Sudan J. Des. Res. Vol. 11 (1) :71-81, 2019

Effect of Deficit Irrigation on Yield and Water Productivity of Maize (*Zea mays* L.) Under Desert Conditions, Northern State, Sudan

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Abstract: A field experiment was carried out for two consecutive seasons (2015/16 and 2016/17) at New Hamdab Research Station (Desert plain soil)to investigate the response of deficit irrigation induced at different growth stages of maize on yield and water productivity. Five irrigation treatments were conducted, I_1 (100% crop water requirement throughout the season (control)), I_2 (75% crop water requirement at vegetative growth stage), I_3(50% crop water requirement at vegetative growth stage), I_4 (75% crop water requirement at ripening stage) and I_5 (50% crop water requirement at ripening stage). The research farm is dominated by sandy loom soil. The full and the deficit irrigation treatments showed similar effects on maize grain yield and yield components. On the other hand the deficit irrigation I_2 (75% crop water requirement at vegetative stage) and I_3 (50% crop water requirement at vegetative stage) resulted in significantly higher water productivity (0.59 kg/m³) with no yield reduction. Therefore, in order to save irrigation water while keeping high productivity of maize under such desert conditions, it is recommended to apply deficit irrigation of 50% crop water requirement at vegetative stage of the crop.

Key words: Deficit Irrigation, Water Productivity, Maize, Desert condition, Northern Sudan.

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INTRODUCTION

Availability of water is the most limiting factor for food production in arid and semi-arid regions. Due to 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 became very expensive when it was 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).

Maize (*Zea mays* L.) is the third most important cereal crop after wheat and rice in the world. It is one of the main source of human food, animal feed as well as raw material for many industries (Nadahi,1984; Rouanet, 1987; Babiker, 1999; Ali, 2003; Dharam *et al.*, 2014). The objective of this study was to investigate the effects of deficit irrigation (DI) strategy on maize yield and its water productivity.

MATERIALS AND METHODS

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

The field experiment was conducted at New Hamdab Research Station farm, which is located in the desert plain of El Multaga area, Northern Sudan for two consecutive winter seasons (2015/16 and 2016/17) with a view to investigate the effects of deficit irrigation (DI|) strategy on maize yield and its water productivity.

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 Capasity (%)	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.

Four DI irrigation treatments at crop non critical stages were tested together 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 maize was predetermined as 673 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 calibrated Parshall flume and 90^o V-notch weir appropriately installed in series.

Maize (variety Hudieba2) was grown in November 18th during both seasons following Agricultural Research Corporation (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 in two equal doses at the rate of 1N (43 Kg N/ha),the first dose was applied after 2-3 weeks from sowing and the second dose was applied at tasselling. Other cultural operations were performed according to the standard practices and the data collected included plant growth parameters and yield attributes.

Data collection:

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

2- Leaf area index (LAI):
Equation (1) was used as suggested by Babiker (1999) and Asim and Abdelmoneim (2011):

$$LAI = \max length \times \max width \times \frac{Noofleaves}{plant} \times 0.75 \times \frac{Noofplant}{m^2} \quad \textbf{(1)}$$

3- water productivity:
Was calculated using the formula suggested by Zwart and Bastiaanssen (2004); Greets and Reas (2009) and Khan(2013) as follows:

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

4- Deficit irrigation stress index (DISI):

The equation used was proposed by Pandey *et al*. (2000) and Dajman (2012) as follows;

$$DISI = \frac{(yield of unstressed treatment - yield of stressed treatment)}{yield of unstressed treatment} \quad \textbf{(3)}$$

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 of 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 no significant differences between the full and deficit irrigation treatments on grain yield and other measured parameters of yield components (plant height, ear height, No. of rows/ear, No. of kernels/row, ear length, ear diameter and 100 seed weight) over the two seasons. This result is in line with those reported by Asim and Abdelmoneim (2011) who stated that there were no significant differences in grain yield, 100 seed weight, number of seed per cob, number of rows per cob, cob length, and plant height at different periods and leaf area index. The result is also similar to what has been reported by Sani *et al.* (2008) in that there were no significant differences between the full and 75% of the consumptive use in grain yield.

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

The statistical analysis(Table 3) indicated that there were no significant differences between the full and deficit irrigation treatments on leaf area index during both seasons, however, the only significant difference between the full and deficit irrigation treatments was indicated by water productivity at ($P \leq 0.05$).

The higher water productivity was obtained under deficit irrigation treatments I_2 and I_3 in the two seasons. Both treatments (I_2 and I_3) resulted in the same values of 0.59 and 0.57 recorded in the first and second seasons respectively, with deficit irrigation stress of 0.00 and 2.10and 1.35 and 3.89 in the first and second seasons, respectively.

