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Yield and Water Productivity of Chickpea (*Cicer arietinum* L.) as Influenced by Different Irrigation Regimes and Varieties 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 chickpea (*Cicer arietinum* L.) yield, yield components and water productivity. The treatments include three irrigation regimes; irrigation every 10 days (I_1 = full irrigation), irrigation every 15 days (I_2 = moderate stress) and irrigation every 20 days (I_3 = severe stress) and two varieties (Borgieg and Wad Hamid). The treatments were arranged in factorial randomized complete block design (RCBD) with 3 replications. Irrigation water being 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 the number of pods per plant, number of seeds per pod, 100-seeds weight, grain yield and irrigation water applied were significantly ($p \le 0.001$) affected by irrigation regimes. The highest values of these traits obtained with full irrigation, whereas the lowest values were recorded under severe water stress conditions. Results also indicated that, moderate and severe water stress regimes saved irrigation water by 24% and 32%, respectively compared with full irrigation. This study indicated that treatment I_1 which was irrigated every 10-days did

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not produce the highest IWP, while treatment I_2 which irrigated every 15-days gave the highest IWP. The lowest IWP occurred at severe water stress regime (I_3). It could be concluded that moderate water stress might be adopted. Contrarily, the adoption of severe water stressed that produce high water savings would lead to yield losses that might be economically not acceptable. The late maturing chickpea variety of Borgieg significantly ($p \leq 0.05$) out-yielded the early maturing variety Wad Hamid by 11%. Borgieg displayed the highest values of CWP and IWP.

Keywords

Water Stress, *Cicer arietinum* L., Borgieg, Wad Hamid, Water Productivity

1. Introduction

The rapid increase of the world population and the corresponding demand for extra water by sectors such as industries and municipals, forces the agricultural sector to use its irrigation water more efficiently on the one hand and to produce more food on the other hand [1]. Although Sudan has sufficient potential water resources, it falls in water scarcity countries (economic water scarcity) because it is extremely difficult to find the financial resources to build enough water development projects [2]. Pump is the main source for irrigation water in Northern Sudan from River Nile (RN), the irrigation cost is considered as the most agricultural constraints and that may refer to the high cost pumping water from RN [3]. Such situation requires more efficient use of irrigation water as a pre-requisite for future agricultural expansion. One of the promising irrigation strategies to obtain "more crop per drop" is deficit irrigation [4]. Deficit irrigation is application of water below full crop water requirements (evapotranspiration) [5], and the crop is exposed to a certain level of water stress either during a particular period or through the whole growing season. The potential benefits of deficit irrigation arise from enhanced water productivity (WP) and lower production costs if one or more irrigation application can be eliminated. WP is useful for looking at potential increase in crop yield that may result from increased water availability [6] [7]. It provides a simple means of assessing whether yield is limited by water supply or other factors [8]. Quantitative information on WP is, therefore, necessary for effective planning of irrigation water management strategies in an area [9]. Crop water productivity (CWP) is generally defined as marketable yield (Y) to the volume of water consumed by the crop (ET) [10] [11], but economists and farmers are most concerned about the yield per unit of irrigation water applied [12].

Chickpea (*Cicer arietinum* L.) is an important source of protein, carbohydrates, vitamins, and certain minerals. While this pulse crop is an important source of dietary protein for human consumption, it is also important for the management of soil fertility due to its nitrogen-fixing ability [13]. Most chickpea producing areas are located in the arid and semi-arid zones, and approximately 90% of world's chickpea is grown under rain fed conditions [14] where terminal drought is one of the major constraints for its productivity. It is cultivated across the world in the Mediterranean Basin, the Near East, Central and South Asia, East Africa, South America, North America and Australia [15]. It has a total global production of 12 million tons from 13 million hectares [16]. In Sudan, chickpea faces competition with other winter legumes such as faba bean and common bean as well as other cash crops like spices. The major cultivated area is concentrated in the northern region of Sudan on basins and Islands along the River Nile and some small areas at Hawata and Jabel Marra. More recently, chickpea cultivation is extended to the central Sudan especially in the irrigated Gezira Scheme and New Halfa. In Sudan, it is either irrigated or utilizes the residual moisture stored in the soil after the River Nile flood recedes. Average area grown with this crop in the River Nile State for the period 2003-2012 was about 5500 ha with an average yield of 1.5 tha^{-1} [17]. In Sudan, many studies have been carried out to determine the response of chickpea to different irrigation levels. The results were based mainly on studies in three ways: 1) imposing different irrigation intervals throughout the crop cycle; 2) timing of the last irrigation; and 3) irrigation schedule during both vegetative and reproductive stages of the crop. Results indicated that frequent (7 - 10 day intervals) irrigation during the whole crop cycle always resulted in the highest grain yield [18]-[20]. It was also found that early termination of irrigation water drastically reduced grain yield [21]-[24]. Grain yield losses of 59% and 40% occurred when irrigation water was terminated after 50 and 70 days from sowing, respectively. Dealing with the crop life cycle as being composed of vegetative and reproductive phases, it was found, as expected, reproductive stage was the most sensitive stage to moisture stress developed through expanded irrigation intervals [22]-[25]. Consequently, the optimum irrigation schedule was established so as to irrigate the crop every 20 days during the vegetative stage and every 10 days during and the reproductive stages. Although data indicated that savings in irrigation water during less sensitive growth stages are possible, the information on quantity and cost of applied water for the different treatments is not adequate. Information pertaining to water productivity on chickpea in the northern Sudan is lacking

