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Assessment of Stage-Wise Deficit Furrow Irrigation Application on Maize Production at Koga Irrigation Scheme, Blue Nile River Basin, Ethiopia

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Abstract
Efficient irrigation management has an imperative role in managing integrated water resources. Deficit irrigation water application is among the most effective water management solutions. This study was conducted with the aim of evaluating the performance of stage-wise deficit irrigation (DI) application on irrigation efficiencies and to identify crop growth stages during which the crop can withstand water deficit with limited effect on yield and water productivity (WP). Maize (Melkassa-4 type) was selected as test crop as it is known to respond well to deficit irrigation. The experiment was conducted at Koga Irrigation Scheme, Blue Nile River Basin. The field experiment was arranged in randomized complete block design (RCBD) with three replications. The result showed that level of stage-wise deficit irrigation water application had a significant ($P<0.05$) impact on performance indices except distribution uniformity. Application efficiency increased with deficit level increases. The maximum application efficiency (83.5%) was noted when 0.25ETc was applied throughout the growing season. Effect of stage-wise application level had a significant ($P<0.05$) effect on agronomic parameters. The highest yield (58.92 qt/ha) was obtained when full irrigation was applied in all growth stages. The highest Physical water productivity (CWP) (1.65 kg/m^3) and economic water productivity (CWP) (4.17 Birr/m^3) were obtained when 50% deficit applied during 2nd and 3rd growth stages. On average, the crop was found to be moderately sensitive to water deficit since the average seasonal maize response factor (Ky) (1.04) value is slightly greater than one. In conclusion, this study showed that much water is saved when the crop is stressed by 50% during 2nd and 3rd growth stages.
Keywords: Deficit irrigation, irrigation performance indices, Koga irrigation scheme, stage-wise, water productivity.

INTRODUCTION

Water is an invaluable resource in the Nile Region. Hence, efficient and effective use wherever it is being consumptively used will have far reaching implications. In the Ethiopian part of the Blue Nile, the subsistence rain-fed agriculture is under the mercy of the erratic rainfall and the water resource development is known to have an imperative role in the agricultural, socio-economic and industrial development. Though the country is known to have plenty of water resources, its availability is constrained by number of factors. One among these is the poor water productivity and inefficient irrigation water application.

Recently deficit irrigation (DI) application to enhance water productivity is getting a new momentum (English and Raja, 1996). Deficit irrigation (DI) is a watering strategy that can be applied by different types of irrigation application methods (Perry *et al*., 2009). The correct application of DI requires thorough understanding of the yield response to water (Kirda and Kanber, 1999) and of the economic impact of reductions in harvest.

The specific reason for initiating the research was that Koga and many other developed schemes suffers from serious water shortage, specifically during late in the dry season. Though the Koga small scale irrigation scheme was designed to irrigate 7000 ha, only about 5000 ha was developed at the time of the study. The specific objectives of the study were to determine the efficiency of furrow irrigation system with deficit irrigation water application, and to evaluate the effect of stage-wise deficit irrigation application to yield components and water productivity.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Koga Irrigation Scheme, which is located at 11.37^0 N latitude and 37.12^0 E longitudes in the Blue Nile Basin. The source of water for the scheme is the Koga River, which is one of the perennial rivers in Mecha Woreda sub-catchment of the Nile River Basin (Fig. 1). The mean annual rainfall in the study area is between 800 to 2,200 mm with a mean value of about 1,420 mm. The mean annual minimum and maximum temperatures are 9^{0}C and 32^{0}C, respectively. The dominant soil type of the area is mainly paleosol with clay texture.

