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INFLUENCE OF DIFFERENT IRRIGATION REGIMES AND VARIETIES ONYIELD AND WATER PRODUCTIVITY OF COMMON BEAN UNDER SEMI DESERT CLIMATIC CONDITIONS OF SUDAN

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ABSTRACT

A field experiment was conducted at Hudeiba Research Station Farm, located at Ed-Damer, Sudan during 2011/2012 and 2012/2013 winter seasons to investigate the effect of different irrigation regimes and varieties on common bean (Phaseolus vulgaris L.) yield, yield components and water productivity. The treatments included three irrigation regimes; irrigation every 10 days (I1= full irrigation), irrigation every 15 days (I2= moderate stress) and irrigation every 20 days (I3= severe stress) and two varieties (Giza3 & Ibraya). The treatments were arranged in factorial randomized complete block design (RCBD) with 3 replications. Irrigation water applied, grain yield, yield components (number of pods per plant, number of seeds per pod and the 100 seeds weight) and crop water productivity (CWP) and irrigation water productivity (IWP) were recorded. Results showed that number of pods per plant, number of seeds per pod, 100-seeds weight, grain yield and irrigation water applied were significantly ($p \leq 0.001$) affected by irrigation regimes. The highest values of these traits obtained with full irrigation, whereas the lowest values recorded under severe water stress conditions. Results also indicated that, moderate and severe water stress regimes saved 591 m3 and 1075 m3 of irrigation water, respectively compared with full irrigation. . This study indicated that, treatment I1 that was irrigated every 10-days did not produce the highest IWP, while treatment I2 which irrigated every 15-days gave the highest IWP. The lowest IWP occurred at severe water stress regime (I3). It could be concluded that moderate water stress may be adopted. Contrarily, the adoption of severe water stress that produce high water savings would lead to yield losses that may be economically not acceptable.
Giza3 was a superior variety under both full and deficit irrigation conditions, compared with Ibraya. This superiority was attributed to the higher number of pods per plant and higher number of seeds under all irrigation treatments. Giza3 significantly obtained ($p \leq 0.001$) higher IWP and CWP.

INTRODUCTION

Under the desert and semi-desert conditions of Northern Sudan agricultural production is mainly dependent on irrigation. River Nile (RN) and Atbara River are the main sources for irrigation water in this region. Cultivated lands are concentrated around the River Nile and Atbara banks as well as terraced areas that surround the banks. Irrigation water is considered as the main constraint facing agricultural production (Faki 1999) and that might refers to the high cost pumping water.

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This problem is more associated with crop production in high terrace land where lifting underground water is extremely costly. Such situation requires more efficient use of irrigation water as a pre-requisite for future agricultural expansion. It is necessary to develop new irrigation scheduling approaches, not necessarily based on full crop water requirement, but ones designed to ensure the optimal use of allocated water (Kirda, 2002). One of the promising irrigation strategies to obtain 'more crop per drop' is deficit irrigation (English, 1990). Deficit irrigation is an irrigation practice whereby water supply is reduced below full crop water requirements (evapotranspiration) (Fereres and Soriano, 2007), the crop is expose to certain levels of water stress during either a particular growth period or throughout the whole growth season, without significant reduction in yields (Kirda, 2002). The potential benefits of deficit irrigation arise from enhanced water productivity and lower production costs if one or more irrigation application can be eliminated (Kipkorir *et al*., 2002; Ali *et al*., 2007). Research results indicate that deficit irrigation can increase water productivity for various crops without causing severe yield reductions if the moisture stress resulting from the deficit is not so severe (Kirda, 2002; Igbadun *et al*., 2006). Deficit irrigation usually maximizes water productivity, and the water saved may be used to irrigate extra land or crops to better increase overall production (Oweis and Hachum, 2008), but this requires a better understanding of crop response to various levels of water stress.