The objective of this research was to investigate the effect of different irrigation regimes and varieties on chickpea (*Cicer arietinum* L.) yield, yield components and water productivity yield, yield components and water productivity.

2. 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 (26), very hot and dry in summer and relatively cool in winter. The average rainfall does not exceed 100 mm per year falling for only three months (July to September) with the rest of the year virtually dry. The prevailing thermal regime as daily mean temperature during the two growing seasons is displayed in **Figure 1**. According to soil profile (**Table 1**) the soil of the study site is clay in texture and is classified as Vertic Torrifluvent, fine Smectitic, calcareous, 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 organic carbon and nitrogen content.

The experiment was a factorial design with three irrigation regimes (selected based on previous studies), namely, I_1 Irrigation every 10 days (full irrigation or normal), I_2 Irrigation every 15 days (moderate water stress), I_3 Irrigation every 20 days (severe water stress) and two varieties introduced from ICARDA, namely, Borgieg (erect, round seed shape, beige color seed, medium seed size, late maturing) and Wad Hamid (erect, round seed shape, beige color seed, large seed size, susceptible to stunt disease, early maturing). 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 × 0.6 m (ridge width) × 12 m (ridge length) = 50.4 m^2. The crop was sown manually in the third week of November in both 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

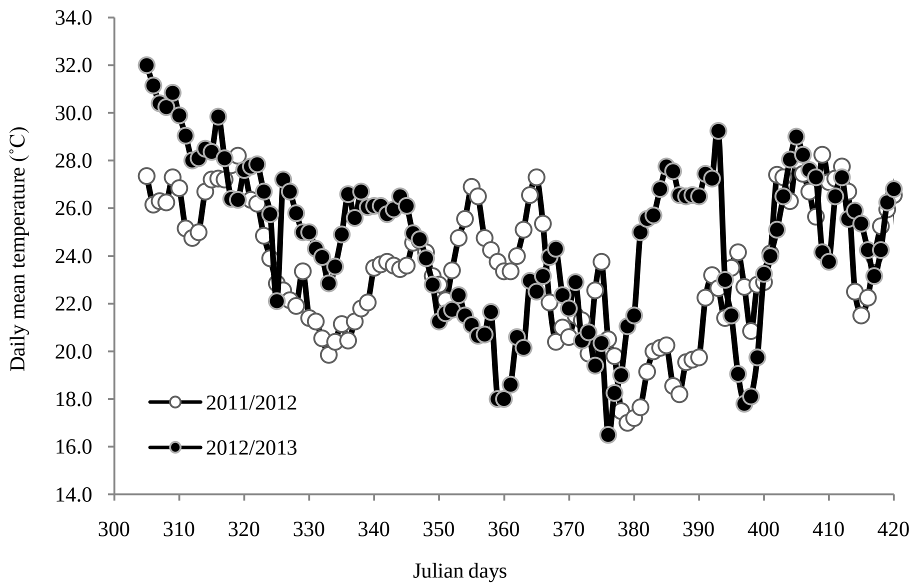

Figure 1. Prevailing thermal regime as daily mean temperature at Hudeiba Research Farm for the crop seasons 2011/2012 and 2012/2013.