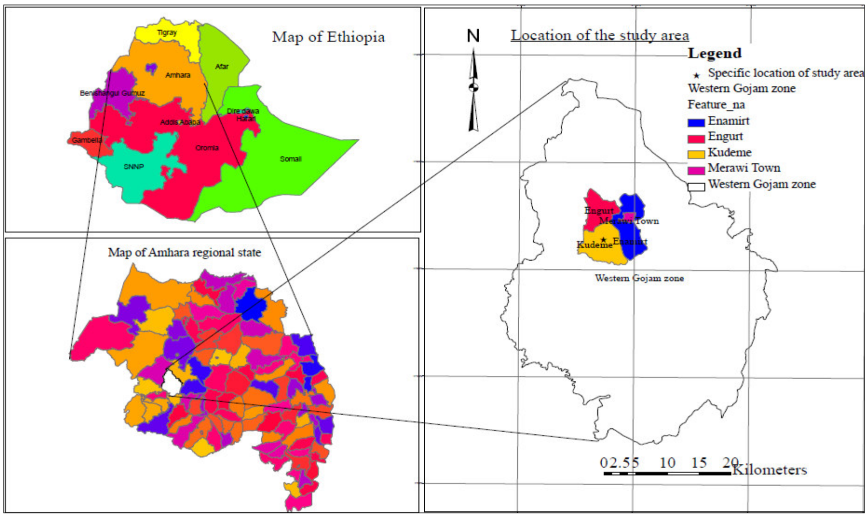

Figure 1. Location map of Koga irrigation scheme

Experimental Designs and Field Layout

The experiment was designed as Randomized Complete Block Design (RCBD) with three replications. There were a total of six treatments made by varying the level of irrigation water throughout the growing season (i.e. 100%, 75%, 50%, and 25% of ETc) and at a specific growth stages. The experiment was considering four growing stages of the crop such as initial (S1), development (S2), flowering (S3) and maturity (S4) stages. Treatment combinations tested are shown in (Table 1).

Table 1: Description of irrigation treatments

Treatment	Growth stage				Description
	S_1	S_2	S_3	S_4	
	One growth stage stress (25% and 50% deficit)				
0011	0	0	1	1	Stress during S_1 and S_2 with 25%
1001	1	0	0	1	Stress during S_2 and S_3 with 50%
1100	1	1	0	0	Stress during S_3 and S_4 with 50%
	Partial stress				
75% deficit	75%	75%	75%	75%	Throughout the growing stage
50% deficit	50%	50%	50%	50%	Throughout the growing stage
	No stress				
1111	1	1	1	1	Full irrigation at all growth stages

Note: 1 indicates normal watering or irrigating 100% of ETc; 25% Deficit indicates irrigating 75% of ETc; 50% Deficit indicates watering 50% of ETc and 75% deficit indicates irrigating 25% of ETc.

The experimental area was divided into 18 plots with 40 m × 30 m of net size, maintaining a barrier zone of 2 m between adjacent blocks (Fig.2). Each plot had four planting ridges having 10 m length and five furrows having 0.15 m bottom width, 0.30 m top width for irrigation water applications and having 30 cm distance between plants. Siphon with 1.5 - inch (3.81 cm) diameter was used to deliver water to every furrow. The average slope of the experimental plot was 0.28% along the irrigation furrow. Sowing was done on January 01/2012 at a row spacing of 76 cm and 30 cm spacing between plants. There was no any incidence of diseases during the experimental season. Harvesting of two internal rows per plot in all the plots was done on May 05/2012. At harvest, a sample area of 15.20 m^2 (i.e. 10 m x 1.52 m) per plot was selected and the grain yield as well as number of plants in that sample plot area was measured. This was then converted to per hectare basis.

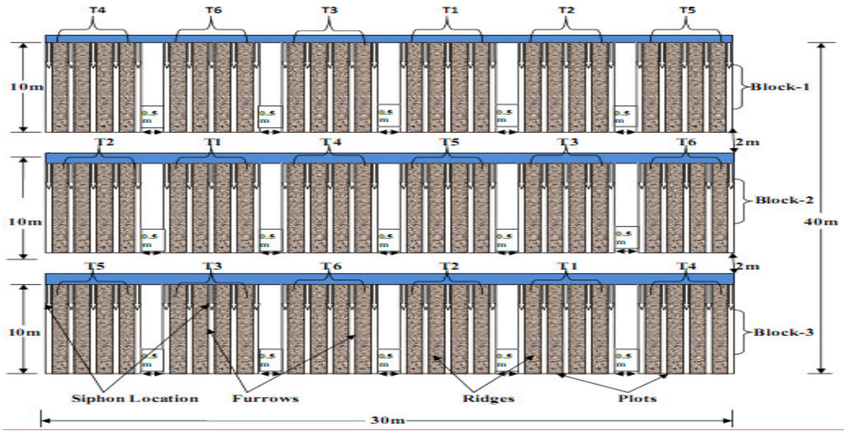

Figure 2. Layout of the experimental field

Estimation of Maize Water Requirement

FAO Cropwat model for window 8.0 was used to determine reference crop evapotranspiration (ETo) using climatic data. Crop factor (Kc) for every growth stage was taken from Allen *et al*. (1998) and then, ETc was calculated using equation 1.

