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Water Productivity as a Tool for Deficit Irrigation Strategy to Optimize Watering Requirements for the Production of Chickpea (*Cicer arictinum* L.) Under Dry Land Conditions of the Northern State, Sudan.*

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Abstract A field experiment was carried out for two consecutive seasons (2015/16 and 2016/17) on the sandy loam desert soil of New Hamdab Research Station with a view to investigating the response of deficit irrigation as induced by the water productivity at different growth stages of chickpea (Cicer arictinum L.)**.** Five irrigation treatments were conducted, I_1 (100% crop water requirement throughout the season was considered control, $\mathbf{I_2}$ and $\mathbf{I_3}$ indicated (75% and 50% crop water requirements at crop vegetative growth stage) respectively, where as $\mathbf{I_4}$ and $\mathbf{I_5}$ indicated (75% and 50% crop water requirements at crop ripening stage) respectively. The full irrigation treatment and the 75% deficit irrigation treatments at the vegetative and ripening stages showed higher chickpea grain yield, higher number of pods per plant and 100 seed weight. On the other hand the deficit irrigation of **50**% crop water requirement applied at the vegetative stage resulted in higher water productivity (0.59 kg/m³) but attaining lower grain yield with higher deficit irrigation stress index (DISI). Therefore, in order to save irrigation water while keeping high productivity of chickpea under such dry conditions, it is recommended to apply deficit irrigation of 50% crop water requirement at vegetative stage of the crop.

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INTRODUCTION

Availability of water is the most limiting factor for food production in arid and semi-arid regions. Due to the growing population and competition for water by other users (i.e., industries, domestic, etc.) the amount of water allocated for agriculture is decreasing throughout the world (Molden, 2007). In northern Sudan water resources for irrigation are limited and become very expensive when it is to be pumped (Arneo, 2007). The application of water below the crop water requirement or actual crop evapotranspiration (ETa) is defined as deficit irrigation (Fereres and Soriano, 2007). Deficit irrigation (DI) and limited irrigation have been proposed as valuable strategies for arid regions (English, 1990; Pereira *et al*.,2002; Fereres and Soriano, 2007) where water is the limiting factor in crop production (Geerts and Raes, 2009). DI is an optimization strategy in which, irrigation is applied during drought–sensitive growth stages of a crop. Water restriction is limited to drought-tolerant phonological stages, often the vegetative stages and late ripening period. DI has the potential to maximize irrigation water productivity and it aims at stabilizing yields and has the potential to optimizing crop water productivity rather than maximizing the yield (Zhang and Oweis, 1999; Geerts and Raes, 2009).

Chickpea (*Cicer arietinum* L.) is an important grain legume (Guri Qbal,2015). It is one of the major grain pulses with an inimitable source of dietary protein in the developing countries where there is very scarce or unaffordable human and animal protein (Fitsume, *et al*., 2015). Also, it is an important source of carbohydrates, vitamins and certain minerals (Maiti, 2001). Chickpea also plays an important role in the maintenance of soil fertility particulary in the dry rain fed areas due to its nitrogen fixing ability (Saxena, *et al*., 1996; Katerji, *et al*., 2001 and Maiti, *et al*., 2001).The objective of this study was to investigate the effects of deficit irrigation (DI) strategy on the yield and water productivity of chickpea (*Cicer arietinum* L.) under the dry conditions of the Northern State of Sudan .

MATERIALS AND METHODS

The soil of the research site is sandy loam, non–saline, non–sodic with coarse texture in the top layer (0 – 40 cm), in which the percentages of sand and clay were 65 and 18%, respectively. This type of soil is classified as Typic Haplocambids, fine loamy, mixed, hyperthermic and super active. It is correlated to Kelly soil series.

Table 1. Soil physical and chemical properties of the experimental site.

