukhi-2 at Gazipur and Satkhira. The canopy coverage and biomass was decreased by the application of deficit irrigation, whereas root length density was increased in compared to full irrigation, and the yield was not severely affected. However, maximum water productivity was achieved by irrigating 60% of the root zone deficit at vegetative and pre-flowering stage in compared to full irrigation. It was recommended that some water must be ensured at the pre-flowering stage to avoid severe yield loss. This treatment also save more than 50% water which can be utilized economically to productive more land with the objective of optimize yield.

Therefore, from the evaluation of yield, seasonal irrigation amount, irrigation water productivity, relative water savings, relative yield reduction and net financial benefit under limited water resources conditions, the following deficit irrigation can be adopted for judicious utilization of water resources and higher water productivity.

- (1) When water is available for two irrigations (about 7–9 cm), irrigation up to 60% of the root zone deficit should be applied at pre-flowering and pod formation stage.
- (2) When water is available for three irrigations (about 13–18 cm), irrigation up to 60% of the root zone deficit should be applied at vegetative, pre-flowering and pod formation stage.

If rainfall occurs at a particular stage, irrigation should be avoided at that stage and if additional irrigation can be applied with the saved water, the critical stage (pre-flowering stage) should be irrigated. When land is available but water is limiting, crop production by the application of a relatively small amount of water with strategic options (two or three irrigation strategies, as mentioned above) could substantially increase total farm income. Therefore, it can be said that utilizing irrigation water over a larger land area with smaller water input per unit area can enable better usage of water resources under water scarce situation.

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