Common bean (*Phaseolus vulgaris* L.) can be grown as a vegetable crop for fresh pods or as a pulse crop for dry seeds. Common bean is a good source of proteins, vitamins, dietary fibre, minerals, complex carbohydrates and free unsaturated fatty acids (Anonymous, 2001). It is an important crop in Latin America for its grain protein content. World production of dry beans is about 23 million tons from 29 million hectares (FAOSTAT, 2011). In the Sudan, common bean is the second most important food legume after faba bean with respect to production and consumption. The major producing areas of the crop are Shendi, Berber and Lower Atbara in the River Nile State and some few areas in different parts of Sudan. The crop is normally cultivated under residual soil moisture stored in basins and islands after the Nile floods recede. However, appreciable areas are also grown to common bean under irrigation. Areas and production of common bean are governed by the amount of the flood, weather conditions and competence with other crops. Average area grown to this crop in River Nile State for the period 2003- 2012 was about 7000 ha with an average yield of 1.8 t/ha (Ministry of Agriculture, River Nile State 2013).

The effect of water deficit on common bean growth and yield depend upon the degree of stress and the development stage at which the stress occurs. Ghassemi-Golezani and Mardfar (2008) stated that Common bean is a sensitive crop to water stress and high yield of this crop can only be obtained under sufficient irrigation conditions. Acosta- Gallegos and Adams (1991) and Ramirez-Vallejo and Kelly (1998) reported that drought stress significantly reduced number of pods and grains per plant, days to maturity, grain weight and grain yield in common bean crop. The objective of this research was to investigate the effect of different irrigation regimes and varieties on common bean (*Phaseolus vulgaris* L.) yield, yield components and water productivity.

MATERIALS AND METHODS

A field experiment was conducted under irrigation, for two consecutive seasons (2011/2012 and 2012/2013), at the Hudeiba Research Station Farm, Ed-Damer, Sudan, located at latitude (17.57°) N, Longitude (33.93°) E, and altitude 350 m above sea level. The local climate is semi-desert (Adam, 2005), very hot and dry in summer and relatively cool in winter. According to soil profile (Table 1) the soil of the study site is clay in texture and is classified as VerticTorrifluvent, fine Smectitic, Calcaleous, hyperthermic, Bergieg series (USA, Soil Taxonomy); with very low permeability, field capacity of 46% by volume and a permanent wilting point of 25% by volume. In general, the soil is non-saline and non-sodic, with alkaline reaction; and low in both organic carbon and nitrogen content

The experiment was a factorial design with three irrigation regimes namely, I_1 Irrigation every 10 days (full irrigation), I_2 Irrigation every 15 days (moderate water stress), I_3 Irrigation every 20 days (severe water stress) and two contrasting varieties (Giza3, representing prostrate growth habit and Ibraya, representing determinate growth habit). The treatments were arranged in randomized complete block design (RCBD) with 3 replications. Water was applied just below the surface of the top of the ridges. The gross plot size was 7 ridges x 0.6 m (ridge width) x 12 m (ridge length) = 50.4 m^2. The crop was sown manually during the first week of November in each of the two crop seasons. All crops were planted in holes on top of 60 cm spaced ridges, with intra-row spacing of 0.1 m between holes and at the rates of 2 seeds per hole. Nitrogen at the rate of 86 kg N ha^{-1} in form of urea was applied uniformly, to all experimental plots. Hand weeding of the experimental area was performed as required. The crop was infested by whitefly. Therefore, the recommended insecticide (confidore) was used to combat the insect in both seasons.

The plots were irrigated by furrow irrigation method. The amount of irrigation water (m^3) for each plot in each irrigation event was measured directly in the field, using a current flow meter (type BFM001) connected to an irrigation pipe, using the following equation:

$$I = A \times T \times V \quad \text{.............................Equation 1}$$

Where,

I = irrigation water (m^3), A = cross section area (m^2), T = total time (s) and V = velocity ($m\ s^{-1}$)

Evapotranspiration (ETc) was determined using a standard water balance equation (Equation 2).

$$ETc = I + P + W - R - D \pm \Delta S \quad \text{.................................... Equation 2}$$

Where,

I = irrigation, P = rainfall, W = capillary rise, R = runoff, D = deep drainage, and S = soil moisture. For the period after irrigation and before the next irrigation, I = 0 as no irrigation water is added. During winter (November-February), the rainfall (P) is zero. The water table is deep so the capillary rise (W) is zero. The runoff (R) is negligible as the land is flat with a very gentle slope (Adam 2005). The soil is impermeable so the deep drainage (D) is almost zero. Therefore the evapotranspiration is equal to the change in soil moisture (ΔS) Soil moisture depletion (S) was calculated from soil water profile, measured in one replication for a depth of 60 cm with 20 cm intervals, 2-3 days after irrigation and immediately before each irrigation event. This was done from planting to harvesting, through gravimetric method. Soil samples were oven-dried at 105 °C for 24 hours.