$$ET_c = ET_o \, x \, K_c \qquad (1)$$

Where; ETc is crop evapotranspiration in mm, Kc is crop factor in fraction and ETo is reference crop evapotranspiration in mm.

After setting out of crop evapotranspiration, it is possible to determine net irrigation water requirement by subtracting effective rainfall during the investigational season and it can be expressed by using equation 2.

$$NIR = ET_c - P_e \qquad (2)$$

Where; NIR is net irrigation water requirement of the crop in mm, and P_e is effective rainfall during the growth period of the crop in mm.

Nevertheless, there was no rainfall at all from the starting to the end of the experimental season in the study area. Therefore, net irrigation water requirement of the crop was equal to only the crop evapotranspiration (ETc).

Application efficiency of 60% was used to estimate the gross irrigation requirement using equation 3. Furrow irrigation application efficiencies in general vary from 45-60% Allen *et al*. (1998).

$$GIR = \frac{NIR}{E_a} \qquad (3)$$

Where; GIR is gross irrigation water requirement of the crop in mm, NIR is net irrigation water requirement of the crop in mm and Ea is application efficiency in percentage.

Determination of the required application depth

The amount of water needed to refill the crop root zone to field capacity at the time of irrigation or the required application depth (Z_{req}) was calculated from field evaluations of the soil moisture content before irrigation which were used to compute the soil moisture deficit SMD (mm), using equation 4 in the root zone (Yonts and Eisenhauer, 2007).

$$Z_{req} = SMD = 10 \times (\theta_{FC} - \theta i) \times D_i \qquad (4)$$

Where; SMD is soil moisture deficit (mm), Z_{req} is the required application depth (mm), θ_{FC} is moisture content at field capacity (% volume), θ_i is moisture content before irrigation event (% volume) and D_i is effective root depth (m).

Determination of the depth of water retained in the soil profile

It is necessary to identify the amount of water applied to the furrow and the depth of water retained in the root zone in order to know the technical performance indicators of deficit irrigation. The depth of water retained in root zone of the soil was computed based on the moisture contents of the soil samples taken using auger before irrigation and two days after irrigation. The samples were taken within three -meter interval from three points (i.e. at 3 m, 6 m and 9 m) along the furrow at four depths with an interval of 25 cm (i.e. 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm) depths. Finally, the depth of water retained in the root zone was calculated using equation5.

$$d = \sum_{i}^{n} \frac{(\theta_f - \theta_i)}{10} x\, A_{si}\, x\, D_i \quad (5)$$

Where; d is depth of water retained into the root zone of the soil (mm); θ_f is moisture content in the i[th] layer of the soil after irrigation on % weight, θ_i is moisture content in the i[th] layer of the soil before irrigation on % weight, A_{si} is apparent specific gravity of the i[th] soil layer (fraction), D_i is depth of the root zone in the i[th] layer (cm) and n is number of layers in the root zone.

Estimation of Non-Erosive Discharge, Siphon Discharge and Irrigation Time

The maximum value of non-erosive discharge was determined using the empirical relationship given by Cuenca (1989 (equation 6).

$$Q_{max} = \left(\frac{0.6}{S_o}\right) \quad (6)$$

Where; Q_{max} is maximum non-erosive discharge (l/s) and S_o is furrow slope in the direction of flow (fraction).