Characters	Soil depth				
	0-20 cm	20-40 cm	40-45 cm	45-85 cm	85-125 cm
CS (%)	52	52	55	55	52
FS (%)	14	13	14	15	12
Si (%)	18	12	15	8	13
C (%)	16	13	16	23	23
Bulk density (g cm^{-3})	1.73	1.49	1.86	1.85	1.71
Porosity (%)	35	44	30	30	35
Wilting point (%)	8.9	9.2	9.0	8.5	8.9
Field Capacity (%)	17.8	18.3	18.3	17.0	17.9
Saturation (%)	36	36	36	41	62
$CaCo_3$ (%)	2.4	2.4	2.0	6.6	19.2
CEC ((Cmol +)kg^{-1} soil)	13	10	12	17	18
EC (dsm^{-1})	0.45	0.86	0.55	1.08	1.47
pH paste	7.9	7.9	7.8	8.0	7.6

Where: CS = Coarse sand, FS = Fine sand, Si = silt, ECe = Electric conductivity, CEC = Cation exchange capacity and ESP = Exchangeable sodium percentage.

The field experiment was conducted at New Hamdab Research Station farm, which is located in the desert plain of El Multaga area, Northern State for two consecutive winter seasons (2015/16 and 2016/17) with a view to investigate the effects of deficit irrigation (DI|) strategy on the yield and water productivity of chickpea. Four DI irrigation treatments at crop non critical stages were tested while a full irrigation treatment was taken as control. The treatments were as follows:

1- 100% Crop water requirement (CWR) throughout the season as full irrigation (control)
2- 75% Crop water requirement (CWR) at crop vegetative stage.
3- 50% Crop water requirement (CWR) at crop vegetative stage.
4- 75% Crop water requirement (CWR) at crop ripening stage.
5- 50% Crop water requirement (CWR) at crop ripening stage.

The optimum crop water requirement of chickpea was predetermined as 519 mm/season at field condition during three consecutive previous seasons.

The treatments were arranged in randomized complete block design (RCBD) with four replicates. The plot size was 28.8 m^2 (8 ridges each 6m long). The experimental plots were separated from each other by a 1m wide buffer zone to prevent surface and lateral movement of water. The predetermined quantities of irrigation water were applied in 10 days intervals using a calibrated Parshall flume and a 90^o V-notch weir appropriately installed in series.

Chickpea (variety Wad Hamid) was grown on November 18th during both seasons following ARC standard practices.

Phosphorus fertilizer in the form of triple super phosphate (TSP) was applied at sowing at the rate of 1P (43 Kg P_2O_5/ha) while Nitrogen in the form of Urea was applied at the rate of 1N (43 Kg N/ha), at the third irrigation. Other cultural operations were performed according to ARC standard practices. The plant growth parameters and yield attributes data were collected.

Data collection:

Yield and yield components were collected based on ARC standard practices and presented in table (2).

Leaf area index (LAI):

Equation (1) was used as suggested by Babiker (1999) and Asim and Abd elmoneim (2011);

(1) $LAI = \max length \times \max width \times \frac{No\ of\ leaves}{plant} \times 0.75 \times \frac{No\ of\ plant}{m^2}$

Water productivity:

Was calculated using formula (2) as suggested by Zwart and Bastiaanssen (2004); Greets and Reas(2009) and Khan(2013) as follows:

$$(2)\ CWP(\mathrm{kg/m^3}) = \frac{\text{grain yield (kg/ha)}}{\text{total water applied}\left(\frac{\mathrm{m^3}}{\mathrm{ha}}\right)}$$

Deficit irrigation stress index (DISI):

The equation used was proposed by Pandey, *et al*. (2000) and Dajman (2011) as follows;

$$(3)\ DISI = \frac{(yield\ of\ un\ stressed\ treatment - yield\ of\ stressed\ treatment)}{yield\ of\ un\ stressed\ treatment}$$

The statistical analysis was performed using SAS and MSTAT statistical package. The tested data were analyzed using the analysis of variance (ANOVA) procedure and the treatments were compared using the means separation procedure Duncan Multiple Range.

