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Effects of skipping one irrigation at different growth stages on yield and water productivity of some maize (*Zea mays* L.) cultivars under heavy clay soils of central Sudan

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ABSTRACT

Crop production in arid and semi-arid regions faces the challenge to ensure high yields with limited supply of water. This study was conducted at the experimental farm of the Faculty of Agricultural Sciences, University of Gezira, during seasons 2014/15 and 2015/16. The objectives of this study were to investigate the effects of skipping one irrigation on yield and yield components of maize (*Zea mays* L.). A split-plot design with four replicates was used. Main plots were assigned to the cultivars namely: Hudaiba1, Hudaiba2 and Mogtamaa -45, and sub-plots to irrigation treatments which consisted of (T_1) irrigation every 10 days throughout the season (control), skipping one irrigation at: Vegetative (T_2), flowering (T_3) and grain filling (T_4) stages. The results indicated that irrigation treatments and cultivars had highly significant effects on all parameters tested. Irrigation every 10 days resulted in the highest values of plant height, cob length, number of grains per cob, 100 seed weight, grain yield and water productivity. Hudaaiba2 outyielded the other two cultivars. Skipping one irrigation at flowering (T_3) stage gave the lowest values of the tested parameters. The highest grain yield was obtained when frequent irrigation (control) and Hudaiba 2 was practiced and the lowest was obtained by skipping of irrigation at flowering, which reflected the sensitivity of this stage for water deficit. Hence, it is recommended to grow Hudaiba2 maize cultivar and irrigate every 10 days.

INTRODUCTION

Due to the serious water shortage, the great challenge for the coming decades is the task of increasing food production with less water, particularly in countries with limited water and land resources (FAO, 2002). Agricultural production in the arid area predominantly depends on both surface water and groundwater. The cost of pumping is increasing due to rising energy costs. Thus, the efficient use of available water is needed to produce high water use crops (Alam *et al.* 2009). The amount of water applied and the frequency of irrigation must be adjusted to the actual consumption of the crop, water- holding capacity of the soil, and depth of rooting (Hansen *et al*. 1979).

When rainfall is not sufficient, plants must receive additional water from irrigation (Brouwer *et al.*, 1989). Farmers in the northern states of the Sudan generally apply large amounts of irrigation water without consideration of changes in climatic factors or growth stages of the crop which are the main factors that determine irrigation water requirements (Ahmed, 1995). Farmers normally over irrigate the fields due to lack of proper knowledge about irrigation scheduling and the belief that more water will produce more yields. Crop water requirement is mainly dependant on climatic factors such as temperature, solar radiation, relative humidity, wind velocity, *etc*, and agronomic factors like stage of crop development (Naheed and Arif, 2000).

The main objective of deficit irrigation is to increase the WUE of maize by skipping irrigations that have little impact on yield. The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops (FAO, 2002). Yenesew and Tilahun (2009) reported that the most critical period for irrigation is the mid season stage. Water stress in the flowering stage reduced grain yield (Cakir, 2004; Kuscu and Demir,2012; Sadalla *et al.* 2013). Also, Rewaily and Ayman (2010) showed that water stress in stages of flowering, seed formation and grain filling in maize caused the most reduction of grain yield. Igbadun *et al*. (2007) found that skipping of irrigation at flowering stage had a more severe impact on grain yield compared to skipping of irrigation at vegetative or grain-filling growth stages.

In general, it can be stated that, of the four growth stages (initial, mid, development and late), the mid-season stage is the most sensitive to water shortage. This is mainly because it is the period of the highest crop water needs. If water shortages occur during the mid-season stage, the negative effect on yield will be pronounced (Brouwer *et al*., 1989). The present experiment was carried out to investigate the effect of skipping irrigation on grain yield and yield components and water productivity of maize, using three cultivars (Hudaiba1, Hudaiba 2 and Mogtamaa-45).

MATERIALS AND METHODS

Experiments were carried out during the winter seasons of 2014/15 (first season) and 2015/16 (second season) at the experimental farm, University of Gezira. It lies north of Wad Medani town, Lat. 14° 06` N, Long. 33° 38` E and altitude of 405 masl. The soil is Vertisol, with a high CEC, a pH of 7.5 and alkaline with low permeability (Alhilo, 1996). The experiment was laid out in a split-plot design with four replicates. The main plots were assigned to the cultivars namely: Hudaiba1, Hudaiba 2 and Mogtamaa-45, and the subplots for irrigation treatments.