The selected non-erosive discharge was 1.28 l/s calculated based on equation 7 (Cuenca, 1989) by considering 10 cm constant hydraulic head. This was less than the maximum non-erosive discharge estimated by using equation 6 (i.e. 2.14 l/s) by using 0.28% average slope of the experimental plot along the irrigation furrow.

$$Q = CA\sqrt{2gh} \quad (7)$$

Where; Q is siphon discharge (m^3/s), C is coefficient of discharge (0.6), A is cross sectional area of the siphon (m^2), g is gravitational acceleration (m/s^2) and h is hydraulic head (m).

The time required to apply the desired amount of irrigation depth into each furrow using rigid siphon was estimated by using equation 8 (Cuenca, 1989).

$$t = \left(\frac{NIR \times l \times w}{6 \times Q_o\, x\, E_a}\right) \quad (8)$$

Where; t is application time (min), NIR is net irrigation requirement (cm), *l* is furrow length (m), w is furrow spacing (m), Q_o is flow rate (discharge) (l/s) and E_a is application efficiency (fraction).

Data collection and analysis

Technical performance (i.e. application efficiency, water storage efficiency, distribution uniformity and deep percolation ratio), and yield and yield related variables, were collected. From this, water productivity and yield response factor (K_y) were estimated. The effects of different treatments on irrigation performance indices, yield components and water productivity were statistically analyzed using analysis of variance technique and mean separation was computed using Least Significance difference (LSD) at 5% and 1% significance levels using GenStat software.

RESULTS AND DISCUSSION

Physical properties of soil

The result of soil physical property values at each soil layer is presented in Table 2.

Table 2. Soil physical properties of the experimental site

Pit no	Depth (cm)	ρ(gm/cm^3)	θ_{FC} (%)		θ_{PWP} (%)		TAW (mm/m)	Particle size distribution (%)			Textural class
			W/W	V/V	W/W	V/V		Sand	Clay	Silt	
1	0-25	1.15	38.02	43.61	21.90	25.12	184.90	3.01	55.99	41.00	clay
	25-50	1.25	34.60	43.15	24.51	30.56	125.82	1.20	77.50	21.30	clay
	50-75	1.32	35.94	47.40	24.61	32.46	149.44	1.00	74.00	25.00	clay
	75-100	1.40	35.78	50.16	25.49	35.74	144.27	0.95	80.05	19.00	clay
2	0-25	1.02	37.22	38.00	22.09	22.55	154.48	6.97	72.00	21.03	clay
	25-50	1.10	35.93	39.59	23.22	25.59	140.06	1.00	70.00	29.00	clay
	50-75	1.40	34.35	48.09	24.79	34.71	133.84	1.11	77.97	20.92	clay
	75-100	1.42	35.24	50.01	24.54	34.82	151.83	1.00	80.00	19.00	clay
3	0-25	1.12	38.79	43.56	22.07	24.78	187.77	5.00	56.00	39.00	clay
	25-50	1.28	37.43	47.80	24.56	31.36	164.35	1.09	83.19	15.72	clay
	50-75	1.40	34.24	47.76	25.06	34.96	128.06	1.00	76.00	23.00	clay
	75-100	1.46	35.51	51.99	24.99	36.59	154.01	0.93	82.00	17.07	clay
4	0-25	1.08	42.16	45.41	23.63	25.45	199.57	4.00	63.00	33.00	clay
	25-50	1.16	36.72	42.63	25.17	29.22	134.10	1.07	79.00	19.93	clay
	50-75	1.42	35.25	50.09	24.86	35.33	147.64	1.00	82.00	17.00	clay
	75-100	1.49	37.88	56.59	25.89	38.68	179.13	4.00	78.00	18.00	clay
Mean	0-100	1.28	36.57	46.71	24.21	30.93	157.84	2.15	74.17	23.69	clay

Crop Water Requirement and Irrigation Water Application Depths

Total water requirement (ETc) of maize crop, net irrigation requirement (NIR) and gross irrigation requirement (GIR) for a total growing period of 115 days is presented in Table 3. Minimum crop water requirement (ETc) of 8.06 mm was obtained during the initial growing season and maximum ETc of 42.55 mm per period was estimated during the mid growing season (Table 3) using Kc values of maize crop estimated Allen *et al*. (1998).

Amount of water required during the growing season and amount of irrigation water applied to each treatment plots is presented in Table 4.