RESULTS AND DISCUSSION

Effect of full and deficit irrigation on grain yield and yield components:

The statistical analysis (Table 2) indicated that there were significant differences between the full and deficit irrigation treatments on grain yield and 100 seed weight in both seasons; the first season at ($P \leq 0.01$) and the second season at ($P \leq .001$). Another significant difference was indicated by number of pods/plant ($P \leq 0.01$) in both seasons.

Table 2. Effect of full and deficit irrigation treatments on chickpea grain yield and yield component during 2015-2016 and 2016-2017 seasons.

Tr	Plant height (cm)	No of pod/plant	No of seed/pod	100 Seed weight (g)	Grain yield (Kg/ha)
			Season 2015-2016		
I_1	51.4	44 a	1.45	22.6 a	2580 a
I_2	50.5	43 a	1.33	21.7 a	2550 a
I_3	49.7	35 b	1.35	19.9 b	2471 b
I_4	52.7	44 a	1.30	22.4 a	2569 a
I_5	51.2	34 b	1.33	19.9 b	2470 b
CV	3.53	10.60	9.68	4.75	1.87
SE±	0.9022	2.1277	0.1	0.5064	23.6881
S.L	NS	**	NS	**	**
			Season 2016-2017		
I_1	54.8	60 a	1.23	23.4 a	2849 a
I_2	53.9	55 a	1.25	23.0 a	2800 a
I_3	56.3	37 b	1.23	21.3 b	2599 b
I_4	53.4	57 a	1.25	23.1 a	2845 a
I_5	56.4	39 b	1.23	21.1 b	2603 b
CV	5.95	20.51	8.52	2.27	1.19
SE±	1.6339	5.0730	0.1	0.2539	32.5619
S.L	NS	**	NS	***	***

***, *** and NS = Significant at $P \leq 0.01$, $P \leq 0.001$ and not significant. Means followed by the same letter(s) within each column are not significantly different according to Duncan's Multiple Range Test.*

Effect of full and deficit irrigation on water productivity and leaf area index:

The statistical analysis (Table 3) indicated that there were significant differences between the full and deficit irrigation treatments in water productivity ($P \leq 0.001$)in both seasons as well as leaf area index ($P \leq 0.01$) and ($P \leq 0.001$)in first and second seasons respectively.

The higher values of leaf area index were recorded by the full irrigation I_1 and the deficit irrigation treatments I_4 and I_5 during the two seasons, while the lower values were indicated by the deficit irrigation I_2 and I_3.This was due to the fact that in the vegetative stage the plant was small having low evapotranspiration process thus could combat water stress by reducing its vegetative canopy and increasing its root system. This was in line with Blum's (2005) and Rao *et al.,* (2006) findings in that the plant would be able to sustain high water stress and cellular hydration under drought condition by formation of stress tolerant molecular mechanisms to reduce transpiration and increase water absorption.

Table 3. Effect of full and deficit irrigation treatments on chickpea deficit irrigation stress index, water productivity and leaf area index during 2015-2016 and 2016-2017 seasons.

Tr	DISI (%)	Water productivity (Kg/m3)	Leaf area index
Season 2015-2016			
I1	0.00	0.50 c	3.81 a
I2	1.16	0.54 b	3.03 c
I3	4.22	0.57 a	3.11 c
I4	0.43	0.52 b	3.55 ab
I5	4.27	0.53 b	3.30 bc
CV		2.48	6.92
S.L		***	**
SE±		0.0066	0.1161
Season 2016-2017			
I1	0.00	0.55 d	3.87 a
I2	1.72	0.59 ab	2.91 b
I3	8.78	0.60 a	2.89 b
I4	0.14	0.58 b	3.56 a
I5	8.63	0.56 c	3.48 a
CV		1.30	7.94
S.L		***	***
SE±		0.0037	0.1326

** and *** = Significant at $P \leq 0.01$, and $P \leq 0.001$.
Means followed by the same letter(s) within each column are not significantly different according to Duncan's Multiple Range Test.