The land was disc plowed, harrowed, leveled and ridged. Maize cultivars Hudaiba1, Hudaiba 2 and Mogtamaa-45 were sown on ridges 80 cm apart by placing 2-3seeds per hole and 25 cm between holes. The plot area was 42 m^2, each plot was separated from the other by 2 m .Three weeks later, plants were thinned to one plant per hole. Urea was side-dressed at the rate of 86 kg N ha^{-1}, as recommended by the Agricultural Research Corporation.

The irrigation treatments were as follows: Irrigation every 10 days throughout the season (control) (T_1), skipping one irrigation at: vegetative (T_2), flowering (T_3) and grain filling (T_4)

stages. Water flow into each plot was measured based on the discharge rate of a small calibrated diesel water pump.

The data collected consisted of the following parameters: Plant height (cm), cob length (cm), number of seeds per cob, 100- seed weight (g) and grain yield (kg/ha). Each plot was harvested separately, air dried and threshed. The grain yield was obtained by converting the yield of the actual harvested area into kg/ha.

Water flow into each plot was measured from a small calibrated diesel water pump (Honda GX160, 1100 L/minute). Crop water productivity was assessed using the following equation:

CWP (kg/m^3) = Yield (kg) / applied water (m^3)

Data were analyzed using standard analysis of variance procedures and means were separated using LSD.

RESULTS AND DISCUSSION Plant height

Plant height of the three maize cultivars under the different irrigation treatments is shown in Table (1). There were highly significant differences ($P \leq 0.01$) among irrigation treatments with respect to each of the maize cultivars. The tallest plants were obtained by frequent irrigation (157, 156.3cm), followed by skipping at vegetative (152.7, 151.2 cm) and the shortest by skipping at flowering (134.3, 138.7 cm) in both seasons, respectively. The effects of cultivars on plant height were highly significant ($P \leq 0.01$). The tallest plants were obtained by Hudaiba2 (151, 151.2 cm), followed by Hudaiba1 (145, 147.3 cm) and the least by Mogtamaa-45 (145.5, 145.9 cm) in both seasons, respectively.

The interaction effects between irrigation treatments and cultivars on plant height were highly significant (Table 2). Results showed that frequent irrigation produced the tallest plant for the three maize cultivars studied in both seasons, whereas skipping one irrigation at flowering produced the shortest plants in both seasons. These results were in line with the findings of Elzubeir and Elamin (2011), Cakir, (2004) and Sadalla *et al.* (2013).

Cob length

The effect of irrigation treatments on cob length in the three maize cultivars is shown in Table 1. There were significant differences ($P \leq 0.05$) among irrigation treatments with respect to each of the maize cultivars tested. The longest cobs were obtained by frequent irrigation (11.6, 12.7 cm), followed by skipping at vegetative (11.7, 12.2 cm) and the shortest by skipping at flowering (11.1, 12 cm) in both seasons, respectively. The effect of cultivar on cob length was not significant in both seasons. The interaction effects of irrigation and cultivars was not significant (Table 2). These results are in agreement with the findings of Sadalla *et al.* (2013).

Table1. Main effects of irrigation treatments on plant height and cob length of maize cultivars grown during seasons 2014/15 and 2015/16.

Treatments	Plant height (cm)	Cob length(cm)

	2014/15	2015/16	2014/15	2015/16
T_1	157.0	156.3	11.6	12.7
T_2	152.7	151.2	11.7	12.2
T_3	134.3	138.7	11.1	12.0
T_4	145.3	146.3	11.6	12.1
Sig. level	**	**	*	*
SE±	0.26	0.65	0.14	0.2
C.V(%)	3.8	9.3	2.65	3.2
V_1	145.0	147.3	11.6	12.2
V_2	151.5	151.2	11.6	12.4
V_3	145.5	145.9	11.2	12.2
Sig. level	**	**	N.S	N.S
SE±	0.26	0.18	0.4	0.12
C.V(%)	2	3	8.7	2.36

N.S= not significant, *and** significantly different at 0.05 and 0.01 probability levels, respectively. T_1=control, T_2= skipping at vegetative, T_3 =skipping at flowering and T_4=skipping at grain filling. V_1=Hudaiba1, V_2= Hudaiba2 and V_3= Mogtamaa-45.