Table 3. Crop water requirement (ETc) and irrigation schedule at the experimental site

Date	Irrigation interval (day)	Growth stage	Kc (-)	ETo (mm/day)	ETo (mm/period)	ETc (mm/period)	NIR* (mm/period)	GIR** (mm/period)
8-Jan	8	Initial	0.30	3.36	26.88	8.06	8.06	13.44
16-Jan	16	Initial	0.30	3.36	26.88	8.06	8.06	13.44
24-Jan	24	Dev	0.48	3.36	26.88	12.90	12.90	21.50
1-Feb	32	Dev	0.79	3.94	31.52	24.90	24.90	41.50
9-Feb	40	Dev	0.79	3.94	31.52	24.90	24.90	41.50
17-Feb	48	Dev	1.09	3.94	31.52	34.36	34.36	57.26
25-Feb	56	Mid	1.19	3.94	31.52	37.51	37.51	62.51
5-Mar	64	Mid	1.19	4.47	35.76	42.55	42.55	70.92
13-Mar	72	Mid	1.19	4.47	35.76	42.55	42.55	70.92
21-Mar	80	Mid	1.19	4.47	35.76	42.55	42.55	70.92
29-Mar	88	Mid	1.19	4.47	35.76	42.55	42.55	70.92
6-Apr	96	End	1.04	4.79	38.32	39.85	39.85	66.42
14-Apr	104	End	0.75	4.79	38.32	28.74	28.74	47.90
22-Apr	112	End	0.54	4.79	38.32	20.69	20.69	34.49
25-Apr	End	End	0.00	0	0.00	0.00	0.00	0.00
Total	112		12.03	58.09	464.72	410.20	410.20	683.64

* NIR simulation was done excluding of rainfall.

** GIR was calculated using 60% application efficiency.

Table 4. Depths of water applied for each treatment with respect to crop growth stage (mm)

Date	Irrigation Interval (day)	Growth Stage	GIR (mm)	Treatments $D_{1,2}25$ (T1)	$D_{2,3}50$ (T2)	$D_{3,4}50$ (T3)	$D_{all,}75$ (T4)	$D_{all,}50$ (T5)	$D_{all,}0$ (T6)
8-Jan	8	Init	13.44	10.08	13.44	13.44	3.36	6.72	13.44
16-Jan	8	Init	13.44	10.08	13.44	13.44	3.36	6.72	13.44
24-Jan	8	Dev	21.50	16.13	10.75	21.50	5.38	10.75	21.50
1-Feb	8	Dev	41.50	31.13	20.75	41.50	10.38	20.75	41.50
9-Feb	8	Dev	41.50	31.13	20.75	41.50	10.38	20.75	41.50
17-Feb	8	Dev	57.26	42.95	28.63	57.26	14.32	28.63	57.26
25-Feb	8	Mid	62.51	62.51	31.26	31.26	15.63	31.26	62.51
5-Mar	8	Mid	70.92	70.92	35.46	35.46	17.73	35.46	70.92
13-Mar	8	Mid	70.92	70.92	35.46	35.46	17.73	35.46	70.92
21-Mar	8	Mid	70.92	70.92	35.46	35.46	17.73	35.46	70.92
29-Mar	8	Mid	70.92	70.92	35.46	35.46	17.73	35.46	70.92
6-Apr	8	End	66.42	66.42	66.42	33.21	16.61	33.21	66.42
14-Apr	8	End	47.90	47.90	47.90	23.95	11.98	23.95	47.90
22-Apr	8	End	34.49	34.49	34.49	17.25	8.62	17.25	34.49
25-Apr	End	End	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total			683.64	636.48	429.67	436.14	170.91	341.82	683.64

The total maximum application depth (637 mm) was obtained at 25% deficit during the first and the second growth stages ($D_{all,}25$ (T_1)) while minimum (171 mm) value was recorded in treatment $D_{all,}75$ (T_4) which was 75% deficit throughout the whole growth period.

Table 5 shows the total amount of water applied and the amount of water saved per treatment assuming a maximum furrow irrigation attainable efficiency of 60%. The amount of water varied from as high as 684 mm to as low as 171 mm.