Then, the calculated gravimetric moisture contents were converted into volumetric values, through multiplication with dry soil bulk density, viz:

$$\Delta S = \frac{\sum_{i=1}^{n} (\theta 1 - \theta 2) d}{\Delta t} \quad \text{..................Equation 3}$$

Where,

n = number of soil layers sampled in the effective root zone which is = 3 (0-20, 20-40, 40- 60); θ1 volumetric moisture content within 2-3 days after irrigation; θ2 = volumetric moisture content before the next irrigation in the i-th layer; d = the thickness of i-th layer (mm), which is = 200 mm; and Δt = the time interval between two consecutive measurements (days).

Irrigation treatments were started from the third irrigation

At harvest time for both seasons, the central three ridges (8 m long) = 14.4 $m^2$of each plot were harvested for determining grain yield. A sub sample of ten plants was taken for determining the yield components (number of pods per plant, number of seeds per pod and the 100 seeds weight).

Crop water productivity is commonly expressed as the economic yield divided by the seasonal crop water use (seasonal evapotranspiration) (Zwart and Bastiaanssen, 2004: Geerts and Raes, 2009), while the Irrigation water productivity is the economic yield divided by the total irrigation water applied (Bouman, 2007; Vazifedoust*et al*., 2008)
Crop water productivity (CWP) was calculated as

$$\mathrm{CWP} = \frac{\mathrm{Y}}{\mathrm{ET}} \quad \text{.................................... Equation 4}$$

Where, Y= yield (kg ha^{-1}), ET= seasonal evapotranspiration (m^3 ha^{-1}).
And

Irrigation water productivity (IWP) was calculated as

$$\mathrm{IWP} = \frac{\mathrm{Y}}{\mathrm{I}} \quad \text{.. Equation 5}$$

Where,

Y= yield (kg ha^{-1}), I= irrigation water applied (m^3 ha^{-1}).

Analysis of variance (ANOVA) was carried out using MSTAT statistical package (1984). The data obtained were analyzed for each season separately, and then combined analysis was run for the two growing seasons because the homogeneity test was positive. As the soil moisture measurements were performed in one block, statistical analyses could not be performed for crop water productivity.

RESULTS AND DISCUSSION

Crop growth environment

The prevailing thermal regime as daily mean temperature during the two growing seasons (2011/2012 and 2012/2013) is displayed in Figure 1. The crop season 2012/2013 experienced warm spells at the beginning and at the end of the season. However, the crop season 2012/2013 was comparatively cooler than 2011/2012 during the middle of the growing season.

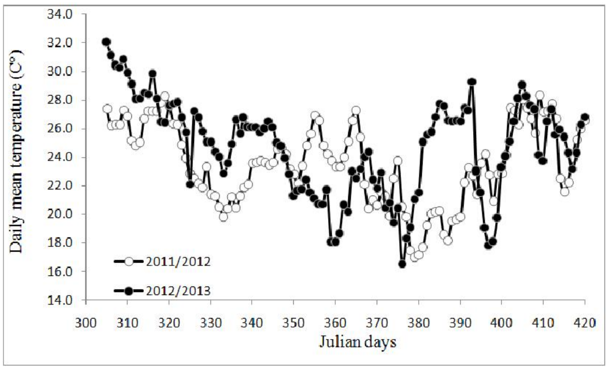

Figure 1. Prevailing thermal regime as daily mean temperature at Hudeiba Research Farm for the crop seasons 2011/2012 and 2012/2013

Soil moisture extraction

Figure (2) shows the effect of Irrigation regime on the moisture extraction patterns of common bean. The water-stressed treatments (I_2 and I_3) extracted more water from deeper layers than in the full-irrigated treatment (I_1). This was due to limited availability of moisture in upper layers. The driest soil moisture regime caused higher moisture depletion. In general, moisture extraction occurred between 0 to 40 cm soil depths and decreased thereafter. Similar soil moisture extraction patterns were reported by several investigators (Panda *et al*., 2003; Ali *et al*., 2007).