Table 2. Interaction effects of irrigation treatments and cultivars on plant height and cob length during seasons 2014/15 and 2015/16.

Treatments	Plant height (cm)		Cob length (cm)	
	2014/2015	2015/2016	2014/2015	2015/2016
T1V1	155	155.7	11.7	12.7
T2V1	150	149.7	12.0	12.0

T3V1	131	139.0	11.0	12.0
T4V1	144	145.0	11.7	12.0
T1V2	160	158.3	11.7	12.7
T2V2	159	153.0	11.7	12.7
T3V2	137	145.0	11.3	12.0
T4V2	149	148.3	11.7	12.3
T1V3	156	155.0	11.3	12.7
T2V3	148	151.0	11.3	12.0
T3V3	135	132.0	11.0	12.0
T4V3	143	145.7	11.3	12.0
Sig. level	**	**	N.S	N.S
SE±	0.32	0.79	0.18	0.23

N.S= not significant, ** significantly different at 0.01 probability levels. T_1=control, T_2= skipping at vegetative, T_3 =skipping at flowering and T_4=skipping at grain filling. V_1=Hudaiba 1, V_2= Hudaiba2 and V_3= Mogtamaa-45.

Number of grains per cob

There were highly significant differences ($P \leq 0.01$) in number of grain per cob among irrigation treatments (Table 3). The largest number of grains per cob was obtained by frequent irrigation, followed by skipping at vegetative and the least by skipping at flowering in both seasons. The effects of cultivars on number of grains per cob were highly significant ($P \leq 0.01$). The largest number of grains per cob was obtained by Hudaiba2, followed by Hudaiba1 and the least by Mogtamaa-45 in both seasons
(Table 3).

The interaction effects of irrigation treatments and cultivars on number of grains per cob showed that frequent irrigation produced the largest number of grains per cob for all cultivars followed by skipping irrigation at vegetative stage whereas skipping irrigation at flowering produced the lowest number of grains per cob. These results support the findings of Khodarahmpour and Hamidi (2012) and Elzubeir and Elamin (2011) who reported that water deficit affected the number of grains per cob thereby compounding the effects on final grain yield. These results also agreed with those reported by Cakir (2004) who stated that moisture deficit at different growth stages had significant effects on number of grains per cob.

One hundred seed weight

Irrigation treatments had highly significant ($P \leq 0.01$) effects on 100seed weight in both seasons (Table 3). The heaviest 100- seed weight was obtained by frequent irrigation followed by skipping at vegetative and the lowest 100- seed weight was obtained by skipping irrigation at flowering. Cultivars, on the other hand, showed highly significant ($P \leq 0.01$) differences in 100-seed weight. The heaviest 100- seed weight was obtained by Hudaiba2 followed by Hudaiba1 and the lowest 100- seed weight was obtained by Mogtamaa-45 (Table 3).

The interaction effects of irrigation treatments and cultivars on 100 seed weight were highly ($P \leq 0.01$) significant (Table 4). Results indicated that frequent irrigation of Hudaiba2 produced the heaviest 100- seed weight. On the other hand, skipping irrigation at flowering produced the lowest 100- seed weight for the three maize cultivars in both seasons. These results support by the findings of Khodarahmpour and Hamidi (2012).Similar results were also obtained by Abo-El-kheir and Mekki (2007) who found that water stress in maize decreased 100–seed weight.

Table 3. Main effects of irrigation treatments on number of seeds per cob and 100 seed weight (gm) of maize cultivars grown during seasons 2014/15 and 2015/16.

Treatments	No. of seeds /cob		100 S.W (g)	
	2014/15	2015/16	2014/15	2015/16
T_1	324.0	331.0	17.7	17.4
T_2	302.4	302.9	16.8	16.9
T_3	216.1	206.1	13.3	13.6
T_4	293.7	293.3	16.0	15.9
Sig. level	**	**	**	**
SE±	1.5	2.4	0.13	0.14
C.V (%)	1.1	1.8	1.77	1.81
V_1	281.2	280.2	16.1	16.2
V_2	296.3	294.9	16.9	16.8
V_3	274.7	274.9	14.9	14.8
Sig. level	**	**	**	**
SE±	2.6	3.1	0.07	0.1
C.V (%)	2.3	2.7	1.12	1.56

** Significantly different at 0.05 probability level. T_1=control, T_2= skipping at vegetative, T_3=skipping at flowering and T_4=skipping at grain filling. V_1=Hudaiba1, V_2= Hudaiba2 and V_3= Mogtamaa-45

Table 4. Interaction effects of skipping of one irrigation on number of seeds per cob and 100 seed weight (gm) of maize cultivars grown during seasons 2014/15 and 2015/16.