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 (m^3/m^3)	38	43	47	44	50	54	46
Moisture content at field capacity (m^3/m^3)	21	23	26	24	27	29	25
Soil bulk density (g/cm^3)	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

per hole. Nitrogen at the rate of 43 kg N ha^{-1} in form of urea was applied uniformly, to all experimental plots before the second irrigation. Hand weeding of the experimental area was performed as required. 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:

$$I = A \times T \times V \tag{1}$$

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

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

$$ETc = I + P + W - R - D \pm \Delta S \tag{2}$$

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 (1). 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:

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

where, n = number of soil layers sampled in the effective root zone which is = 3 (0 - 20, 20 - 40, 40 - 60); $\theta 1$ volumetric moisture content within 2 - 3 days after irrigation; $\theta 2$ = 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 in both seasons, grain yield was calculated from the central three ridges (8 m long) = 14.4 m^2 of each plot. 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) [10] [11], while the Irrigation water productivity is the economic yield divided by the total irrigation water applied [12]-[27].

Crop water productivity (CWP) was calculated as

$$\text{CWP} = \frac{\text{Y}}{\text{ET}} \tag{4}$$

where, Y = yield ($kg \cdot ha^{-1}$), ET = seasonal evapotranspiration ($m^3 \cdot ha^{-1}$). And Irrigation water productivity (IWP) was calculated as

$$\text{IWP} = \frac{\text{Y}}{\text{I}} \tag{5}$$

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

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

3. Results and Discussion

3.1. Crop Growth Environment

The prevailing thermal regime as daily mean temperature during the two growing seasons is displayed in **Figure 1**. The second season experienced warm spells at the beginning and at the end of the season. However, it was comparatively cooler than the first season in the middle of the growing season.

3.2. Yield and Yield Components

Grain yield and yield components of chickpea as affected by irrigation regime and variety are presented in **Table 2**.

Analysis of variance showed that number of pods per plant and grain yield were significantly affected by irrigation regime and variety, but number of seeds per plant and 100 seeds weight were affected by irrigation regime. Statistic analysis indicated no significant interaction between irrigation regimes and varieties.

Table 2. Mean grain yield and yield components of chickpea as affected by irrigation regime and variety (averaged over seasons 2011/2012-2012/2013) at Hudeiba Research Farm.

	Grain yield (kg/ha)			No. of pods/plant			No of seeds/pod			100 seed weight (g)		
	Borgieg	Wad Hamid	Mean	Borgieg	Wad Hamid	Mean	Borgieg	Wad Hamid	Mean	Borgieg	Wad Hamid	Mean
I_1	1234	1096	1165	45	41	43	0.84	0.82	0.83	22.8	23.3	23.1
I_2	997	890	944	41	37	39	0.79	0.75	0.77	21.1	21.9	21.5
I_3	543	472	508	28	25	27	0.63	0.59	0.61	17.5	18.2	17.9
Mean	925	819	872	38	34	36	0.75	0.72	0.74	20.5	21.1	20.8
SE ± (I)		41.11^{***}			0.82^{***}			0.016^{***}			0.404^{***}	
SE ± (V)		33.57^{*}			0.67^{**}			0.013 ns			0.330 ns	
SE ± (I × V)		58.14 ns			1.16 ns			0.022 ns			0.571 ns	
C.V (%)		16.3			7.8			7.4			6.7	

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

Number of pods per plant decreased significantly ($p \leq 0.001$) with the increase in water deficit (**Table 2**). The highest number of pods per plant was observed in I_1 (full-irrigation). Similar results were reported by [28]. The variety Borgieg produced significantly ($p \leq 0.01$) more pods per plant than Wad Hamid (**Table 2**).

There were also significant ($p \leq 0.001$) reduction in number of seeds per pod and 100-seeds weight with water deficit and the trend was similar to the number of pods per plant trend (**Table 2**). The highest values of these traits obtained with full irrigation, whereas the lowest values recorded under severe water stress conditions. These results are in accordance with the finding of [29].

The two varieties were not significantly different in 100 seed weight. However, higher average weight (21.1 g) was recorded for Wad Hamid Grain yield was significantly decreased ($p \leq 0.001$) as water deficit increased (**Table 2**). The decrease in grain yield was more pronounced in severe water stress (irrigation every 20 days) than that in the moderate water stress (irrigation every 15 days). Application of moderate water stress (I_2) and severe water stress (I_3) caused 19% and 56% decrease in grain yield of water stressed plants, respectively when compared with the fully irrigated one (**Table 2**). Similar results were reported by [29] [30]. The variety Borgieg significantly ($p \leq 0.05$) out-yielded Wad Hamid by 11%. Wad Hamid was observed to be highly susceptible to stunt disease.