The higher water productivity was indicated by the deficit irrigation treatment I_3 (o.57 and o.6o) in the first and second seasons respectively, while the lower values were the result of the full irrigation treatment (0.50 and 0.55) recorded in the first and second season respectively.
Although the treatment I_3 gave higher value, it resulted in a significant lower grain yield with higher deficit irrigation stress index of 4.22% and 8.78% in the first and second seasons respectively thus the deficit irrigation treatment I_2 and I_4 which resulted in a higher water productivity than the full irrigation treatment recommended for growth of chickpea (*Cicer arictinum* L.) under dry conditions .

CONCLUSIONS

- The full irrigation treatment $\mathbf{I_1}$ with the deficit irrigation treatments $\mathbf{I_2}$ (75% CWR applied at vegetative stage) and $\mathbf{I_4}$ (75% CWR applied at ripening stage) resulted in higher grain yield, higher No of pod per plant and higher 100 seed weight.
- The deficit irrigation $\mathbf{I_3}$ (50% CWR applied at vegetative stage) resulted in highest water productivity than all other tested treatments, but it attaining the lower grain yield with higher deficit irrigation stress index (DISI).
- The deficit irrigation treatments $\mathbf{I_2}$ (75% CWR applied at vegetative stage) and $\mathbf{I_4}$ (75% CWR applied at ripening stage) resulted in higher water productivity compared with full irrigation treatment $\mathbf{I_1}$ with no reduction in grain yield.
- The full irrigation treatment $\mathbf{I_1}$ with the deficit irrigation treatments $\mathbf{I_4}$ (75% CWR applied at ripening stage) and $\mathbf{I_5}$ (50% CWR apply at ripening stage) recorded higher LAI.

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مؤشر الانتاجية المائية لأستراجية الري الناقص لترشيد الاحتياجات المائية لانتاج محصول الحمص (*Cicer arictinum* L) تحت ظروف الاراضى الجافة بالولاية الشمالية، السودان[*]

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مستخلص البحث:اجريت التجارب خلال موسمين متتالين (2016/2015- 2017/2016) في محطة ابحاث الحامداب ذات تربة السهل الصحراوي الرملية الطمية لدراسة تاثير الري الناقص على الانتاج وانتاجية الماء (WP) لمحصول الحمص خلال مراحل النمو المختلفة. اشتملت التجربة على خمسة معاملات؛ الري الكامل $\mathbf{I_1}$ (100% من الاحتياج المائي خلال كل الموسم) والذي يمثل الشاهد، $\mathbf{I_2}$ (75% من الاحتياج المائي عند مرحلة النمو الخضري)، $\mathbf{I_3}$(50%من الاحتياج المائي عند مرحلة النضج)، $\mathbf{I_4}$ (75% من الاحتياج المائي عند مرحلة النمو الخضري) و $\mathbf{I_5}$ (50% من الاحتياج المائي عند مرحلة النضج). اظهرت النتائج ان الري الكامل $\mathbf{I_1}$ (100%) والري الناقص $\mathbf{I_2}$ و $\mathbf{I_4}$ (75% من الاحتياج المائي عند مرحلتي النمو الخضري والنضج على التوالي) قد حصلوا على اعلى انتاجية للمحصول وعدد القرون ووزن ال 100 حبة ؛ ومن ناحية اخرى اتضح ان معاملة الري الناقص $\mathbf{I_3}$(50%من الاحتياج المائي عند مرحلة النضج) قد نتج عنها اعلى زيادة ملحوظة في الانتاجية المائية(WP) للمحصول عباره عن 0.57 و 0.60 كيلوجرام لكل متر^{٣} ماء في الموسم الاول والثاني على التوالي، الا انها قد حصلت على اقل انتاج للمحصول مع اعلى موشر للاجهاد للري الناقص مما يعني نقص في الانتاجية مع تقليل الاحتياج المائي؛ وعليه لتوفيرمياه الري مع المحافظة على زيادة الانتاجية فان الدراسة توصي باستخدام الري الناقص 75% من الاحتياج المائي عند مرحلتي النمو الخضري والنضج لمحصول الحمص في الظروف البيئية المشابهة.

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