	No. of seed /cob		100 S.W(g)	
Treatments	2014/2015	2015/2016	2014/2015	2015/2016
T1V1	322.3	325.3	18.0	18.0
T2V1	299.3	299.3	17.0	17.2
T3V1	212.0	203.7	13.2	13.5
T4V1	291.0	292.3	16.3	16.2
T1V2	332.7	352.3	18.7	18.0
T2V2	314.7	313.7	17.8	17.8
T3V2	224.7	210.7	14.0	14.2
T4V2	303.3	303.0	17.1	17.1
T1V3	317.0	315.3	16.3	16.1
T2V3	293.3	295.7	15.7	15.5
T3V3	201.7	204.0	13.0	13.2
T4V3	286.7	284.7	14.5	14.3
Sig. level	**	**	**	**
SE±	1.78	2.91	0.16	0.17

** Significantly different at 0.05 probability levels. T_1=control, T_2= skipping at vegetative, T_3=skipping at flowering and T_4=skipping at grain filling. V_1=Hudaiba 1, V_2= Hudaiba2 and V_3= Mogtamaa-45

Grain yield

The effects of irrigation treatments on grain yield were highly significant ($P \leq 0.01$) (Table 5). The highest grain yield was obtained by frequent irrigation (3116.4 and 3110.1 kg/ha) followed by skipping at vegetative (3042.6 and 3018.3 kg/ha) and the lowest grain yield was obtained by skipping irrigation at flowering (2815.7 and 2789.4 kg/ha). Significant ($P \leq 0.05$) differences were detected among cultivars on grain yield. The highest grain yield was recorded by Hudaiba2 (3030.7 and 3016.6 kg/ha) followed by Hudaiba1 (2978.7 and 2962.6 kg/ha) and the lowest grain yield was obtained by Mogtamaa-45 (2936.7 and 2922.6 kg/ha) for the first and second seasons, respectively.

The interaction effects of irrigation treatments and cultivars were significant (Table 6). Frequent irrigation produced the highest grain yield followed by skipping irrigation at vegetative treatment in both seasons. On the other hand, skipping irrigation at flowering produced the lowest grain yield for all cultivars in both seasons. These results support the findings of Ayana (2011), who reported that water stress during flowering and grain filling stages produced lower yields. Skipping one irrigation during flowering stage reduced grain yield (Cakir, 2004; Kuscu and Demir, 2012; Sadalla *et al.* 2013). These results were in line with the findings of Rewaily and Ayman (2010) who stated that water deficit in stages of flowering, seed formation and grain filling in maize caused the most reduction of grain yield.

Water productivity (kg/m^3)

Results showed that irrigation treatments had highly significant ($P \leq 0.01$) effects on water productivity (Table 5). Skipping irrigation at the vegetative stage had the highest water productivity (0.344 and 0.341 kg/m^3) followed by frequent irrigation (0.308 and 0.307 kg/m^3). On the other hand, skipping irrigation at flowering produced the lowest water productivity (0.282 and 0.287 kg/m^3) for the first and second seasons, respectively. Results indicated no significant ($P \leq 0.01$) differences among cultivars in water productivity.

The results of the interactions between the different treatments are shown in Table 6. The interaction effects of irrigation treatments and maize cultivars were not significant on water productivity. Results showed that skipping irrigation at vegetative treatment produced the highest water productivity followed by normal irrigation treatment. On the other hand, skipping irrigation at flowering produced the lowest water productivity. These results support the findings of Alfalahi *et al*. (2015), who reported that deficit irrigation was effective in increasing water productivity of maize. Zwart and Bastianssen (2004) found that crop-water productivity of maize ranged between 0.22 and 3.99 kg/m^3. Zhao and Nan (2004) reported that water productivity of maize varied from 1.39 to 1.72 kg/m^3.

Table 5. Main effects of irrigation treatments and maize cultivars on grain yield and water productivity for 2014/15 and 2015/16 seasons.