The results of this study indicated that the yield decrease due to water deficit was attributed to reduction in number of pods per plant, number of seeds per pod and 100-seeds weight. A positive and highly significant correlation was found between grain yield and these traits (**Figure 2**). Similar results were reported by [30]-[33].

No significant difference for variety X irrigation regime interaction indicates that the two varieties responded in a similar manner for water stress.

In this study, the unexpected low grain productivity of chickpea is attributed to the severe infestation of the crop by stunt disease.

3.3. 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. The total numbers of irrigations given in each irrigation regime in both seasons for I_1, I_2, and I_3 were 9, 6 and 5, respectively.

The mean seasonal ET varied between 3370 $m^3 \cdot ha^{-1}$ and 2311 $m^3 \cdot ha^{-1}$ (**Table 3**). The highest seasonal ET was recorded in treatment I_1, whereas the lowest seasonal ET recorded under I_3.

The analyses of variance (**Table 3**) revealed that irrigation water applied (I) was significantly ($p \leq 0.001$) affected by irrigation regime treatments. The highest 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 1610 m^3 and 2100 m^3, respectively.

The amount of irrigation water applied to Borgieg was higher than that applied to Wad Hamid. This was due to less water requirement of short duration variety.

3.4. Yield-ET Relationship

The relationship between chickpea grain yield and seasonal ET is presented in **Figure 3** using all 12 data points

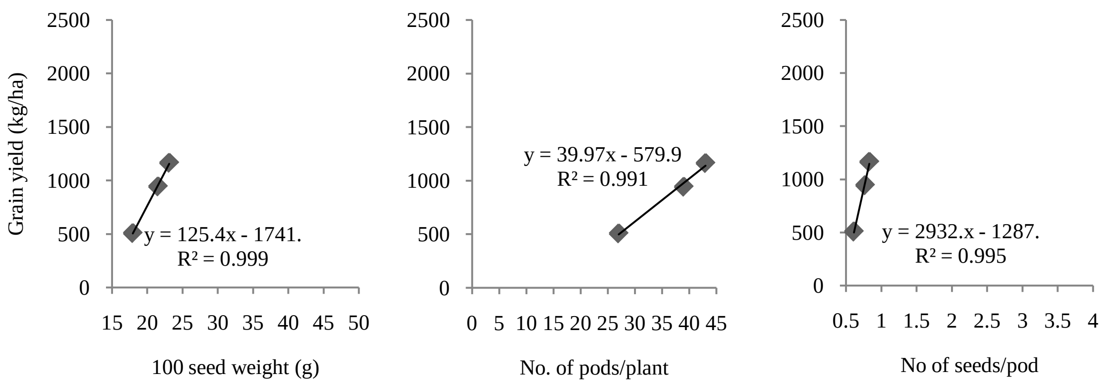

Figure 2. Relationship between grain yield and yield components of chickpea as affected by irrigation regime.

Table 3. Amount of irrigation water applied ($m^3 \cdot ha^{-1}$), number of irrigation events and crop evapotranspiration ($m^3 \cdot ha^{-1}$) of chickpea as affected by irrigation regime and variety (averaged over seasons 2011/2012-2012/2013) at Hudeiba Research Farm.

	Irrigation water applied ($m^3 \cdot ha^{-1}$) (number of irrigations)			Crop ET ($m^3 \cdot ha^{-1}$)		
	Borgieg	Wad Hamid	Mean	Borgieg	Wad Hamid	Mean
I_1	6843	6715	6779 (9)	3545	3195	3370
I_2	5217	5121	5169 (6)	2702	2437	2570
I_3	4750	4522	4636 (5)	2462	2160	2311
Mean	5603	5453	5528 (7)	2903	2597	2750
SE ± (I)		54^{***}				
SE ± (V)		44^{*}				
SE ± (I × V)		77 ns				
C.V (%)		3.4				