Table 5. Irrigation water applications and water saving under different treatments

Treatment	NIR (mm)	NIR (m^3/ha)	GIR (mm)	GIR (m^3/ha)	Water saved (mm)	Water saved (m^3/ha)	Water saved (%)
$D_{all,}0$ (T6)	410.20	4102.00	683.64	6836.40	0.00	0.00	0
$D_{1,2,}25$ (T1)	381.88	3818.80	636.48	6364.80	47.16	471.6	7
$D_{3,4,}50$ (T3)	261.68	2616.80	436.14	4361.40	247.5	2475.0	36
$D_{2,3,}50$ (T2)	257.79	2577.90	429.67	4296.70	253.97	2539.7	37
$D_{all,}50$ (T5)	205.09	2050.90	341.82	3418.20	341.82	3418.2	50
$D_{all,}75$ (T4)	102.54	1025.40	170.91	1709.10	512.73	5127.3	75

Application efficiency - the effect of irrigation treatments on mean values during initial, development, mid and late season shows that application efficiency were statistically significant (P<0.05) (Table 6).

Table 6. The effect of irrigation application level on the mean application efficiency related with crop growth stages.

Treatment	Mean application efficiency (%)* Growth stages: Initial	Development	Mid	Late
$D_{1,2}25$ (T1)	53.93[b]	58.00[c]	59.67[d]	63.00[d]
$D_{2,3}50$ (T2)	44.21[c]	71.46[b]	72.96[c]	66.50[c]
$D_{3,4}50$ (T3)	44.21[c]	57.54[c]	72.92[c]	79.25[b]
$D_{all,}75$ (T4)	65.72[a]	78.59[a]	81.75[a]	83.50[a]
$D_{all,}50$ (T5)	63.60[a]	76.47[a]	77.36[b]	79.14[b]
$D_{all,}0$ (T6)	40.95[c]	55.46[c]	60.22[d]	62.02[d]
SEm±	1.559	1.489	1.251	0.751
LSD (0.05)	3.474	3.319	2.787	1.673
CV (%)	3.7	2.8	2.2	1.3

*mean of three observations. Treatment means followed by the same superscript letter(s) are not significantly different.

Storage efficiency- the storage efficiency mean values during initial, development, mid and late season shows that the effect of irrigation treatments on storage efficiency were statistically significant (P<0.05) (Table 7).

Table 7. The effect of irrigation application level on the mean storage efficiency

	Mean storage efficiency (%)*			
	Growth stages			
Treatment	Initial	Development	Mid	Late
$D_{1,2}25$ (T1)	86.91[b]	45.96[b]	24.99[b]	20.68[c]
$D_{2,3}50$ (T2)	95.22[a]	31.27[c]	21.94[c]	31.48[a]
$D_{3,4}50$ (T3)	97.12[a]	53.42[a]	27.53[a]	25.33[b]
$D_{all,}75$ (T4)	11.88[d]	8.23[e]	6.43[e]	4.46[e]
$D_{all,}50$ (T5)	29.90[c]	17.23[d]	12.72[d]	10.03[d]
$D_{all,}0$ (T6)	97.19[a]	49.53[ab]	24.89[b]	30.61[a]
SEm±	2.177	1.840	0.766	0.801
LSD (0.05)	4.850	4.101	1.708	1.784
CV (%)	3.8	6.6	4.8	4.8

*mean of three observations. Treatment means followed by the same superscript letter(s) are not significantly different.

Distribution uniformity- the distribution uniformity mean values during initial, development, mid and late season shows that the effect of irrigation treatments on distribution uniformity were not statistically significant at 5 % probability level (Table 8).