Treatments	Yield (kg/ha)		W.P (kg/m^3)	
	2014/15	2015/16	2014/15	2015/16
T_1	3116.4	3110.1	0.31	0.31
T_2	3042.6	3018.3	0.34	0.34
T_3	2815.7	2789.4	0.23	0.24
T_4	2953.3	2951.1	0.28	0.29
Sig. level	**	**	**	**
SE±	14.31	15.57	0.007	0.01
C.V(%)	1.02	1.11	5.46	6.74
V_1	2978.7	2962.6	0.29	0.29
V_2	3030.7	3016.6	0.29	0.30

V_3	2936.7	2922.6	0.29	0.29
Sig. L	*	**	N.S	N.S
SE±	16.03	9.028	0.013	0.012
C.V(%)	13.2	7.5	10.97	10.18

N.S= not significant, *and** significantly different at 0.05 and 0.01 probability levels, respectively. T_1=control, T_2= skipping at vegetative, T_3 =skipping at flowering and T_4=skipping at grain filling. V_1=Hudaiba 1, V_2= Hudaiba2 and V_3= Mogtamaa-45

Table 6. Interaction effects of irrigation treatments and cultivars on grain yield and water productivity (kg/m^3) of maize during seasons 2014/15 and 2015/16.

Treatments	Grain yield (kg/ha)		W. P (kg/m^3)	
	2014/2015	2015/2016	2014/2015	2015/2016
T1V1	3119.3	3113.7	0.30	0.31
T2V1	3027.0	3004.3	0.34	0.34
T3V1	2805.7	2797.0	0.23	0.24
T4V1	2962.7	2935.3	0.28	0.28
T1V2	3186.3	3176.0	0.31	0.31
T2V2	3118.7	3104.7	0.34	0.35
T3V2	2824.3	2792.3	0.22	0.24
T4V2	2993.3	2993.3	0.29	0.29
T1V3	3043.7	3040.7	0.31	0.31
T2V3	2982.0	2946.0	0.35	0.34
T3V3	2817.0	2779.0	0.24	0.24
T4V3	2904.0	2924.7	0.28	0.29
Sig. level	*	*	N.S	N.S
SE±	17.5	19.1	0.009	0.011

N.S= not significant, * significantly different at 0.05 probability levels, respectively. T_1=control, T_2=skipping at vegetative, T_3 =skipping at flowering and T_4=skipping at grain filling. V_1=Hudaiba1, V_2= Hudaiba2 and V_3= Mogtamaa-45.

CONCLUSION

In conclusion, it is recommended to grow Hudaiba2 maize cultivar and irrigate every 10 days.

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الخلاصة

إنّ انتاج المحاصيل في المناطق الجافة وشبه الجافة يواجه العديد من التحديات لتامين الانتاج مع محدودية مصادر الامداد المائي. أجريت هذه الدراسة بمزرعة كلية العلوم الزراعية ، جامعة الجزيرة في موسم 5/14 و 201م بولاية الجزيرة في موسم 15/ 2016م. بهدف دراسة تأثير حذف رية و كفاءة استخدام مياه الري على الانتاج ومكوناته لمحصول الذرة الشامية. وزعت المعاملات باستخدام تصميم القطع المنشقة بأربع مكررات حيث تم وضع الاصناف (حديبة1 وحديبة 2 ومجتمع45) في القطع الرئيسية في حين ان معاملات الري والتي تشتمل على ري كامل كل عشرة ايام (T_1) وترك رية اثناء فترة النمو الخضري (T_2) ، الازهار (T_3) ، النضج (T_4) وضعت في القطع المنشقة. اوضحت النتائج وجود فروق معنوية عالية ($P \leq 0.01$) لمعاملات الري والاصناف على كل الصفات المدروسة. الري كل عشرة ايام اعطى اعلى قيم لطول نبات وطول العرنوس و عدد الحبوب لكل عرنوس و وزن المائة حبة و انتاجية الحبوب وكفاءة استخدام المياه. الصنف حديبة2 اعطى اعلى انتاجية مقارنة بالأصناف الأخرى. حذف رية عند الازهار اعطى اقل قيم للصفات المدروسة. تم الحصول اعلى قيمة للإنتاج بالري كل عشرة ايام بزراعة الصنف حديبة2 واقل قيمة كانت عند حذف رية عند مرحلة الازهار مما يعكس جليا حساسية هذه المرحلة للري الناقص. عليه نوصى بزراعة الصنف حديبة2 والري كل عشرة ايام.