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

Tr	**Plant height (cm)**	**Ear height (cm)**	**No of rows/ear**	**No of kernel /row**	**Ear length (cm)**	**Ear diameter (cm)**	**100 seed weight (g)**	**Grain yield (Kg/ha)**
	Season 2015-2016							
I_1	140.5	54.9	14	24	13	4.0	21.7	3666
I_2	142.9	57.7	14	21	12	3.9	22.3	3666
I_3	148.0	58.1	13	22	13	3.8	21.9	3589
I_4	137.6	56.0	13	21	12	3.9	22.2	3498
I_5	141.7	54.7	14	22	12	3.8	21.5	3411
CV	5.68	8.96	5.45	11.94	7.25	3.13	11.60	4.51
S.L	NS	NS	NS	NS	NS	NS	NS	NS
SE±	4.0345	2.5223	0.2689	1.2950	0.4449	0.0608	1.2702	80.3378
	Season 2016-2017							
I_1	151.3	64.2	14	31	15	4.3	21.6	3642
I_2	147.2	61.4	14	30	15	4.2	21.6	3593
I_3	149.0	61.8	14	31	15	4.3	21.5	3500
I_4	149.8	62.5	14	30	15	4.2	26.6	3560
I_5	147.5	62.5	14	30	15	4.3	21.5	3474
CV	3.42	8.56	3.09	5.17	3.66	2.90	2.08	2.879
S.L	NS	NS	NS	NS	NS	NS	NS	NS
SE±	2.5475	2.6734	0.2184	0.7813	0.2854	0.0614	0.2242	51.1618

NS = not Significant

These results were similar to those obtained by Djaman and Irmak (2012), who stated that 60% CWR and 75% CWR had similar or greater crop water use efficiency; also the results were in line with those reported by Piccinni *et al.* (2009) in that irrigation management of maize at 75% evapotranspiration showed an increased in crop water use efficiency.

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

Tr	DISI (%)	Water productivity (Kg/m^3)	Leaf area index
Season 2015-2016			
I_1	0.00	0.54 b	2.04
I_2	0.00	0.59 a	2.03
I_3	2.10	0.59 a	2.16
I_4	4.58	0.54 b	2.00
I_5	6.96	0.55 ab	2.11
CV		4.51	11.67
S.L		*	NS
SE±		0.0126	0.1206
Season 2016-2017			
I_1	0.00	0.54 b	2.08
I_2	1.35	0.57 a	2.05
I_3	3.89	0.57 a	2.01
I_4	2.25	0.55 ab	2.00
I_5	4.61	0.56 ab	2.01
CV		2.70	3.02
S.L		*	NS
SE±		0.0075	0.0306

* and NS = Significant at $P \leq 0.05$and not significant.
Means followed by the same letter(s) within each column are not significantly different according to Duncan's Multiple Range Test.

When there was no significant reduction in grain yield and with attaining significantly higher water productivity, this made the maize crop well suited to deficit irrigation practices with reduced evapotranspiration imposed at predetermined growth stage as reported by Kirda (2002). So the deficit irrigation I_2 and I_3 were very comparable to the fully irrigated treatment in term of productivity performance and are suited to deficit irrigation strategies for increasing crop productivity of maize.

CONCLUSIONS

- The full and the deficit irrigation treatments have the same effect on grain yield and yield components.
- The deficit irrigation I_2 (75% CWR apply at vegetative stage) and I_3 (50% CWR apply at vegetative stage) gave significantly higher water productivity with no reduction in yield.
- When saving water is main objective, the deficit irrigation treatment I_3(50% CWR apply at vegetative stage) is more efficient and very comparable to fully and deficit irrigation treatments in term of water productivity performance and is suited to deficit irrigation strategies for increasing crop water productivity.

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تاثير الري الناقص على الانتاج وانتاجية الماء للذرة الشامية (*Zea mays* L.) تحت ظروف السهل الصحراوي- الولاية 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 الذرة الشامية خلال مراحل النمو المختلفة. اشتملت التجربة على اربع معاملات بالاضافة الى الشاهد والذي يمثل الري الكامل للاحتياج المائي (100% CWR) ومعاملتا ري لكل من مرحلتي النمو الخضري والنضج ويمثلان 75% CWR و 50% CWR من الاحتياج المائي في كل من الحالتين. اظهرت النتائج توافقا في التاثير بين الانتاج وعوامله في حالتي الري الكامل والري الناقص لمحصول الذرة الشامية ومن ناحية اخرى اتضح ان معاملتي الري الناقص في حالتي 75% CWR و 50% CWR عند النموء الخضري قد نتج عنها زيادة ملحوظة في الانتاجية المائية (WP) للمحصول عباره عن 0.59 كيلوجرام لكل متر^{٣} ماء مما يعني عدم نقص في الانتاجية مع تقليل الاحتياج المائي وعليه فان الدراسة توصي باستخدام ري ناقص 50% CWR للذرة الشامية في الظروف البئية المشابهة.

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