Table 8. The effect of irrigation application level on the mean distribution uniformity

	Mean distribution uniformity (%)*			
	Growth stages			
Treatment	Initial	Development	Mid	Late
$D_{1,2}25$ (T1)	94.04[a]	95.97[a]	96.17[a]	95.50[a]
$D_{2,3}50$ (T2)	95.96[a]	98.50[a]	96.96[a]	97.03[a]
$D_{3,4}50$ (T3)	97.33[a]	96.60[a]	97.35[a]	97.46[a]
$D_{all,}75$ (T4)	96.72[a]	94.44[a]	95.58[a]	96.66[a]
$D_{all,}50$ (T5)	96.82[a]	98.25[a]	97.81[a]	96.49[a]
$D_{all,}0$ (T6)	98.55[a]	98.26[a]	96.61[a]	96.83[a]
SEm±	1.476	1.949	1.660	2.727
LSD (0.05)	Ns	Ns	Ns	Ns
CV (%)	1.9	2.5	2.1	3.5

*mean of three observations. Treatment means followed by the same superscript letter(s) are not significantly different. Ns = no significant difference among effects of treatments.

Deep percolation ratio- the deep percolation ratio mean values during initial, development, mid and late season shows that the effect of irrigation treatments on deep percolation ratio were statistically significant ($P<0.05$) (Table 9).

Table 9. The effect of irrigation application level on the mean deep percolation ratio

	Mean deep percolation ratio (%)*			
	Growth stages			
Treatment	Initial	Development	Mid	Late
$D_{1,2,}25$ (T1)	46.07[b]	42.00[a]	40.33[a]	37.00[a]
$D_{2,3,}50$ (T2)	55.79[a]	28.54[b]	27.04[b]	33.50[b]
$D_{3,4,}50$ (T3)	55.79[a]	42.46[a]	27.08[b]	20.75[c]
$D_{all,}75$ (T4)	34.28[c]	21.41[d]	18.25[d]	16.50[d]
$D_{all,}50$ (T5)	36.40[c]	23.53[d]	22.64[c]	20.86[c]
$D_{all,}0$ (T6)	59.05[a]	44.54[a]	39.78[a]	37.98[a]
SEm±	1.559	1.489	1.251	0.751
LSD (0.05)	3.474	3.319	2.787	1.673
CV (%)	4.0	5.4	5.2	3.3

*mean of three observations. Treatment means followed by the same superscript letter(s) are not significantly different.

Crop Yields and Yield Components: According to Table 10, irrigation treatments on the mean grain yield were statistically significant ($p<0.05$). Maximum grain yield of 58.92 qt/ha was obtained when full irrigation was applied in all growth stages ($D_{all,}$ 0 (T6)). On the other hand, minimum yield of 13.10 qt/ha was obtained under 0.25ETc throughout the growth period ($D_{all,}75$ (T4)). Both treatments $D_{2,3}50$ (T2) and $D_{3,4}50$ (T3) provided with full irrigation during the initial growing season, and followed by a period of stress at the development and mid stages for treatment $D_{2,3}50$ (T2), and at the mid and late season stages for treatment $D_{3,4}50$ (T3) resulted in grain yields of 42.62 qt/ha and 39.62 qt/ha, respectively. This tendency might be attributed to the fact that water stressing conditions during highly sensitive stages of maize crop in the season affected grain yield by affecting root development, cob length, and number of grains per cob and leaf area cover.

Yield reduction and harvest index: Water deficit by 75% during the whole growing seasons ($D_{all,}$75 (T4)) had a maximum (77.77 %) yield reduction and treatments which were stressed by 50% throughout all growth stages ($D_{all,}$50 (T5)) had a yield reduction of about 53.12 % respectively, as compared with the yield obtained under normal watering (T6). But, water deficit by 25% during first and second consecutive growth stages ($D_{1,2}$ 25 (T1)) as compared with this experimental control (T6) has a minimum yield reduction (6.16 %) (Table 10).

Table 10. Relative yield reduction of maize and Harvest index with respect to the optimum irrigation level

Treatment	GIR (mm)	Actual yield (qt/ha)	Aboveground biomass (qt/ha)	Harvest index (%)	Yield reduction (qt/ha)	Yield reduction (%)	Rank based on yield reduction
$D_{1,2}$25 (T1)	636.48	55.29	161.89	34.15	3.63	6.16	5
$D_{2,3}$50 (T2)	429.67	42.62	152.29	27.99	16.30	27.66	4
$D_{3,4}$50 (T3)	436.14	39.62	153.90	25.74	19.30	32.76	3
$D_{all,}$75 (T4)	170.91	13.10	130.34	10.05	45.82	77.77	1
$D_{all,}$50 (T5)	341.82	27.62	144.20	19.15	31.30	53.12	2
$D_{all,}$0 (T6)	683.64	58.92	164.28	35.87	0.00	0.00	6

Mansouri-Far *et al*. (2010) also found that deficit irrigation of maize during reproductive stage resulted in more yield reduction than during vegetative stage.