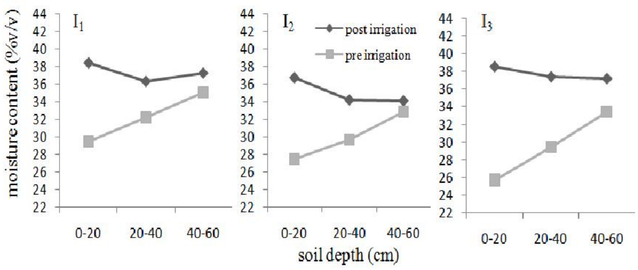

Figure 2. Soil moisture extraction patterns of common bean

Yield and yield components

Grain yield and yield components of common bean as affected by irrigation regime and variety are presented in Table (2). The results showed that the yield of common bean was significantly ($p \leq 0.001$) decreased under water deficit conditions. The highest grain yield (740 kg/ha) was obtained under full irrigation (Table 2) and decreased by 9% and 55% under moderate and severe water stress, respectively. There were also significant ($p \leq 0.001$) reductions in number of pods per plant, number of seeds per pod and 100-seeds weight with water deficit stress and the trend was similar to the yield trend. The highest values of these traits recorded with full irrigation, whereas the lowest values recorded under severe water stress conditions (Table 2). Similar results were reported by Acosta-Gallegos and Adams (1991) and Ramirez-Vallejo and Kelly (1998).

Table 1. Selected physical and chemical properties of the soil at the experimental site in Northern Sudan

Depth (cm)	0-23	23-44	44-87	87-120	120-157	157-203	Mean
Sand (%)	4	3	3	3	4	3	4
Silt (%)	47	42	39	37	40	37	40
Clay (%)	49	55	58	60	56	60	56
Hydraulic conductivity (cm/hr)	0.32	0.1	0.1	0.11	0.07	0.07	0.13
Moisture content at wilting point (m3/m3)	38	43	47	44	50	54	46
Moisture content at field capacity (m3/m3)	21	23	26	24	27	29	25
Soil bulk density (g/cm3)	1.77	1.66	1.85	1.74	1.71	1.83	1.76
pH	7.8	8	7.9	7.7	8	7.9	7.9
Electrical conductivity (dS/m)	0.3	2.4	3.6	3.5	3.6	4.9	3.1
Calcium carbonate (%)	6	4.6	5.4	6	5.2	5.4	5.4
Total nitrogen (%)	0.045	0.04	0.045	0.03	0.035	0.035	0.038
Organic carbon (%)	0.499	0.312	0.203	0.265	0.187	0.218	0.281
Cation exchange capacity (meq/100g soil)	48	54	53	52	53	58	53
Sodium absorption ratio	1	7	10	12	7	7	7

Table 2. Mean grain yield and yield components of common bean as affected by irrigation regime and variety (averaged over seasons 2011/2012- 2012/2013) at Hudeiba, northern Sudan

	Grain yield (kg/ha)			No. of pods/plant			No of seeds/pod			100 seed weight (g)		
	Ibraya	Giza3	mean	Ibraya	Giza3	mean	Ibraya	Giza3	mean	Ibraya	Giza3	mean
I_1	643	837	740	14.0	15.4	14.7	3.8	4.1	4.0	29.5	21.0	25.3
I_2	593	749	671	9.9	14.0	12.0	3.7	3.8	3.8	28.1	18.2	23.2
I_3	254	416	335	5.9	9.7	7.8	2.7	3.1	2.9	21.9	16.6	19.3
Mean	497	667	582	9.9	13.0	11.5	3.4	3.7	3.5	26.5	18.6	22.6
SE ± (I)		23.87***			0.53***			0.11***			0.75***	
SE ± (V)		19.49***			0.43***			0.09*			0.62***	
SE ± (I x V)		33.75 ns			0.74 ns			0.16 ns			1.07 ns	
C.V (%)		14.2			5.9			11.1			11.6	

Ns: Not significant. *, **, *** Significant at $p \leq 0.05$, 0.01 and 0.001 respectively

Table 3. Amount of irrigation water applied (m^3ha^{-1}), number of irrigation events and crop evapotranspiration (m^3ha^{-1}) of common bean as affected by irrigation regime and variety (averaged over seasons 2011/2012- 2012/2013) at Hudeiba, northern Sudan