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

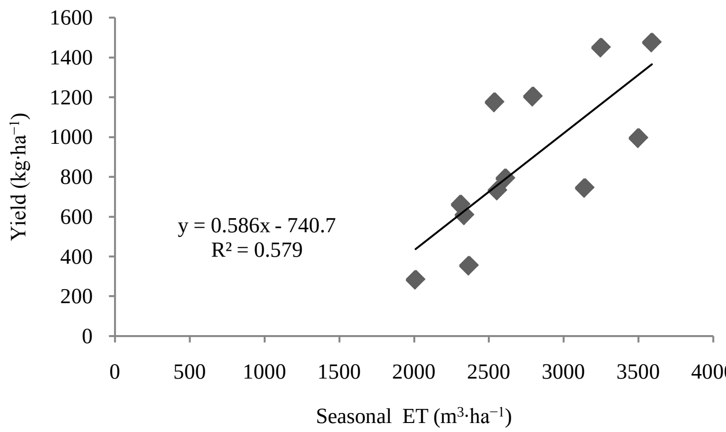

Figure 3. The relationship between grain yield of chickpea and seasonal evapotranspiration (ET).

obtained during the study period (6 treatments - 2 years). Grain yield varied from 238 to 1474 $kg \cdot ha^{-1}$ and ET values from 2009 to 3590 $m^3 \cdot ha^{-1}$. The linear regression between grain yield and ET showed that about 58% of the variation in grain yield could be attributed to variations in ET. Within the range of observed ET values, the regression slope predicts a yield increase of 58.6 $kg \cdot ha^{-1}$ for each 100 m^3 increase in ET. The negative value of the intercept indicates that a certain ET threshold value must be reached before any grain yield is obtained, which was 1264 $m^3 \cdot ha^{-1}$ in this study. Several previous studies have also shown a linear relationship between grain yield and ETc [34]-[37].

3.5. Water Productivity

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

CWP ranged from 0.220 $kg \cdot m^{-3}$ for treatment I_3 to 0.367 $kg \cdot m^{-3}$ for treatment I_2, while IWP for the same treatments ranged from 0.108 $kg \cdot m^{-3}$ for treatment I_3 to 0.182 $kg \cdot m^{-3}$ for treatment I_2 (**Table 4**). Treatment I_1 (full irrigation) did not produce the highest IWP, while treatment I_2 (moderate stress) gave the highest IWP. IWP for I_2 was 6% higher than that of I_1. Maximum CWP and IWP occur at crop water use less than the maximum. Moderate water-stress had improved IWP. However, reduction in grain yield occurred under this treatment.

Table 4. Mean irrigation water productivity (IWP) and crop water productivity (CWP) of chickpea as affected by irrigation regime and variety (averaged over seasons 2011/2012-2012/2013) at Hudeiba Research Farm.

	IWP (kg/m^3)			CWP (kg/m^3)		
	Borgieg	Wad Hamid	Mean	Borgieg	Wad Hamid	Mean
I_1	0.181	0.163	0.172	0.348	0.343	0.346
I_2	0.191	0.173	0.182	0.369	0.365	0.367
I_3	0.114	0.102	0.108	0.221	0.219	0.220
Mean	0.162	0.146	0.154	0.319	0.315	0.317
SE ± (I)		0.0078^{***}				
SE ± (V)		0.0064 ns				
SE ± (I × V)		0.0110 ns				
C.V (%)		17.5				

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

Similar findings were reported by [38] 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 regime (I_3) (**Table 4**). This might be due to the fact that water savings at 20 = day intervals are not enough to overcome the concurrent yield losses. IWP for I_2 was 41% higher than that of I_3. Borgieg displayed the highest values of CWP and IWP.

4. Conclusion

Under the conditions of this study, grain yield and yield components were significantly ($p \leq 0.001$) affected by irrigation regimes. Exposing chickpea crop to water stress throughout the growing season significantly reduced grain yield. The low grain yield under water stress regimes was 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 seasonal ET was recorded in treatment I_1, which exceeded those of I_2 and I_3 by 24% and 31%, respectively. 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. Treatment I_1 (full irrigation) did not produce the highest IWP, while treatment I_2 (moderate water stress) gave the highest IWP. Maximum CWP and IWP occurred at crop water use less than the maximum. 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 moderate water stress may be adopted. Contrarily, the adoption of severe water stress that produced high water savings would lead to yield losses that might be economically not acceptable. The late maturing chickpea variety of Borgieg significantly ($p \leq 0.05$) out-yielded the early maturing variety Wad Hamid by 11%. Borgieg displayed the highest values of CWP and IWP.

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