Water Productivity: The effect of irrigation application level on mean Physical water productivity (CWP) values were statistically significant ($P<0.05$). However, there was no difference between treatment $D_{1,2,}$25 (T1) and $D_{all,}$0 (T6). Physical water productivity increased as deficit irrigation level increased up to 25% stressed during first and second growth stage ($D_{1,2,}$25 (T1)) and then declined after continuously stressed by half of the total ETc ($D_{all,}$50 (T5)). Treatment $D_{2,3,}$50 (T2) had maximum CWP as compared to treatment $D_{3,4,}$50 (T3) with the same percentage of water stressed during flowering and late season. Minimum CWP was found to be 1.29 kg/m^3 at 75% water stressed treatment throughout the growing season and less than the values presented in (Yenesew and Ketema, 2009), which was 2.96 kg/m^3 with the same percentage of water stressed throughout the growth period. Zhang et al. (2004) reported CWP of corn that varied from 1.39 to 1.72 kg/m^3. The variations of these figures might be due to the variation of the environmental conditions. Mohammed *et al*. (2012) conducted a field experiment to investigate yield and water productivity of maize under deficit irrigation practices in Egypt and reported a mean value of 1.86 kg/m^3. The variations of these figures may be attributed to crop variety, environment and field management conditions.

Table 11. Effect of irrigation treatments on water productivity and yield response factor (Ky) of maize crop.

Treatment	NIR (m^3/ha)	Mean CWP (kg/m^3)*	GIR (m^3/ha)	Mean EWP (Birr/m^3)*	Ky (-)*
$D_{2,3}$50 (T2)	4102.00	1.65^a	6836.40	4.17^a	0.745^c
$D_{3,4}$50 (T3)	3818.80	1.51^b	6364.80	3.82^b	0.904^b
$D_{1,2}$25 (T1)	2616.80	1.45^c	4361.40	3.65^c	0.891^b
$D_{all,}$0 (T6)	2577.90	1.44^c	4296.70	3.62^c	---
$D_{all,}$50 (T5)	2050.90	1.35^d	3418.20	3.39^d	1.062^a
$D_{all,}$75 (T4)	1025.40	1.29^e	1709.10	3.22^e	1.037^a
SEm±		0.0291		0.0734	0.0347
LSD (0.05)		0.0648		0.1635	0.0773
CV (%)		2.5		2.5	5.5

*mean of three observations. Treatment means followed by the same superscript letter(s) are not significantly different.

Seasonal maize response factor: The variability of the seasonal crop yield response factor (Ky) was statistically significant ($P<0.05$). The maximum of 1.06 and minimum of 0.745 Ky values were calculated under treatment $D_{all,}$50 (T5) and $D_{2,3,}$50 (T2), respectively.

CONCLUSIONS AND RECOMMENDATIONS

In terms of application efficiency, the overall maximum of 83.50% was obtained when the field is continuously stressed by 50% and 75% of ETc, while good storage efficiency was measured when the field is irrigated by full application level.

The stage comparisons showed that the maximum amount of water (253.97 mm) during the growing season relatively with minimum yield reduction (16.30 qt/ha), applying deficit irrigation at the middle stages was found more beneficial. Maximum CWP (1.65 kg/m^3) and EWP (4.17 Birr/m^3) were obtained when 50% deficit irrigation was applied during development and mid-season stage stresses.

The selection of stage-wise deficit irrigation application treatments was very much restricted to taking two consecutive growth stages. This is purely due to logistical constraints. Therefore, future work with more resource needs to be designed by considering every stage individually or in combination with different deficit levels, and the test of deficit irrigation application should also be made for other crops for comprehensive irrigation water management recommendations.

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