	Irrigation water applied (m^3ha^{-1}) (number of irrigations)			Crop ET (m^3ha^{-1})		
	Ibraya	Giza3	Mean	Ibraya	Giza3	Mean
I_1	5765	5850	5808 (8)	2860	2741	2801
I_2	5213	5220	5217 (7)	2573	2422	2497
I_3	4702	4764	4733 (6)	2159	2292	2226
Mean	5227	5278	5252 (7)	2531	2485	2508
SE ± (I)		62.90***				
SE ± (V)		51.36 ns				
SE ± (I x V)		88.96 ns				
C.V (%)		4.2				

ns Not significant. *, and *** Significant at $p \leq 0.05$ and 0.001 respectively

A positive and highly significant correlation was found between grain yield of common bean and number of pods per plant, number of seeds per pod and 100-seeds weight (r^2 = 0.94, 0.99 and 0.96, respectively) Figure (3). Which, indicate that the decrease in grain yield due to water deficit was attributed to reduction in these traits.

The decrease in yield and yield components of common bean, due to water stress, has also been reported by other researchers Acosta- Gallegos and Adams (1991), Ramirez-Vallejo and Kelly (1998), szilagyi (2003) Ghassemi-Golezani and Mardfar (2008) Al-Suhaibani (2009), Emam *et al*. (2010) and Ghassemi-Golezani *et al*., (2013). Concerning the effect of variety, the prostrate growth habit variety Giza3 significantly ($p \leq 0.001$) out-yielded the determinate growth habit Ibraya by 25% (Table 2). The high yield of Giza3 was mainly due to the significant ($p \leq 0.001$) higher number of pods per plant and significant ($p \leq 0.05$) higher number of seeds per pod of Giza3 in comparison to these of Ibraya. On the other hand Ibraya had significant ($p \leq 0.001$) biggest grain size (Table 2).

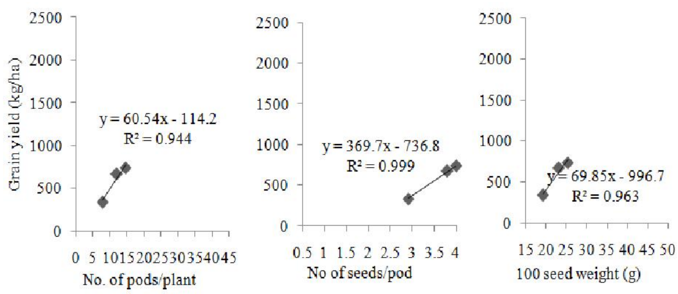

Figure 3. Relationship between grain yield and yield components of common bean as affected by irrigation regime

No significant variety X irrigation regime interaction indicates that Giza3 was superior both under full irrigation and water stress conditions.

In this study, the unexpected low grain productivity of common bean is attributed to the severe infestation of the crops by insect pest of whitefly.

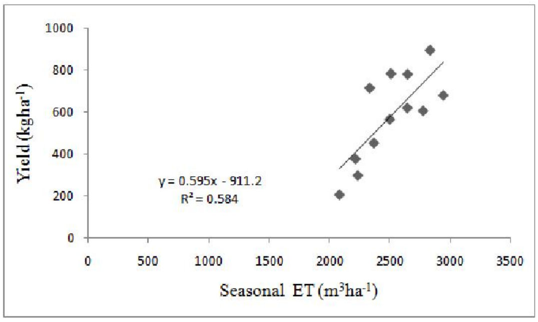

Figure 4. The relationship between grain yield of common bean and seasonal evapotranspiration (ET)

The amount of irrigation water applied and crop water use

Table (3) shows the number of irrigations, amount of irrigation water applied (including the first irrigation) and seasonal water used by the crop as an evapotranspiration (ET) in cubic meter per hectare.

Water productivity

Table (4) shows crop water productivity (CWP) and irrigation water productivity (IWP) of common bean as affected by irrigation regime and variety.

CWP ranged from 0.150 $kgm^{-3}$for treatment I_3 to 0.270 $kgm^{-3}$for treatment I_2, whereas IWP ranged from 0.071 kgm^{-3} for treatment I_3 to 0.128 kgm^{-3} for treatment I_2. Treatment I^1, which obtained the highest grain yield, did not produce the highest CWP and IWP. The results of this study indicated that despite reduction in grain yield, plants under moderate water-stress regime can utilise water efficiently as shown by high irrigation water productivity. Similar findings were reported by Oweis *et al*. (2000) who found that maximum wheat yields were obtained at full irrigation, though maximum water productivity was reached at two thirds of the seasonal irrigation water requirement. The lowest IWP occurred at severe water stress level (I_3).

Table 4. Mean irrigation water productivity (IWP) and crop water productivity (CWP) of common bean as affected by irrigation regime and variety (averaged over seasons 2011/2012- 2012/2013) at Hudeiba, northern Sudan

	IWP (kg/m^3)			CWP (kg/m^3)		
	Ibraya	Giza3	Mean	Ibraya	Giza3	Mean
I_1	0.112	0.143	0.128	0.225	0.305	0.265
I_2	0.114	0.143	0.129	0.230	0.309	0.270
I_3	0.054	0.088	0.071	0.118	0.181	0.150
Mean	0.093	0.125	0.109	0.191	0.265	0.228
SE ± (I)		0.0047***				
SE ± (V)		0.0038***				
SE ± (I x V)		0.0066ns				
C.V (%)		14.9				

ns Not significant. *, and *** Significant at $p \leq 0.05$ and 0.001 respectively

The total numbers of irrigations given in each irrigation regime in both seasons for I_1, I_2, and I_3 were 8, 7, and 6, respectively. The seasonal ET varied between 2801 m^3ha^{-1} and 2226 m^3ha^{-1} (Table 3). Among the different irrigation regimes, the highest seasonal ET was recorded in treatment I_1, which exceeded those of (I_2) and (I_3) by 11% and 21%, respectively. The analyses of variance (Table 3) revealed that irrigation water applied was significantly ($p \leq 0.001$) affected by irrigation regime treatments. The greatest amount of irrigation water was applied in the full irrigation and significantly ($p \leq 0.001$) reduced through the use of moderate and severe water stress regimes with volume of water saved 591 m^3 and 1075 m^3, respectively.

Yield–ET relationship

The relationship between common bean grain yield and Seasonal ET is presented in Figure 3 using all 12 data points obtained during the study period (6 treatments -2 years). The data showed that good linear relationship between grain yield and ET (R^2 = 58%) The relationship implies that a threshold of approximately 1533 $m^3ha^{-1}$of crop water consumption of common bean will be observed before the yield is initiated and that thereafter, a yield of approximately 50 kg/ha will be obtained for every increment of 100 m^3ha^{-1} ETc (Fig.3). Several previous studies have also shown a linear relationship between grain yield and ETc (Zhang and Oweis 1999; Al-Jamal *et al*., 2000; Kipkorir *et al*., 2002; Igbadun *et al*., 2012)

This might be due to water savings at 20=day intervals are not enough to overcome the concurrent yield losses. With respect to the performance of the varieties, Giza3 significantly obtained ($p \leq 0.001$) higher IWP. For every 100 m^3 of water applied Giza3 gave 13 kg of grain per hectare, while Ibraya gave only 9 kg of grain per hectare

Conclusion

Under the conditions of this study, grain yield and yield components were significantly ($p \leq 0.001$) affected by irrigation regimes. Exposing common bean crop to water stress throughout the growing season significantly reduced grain yield. The low grain yield under water stress regimes is attributed to adverse effects of water stress on the yield components, mainly number of pods per plant, number of seeds per pod and 100-seeds weight.

The highest amount of irrigation water was applied in the full irrigation regime and significantly ($p \leq 0.001$) reduced through the use of moderate and severe water-stress regimes. Maximum CWP and IWP occur at crop water use less than the maximum. Treatment I_1 (full irrigation) did not produce the highest IWP, while treatment I_2 (moderate water stress) gave the highest IWP. The lowest IWP occurred at severe water stress regime (I_3). This might be due to the fact that water savings at 20=day intervals are not enough to overcome the concurrent yield losses. In conclusion, when water is scarce and irrigable land is relatively abundant as is the case in Sudan, adopting the moderate water stress (Irrigation every 15 days) could be recommended. Contrarily, the adoption of severe water stress that produce high water savings would lead to yield losses that may be economically not acceptable. The water saved from the moderate water-stress can be used to irrigate extra area to increase total production. It also reduces the cost of production by pumping less water. Regarding the performance of the varieties, the prostrate growth habit Giza3, significantly out-yielded the determinate growth habit Ibraya by 25%. Giza3 significantly obtained higher IWP and CWP. For every 100 m^3 of water applied Giza3 gave 13 kg of grain per hectare, while Ibraya gave only 9 kg of grain per hectare.

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